Important Canine Zoonoses from a Public Health Perspective and the Introduction of Companion Animal Surveillance in the Prairie Provinces of Canada

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ABSTRACT

Prioritizing zoonotic and/or sapronotic pathogens of domestic animal populations and initiating ongoing surveillance of such pathogens is needed in Canada. From a One Health perspective, gathering and recording more comprehensive disease data on the population of animals most closely associated with humans is extremely valuable and necessary. Therefore, the purpose of this thesis was to identify a subset of domestic canine pathogens of public health significance specific to the Prairie Provinces of Canada and to establish a framework for a companion animal surveillance initiative to the region. This research was conducted within a two-year period from September 2019 to April 2021.

The first component of this research involved the creation of a comprehensive list of any pathogen historically reported in the domestic dog by reviewing several companion animal infectious disease textbooks, which resulted in 594 pathogens total. This list was then pared down to identify only those pathogens that were significant from a public health perspective in Canada and the prairies. This was accomplished using a formulated stepwise approach that pathogens only moved on to the final list if: (1) the pathogen was zoonotic/sapronotic/anthroponotic, (2) the domestic dog was involved in transmission, maintenance or detection of the pathogen, and (3) there was a level of risk for occurrence of the pathogen in Canada. Following this stepwise approach, of the initial 594 canine pathogens 84 pathogens were deemed important in Canada and the prairies from a public health perspective.

A follow-up study to this research involved a prioritization exercise using experts in the field of veterinary medicine, public health, and epidemiology to identify the top 5 highest priority pathogens from the final list of 84 canine pathogens upon which to focus a companion animal surveillance program specific to the Prairie Provinces. The exercise was accomplished through a

voluntary survey using a semi-quantitative ranking strategy. The resulting top 5 pathogens to come out of the exercise were: (1) *Echinococcus spp*. (*granulosus, multilocularis*), (2) MRSA, (3) *Salmonella enterica*, (4) MRSP, and (5) *Borrelia burgdorferi*.

The final component of this research examined the utility of clinical veterinarians and veterinary clinics in a companion animal surveillance program. In addition, responses from clinical veterinarians were used to formulate case definitions for the top 5 highest priority pathogens intended for surveillance. Assessing dogs as sentinels for pathogens of public health concern using Lyme disease as an example was also conducted in this research chapter. Data was gathered through a voluntary survey disseminated to clinical veterinarians in the provinces of Alberta, Saskatchewan, and Manitoba. The results of this survey identified that clinical veterinarians are willing to participate in a surveillance program, that there is important in-clinic veterinary data not currently being captured from a population or disease monitoring standpoint, and that domestic dogs can serve as good sentinels for Lyme disease risk in humans, specific to the prairies.

This thesis provided the foundational steps for a companion animal surveillance initiative specific to the Prairie Provinces of Canada. It identified which pathogens involving the domestic dog pose a significant public health risk in Canada and the prairies, prioritized these pathogens from highest to lowest concern using expert opinion, and established the importance of cooperation with practicing veterinarians and veterinary clinics for a companion animal surveillance program to be successful.

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DEDICATION

I dedicate this thesis to my four-legged companions Scarlet and Winter.

I completed this research during an incredibly challenging time in the world, when uncertainty and fear were extremely high. Having Scarlet and Winter curled up at my feet during the majority of this writing was the constant reminder I needed that we can always find joy and love in our surroundings.

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LIST OF ABBREVIATIONS

AB	Alberta
ABVMA	Alberta Veterinary Medical Association
AMR	Antimicrobial resistance
AMU	Antimicrobial use
CALLISTO	Companion Animals Multisectorial Interprofessional Interdisciplinary Strategic Think Tank on Zoonoses
CAVM	Calgary Academy of Veterinary Medicine
CIPARS	Canadian Integrated Program for Antimicrobial Resistance Surveillance
EMR	Electronic medical records
ESBL	Extended-spectrum beta-lactamase
ESC	Extended-spectrum cephalosporinase
MB	Manitoba
MDR	Multi-drug resistant
MVMA	Manitoba Veterinary Medical Association
MRSA	Methicillin-resistant *Staphylococcus aureus*
MRSP	Methicillin-resistant *Staphylococcus pseudintermedius*
MRSS	Methicillin-resistant *Staphylococcus schleiferi* subsp. *coagulans*
NCASP	National Companion Animal Surveillance Program
OAHN	Ontario Animal Health Network
OIE	World Organisation for Animal Health
OVC	Ontario Veterinary College
PDS	Prairie Diagnostic Services
PU/PD	Polyuria/polydipsia

SAVSNET	Small Animal Veterinary Surveillance Network
SK	Saskatchewan
SVETPET	Veterinary Surveillance of Pets
SVMA	Saskatchewan Veterinary Medical Association
UK	United Kingdom
VRE	Vancomycin-resistant enterococci
WHO	World Health Organization

CHAPTER 1: INTRODUCTION & LITERATURE REVIEW

1.1 Introduction

The relationship between humans and companion animals has become increasingly intimate in modern society. Several benefits to pet ownership include but are not limited to companionship, increased mental welfare, and physical well-being. In addition, many pets are trained working animals or serve as therapy aids[1–4]. Unfortunately, pet ownership also comes with certain public health risks including the potential for zoonotic pathogen exposure[1–3]. This is of particular importance to individuals who are immunocompromised[5–8]. Indigenous communities are also vulnerable to companion animal zoonoses as a result of limited access to veterinary and medical resources[9–12].

It is well established that a large proportion of infectious diseases originate from animal sources. In fact, Taylor et al. states that of the approximately 1500 pathogens known to cause human illness, greater than 60% of these are zoonotic[13]. Furthermore, 75-85% of emerging pathogens are also zoonotic[4,14,15]. As the relationship with domesticated animals has changed in Canada, so should the response to achieving a "One Health" approach to public health risks from the animals with which humans spend the most time and closest contact. This concept of One Health has become particularly prominent in recent years, seeking to unify the following: human, animal, environmental, and ecosystem health[4]. Several strategies have been adopted in epidemiology to monitor zoonotic disease threats including pathogen prioritization and the creation of surveillance programs[16–19]. This helps to bridge the gap between human health and animal health as part of an overarching One Health strategy.

The following literature review has three main objectives. First, to provide an overview on canine zoonoses and public health implications within a Canadian context. Second, to compare

current methods of pathogen prioritization using human and animal examples. And third, to assess the current knowledge on surveillance systems as they relate to companion animal zoonoses with a particular relevance to Canada. Because rabies is one of the few canine zoonotic pathogens monitored in Canada and has been heavily researched, it will not be the focus of this literature review.

1.2 An Overview of Canine Zoonoses and Public Health Implications in Canada

1.2.1 An Introduction to Canine Zoonotic Pathogens in Canada

1.2.1.1 Zoonotic Terminology and How it Relates to the Role of the Dog

Zoonoses are defined as pathogens that are transmitted from animals, or animal tissue, to people and result in human disease. This includes direct transmission to humans (by skin, inhalation or ingestion), as well as indirect transmission through vectors, fomites or environmental contamination[5,20,21]. *Sapronoses* are defined as pathogens that can infect both animals and humans from a shared environment, without direct transmission between hosts. Sapronoses survive on abiotic substrates but can replicate in the environment, making their classification different than environmental contamination alone[21]. *Anthroponoses* are defined as pathogens that are transmitted from human to human. This term was previously used interchangeably with *anthropozoonoses* and the term *zooanthroponoses* defined human to animal transmission (reverse zoonoses)[21,22]. It is now widely accepted that zoonoses represent those diseases that pass naturally between humans and vertebrate animals in either direction[22,23]. In general, once humans are infected with a zoonotic pathogen they do not typically transmit from person to person[21]. This is excluding anthroponoses where human to human transmission can occur[5,21].

When addressing the role of dogs from a One Health perspective and the effect of canine diseases on human health, it is important to consider zoonoses, sapronoses and anthroponoses

because dogs can play several roles in the spread of disease from a public health perspective. These roles include the direct transmission of a pathogen from dogs to humans[6,15,24–26], dogs maintaining a pathogen in the environment as a definitive or reservoir host[6,15,27,28], and finally, that dogs may be used to detect a pathogen in the environment as sentinels for human exposure[6,26,29–32]. Canine pathogens that are strictly zoonotic should always be considered a public health concern. Although sapronoses are not directly zoonotic, dogs can serve as sentinels for sapronotic pathogens revealing a risk for human exposure from a shared environment, and thus are also important from a public health perspective[33]. If a pathogen can be transmitted in the direction of human to dog, it is considered possible for transmission to occur in the other direction[6,22,24,25]. Therefore, primarily anthroponotic pathogens and reverse zoonoses are important to recognize from the canine perspective as well. Because it is often challenging to verify zoonotic transfer versus shared environmental exposure[6], it is useful to consider dogs as sentinels for many pathogens of human importance.

1.2.1.2 Important Canine Zoonoses in Canada

Several examples of canine zoonoses are emphasized and well documented in Canada through prevalence studies. In addition to rabies, the literature on canine zoonoses in Canada appears to focus on gastrointestinal pathogens, vector-borne diseases, dog bites, and antimicrobial resistance.

1.2.1.2.1 Gastrointestinal Pathogens

Dogs can serve as a source of parasitic infection in humans and have also been evaluated as sentinels for parasitic risk in both human and wildlife populations within Canada[34,35]. Examples of zoonotic helminths historically reported in dogs in Canada include *Echinococcus spp*. and *Toxocara canis*, particularly in northern and remote locations where free-roaming dogs are

common[9,10,26]. These parasites have also been identified specifically in shelter dogs through prevalence studies[36]. One study however, reported *Echinococcus granulosus* (alternatively referred to as *E. canadensis*) in one canine fecal sample obtained in the more urban location of Winnipeg, Manitoba[37]. Additional but less commonly identified helminths include *Diphyllobothrium spp., Toxascaris leonina, Uncinaria stenocephala, Alaria spp., Strongyloides spp., Trichuris spp.,* as well as unidentified roundworms, hookworms, tapeworms and whipworms[10,26,38,39]

Other gastrointestinal protozoal and bacterial pathogens documented in dogs in Canada include *Giardia duodenalis, Cryptosporidium spp., Campylobacter spp., Salmonella spp., Yersinia spp.,* and *Escherichia coli* [9,38–41]. While increased prevalence in free-roaming dogs is apparent for many of these studies, in comparison, Julien et al. discovered prevalence of *Giardia spp.* and *Cryptosporidium spp.* in fecal samples to be highest in sled-dogs when compared to shelter or community dogs in Iqaluit, Nunavut[40]. Like many canine gastrointestinal helminths, these protozoal and bacterial pathogens also have zoonotic potential[9,40,41].

1.2.1.2.2 Vector-borne Diseases

The majority of vector-borne disease research in Canada, where the role of the domestic dog is also examined, is largely based in Lyme disease research. This is because Lyme disease is the most common tick-borne disease plaguing North America[42]. Many Canadian studies propose the use of dogs as sentinels for *Borrelia burgdorferi* as a way to assess disease risk in humans in a given population. This is because dogs have a higher chance of tick exposure, clinical impact is much lower in dogs, and serology testing is common and inexpensive[26,29,42–44]. In areas of Canada where Lyme disease is emerging, dogs are typically identified as sero-positive sooner than humans and in larger numbers[42]. Other vector-borne diseases reported in Canada, where the dog can play

a role in detection of the pathogen as sentinels for human exposure include *Anaplasma spp., Ehrlichia spp., Rickettsia rickettsia* and *Dirofilaria immitis*[1,15,29,44–47].

Although the exact incidence of *B. burgdorferi* in dogs in Canada is unknown, in one study, the mean seroprevalence was calculated as 0.72% in the overall Canadian dog population, but as high as 2.15% in dogs residing in Nova Scotia[42,47]. Furthermore, 2/3 of all infections were suspected to be infections acquired within Canada and were not related to international travel[42]. In a Saskatchewan study, where Lyme disease is not endemic, 3.0% (2/77) of dogs tested in a southeastern Indigenous community were positive for *B. burgdorferi*[26]. A second Saskatchewan study found a positive rate of 2.3% (12/515) in dogs, with and without travel history[48]. Evason et al. reported an overall prevalence of 2.0% for Lyme disease in dogs in Canada[46]. This study evaluated 753,468 canine serological test results over a 7-year period. Finally, Herrin et al. reported a total of 2.5% prevalence of borreliosis in dogs in Canada over a 1-year study period[44]. Dogs should continue to be part of the surveillance strategy to detect Lyme disease in Canada, in addition to tick surveillance and human testing[1,29,43,44].

1.2.1.2.3 Dog Bites

Dog bites are a common canine public health concern reported in Canada. Dog bites are examined from both the perspective of zoonotic disease transmission as well as physical injury rates in people. Normal oral bacteria present in dogs can be transmitted to humans through bites leading to infection. This includes *Pasteurella spp., Streptococcus spp., Staphylococcus spp., Moraxella spp., Capnocytophaga canimorsus, Fusobacterium spp., Neisseria spp., Clostridium spp., Bacteroides spp., Prevotella spp.,* and *Porphyromonas spp.*[6,11,15,49,50]. Bacteria, however, are not the only pathogens that can be transmitted directly to humans through a dog bite. The

transmission of Rabies virus from dog bites is a world-wide concern due to its fatal disease progression[3,11].

The frequency of dog bites as well as fatalities related to dog attacks in Canada is also significantly higher in Indigenous communities compared to urban centers[3,10,11,39]. This could be related to higher populations of free-roaming dogs in some communities[3,11,39]. A 2015 study which looked at animal bite records over a 7-year period from two Indigenous communities revealed that out of 57 individuals who sought medical attention 27 were specific to a dog bite related injury[39]. This was higher than any other animal bite injury. A survey conducted in the Nunavik region of Quebec reported that 40.3% (27/67) of participants suffered from dog bites. Of these, 22 individuals were Inuit and 5 individuals were Non-Inuit[3]. In an urban study conducted in Ontario, of 641 survey participants, 15 individuals reported being bitten by their own dog, while 5 individuals reported being bitten by another dog; none resulted in fatalities[51]. Dog bite data obtained from such studies is likely an under-representation of dog-bite prevalence in Canada due to under-reporting[39].

1.2.1.2.4 Antimicrobial Resistance

Antimicrobial resistance (AMR) in both veterinary and human medicine is a growing area of concern. The use of antibiotics in veterinary medicine, including the use in companion animals, has a direct impact on public health[52]. This is because antimicrobial resistant and multi-drug resistant (MDR) pathogens can be shed from household pets to humans within a shared environment[6,53].

In Canada, a large proportion of companion animal related AMR research is focused on methicillin-resistant *Staphylococcus aureus* (MRSA) and methicillin-resistance *Staphylococcus pseudintermedius* (MRSP). For example, Rubin et al. examined 126 canine and human *S. aureus*

samples in Saskatoon from the years 2006-2008 and found resistance to 10 antimicrobial classes and multi-drug resistance in several samples[24]. Isolates were not resistant to vancomycin. Furthermore, canine and human isolates shared genetic similarities, indicating interspecies transmission to be likely[24]. This interspecies relatedness supports possible reverse zoonotic transmission of MRSA from humans to their pets which has been documented in the literature extensively[5,6]. Weese et al. identified MRSA in 5 canine patients with clinical infections in an Ontario study where interspecies transmission was suspected in both directions. Of note, vancomycin resistance was not observed in any sample[25].

Another Canadian study tested 193 dogs admitted to the Ontario Veterinary College (OVC) Veterinary Teaching Hospital for coagulase positive staphylococcal infections[54]. MRSP was identified in 2.1% (4/193) of samples, while MRSA and methicillin-resistant *Staphylococcus schleiferi* subsp. *coagulans* (MRSS) were isolated in 0.5% (1/193) of samples respectively. All dogs in this study were non-clinical for methicillin-resistant coagulase positive staphylococcal infections and presented to the hospital for unrelated medical concerns. The role of colonization of MRSA/MRSP/MRSS in dogs without clinical signs and potential carrier status is still not well understood[54].

In 2002, Prescott et al. examined canine urinary isolates over a 15-year period in Ontario and found changes to the susceptibility patterns of both *S. aureus* and *S. pseudintermedius*[55]. These changes reflected the shift in antimicrobial classes more likely to be used during this time frame. An alarming finding included marked increased resistance to enrofloxacin. In addition, this study also found increases in the resistance patterns of several other bacterial species, including *Enterococcus spp., Enterobacter spp.,* and *Pseudomonas aeruginosa*[55].

Other AMR pathogens of concern in dogs in Canada include vancomycin-resistant enterococci (VRE), extended-spectrum beta-lactamase (ESBL) *E. coli,* extended-spectrum cephalosporinase (ESC) *E. coli*, and *Salmonella spp*. Lefebvre et al. examined fecal pathogen shedding in therapy dogs fed raw food diets in Ontario and Alberta[56]. ESC *E. coli* was detected in 106 fecal samples. ESBL *E. coli,* MRSA and VRE were not observed[56]. In a 2019 study that looked at both companion animal and food animal isolates in both the United States and Canada, resistance patterns were discovered in pathogenic *E. coli* isolates to macrolides, fluoroquinolones and cephalosporins[57]. One *E. coli* isolate was resistant to cephalosporins, macrolides, fluoroquinolones, aminoglycosides, and tetracyclines. This study also observed resistance genes in *S. pseudintermedius* samples to several classes of antimicrobials including beta-lactam antibiotics, tetracycline, aminoglycosides, streptothricin, streptomycin and fluoroquinolones. Resistance genes were not identified in *Salmonella* isolates for this particular study[57]. Leonard examined canine fecal samples in a 2012 southwestern Ontario study and found 14% (17/120) of *Salmonella* isolates and 10% (41/395) of *E. coli* isolates were resistant to two or more classes of antimicrobials[58]. The most common classes of antimicrobials that exhibited resistance patterns included the beta-lactam antibiotics and cephalosporins[58]. Each of these studies highlight the growing risk of AMR and MDR in companion animal bacterial isolates that also have zoonotic potential.

1.2.2 Public Health Considerations with Companion Animal Ownership

1.2.2.1 The Human-Canine Bond and Benefits of Pet Ownership

It is well documented that there are many benefits to companion animal ownership. As the domestication of animals has evolved throughout history, companion animals (including but not limited to cats and dogs) have become an important part of modern human culture from a social

and psychological standpoint[1,2,6]. Studies have shown that caring for pets creates a sense of nurturing in people, and pets have become well-established members of the family that benefit all age groups including children and the elderly[2]. Children who are raised with pets have improved social skills and self-esteem. Furthermore, they develop a sense of identity and have increased empathy toward others[2,6,59].

Pets have also been associated with improved physical health and well-being in humans. This includes but is not limited to: reduced stress levels, reduced risk of cardiovascular related illness, and reduced risk of asthma in children who are exposed to a pet within the first year of life[2]. The relationship between animal ownership and decreased incidence of cardiovascular disease has been attributed to increased physical activity and reduced stress levels. This in turn decreases the risk of obesity, hypertension, hyperlipidemia and depression which can exacerbate cardiovascular events[4].

Additionally, companion animals can support humans in other ways. Working and therapy animals assist with both mental and physical needs. For example, studies show that the use of dogs during cancer treatment can aid in the patient's overall morale and attitude toward treatment[4]. Dogs have also been utilized in therapy for Autism spectrum disorder[4]. In Inuit cultures in Canada, dogs are used for travel and hunting purposes and are an important part of the Inuit history and ancestry[3]. Although several companion animal diseases can impact human health, efforts to minimize human disease should not take away from the important benefits of owning a pet.

1.2.2.2 The Effects of Dog Ownership on the Immunocompromised

Individuals who are immunocompromised are at an increased risk of canine zoonotic disease transmission that comes with pet ownership. Shedding of gastrointestinal pathogens by dogs, both bacterial and parasitic, is a primary concern, with a growing risk from other agents

including fungal and viral infections[5,8,60]. Immune status has become particularly concerning in recent years as the popularity of owning a pet continues to rise. Immunocompromised individuals include children, the elderly, pregnant woman, individuals on immunosuppressive medications, and those with diseases that affect the immune system[8,59]. However, it is also important to consider pets who are immunosuppressed themselves to be an increased public health risk[8]. Dogs with immunodeficiencies are a risk to human health because they are less likely to mount their own immune response to infectious agents and therefore can shed large quantities of harmful zoonotic pathogens in a shared environment. Furthermore, these dogs are also less likely to mount an immune response to preventative measures like vaccinations[8].

There is an evident gap in communication between veterinary and medical professionals when it comes to companion animal zoonoses and immunocompromised individuals[8,59,60]. Studies show that physicians do not regularly ask patients about pet ownership or discuss zoonotic disease risk[59]. In a study on immunocompromised children and pet ownership, 73% of households obtained a high-risk pet shortly after their child was diagnosed with diabetes[61]. In addition, 77% of households obtained a high-risk pet shortly after a cancer diagnosis in their child[61]. Furthermore, there is a lack of communication between veterinarians and clients in terms of immunosuppression and increased zoonotic disease risk from companion animals[6]. Less than 1% of HIV positive individuals reported receiving information from their veterinarian on dog ownership and zoonotic diseases[8]. Client education from veterinarians and human physicians, as well as better communication between the two professions, is of the upmost importance in addressing the risk of canine zoonoses in immunocompromised individuals[8,59,60].

Immunocompromised individuals can still benefit greatly from pet ownership as companionship from a pet can combat feelings of isolation and improve overall mental well-being

in those who are immunocompromised[5,7]. This benefit has been established in studies on HIV patients and newly diagnosed cancer patients[6,8,59,61]. Although the risk of pet ownership in immunocompromised individuals should not outweigh the benefits, open communication between the veterinarian and owner can contribute toward safe interaction. Several recommendations can be adopted by immunocompromised individuals looking to own a dog or pet which include improved hygienic practices, acquiring a dog greater than 6 months of age, feeding appropriately cooked diets, avoiding bites/scratches, as well as keeping the dog or pet up to date on immunizations and parasitic control[7,8,59]. Improved surveillance on this population of animals should also be part of the solution as it can further inform these recommendations.

1.2.2.3 Public Perceptions of Zoonotic Risk in Companion Animals

Few Canadian studies have examined the general public's knowledge on zoonotic disease risk with companion animal ownership. In a 2012 survey conducted in the city of Waterloo, Ontario, Stull et al. examined the public's perception of pet-related zoonoses[51]. Of the 641 participants, 64% owned at least one pet. In participants who did not own a pet, 37% still had regular contact with animals outside of the home at least once a week. Furthermore, 55% of individuals who owned at least one pet were classified as "high-risk". This group was defined by age (under 5 or greater than 65 years of age) or immune status of the participant. A large proportion of participants (64%) revealed that they had not received any information on companion animal zoonoses and other risks from either a veterinarian, physician, or self-motivated resource. The remaining 36% of participants who acknowledged receiving some information on pet-related risks were able to correctly identify zoonotic pathogens at a significantly higher proportion than individuals who had no prior knowledge. Despite this, scores for both groups were considered low. Of participants living in households with a pet, 30% reported having no concerns of pet-

associated diseases. The majority of participants, regardless of pet ownership, identified rabies as a high concern. There was no difference in perceived risk to companion animal zoonoses in participants who identified as high-risk compared to individuals who were categorized as low risk[51]. A follow-up study by the same authors examining pet husbandry practices in Ontario reported 46-57% of participants (n = 401) who owned a pet to be high-risk owners[62]. Thirteen percent of participants revealed that the household dog slept in their child's bed, while 24% of participants admitted to allowing the dog to lick their child's face. Furthermore, 28% of respondents fed their dog raw-food diets or treats[62].

Lefebvre evaluated the knowledge of Ontario dog owners who enrolled their dogs in hospital and health care visitation programs[63]. Hospital requirements for admittance of dogs into these programs was also examined. Ninety individuals and 231 hospitals participated in this study. Seventy-nine percent of owners (71/90) revealed that their dogs were allowed to lick patients. In addition, 73% (66/90) allowed their dog to be on patients' beds. Despite 89% (80/90) of participants indicating that they had told their veterinarian of their dog's enrollment in a visitation program, only 14% (13/90) reported any conversations with their veterinarian on zoonotic disease risk. When asked to name "two diseases that people can catch from dogs", 40% (36/90) of participants could not answer the question. Twenty-five owners could identify one pathogen, with rabies being the most common answer. Only 40% of hospitals who participated in this study expressed interest in free testing of all dogs included in visitation programs. The most common requirement from hospitals for inclusion of a dog in the program was proof of current core-vaccination status. Only 2 owners reported that deworming was necessary to be admitted into the hospitals they visited. Temperament testing and health certification from a veterinarian were commonly required. Of alarming concern, 36% of participants admitted to being permitted to

wander hospital wards without any supervision from hospital staff[63]. These studies reveal an overall lack of public awareness on the potential severity of companion animal pathogens and public health implications in Canada.

1.2.2.4 Veterinary Perceptions of Zoonotic Risk in Companion Animals

There is an evident disconnect in the communication between veterinarians and their clients with regard to public education on zoonotic diseases. It is therefore important to assess the overall knowledge of veterinarians on zoonotic disease risk. One study in Canada that has evaluated the perceptions of veterinarians on companion animal zoonoses looked at endoparasitic zoonoses specifically[64].

An examination of this study showed that of the 545 veterinarians surveyed in western Canada, only 13% recommended a deworming protocol for puppies, while 39% recommended a deworming protocol for kittens[64]. Over 85% of respondents did not use an appropriate deworming protocol for puppies and 60-90% of deworming protocols were inappropriate for kittens (dependent on age of kitten at time of deworming). Veterinarians who perceived a high risk for *Toxocara canis* were more likely to have an appropriate deworming protocol for puppies. Similarly, individuals who perceived a high risk of *Toxocara cati* were also more likely to have an appropriate deworming protocol for kittens. Ninety-seven to ninety-nine percent of participants followed appropriate guidelines for adult dogs and cats[64].

Only 44% of veterinarians in this study reported discussing zoonotic endoparasitic disease risk with every client[64]. Of the remaining veterinarians, 10% discussed zoonoses with clients if they perceived the client to be high risk. Forty percent of veterinarians reported rare discussions with clients on companion animal zoonoses if "prompted by the client" or "when worms were diagnosed" on fecal examination[64]. There were 3 respondents who confessed to never discussing

zoonotic disease risk with their clients on any occasion[64]. Although veterinarians and veterinary professionals should be a wealth of knowledge on canine zoonoses and associated public health risks, this study highlighted the gaps in deworming protocols by veterinarians as well as overall client education. Addressing such gaps can benefit both human and animal health.

1.2.3 The Overall Canadian Context

1.2.3.1 The Role of Climate Change and Canine Zoonoses

Because Canada is situated in a northern part of the globe, it is more dramatically affected by climate change compared to other parts of the world, particularly its northernmost arctic regions[65]. Climate change plays a crucial role in zoonotic diseases for several reasons. A warming climate can increase the range and number of reservoir animals and vector species in a given area. The importation of vectors, reservoirs and pathogens that would not ordinarily survive in the harsher climate is also intensified. Furthermore, climate change can prolong pathogen transmission cycles[66].

In terms of vector distribution, ticks are a good example of the role climate change has played. The distribution of ticks in Canada, and therefore Lyme disease, has changed substantially due to climate change[42,65–67]. This is because changes in climate have altered how ticks survive, act and develop within the changing environment[42]. Leishmaniasis is a second example where the distribution of sandfly vectors can be altered by climate change and therefore geographical distribution of the pathogen[66]. Other pathogens affected by changes to climate include fungal agents like *Blastomyces dermatitidis* and *Cryptococcus gatti* which rely heavily on soil ecology and the temperature. In addition, heavy rainfall can increase the distribution of water-borne pathogens like *Giardia spp*[66].

Climate change also disrupts the ecology of wildlife and therefore the distribution of pathogens carried by wildlife reservoirs[66]. For example, climate change has affected the habitats and therefore distribution of arctic and red foxes who are the sylvatic reservoirs for Rabies virus[28]. Other examples include the distribution of parasites like *Echinococcus spp*. commonly seen in wild canids[10,28,66]. Warmer climates will lead to longer survival times of environmental stages for canid parasites. Furthermore, the distribution and densities of these wild canids will also shift as a result of climate change[10,28]. Jenkins et al. predicts the introduction of *Diphyllobothrium latum, Toxocara canis* and *E. multilocularis* into new regions as a product of Canada's changing climate[10]. The distribution of freshwater fish, the intermediate host in many parasitic life cycles, will also be significantly affected by climate change[10,28]. Particularly in northern communities, dogs can act as a bridge between wildlife and humans, and therefore increase the exposure risk of many of these pathogens to humans[10].

The effects of climate change will impact northern communities within the Artic substantially[3,10]. Milder climates in the north will also cause growth in tourism, agriculture, and local businesses. This will further promote the movement of dogs into these communities, and with them, parasites they may be carrying that are foreign to the area[10]. Several authors agree that establishing a One Health initiative is part of the solution. As climate change continues to effect ecosystems and the health of vegetation, fish, wildlife and humans (particularly the Indigenous), health professionals, public health officials, veterinarians, environmental scientists, ecologists, geographers, biologists and epidemiologists will all play a role in the solution to combatting the effects of climate change and zoonotic disease risk in Canada[10,28,66].

1.2.3.2 The Impacts of Canine Zoonoses on Indigenous Communities in Canada

Dogs represent valued members of Indigenous communities and are used for a variety of reasons including companionship, protection, social status, tradition, hunting, and travelling[3,10,39]. Increased zoonotic risk is largely due to the profound effects of climate change (particularly in northern regions), cultural and lifestyle practices, as well as the increased likelihood of free-roaming dogs[3,10,26,66]. From the Indigenous perspective, allowing dogs to roam does not indicate abandonment, but provides increased opportunities for exercise in their dogs as well as socialization with other dogs in the community[3]. Additionally, a large proportion of dogs in remote communities are often of a young age, where the rate of parasitism is high[26,30]. Schurer et al. identified a high proportion of parasitic infections in members of an Indigenous community who did not directly own a dog, indicating environmental exposure as a source of canine zoonotic disease spread[30]. Because dogs are more likely to be free-roaming in Indigenous and Inuit communities, the widespread risk of pathogen exposure, including canine endoparasites, is comparatively greater than in urban centers[3].

When dogs from 5 Indigenous communities in Saskatchewan were surveyed for *T. canis*, a positive rate of 11% from 321 fecal samples was considerably higher than the 0.2% prevalence rate found in client-owned dogs in Saskatoon around the same time[10]. Risk of parasitic disease transmission from dogs to humans is also higher in Indigenous communities because these dogs are often not on endoparasitic preventatives. For example, in one Canadian study, less than 1/3 of individuals living in the Northwest Territories reportedly dewormed their dogs[68]. A Saskatchewan study that examined a northern Indigenous community found that only 1 out of 22 households who owned at least one dog had dewormed their animal(s)[69]. Many of these communities have

extremely limited access to veterinary services, further exacerbating the risk of canine zoonotic disease transmission[3,10,11,26,39].

Several studies have revealed a disproportionally higher rate of zoonotic parasitic infections in Indigenous peoples compared to the general population[10,26,28]. For example, a Canadian study from the 1950's found that out of 141 human cases of cystic hydatid disease (*E. granulosus*) 139 of these were Indigenous people[10,70]. Today, Indigenous people are still diagnosed at a proportionally higher rate than other Canadians[30]. A more recent 2010 study found that 11% of Indigenous residents (n=106) were seropositive for *Echinococcus spp*. in Saskatchewan[10,69]. According to Dudley et al., an alarming 40% of tapeworm infections are reported in Alaska Native and Inuit communities in northern parts of Canada. In particular, echinococcal infections remain significantly higher in these communities compared to the general population[28].

Although a heavy focus is placed on northern Indigenous communities in Canada, southern Indigenous communities must not be overlooked. Prevalence of canine zoonotic parasites obtained from canine and environmental samples in two southern Saskatchewan Indigenous communities were comparable to northern studies[26]. In general, the rate of parasitism in dogs was ten times higher than what's been documented in more urban locations. Of interest, the overall human risk to zoonotic exposure was found to be lower in southern Indigenous communities when compared to northern Indigenous communities of the same province. This was attributed to major differences in lifestyles and diet[26]. In addition to *Echinococcus spp.,* other parasites of growing concern in both northern and southern Indigenous communities include *Toxoplasma spp., Trichinella spp*. and *Toxocara spp*[26,30].

There are numerous factors that contribute to why communities are without access to veterinary services. As an example, dogs in the Nunavik region of Quebec require transportation

by air to receive spay and neuter procedures at the nearest veterinary clinic[3]. Resources often do not allow for the delivery of preventatives or treatment aids, and there is an overall lack of training for personnel in these remote locations[10]. Furthermore, community members may disagree with intervening methods from a cultural standpoint, which includes deworming, vaccinations and surgical desexing[3,26,39]. In addition, socioeconomic factors often inhibit the success of educational tools or public health measures[3,10]. All of this highlights a lack of trust and communication between collaborators within and outside the community and a need for "transdisciplinary partnerships"[3]. While surveillance of canine zoonoses in these populations would be of significant benefit to dealing with zoonotic disease threats, lack of veterinary and medical services remains a huge limitation for ongoing disease surveillance in these regions[10]. Additional work and support are required to combat canine zoonotic pathogens and public health risks in Indigenous communities throughout Canada in a sensitive and collaborative manner[3,39].

1.3 Current Methodologies for Pathogen Prioritization

1.3.1 The Purpose of Pathogen Prioritization

Pathogen prioritization is a necessary first step in the development of any surveillance system[71,72]. Whether acquiring public health or animal health data, limited resources must be allocated in a way that is meaningful, while avoiding potential biases[16,17,19,71,73–77]. In addition to this, it is simply not possible to obtain survey data on every zoonotic disease present in a country[19,76,78]. Finances and personnel required to gather such information are both finite resources[18,79–81]. This is why only certain infectious diseases are nationally notifiable in Canada[80,81]. In addition, pathogen prioritization is crucial for emerging disease preparedness to predict where to invest resources as part of an early warning system for novel disease threats[16,71] . Efforts are often focused on the impacts of climate change and social drivers on disease transmission[65,71,82].

Ultimately, the final goal of a pathogen prioritization exercise is to identify where prevention and control efforts should be utilized[17,18,65,77,81,83].

Pathogen prioritization strategies will vary greatly between countries and must continuously evolve over time. Furthermore, pathogens of interest will vary depending on research or surveillance objectives[16]. Therefore, it is important to establish which pathogens are relevant to the project, for a particular region, at the time of study. Lastly, pathogen prioritization is a way to inform decision-makers, stakeholders, and members of the public invested in a project[18,67,71,81,83].

1.3.2 A Lack of Universal Methods for Pathogen Prioritization

Prioritization methods have been well studied and adapted over the years. A continued challenge is the lack of a "universal" method which would improve objectivity and reduce biases in prioritization exercises[71,73]. This is because prioritization methods need some degree of flexibility. Project and surveillance goals will vary by region, research interests, and time of study[71,74]. In addition, variability in incidence, transmissibility, clinical manifestations, social and economic impacts, and prevention and control capabilities vary greatly between diseases, making universal methods for individual prioritization exercises implausible[73]. In other words, the methods used need to also reflect the pathogens of interest. To help combat these challenges, prioritization exercises should be repeated at regular intervals and adjusted accordingly based on the purpose of the program and stakeholder needs[16,19,71,76,78,81].

1.3.3 Current Prioritization Examples

The majority of prioritization examples described in the literature are for human diseases. Many prioritization exercises focus on communicable diseases in humans, including some zoonoses, as well as food-borne diseases[71,73,79]. Few animal examples exist. In particular, there is

only one companion animal specific example in the literature which prioritized pathogens from cats, dogs, pet pigs, hobby sheep and goats, as well as reptiles[78].

In general, there are three approaches to prioritization: quantitative, semi-quantitative and qualitative methods[18,71]. Quantitative methods rely strictly on numerical scales that allow ranking of selected pathogens to be based on objective values, such as incidence and prevalence[18]. Qualitative methods are much more subjective, relying on individual preferences or group consensus for pathogen ranking. Although semi-quantitative methods still rely on subjective preferences, choices are ranked relative to each other on a numerical scale, offering a combination of qualitative and quantitative methods[18].

Quantitative methods offer the most objectivity and reduce biases in a prioritization exercise; however, they are reliant on established scientific evidence and data already available in the literature[74]. Therefore, semi-quantitative and qualitative methods are recommended when there is limited information on a disease[71,78]. This is often the case for animal diseases, particularly companion animal zoonoses. For example, the prevalence of many companion animal diseases is unknown. Additionally, the incidence of human illness attributed to companion animal zoonoses is not well established[78]. Qualitative methods are more subjective because there can be variability in scoring decisions due to individual opinions and lack of scientific evidence[71,78]. Ng et al. argues that pathogen scores are always somewhat arbitrary, even when quantitative methodologies are used[73]. Different methods may be better suited for different needs and this should be established during the planning phase of the prioritization exercise[71].

Although several methods and prioritization strategies have been described, the overall steps of pathogen prioritization remain relatively consistent between many studies. These steps often include: choosing the diseases to be prioritized, selecting criteria upon which to assess each

disease, weighing the criteria based on level of importance, scoring each disease for every criteria selected, multiplying these scores by the weighted value, and finally ranking the diseases based on the total summed scores[16–19,71,73,75,77]. In addition to these steps, certain methodologies also choose a cut-off point within the final list to determine the inclusion or exclusion of diseases in a surveillance system[17,80]. Several authors emphasized that the final numerical score is not the most important factor, but rather, it is where diseases fall in relationship to one another that is most valuable[16,74,80].

Selection of the initial pathogen list is often based on pre-existing documents such as notifiable disease lists or other surveillance data[16,71,73,75]. Where data is lacking, expert opinion can be used to select pathogens of interest[71]. The initial disease list may consist of individual pathogens or groups of pathogens (ex. food-borne pathogens, vector-borne diseases, etc.)[18]. Although criteria selection should reflect each individual exercise, many studies have employed similar criteria. Examples of comparable criteria between studies included: burden of disease (incidence, prevalence, mortality), case-fatality rate, transmissibility, epidemic potential, socioeconomic impact, public perception, disease emergence potential, availability of diagnostic tests, and treatment and preventative options[17,19,72,76,81]. The objectives of the organization or group performing the prioritization exercise will alter the criteria used[71,74,79]. Several authors recommended that the number of criteria used should be limited, ranging from 5 to 12 criteria per exercise[17–19,75].

In general, experts with a background in human and animal health, such as doctors, veterinarians, public health officials, researchers and epidemiologists, are more commonly engaged in prioritization exercises[16,83]. Specialization of experts can make it difficult to prioritize a wide range of diseases which can lead to biases. Therefore a range of experts is needed to

increase objectivity[78]. Alternatively, some studies used the general public for similar ranking exercises[71,76,84]. Ng et al. found that the general public still produced meaningful results; however, better-fit models were produced by health professionals who partook in a similar prioritization exercise[73,84]. Similarly, Kadohira et al. found that the top 6 pathogens established in their ranking exercise were consistent between all stakeholder groups, including local citizens who participated in the study[76]. Regardless of the public's involvement in a ranking exercise, it is important to acknowledge public concern and improve risk communication because priorities for the general public may differ from that of stakeholders[82].

For each pathogen, criteria scoring typically followed a 3 (-1, 0, +1), 4 (0, 1, 3, 5), or 5-point (1-5) system in reported examples[17]. Each point value corresponded to a specific definition for the criteria of interest. For example, in Krause et al.'s 3-point system, under the criteria "mortality" a pathogen was awarded a score of -1 if "< 50 deaths/year" occurred in Germany as a result of the disease[75]. If "between 50 and 500 deaths/year" or "more than 500 deaths/year" occurred in Germany as a result of the disease, a score of 0 or 1 was awarded respectively[75]. In some methods, individual scoring is completed initially, then final pathogen scores and ranking are discussed as a group[19,78]. If group consensus is not reached for the final disease list, then re-ranking may be required where participants can adjust their scores[19].

Weights for criteria are also usually established by an expert panel[16,65,67,71,72,74,77,82]. Experts may be hand selected based on specific requirements[72,74] or randomly chosen[16,65,67,71,77,82]. These may be the same individuals participating in pathogen scoring or different individuals may be utilized between weighing criteria and pathogen scoring[16,65,71,72,75,79]. Clear definitions of each criteria, as well as weighing the criteria, can help to reduce bias[16,71,74]. Nonetheless, differing opinions on criteria weights may be evident between expert groups[16,74]. For example, Balabanova

et al. found that between epidemiologists, public health specialists, laboratory specialists, and clinicians, groups weighted some criteria differently based on varied motivations and priorities. Other criteria were weighted similarly between all expert groups[16]. Among several studies, the criteria "case-fatality rate" was often weighted with the highest importance[16,65,67,73,76,84]. Despite the variability in examples described here, prioritizing pathogens of interest is always a crucial step in the development of disease surveillance programs.

1.4 A Closer Look at Surveillance Systems

1.4.1 An Overview of Surveillance

1.4.1.1 Defining Surveillance

Surveillance is defined by the World Health Organization (WHO) as "the process of systematic collection, collation and analysis of data with prompt dissemination to those who need to know, for relevant action to be taken"[85]. A key difference between surveillance and disease monitoring is that surveillance should lead to a public health response[19].

Surveillance systems can be described as either "active" or "passive". In active surveillance, health agencies directly seek out data of interest. Although this collects more accurate information, active surveillance is timely and costly[14]. Alternatively, passive surveillance requires voluntary reporting from individuals enrolled in a surveillance program. While cost-efficient and relatively easy to execute, passive surveillance is prone to under-reporting, incomplete data, biases, and lack of a true denominator (the population at risk)[14]. Regardless of the approach used, surveillance systems should be evaluated at regular intervals[14,81]. Data obtained from companion animal surveillance programs can increase the understanding of zoonotic disease transmission from pets to humans, and fill a clear gap within the One Health space[86].

1.4.1.2 The Importance of Establishing Case Definitions

Once diseases of interest are determined through prioritization exercises, uniform case definitions for each disease are required for any surveillance system to be successful. This is true at both the provincial and national levels in Canada[80,81,87,88]. This is because case definitions create a level of standardization for what constitutes a case that is therefore eligible for reporting[87]. Usually, only confirmed cases are reported, using clinical, laboratory and epidemiological criteria; however, both "confirmed" and "probable" case definitions can be created for a disease[81,87,89]. As new pathogens are added to notifiable disease lists, or as knowledge on a disease increases, case definitions need to be periodically updated[88,89].

Rijks et al. performed a risk assessment on several companion animal zoonotic pathogens selected through a prioritization exercise as part of a European initiative called the Companion Animal Multisectorial Interprofessional Interdisciplinary Strategic Think Tank on Zoonoses (CALLISTO) Project[90]. The purpose of the risk assessment was to determine the role companion animals may play in disease risk to humans and livestock for their selected pathogens. A key finding to this study was inconsistencies between case definitions for several pathogens. This made risk analysis and therefore targeted prevention incredibly challenging. For example, the authors found that leptospirosis cases in one study would have been classified as controls in a second study. Therefore, Rijks et al. recommended the standardization of case definitions for pathogens shared between humans, companion animals and livestock. To assess the status of companion animal disease risk, good diagnostic tests must also accompany harmonized case definitions[90].

1.4.1.3 Gaps in Surveillance from the Companion Animal Perspective

Surveillance systems are well established for human, production animal, and wildlife diseases throughout the world at national and global levels[1,15,91–93]. In comparison, companion animal surveillance, including zoonotic, animal health, and welfare surveillance, is still underdeveloped worldwide[1,91,93–95]. Animal disease data currently collected for companion animal species is not representative of the massive pet population worldwide[96]. The majority of companion animal surveillance includes only a small number of diseases, with a particular emphasis on rabies[1,15,89,91,92,95]. Additionally, international health agencies are not required to coordinate companion animal disease reporting between countries. In production animals, this task is completed by the World Organisation for Animal Health (OIE)[1]. Companion animal surveillance is often only performed at national or regional levels, usually as part of a specific research objective. Standardization of nomenclature, case definitions, and laboratory testing are often not included in these efforts[1,92].

Furthermore, there is lack of integrated surveillance and public health collaboration at the human and veterinary interface, and these systems operate independent of one another[1,97]. In fact, Day et al. reported that only 19% of zoonotic surveillance systems included both humans and animals in a 2012 review[1]. A 2018 study used leptospirosis cases in humans and animals from Washington State to highlight how collaborative surveillance efforts for both human and animal cases would be beneficial[97]. The overall lack of companion animal surveillance data must be addressed "as a priority of the One Health perspective"[92]. Without companion animal surveillance, overall disease burden from pets remains unknown and the quick identification of emerging or novel disease threats is not possible[96]. Surveillance systems are also critical for developing prevention and control measures[94]. Given the intimate relationship humans have with their pets in

modern society, improving companion animal surveillance systems in Canada and across the globe is essential for public health advancement[93,94].

In Canada, there is no national directive for companion animal disease surveillance and only a small number of companion animal diseases are reportable at provincial and federal levels[15,89,98,99]. At the federal level, rabies is the only companion animal disease that is nationally reportable[100]. Although brucellosis is also federally reportable in Canada, it is specific to *B. abortus, B. suis,* and *B. melitensis* from a livestock perspective[100], excluding *B. canis* which is an emerging issue[94,101].

At the provincial level reportable diseases vary by province. For example in Alberta, Lyme disease and *Salmonella spp*. are reportable companion animal related diseases[89]. In Manitoba, brucellosis (including but not limited to *B. canis*) is provincially reportable[102]. While Smith et al. commends Canada's "robust" surveillance system for reportable diseases like rabies, similar surveillance efforts should be considered for non-reportable diseases[15]. This is emphasized by Smith et al. because 68% (28/41) of the companion animal zoonoses described in the 2012 review were non-reportable[15].

1.4.1.4 Current Examples of Companion Animal Surveillance Systems

There are only a small number of ongoing companion animal surveillance systems described in the literature. The Small Animal Veterinary Surveillance Network (SAVSNET) is a successful companion animal surveillance system in the United Kingdom (UK) that captures real-time surveillance on canine and feline infectious disease outbreaks by region[96,103]. The goal of SAVSNET is to understand breed distribution, susceptibility and trends, spread of diseases and "hotspots", to improve the prevention and treatment of infectious diseases among pets in the UK[104]. In particular, SAVSNET has done extensive work in syndromic surveillance. This program works

in conjunction with national laboratories to obtain companion animal surveillance data[96]. Across Australia, VetCompass offers real-time surveillance data using electronic medical records from participating small animal veterinary clinics[105]. A drawback to this system is that inconsistencies in medical record keeping can make data extraction from these large datasets inaccurate[105,106]. In addition, only a subset of the total population of animals is included in the program which may lead to selection biases[105].

Other smaller companion animal surveillance projects have also been described. An Italian program called Veterinary Surveillance of Pets (SVETPET) was a web-based reporting system for transmissible and non-transmissible diseases of cats and dogs in the country[92]. This system ran on voluntary submissions by veterinarians. Although the focus of this project was companion animal health, analyzing general pet health on a population scale contributed to human and public health concerns. Similarly to VetCompass, this program only represented a subset of the pet population[92]. Disease WatchDog was a previous national disease surveillance project created in Australia for dogs and cats, however, poor compliance from participating veterinary clinics lead to inaccurate data[105,107]. It is unclear whether SVETPET and Disease WatchDog are still operating at present.

Although the primary purpose of the 2-year CALLISTO project in Europe was to evaluate the role companion animals play in zoonotic disease transmission to humans, this project also proposed the development of a storage system using implanted patient microchips as part of an internationally accessible online database housing companion animal data[108]. In the United States, the Companion Animal Parasite Council is a national surveillance program that displays up to date tick-borne disease, intestinal parasite, and heartworm distribution data by month or year[1,109]. Currently, the only Canadian example of continuing companion animal surveillance is the Ontario Animal Health Network (OAHN)[110]. The purpose of the OAHN is to inform veterinarians of

animal health and disease trends in Ontario for several animal species, including companion animals. This is accomplished by collecting data from a network of veterinary professionals (through private practice, industry, academia, government, and producer groups) using quarterly surveys. Data obtained through these surveys are summarized and disseminated back to veterinarians with quarterly reports published directly on the OAHN website[110].

1.4.2 Surveillance Strategies Related to Public/Companion Animal Health

1.4.2.1 Dogs as Sentinels

One such method for using companion animals in a surveillance program is to use them as animal sentinels[86]. The use of pets as sentinels for assessing disease risk in humans has been well described in recent literature. For both infectious and non-infectious hazards, pets can be used as part of an early warning system for estimating disease risk in humans sharing the same environment[1,14,29,31,92,99]. Dogs in particular have served as sentinels for both human and wildlife populations[29,34,35]. Sentinel dogs can estimate disease risk for certain wildlife species, which in turn provides data for conservation efforts[35].

Sentinels can be further described as "incidental" or "intentional". For example, a dog sharing the same tap water as an owner may serve as an incidental sentinel for a hidden water-borne illness[31]. When the dog becomes sick, the owner may be incidentally alerted to the hazard in a shared water supply. Alternatively, intentional sentinels are consciously placed in an area to assess a suspected risk factor as the cause of disease[29,31]. For example, if researchers were interested in obtaining epidemiological data for a particular pathogen, they may elect to use a specific sentinel to estimate exposure potential[29].

There are several key factors that make an animal a good sentinel for the disease of interest. An ideal sentinel must be susceptible to the illness, survive the disease, be readily exposed to the

risk factor, and mount a response to the disease that can be detected quickly and easily (with observable clinical signs or through diagnostic testing)[29–31]. In addition, a good sentinel should not pose a direct transmission risk to humans, amplify and spread the pathogen, or act as a reservoir host[29,31]. Pets make good sentinels for several infectious diseases because they are in close contact with their owners. Therefore, disease risk from a shared environment is similar between pets and their owners because the source of infection will be the same[29,31,86,89]. Furthermore, the popularity of pet ownership means dogs and cats are easily accessible across many locations[89]. Ideally, sentinel data for the purpose of surveillance should be collected, analyzed and reported in real-time to act as an early warning system. Depending on the disease of interest, certain species will function as better sentinels than others[86].

Dogs are particularly good sentinels for vector-borne and other emerging disease threats, including Lyme disease and Rocky Mountain spotted fever[1,31,32,111,112]. This is because dogs are more susceptible to tick exposure than humans. They are closer to the ground, readily exposed, and are more likely to seek densely wooded areas[32,111]. Hunting dogs in particular have been shown to be at the greatest risk for contracting Lyme disease[32]. In addition, dogs do not present a direct transmission risk of Lyme disease to humans, although they may transport ticks into an owner's environment[32]. Not only are dogs good for assessing tick-borne disease risk in a population, collecting ticks from dogs through passive surveillance can reveal what species of ticks are present in a geographical area[111]. Because it is difficult to estimate the overall burden of Lyme disease in a human population, using dogs as sentinels for Lyme disease risk is an excellent alternative. In fact, a 2012 study in the UK demonstrated that the tick population is much higher than previous estimates[32].

Other vector-borne disease examples where dogs have been used as sentinels include Leishmaniasis and Trypanosomiasis. In non-endemic regions, a sudden increase in canine cases can serve as an early warning sign that geographical distribution of vectors has changed, or that vector control programs are inadequate. In endemic regions, dogs are main reservoir hosts for both Leishmaniasis and Trypanosomiasis, making them less ideal as sentinels once disease is established in an area[31]. In addition to vector-borne disease threats, dogs have also been used as sentinels in syndromic surveillance[86,113]. A sudden increase in cases of canine gastrointestinal disease in a particular region can signal a food or water-borne infectious disease risk to humans[113]. Utilizing dogs as sentinels through surveillance programs is all part of a cohesive One Health strategy[1,14,29].

Dogs may also act as sentinels for environmental hazards and non-communicable disease threats[29,31,89,92,112,114]. For example, domestic dogs have been used as incidental sentinels for lead toxicity in contaminated residential pipes or other household items[31]. In particular, dogs are good sentinels for environmental risk factors in children, as young children are more likely to exhibit similar behaviours to dogs[31]. Dogs and cats acted as incidental sentinels in 2007 when pet food containing melamine-contaminated gluten was detected after a rise in the number of renal failure cases was observed in the pet population. This alerted public health authorities to additional contaminated feed that had been fed to pigs and chickens destined for human consumption[29,31]. Pets as sentinels for bioterrorism and chemical terrorism has also been proposed[29,31].

In Canada, the use of dogs as sentinels from a public health perspective is currently underutilized[29]. A 2018 review evaluating the use of dogs as sentinels discovered only 6 Canadian studies out of 142 worldwide examples[29]. The most common examples of dogs as sentinels in Canada are reported in Indigenous communities[29,30,34]. This is because free-roaming dogs have

access to wild game, fish and garbage, and are subsequently exposed to many zoonotic pathogens[29,30]. Because these dogs are potentially consuming the same food as individuals in the community, these dogs are excellent sentinels[30,34]. Schurer et al. proposed the use of dogs as sentinels for parasitic exposure risk in humans living in Saskatchewan Indigenous communities[30]. More research is needed to assess the utility of dogs as sentinels for several pathogens emerging in Canada[29]. Using dogs as sentinels for public health purposes may be an efficient and economically viable solution to obtaining surveillance data relevant to both human and animal populations[29,30].

1.4.2.2 Syndromic Surveillance

Syndromic surveillance is a surveillance strategy that uses clinical signs specific to a "syndrome" of interest, rather than focused surveillance on a specific disease, in a defined region[14]. Syndromic surveillance may encompass several diseases that produce similar symptoms. The purpose of syndromic surveillance is to act as an early warning system[86], therefore, the benefit of syndromic surveillance is that it signals the possibility of an outbreak quickly without the need for laboratory confirmed diagnoses[14,98]. The drawbacks of syndromic surveillance programs are that they are costly, heavily dependent on available resources, and a higher false positive rate compared to disease-focused surveillance programs[14]. As with any surveillance system, clear definitions for the syndrome of interest is required prior to the start of the program[86,115]. When appropriate, syndromic surveillance can evolve into a disease-specific surveillance system[86].

SAVSNET has several examples where syndromic surveillance has been utilized. Arsevska et al. reported on canine and feline respiratory disease data that were identified via SAVSNET over the course of 2017[116]. In addition, temporal patterns for gastrointestinal illness and pruritis were also reported from 2014 to 2017. Although the primary focus of SAVSNET is

to obtain animal health related data, the zoonotic respiratory pathogen *Streptococcus equi* subsp. *zooepidemicus* was cultured in 198 samples (from dogs, cats and Guinea Pigs) from 2010 to 2017. Seventy-five percent of the canine samples were isolated from the upper respiratory tract (nose, trachea, or oropharynx). This demonstrated the public health benefits of syndromic surveillance in companion animal species[116]. Additionally, from May 2010 to August 2011, gastrointestinal data from SAVSNET was used to evaluate cases of diarrhea in companion animals from 42 veterinary clinics throughout the UK[113]. Surveillance data on dogs and cats presenting to clinics for diarrhea included species, gender, breed, duration of illness, severity of disease, diagnostic tests performed, and treatment given. Furthermore, this data was available in near real-time. In this example, companion animals were used as sentinels for zoonotic and emerging gastrointestinal pathogens[113].

A 2017 piloted surveillance program created in Washington, D.C. involved both disease-specific surveillance and syndromic surveillance[117]. The syndromic surveillance system identified spikes in companion animal respiratory infections and dead-on arrival cases over the course of one year. The goal of this pilot program was to provide evidence that companion animal surveillance data (disease-specific and syndromic) may be useful from a public health perspective[117]. Lastly, Anholt et al. investigated the use of electronic medical records (EMR) in small animal veterinary clinics as a tool for gathering syndromic surveillance data on gastrointestinal diseases in pets living in Calgary, Alberta[98,115]. This data was used to assess possible animal and public health threats in the region of interest. While clustering of gastrointestinal cases in pets from enrolled clinics could be captured, the utility of EMR data extraction for surveillance purposes had some limitations. This was largely related to non-standardised medical nomenclature within medical records or lack of complete information[98,115]. Despite these challenges, text mining software retrieved relevant

enteric cases at a sensitivity of 87.6% and a specificity of 99.3% when compared to human reviewers of the same data[115].

1.4.2.3 Surveillance of Antimicrobial Resistant Pathogens

The majority of current AMR surveillance systems focus on antimicrobial use (AMU) and AMR in humans and production animal species[24,57,118,119]. As previously identified, companion animals can also be a transmission source for AMR pathogens to humans[6,24,53,118]. Several authors recommend the inclusion of companion animal AMU and AMR data in surveillance programs[24,53,57,118,120,121]. Historically, data on AMU and AMR in the pet population has been extremely limited[52].

Because of the zoonotic potential of resistant pathogens, including but not limited to MRSA, MRSP, VRE, *Salmonella spp*., and ESBL *E. coli*, AMR in companion animal species is a serious public health threat[6,52,53,94,118]. Companion animal surveillance data on AMR would help establish the role of pets as possible reservoirs for these pathogens[118]. In addition, surveillance data on AMU in small animal veterinary clinics would help address where antimicrobial stewardship efforts need to be focused[94,122]. For example, SAVSNET has gathered prescribing data from more than 22,000 companion animal veterinary consultations throughout the UK[122]. This baseline data can be combined with susceptibility data from laboratory surveillance to better assess public health risks related to AMU in companion animals[57,122]. In Canada, the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) is a national surveillance system that monitors AMU and AMR in humans, animals (largely livestock) and food[119,123]. AMR surveillance regulated at the provincial level has also been suggested to help prevent gaps in data[24]. Regardless, including companion animals in AMR surveillance systems is required to successfully achieve a One Health objective[57].

1.4.3 The Role of Veterinarians and Veterinary Clinics

There are several examples where the utility of veterinarians and veterinary clinics in surveillance programs have been explored. The first examination is the use of veterinary clinics as part of a sentinel network[1,89,106,111,124]. This involves the enrollment of willing participants to share companion animal health data of canine and feline patients. Surveillance data from veterinary laboratories are often incorporated[53,124]. Establishing the willingness of veterinarians to participate in such surveillance programs is a key initial step to creating a surveillance system[117,125]. Companion animal surveillance systems have the opportunity to incorporate primary-care facilities and/or referral practices[106].

One area that has been well studied is the use of electronic medical records (EMR) for syndromic surveillance data[14,89,98,99,105,106,111,115,124]. The goal of such systems is to extract data from medical records to uncover and evaluate disease trends in the companion animal population. This is for a defined geographical area where disease patterns identified in the pet population may be relevant from a public health perspective (for example, enteric pathogens of zoonotic potential). A major obstacle for the utility of these surveillance systems is a lack of standardization in medical record keeping and incomplete records[14,89,98,105,106]. This means that data may not be properly captured by extraction software if nomenclature used between medical records is inconsistent.

Additionally, the overall management and analysis of large datasets can be challenging[106]. The National Companion Animal Surveillance Program (NCASP) designed in 2004 by Purdue University attempted to gather and use EMR data from more than 500 Banfield Veterinary Hospitals across the United States[124]. O'Neil et al. indicated that "NCASP surveillance was limited by confidentiality issues, delayed dissemination of results and difficulties in managing such large volumes of data" and at present, NCASP is no longer in operation[106]. It is important to also

recognize that sentinel practices enrolled in surveillance programs represent only a subset of the canine and feline population[89,106]. In syndromic surveillance, data is only being captured from animals for which owners sought medical attention. Therefore, owners have to be willing to seek out veterinary services when their animal is exhibiting signs of illness; but also suggests that subclinical cases are likely not identified[106].

Alternative methods that have been explored include the utility of web-based systems where participating veterinarians input surveillance data directly[1,53,92,117]. Although this involves a larger time commitment from the veterinarian[92], it avoids the limitations surrounding standardization of medical record keeping. Participation of veterinarians for the web-based reporting system developed by Martini et al. was completely voluntary[92]. A key feature of this system was that whatever level of clinical detail was available could be included in the submission, from symptoms and presumptive diagnoses to definitive diagnoses[92]. Web-based surveillance platforms are favorable for the real-time dissemination of surveillance data, for example, in the form of disease-distribution maps or disease alerts[1]. A few limitations of these systems is often low compliance from participating veterinary clinics, and data is also not representative of the entire population[92,117]. Other methods that have been described include active surveillance using veterinary practice questionnaires[106,110]. Veterinarians, staff, and clients can contribute data. While clinic questionnaires are a quick, inexpensive and reliable method for obtaining surveillance data, limitations include poor response rates and recall bias. Similarly to other methods, only a portion of the pet population can be captured[106].

It is evident that veterinarians can play a crucial role in contributing data to a companion animal surveillance program. In addition, veterinarians will be able to use gathered surveillance data to make evidence-based decisions regarding their own patients and cases[124]. This is

particularly relevant for AMR surveillance data[52]. Veterinarians are also essential in surveillance programs as client educators; to help raise public awareness for the human health risks associated with animal ownership[42,53]. In addition, veterinarians are critical for One Health collaboration, to bridge the gap between human and animal health[14,53]. Veterinary medical associations should be included in the conversation, as a resource for veterinarians in regard to companion animal disease reporting[14].

1.5 Conclusions and Rationale for Study

This literature review has addressed three main objectives. First, it provided an overview of canine zoonoses and public health considerations in Canada. Zoonotic terminology, the role of dogs in disease spread, and the benefits and risks of dog ownership were examined, with a particular emphasis on the immunocompromised and Indigenous groups. Furthermore, the role of climate change as it pertains to canine zoonotic disease transmission and emerging risks within Canada was also explored.

The second and third objectives of this review looked at current pathogen prioritization strategies and surveillance systems, revealing an overall lack of research in prioritization and surveillance programing for companion animals specifically. The only companion animal prioritization example identified was the European CALLISTO project[78]. In addition, there are few examples of companion animal surveillance programs, particularly within Canada. This included but is not limited to dog bite and AMR surveillance. No formal reporting strategies exist for such public health concerns in Canada. The only formal companion animal surveillance system in Canada can be found in the OAHN[110]. The Prairie Provinces specifically have minimal ongoing prevalence data on canine pathogens of public health concern.

Collaboration between veterinary and medical professionals is required to improve both animal and human health as part of a One Health approach. The role of veterinarians in companion animal surveillance programs from a public health perspective also needs to be further explored. Although companion animal surveillance can identify animal health trends and promote action that improves the lives of animals, a large portion of any surveillance initiative is to inform public health. This is why there was a heavy focus in this review on the public health significance of canine pathogens and companion animal surveillance. The implications and importance of public health will be a strong focus in the research chapters to follow.

Based on the knowledge gaps outlined above, this study was designed with the following research objectives in mind:

- First, to create a comprehensive list of canine pathogens and establish a shortlist of important canine zoonotic pathogens relevant to the Prairie Provinces of Canada from a public health perspective.
- Second, to prioritize this shortlist using combined expert opinion to identify pathogens that should be considered in a companion animal surveillance initiative.
- Third, to investigate the role of veterinarians and veterinary clinics in a companion animal surveillance system in the region of interest, to use veterinarians to develop case definitions for canine pathogens of interest, and to assess domestic dogs as sentinels for human health risks using Lyme disease as an example.

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CHAPTER 2: DEFINING IMPORTANT CANINE ZOONOTIC PATHOGENS WITHIN THE PRAIRIE PROVINCES OF CANADA

2.1 Abstract

The goal of this study was to establish a shortlist of zoonotic pathogens involving the domestic dog that can be prioritized for a companion animal surveillance program specific to the Prairie Provinces of Canada. A list of pathogens ever documented in canines was created through a comprehensive review of infectious disease textbooks for the following taxonomical categories: bacteria, ectoparasites, fungi, helminths, protozoa, rickettsia and viruses. This created an initial list of 594 pathogens that was then pared down through an extensive review of the literature using the following criteria: (1) the pathogen is zoonotic/sapronotic/anthroponotic, (2) the dog is involved in transmission to humans, maintenance, or detection of the pathogen, and (3) there is a level of risk for occurrence of the pathogen in Canada. This process yielded a final list of 84 pathogens and three supplementary lists of canine zoonotic/sapronotic/anthroponotic pathogens that may become relevant to future surveillance programs. The next phase of study will include prioritization of these pathogens using experts in the field to advise public/animal health policy and the investment of resources[1,2]

2.2 Introduction

The relationship between humans and companion animals has become increasingly intimate over time[3,4]. According to the Canadian Animal Health Institute, there were an estimated 8.2 million dogs and 8.3 million cats residing in Canada in 2018. It is reported that 41% of Canadian households own at least one dog and 38% own at least one cat[5]. Unfortunately, there is limited information on zoonotic disease prevalence in the animals with which people share the most time and closest contact[3]. Thus, there is a growing need in the Prairie Provinces of Canada for information on companion animal diseases that can also affect humans. Of the approximately

1500 infectious organisms known to cause human disease, it is reported that 60% of these are zoonotic and originate from animal sources[6]. Exploring companion animal zoonotic pathogens from a One Health perspective becomes especially important for the most vulnerable populations. This includes those who are immunocompromised[7], and remote communities with limited access to both medical and veterinary resources[8,9].

There is currently little to no data on the prevalence of canine zoonotic pathogens within the Prairie Provinces of Canada. While several studies exist in the Prairie Provinces for individual canine pathogens[8,10–12], those most significant from a public health standpoint, as well as prioritization of these pathogens to guide public/animal health policy has yet to be explored. Determining pathogens of significance is a foundational step in developing a surveillance program.

Surveillance systems are already well established in human medicine[3,6]. Several examples also exist in the Canadian livestock industry from both a veterinary and public health perspective[13–15]. In addition, wildlife surveillance occurs in Canada at both the provincial and federal level[16,17]. Currently, rabies is one of the only companion animal zoonotic pathogens that is routinely monitored through federal and provincial surveillance programs[18,19]. The Ontario Animal Health Network (OAHN) is the first provincial initiative to collectively monitor companion animal disease trends in this nation[20]. While companion animal surveillance programs are well established in other parts of the world[21], there is a clear gap that needs to be filled for companion animal health data in the Prairie Provinces. A companion animal surveillance program can provide both animal health data (demographic and disease data) in addition to relevant public health data.

The first step to establishing a companion animal surveillance program in the location of interest was to determine which pathogens are significant, focusing on the domestic dog. The primary objective of this study was to establish a shortlist of pathogens seen in the domestic canine

population that have public health implications within the Prairie Provinces. A secondary objective was to formulate any additional pathogen lists that represent those pathogens that may be important to future surveillance initiatives.

2.3 Materials and Methods

2.3.1 Initial List and Stepwise Approach

A list of pathogens in the taxonomical categories bacteria, ectoparasites, fungi, helminths, protozoa, rickettsia and viruses ever documented in canines was created by reviewing the most up to date, authoritative veterinary infectious disease textbooks[7,22–24]. If a pathogen was listed as having been identified in domestic canines in any of these textbooks, it was included in this initial list. In addition, the list was supplemented with the pathogen *Sars-CoV-2* (Covid-19)[25]. Several ectoparasites were also included but were limited to mites and fleas. Pathogens were classified to species level whenever possible. This was often dependent on how taxonomic ranking was documented in the literature. When a number of species were involved (for example, with dog bite and enteric pathogens), or when the species level was not reported, pathogens were characterized no further than the genus level.

A subsequent extensive and structured literature search followed a stepwise approach (Fig. 2.1) to narrow down this initial pathogen list using the following steps. The first step was to assess any evidence that the pathogen was zoonotic, sapronotic, or anthroponotic. The second step was to assess any evidence that the dog played a role in how humans acquire the pathogen. Roles included the direct transmission of the pathogen from dogs to humans, dogs maintaining the pathogen in the environment as a definitive or reservoir host, and finally, that dogs can be used to detect the pathogen in the environment as a sentinel for human exposure. The third step was to assess any evidence for each pathogen's level of risk for occurrence in Canada, since few

publications were known to exist specifically for the Prairie Provinces. These steps were developed through in-depth discussions by the primary researchers.

2.2.2 Defining Zoonotic/Sapronotic/Anthroponotic (Step 1)

For the purposes of this study, pathogens advanced from Step 1 if they were zoonotic, sapronotic or anthroponotic. *Zoonotic* was defined as any pathogen that is transmitted from animals (or animal tissue) to people and results in human illness[26]. Transmission can include direct contact (by skin, inhalation, or ingestion), indirect contact through fomites or a contaminated environment, as well as vector transmission[7,23,26]. *Sapronotic* represented any pathogen that replicates on abiotic substrates in the environment with the ability to infect both animals and humans without direct transmission between hosts[7,26]. Finally, in this study, *anthroponotic* represented predominantly human pathogens that have the potential to be transmitted from humans to animals (as reverse zoonoses)[7].

An extensive search of the literature and infectious disease textbooks[7,22–24] was done to determine if a pathogen from the initial canine list was zoonotic, sapronotic or anthroponotic. This included searches using the pathogen name, followed by "human illness", "in humans" or "human disease" in research databases Google Scholar and PubMed. There were no limitations placed on publication year during searches. If at least one source identified the pathogen as zoonotic/sapronotic/anthroponotic, or if the pathogen was reported to cause clinical illness in humans, then the pathogen was not discarded (this included opportunistic pathogens). Pathogens were assessed in Step 1 regardless of whether or not the dog was involved in transmission of the pathogen to humans. If a pathogen did not meet the definition of zoonotic/sapronotic/anthroponotic, or if evidence in the literature to support infection in humans could not be found, it was removed from the list.

2.2.3 Role of the Dog (Step 2)

An extensive review of the literature and infectious disease textbooks[7,22–24,27] was used to evaluate the role of the dog for all of the pathogens that advanced from Step 1. This included searches using the pathogen name, followed by "dog to human", "dog transmission" and "dog sentinel" in research databases Google Scholar and PubMed. Pathogens advanced if the dog was involved in direct transmission of the pathogen, acted as a reservoir host and helped to maintain the pathogen in the environment (for example, acted as a definitive host in a parasitic life cycle), or acted as a sentinel for human infection and detection of the pathogen. If the dog was historically involved in transmission to humans, maintenance or detection of the pathogen, regardless of how common the pathogen is, it advanced to Step 3. If there was not enough evidence in the texts or literature, such that the role of the dog was still largely unknown, it was discarded from the list. For several pathogens, there was not enough evidence in the literature to prove or disprove the role of the dog in transmission to humans, maintenance or detection of the pathogen from a public health perspective. Therefore, a supplementary list denoted *Grey-Zone Pathogens* was created to highlight these particular pathogens for their possible public health significance in the domestic canine population.

2.2.4 Presence in Canada (Step 3)

Once it was established that the dog was involved in transmission to humans, maintenance, or detection of the pathogen, Step 3 was to determine the level of risk for occurrence in Canada of each remaining pathogen using a four-tiered approach (Fig. 2.2). These tiers included (1) the pathogen has been reported in dogs in Canada historically at least once, (2) the pathogen has been reported in Canada historically at least once, but canine-specific reports are lacking, (3) the pathogen has not historically been reported in Canada, or its distribution is unknown, but there is

a level of risk for occurrence of the pathogen in Canada due to appropriate climate, vectors, reservoir hosts, and lifestyle, and (4) the pathogen is unlikely to occur in Canada because the main reservoir host is missing, the current climate in Canada would not support survival of the pathogen or vector, or lifestyle does not fit with pathogen occurrence.

The purpose for using a four-tiered approach allowed for the recognition of those pathogens that may not be significant to the Canadian canine and human population currently but could become relevant in the future. Information about each pathogen's presence or capacity for occurrence in Canada was obtained through an extensive search of the literature using the pathogen name followed by "in Canada" and "in Canada in dogs" in research databases Google Scholar and PubMed. This step included reports of pathogens in all of Canada because of the limited research available for the Prairie Provinces exclusively. If a Canadian report specifically involved the dog, the pathogen was placed in *Tier 1*. If canine-specific reports were not identified but the pathogen has been documented in Canada (in human studies or other species, as well as environmental examples) these pathogens were placed in *Tier 2*. If the pathogen was not documented in Canada at the time of this study, additional searches were performed to identify whether the pathogen had the potential to occur in Canada. For example, searches were completed to determine the geographical distribution of vectors, or first and second intermediate hosts depending on the pathogen. If this information supported possible survival of the pathogen in Canada (ie. the vector or intermediate hosts have been reported in Canada), then these pathogens were placed in *Tier 3*. It was assumed that bacterial pathogens not currently reported in Canada (such as several dog bite pathogens) have the capacity to occur in Canada since they are not reliant on vectors or intermediate hosts. For this reason, additional searches were not required for bacterial pathogens that did not qualify for *Tier 1* or *Tier 2,* and these bacteria were automatically placed in *Tier 3*. If

there was no evidence at the time of this study to support survival of the pathogen in Canada, or the distribution of vectors and intermediate hosts did not include Canada, these pathogens were placed in *Tier 4*. Pathogens grouped in *Tier 1* represented the final shortlist. *Tier 2* and *Tier 3* pathogens represented supplemental shortlists to highlight pathogens that may become significant to canine surveillance initiatives in the future. *Grey-Zone Pathogens* identified in Step 2 were also further categorized as being present in Canada or having the potential to occur in Canada using the same search strategy.

2.4 Results

A total of 594 infectious pathogens were identified in canines (Appendix A; Fig. 2.3). Of these, 235 were bacteria (40%), 14 were ectoparasites (2%), 79 were fungi (13%), 109 were helminths (19%), 62 were protozoa (10%), 19 were rickettsia (3%), and 76 were viruses (13%). From this initial list, a total of 486 pathogens (82%) were then identified as zoonotic/sapronotic/anthroponotic. Of these 486 pathogens, 71 were specifically classified as *sapronoses* (15%).

From the previous 486 pathogens, a total of 241 pathogens (50%) were further identified as involving the dog in human infection through either direct transmission, maintenance of the pathogen in the environment, or as sentinels for human exposure (Appendix A). An additional 29 pathogens were classified as *Grey-Zone Pathogens*. This represented pathogens where there was evidence to suggest the dog's role in transmission to humans, maintenance or detection of the pathogen but there was not enough evidence to prove or disprove the role of the dog at this time. Of these 29 pathogens, 19 were present in Canada and 7 had the potential to occur in Canada (Appendix B).

Of the previous 241 pathogens, 84 pathogens were identified in canines in Canada (*Tier 1*; Table 2.1), 74 were reported in Canada but canine-specific reports were lacking (*Tier 2*; Appendix C), and 31 pathogens were classified as having the potential to occur in Canada (*Tier 3*; Appendix D). A total of 52 pathogens were identified as unlikely to occur in Canada (*Tier 4*).

2.5 Discussion

Using a stepwise approach, an initial list of 594 pathogens identified in canines was created and reduced to 84 pathogens (*Tier 1*) relevant to the Prairie Provinces from a public health perspective. In addition, three supplemental lists (*Tier 2 & 3*, and *Grey-Zone Pathogens*) were formulated to highlight several other groups of pathogens that may become relevant to future surveillance initiatives. To the best of the author's knowledge this is the first study in Canada to summarize and list important canine zoonotic/sapronotic/anthroponotic pathogens with the intent to prioritize these pathogens to help establish a companion animal surveillance program. A follow-up study will rank the final pathogen list using combined expert opinion to advise public/animal health policy on which pathogens should be prioritized for a companion animal surveillance program in the Prairie Provinces of Canada.

The initial list may not be completely exhaustive and there is an opportunity for rare pathogens to be missed. The veterinary infectious disease textbooks used to create the initial pathogen list are comprehensive and well-founded, and are likely to capture the majority of the pathogens identified in dogs. Because the world is constantly changing it is also possible that emerging pathogens will arise during the course of this research. Depending on how one chooses to define *zoonotic*, classification of a pathogen may be subjectively based on who is creating the list and their personal objectives. Therefore, the final shortlist is not completely rigid but is not likely to change substantially. The investigators did not employ double-blind methods for paring

down the list and doing so may have altered the final shortlist. Follow-up ranking exercises will provide the opportunity to revise pathogens on the list.

A significant portion of this review became an exercise on what constitutes a zoonotic pathogen. There were several instances of contradicting views in the literature on whether or not a pathogen was categorized as zoonotic[7,23,24,28]. This was why having a clear definition of *zoonotic/sapronotic/anthroponotic* prior to condensing the list was extremely important. A priority for this study was to ensure that if a canine pathogen impacted human health in any way it was not overlooked if it was not *zoonotic* in the traditional sense (direct animal to human transmission). Several definitions were utilized to explore how a pathogen related to human disease. For example, sapronoses were assessed in Step 1 because although they are not directly zoonotic, dogs can serve as sentinels for sapronotic pathogens and reveal a risk for human exposure from a shared environment[7]. Anthroponoses were also assessed in Step 1 to explore the idea that if a human pathogen can be transmitted from human to canine, there is also a concern for transmission to occur in the other direction. Unfortunately, it is often challenging to verify zoonotic transfer versus shared environmental exposure[27], which is why it is also important to consider dogs as sentinels for many of these pathogens.

Several ectoparasites were included in the initial list of pathogens. Many ectoparasites (including fleas, ticks and sandflies) are important from a public health perspective because they can act as vectors for zoonotic disease transmission[29–31]. This exercise explored whether the ectoparasite itself should be classified as *zoonotic*. This became particularly relevant for the flea. Fleas are known to transmit several very serious pathogens to humans[31–34] but they can also cause clinical signs in humans on their own. This includes erythema, pruritis and dermatitis[24,35]. Because of this, the flea was also classified as zoonotic in addition to the many pathogens this vector can

harbor and transmit to humans. While the clinical signs caused by the flea are far less severe than many of the pathogens they harbor, based on the extensive definitions employed in this study, the flea was included in the zoonotic category.

In exploring how the dog plays a role in transmission to humans, maintenance and detection of these zoonotic/sapronotic/anthroponotic pathogens, a subcategory denoted *Grey-Zone Pathogens* was also created. This represented pathogens where there was some evidence in the literature that dogs are likely to contribute to human infection, either directly or as sentinels, however nothing has been definitively proven at this time. This is either because there has not been enough research done on the pathogen, or it could not be determined whether transmission or shared environmental exposure occurred if infection in the dog was not explicitly identified[27]. These pathogens may play a role in canine zoonoses in the future and should not be overlooked. Step 2 in particular exposed an overall lack of research in canine transmission of zoonotic pathogens. Several pathogens were excluded from Step 2 because there is simply not enough evidence at this time for the dog's role in transmission, maintenance or detection of the pathogen. These *Grey-Zone* pathogens were further assessed for presence in Canada, and the potential to occur in Canada as a way to help highlight those pathogens that may become most important to the Prairie Provinces.

There was limited research available specific to the Prairie Provinces, therefore, literature encompassing all of Canada was included in Step 3 to evaluate occurrence of a pathogen in Canada. This lack of research emphasizes the need to identify pathogens relevant for surveillance programs because companion animal zoonotic disease prevalence is so limited in local regions. It is important to note, that inclusion of a pathogen in Step 3 was based on what is currently available in the literature. In the evolving world, through globalization and the impacts of climate change,

some of the pathogens listed in the third and fourth tiers may become more relevant to Canada in the future and should not be completely discounted for prospective surveillance studies. For example, non-native species of snails that act as first intermediate hosts in several parasitic life cycles have invaded regions of the world where they were not previously seen[36]. In particular, climate change also impacts the distribution of many important vectors[37,38]. Pathogens in *Tier 2* and *Tier 3* were highlighted as a reminder that just because a pathogen hasn't been recorded in Canada, or identified specifically in the dog in Canada, doesn't mean the pathogen isn't relevant for canine surveillance. It could simply mean these canine pathogens haven't yet been identified in this region because researchers haven't been looking for them. It is important to also acknowledge the effect of canine zoonotic pathogens on rural populations within the Prairie Provinces and the challenges these areas face with limited access to both medical and veterinary services[8,9].

Several other interesting findings emerged during the course of this study including dog-bite relevance in Canada. During the review process it became apparent that specific information on dog bite pathogens and reports in Canada are limited. Although it is suspected that several dog bite pathogens are present in Canada, for many of these pathogens there were no reports to confirm this. This is likely related to the challenges associated with bacterial isolation from contaminated bite wounds. Often initial cultures are not representative of true infection[39,40]. The recommended treatment for dog bite wounds is wound management alone and cultures are only performed in persistent infections[39,40]. In cases where the wound persists and cultures are collected, a surveillance program to monitor pathogens isolated in unresolving dog bite wounds may be worth exploring. This is of particular importance for dog bite pathogens such as *Capnocytophaga canimorsus* which can be fatal[41]. One particular Canadian study explored the overall occurrence

of dog bites and degree of injury in children; however, the pathogens involved in these wounds were not the focus of the study[39].

Additionally, antimicrobial resistant pathogens in canines became significant in this study as this continues to be a growing area of concern and research. Canine bacterial isolates of interest on the final shortlist included MRSA, MRSP, VRE, *E. coli*, *Salmonella spp.,* and urinary isolates *Klebsiella spp*. and *Pseudomonas aeruginosa*. Pathogens that are resistant to antimicrobials, particularly multi-drug resistant (MDR) pathogens, are a major public health concern. Dogs living in close contact with their owners can potentially shed these pathogens in the environment and act as a source for human infection[42–46]. For a large number of pathogens identified in this study, including antimicrobial resistant and MDR pathogens, emphasis should be placed on the consequences of these infections in immunocompromised individuals[7,27]. Surveillance of antimicrobial resistance in canines and other companion animals is an area where additional research should be considered.

The current study chose to focus on the domestic dog only. Other companion animals such as cats, exotic pets, small mammals, and birds were excluded. These species should be considered for future research. Because the primary goal of this research is to advise a companion animal surveillance program, the current study focused on evidence in the literature based specifically on the domestic canine. The author recognizes that several of the zoonotic pathogens identified here are also relevant to wild canids within Canada[47–50]. This is an additional area to be explored for provincial surveillance programs. The methods applied in this study can be used for any of the above-mentioned species.

Challenges in this study included reclassification of pathogen names or several names applying to the same pathogen, in particular with bacterial and parasitic species. This often made

it challenging to find accurate information in the literature and many pathogens have been potentially misclassified in older studies. For example, with over 2500 serovars for *Salmonella spp*. and variations between authors on naming, it was difficult to find consistent reports on which *Salmonella* species were actually isolated in each particular case[51]. For simplicity, *Salmonella enterica* was grouped together and emphasis was placed only on serovars *enteritidis* and *typhimurium* where distinct reports related to the dog were found[52–54].

2.6 Conclusions

This study successfully identified 84 pathogens present in canines that are of possible public health importance within the Prairie Provinces of Canada. In addition, several other groups of pathogens were highlighted that may become important in the Prairie Provinces for future surveillance research.

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Table 2.1. Shortlist of 84 canine pathogens (*Tier 1*) identified as having public health implications in Canada (including the Prairie Provinces)

Taxa	Pathogen		
Bacteria	*Actinomyces viscosus* [c]	*Coxiella burnetii*	*Pasteurella canis* [c]
	Bartonella henselae	*Enterococcus faecium*	*Pasteurella multocida* [c]
	Bartonella vinsonii subsp. berkhoffii	*Enterococcus spp.*	*Pasteurella spp.*[c]
		Escherichia coli [a]	*Pseudomonas aeruginosa*
	Bordetella bronchiseptica	*Francisella tularensis*	*Salmonella enterica (enteritidis, typhimurium)*
	Borrelia burgdorferi senso stricto	*Fusobacterium spp.*[c]	
		Helicobacter heilmannii	
	Brucella canis	*Klebsiella spp.*	*Staphylococcus aureus* [c]
	Campylobacter coli	*Leishmania infantum*	*Staphylococcus pseudintermedius* [c]
	Campylobacter jejuni	*Leptospira interrogans* [b]	
	Campylobacter upsaliensis	MRSA	*Streptococcus canis*
	Capnocytophaga canimorsus [c]	MRSP	*Streptococcus spp.*[c]
	Clostridium difficile	*Moraxella spp.*[c]	*Yersinia enterocolitica*
	Clostridium perfringens	*Neisseria weaver* [c]	*Yersinia pestis*
Ectoparasites	*Cheyletiella yasguri*	*Pulex irritans*	
	Ctenocephalides canis	*Sarcoptes scabiei var canis*	
	Ctenocephalides felis		
Fungi	*Blastomyces dermatitidis*	*Microsporum canis*	
	Cryptococcus gattii	*Sporothrix schenckii*	
	Histoplasma capsulatum	*Trichophyton spp.*	
	Malassezia pachydermatis		
Helminths	*Acanthocheilonema reconditum*	*Cryptocotyle lingua*	*Nanophyetus salmincola*
		Diphyllobothrium spp.	*Paragonimus kellicotti*
	Alaria alata	*Dipylidium caninum*	*Taenia serialis*
	Alaria americana	*Dirofilaria immitis*	*Taenia spp.*
	Alaria canis	*Echinococcus granulosus*	*Toxocara canis*
	Alaria marcianae	*Echinococcus multilocularis*	*Uncinaria stenocephala*
	Apophallus donicus	*Mesocestoides spp.*	
	Baylisascaris procyonis	*Metorchis conjunctus*	
Protozoa	*Cryptosporidium canis*		
	Giardia duodenalis assemblage A1		
	Giardia duodenalis assemblage B		
	Trypanosoma cruzi		
Rickettsia	*Anaplasma phagocytophilum*		
	Ehrlichia canis		
	Rickettsia rickettsia		
Viruses	*Rabies*		

[a]*Escherichia coli* pathovars enterohemorrhagic *E. coli* (EHEC), enteropathogenic *E. coli* (EPEC), adherent invasive *E. coli* (AIEC), uropathogenic *E. coli* (UPEC), necrotoxigenic *E. coli* (NTEC), enterotoxigenic *E. coli* (ETEC)

[b]*Leptospira interrogans* serovars autumnalis, bratislava, canicola, grippotyphosa, hardjo, icterohaemorrhagiae, pomona

[c]Dog bite specific pathogen

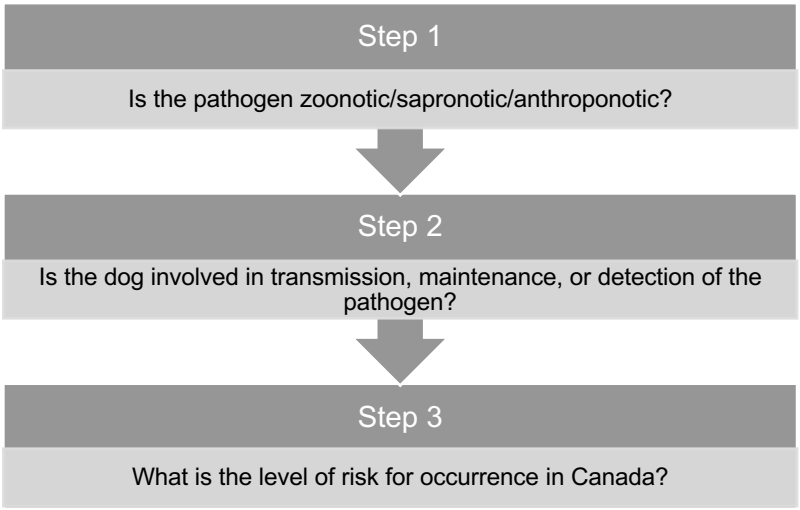

Figure 2.1. Stepwise approach used to pare down initial pathogen list to identify important canine pathogens from a public health perspective in Canada (including the Prairie Provinces).

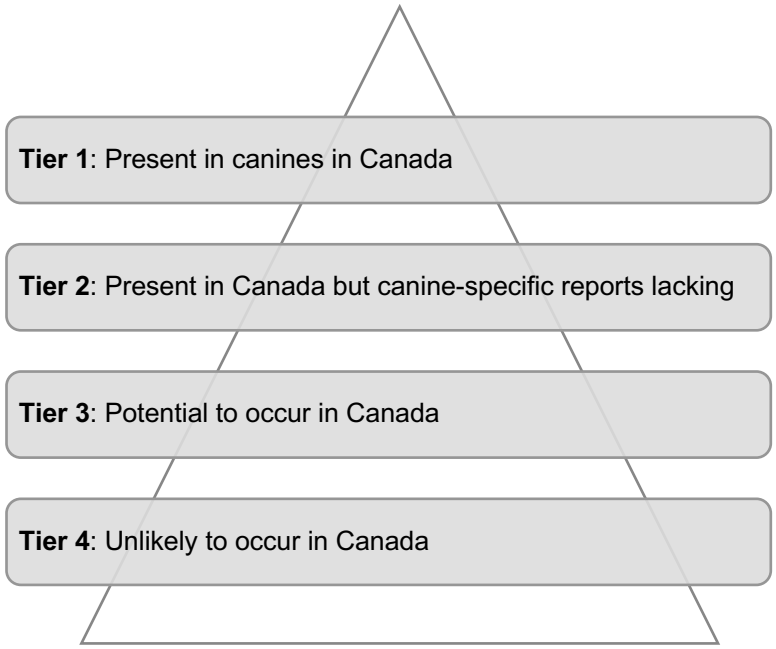

Figure 2.2. Four-tiered approach to categorize a pathogen's level of risk for occurrence within Canada.

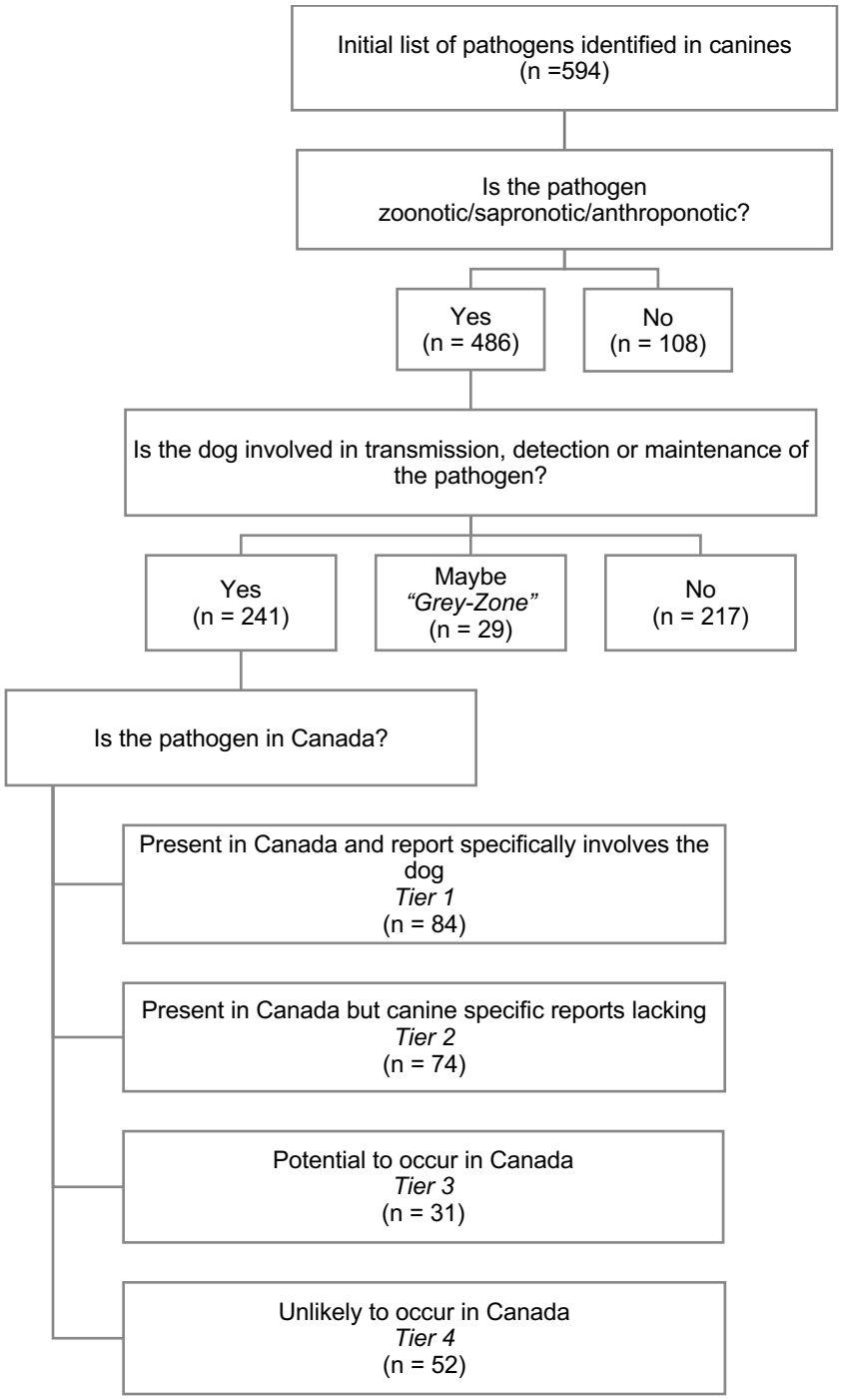

Figure 2.3. Resulting number of pathogens that fulfilled the criteria for each step. *Tier 1* = final shortlist. "*Grey-Zone*", *Tier 2* & *3* = supplementary lists.

CHAPTER 3: CANINE ZOONOTIC SURVEILLANCE IN THE PRAIRIE PROVINCES OF CANADA: PRIORITIZING PATHOGENS

3.1 Abstract

A pathogen prioritization exercise was performed using experts in the field of veterinary medicine and public health to establish 3-5 canine pathogens of public health concern for consideration in a companion animal surveillance initiative specific to the Prairie Provinces of Canada. A list of 51 diseases specific to the domestic dog was provided to participating experts to select and rank their top 10 pathogens of concern from a public health perspective. In addition, participants were required to select 5 pathogens from the list of lowest public health concern in their opinion. Scores were assigned to each pathogen selected based on ranking position and a total sum of these scores provided the final ranking. Based on this final ranking, the overall top 5 canine pathogens of public health concern in the Prairie Provinces were: (1) *Echinococcus spp.,* (2), MRSA, (3) *Salmonella enterica,* (4) MRSP, and (5) *Borrelia burgdorferi*. These pathogens should be considered for a companion animal surveillance initiative specific to the prairies. A follow-up study will define case definitions for these pathogens to assist in developing the best surveillance system indicators for informing public health decision making.

3.2 Introduction

Companion animal surveillance data is extremely limited in the Prairie Provinces of Canada from both the animal health and public health perspective. Currently, rabies is one of the only canine specific pathogens that is routinely monitored through federal and provincial surveillance programs[1,2]. Data on other relevant canine zoonoses with implications to human health are not monitored in a centralized or ongoing surveillance system. As the popularity and intimacy of pet ownership continues to grow, the impacts of canine zoonoses on public health requires further examination as part of an overall One Health strategy[3]. This is particularly

important for individuals who are immunocompromised[4]; or locations with high populations of free-roaming dogs and/or limited access to veterinary and medical resources, such as northern or Indigenous communities[5].

The first step to formalizing a companion animal surveillance system is to determine which pathogens to focus surveillance on. The primary purpose of pathogen prioritization is to identify where to invest finite resources[6]. Additionally, pathogen prioritization is used for emerging disease preparedness, and can guide prevention and control efforts for diseases of concern[6–8]. Unfortunately, there is an overall lack of standardization for pathogen prioritization methods in Canada[8]. This is largely because objectives vary based on stakeholder interests and the region of concern; therefore, some flexibility and adaptation is required[6].

Approaches to pathogen prioritization are often described as quantitative, semi-quantitative, or qualitative[6,7]. Quantitative methods use a numerical scale for ranking selected pathogens based on objective criteria, such as incidence and prevalence[7]. An example of a strictly quantitative prioritization method includes Multi-Criteria Decision Analysis (MCDA)[6,7]. Alternatively, qualitative methods rely more heavily on individual or group opinions for pathogen ranking, such as the Delphi method, and expert opinion or focus group consensus[6,7]. Semi-quantitative methods offer a combination of the two approaches where pathogen scoring is subjective, but choices are ranked relative to each other on a numerical scale[7].

While quantitative methods have become more common due to their increased objectivity, they are only possible if existing evidence and surveillance data is available. For example, if prevalence, mortality, or transmissibility are selected criteria used to score each pathogen during a prioritization exercise, this information must be readily accessible based on previous research[6,9]. Semi-quantitative and qualitative methods can be advantageous when limited data exists, however,

they can increase bias and subjectivity of the prioritization exercise[6,9]. For most companion animal zoonoses, data is extremely limited because surveillance is not well established, and qualitative or semi-quantitative methods must be utilized. Currently, only one example of companion animal pathogen prioritization exists in the literature[9].

The primary objective of this study was to identify the top 3-5 canine pathogens of public health significance experts in the fields of veterinary medicine and public health would be most interested in seeing in a companion animal surveillance program specific to the Prairie Provinces of Canada using a semi-quantitative approach. Because extensive surveillance data already exists for rabies, rabies was deliberately excluded from this prioritization exercise. Rather, the goal was to define which other canine zoonotic pathogens should be included in a companion animal specific surveillance initiative.

3.3 Materials and Methods

3.3.1 Pathogen Selection

Eighty-four individual canine pathogens of possible public health significance in the Prairie Provinces of Canada were selected based on previously described methods[10]. This list was further condensed by organizing pathogens into logical groupings to limit redundancy (Appendix F). For example, it seemed unnecessary to list all *Campylobacter* species individually for the prioritization exercise, therefore, individual *Campylobacter* species were grouped together as a single entry. Similarly, individual *Leptospira interrogans* serovars were grouped as one entry. This was applied to several genera where more than one species was included on the initial list of 84 pathogens. Additionally, a collection of bacteria specific to dog bites were categorized together as "dog bite pathogens", as were groupings for "dermatophytes", "fleas", and "mites". These groupings were chosen as individual species within these categories were considered irrelevant from a public

health perspective, favoring collective examination for the purposes of prioritization. In the end, 51 pathogens and groups of pathogens/parasites were established for the prioritization exercise. For simplicity, these 51 pathogens and groups of pathogens/parasites will collectively be referred to as "canine pathogens" from this point forward.

3.3.2 Recruiting Experts and Survey Dissemination

An expert was defined as anyone with veterinary, epidemiology, or public health knowledge within Canada, but particular emphasis was placed on anyone residing or working in Alberta, Saskatchewan and Manitoba. A list of colleagues with varying backgrounds in these disciplines from both research/academic and governmental institutes was compiled for an initial email invitation to participate in the survey. The intent of this initial email was to also have participants further disseminate the survey to their networks as a "snowball" method to recruit additional experts in their field. The email included the survey invitation, survey introduction, intent of study, and ethics approval. A description as to why rabies was excluded from the prioritization exercise was also provided. Participation in the survey was completely voluntary. In addition, survey invitations were provided through each of the three veterinary medical associations in Alberta (ABVMA), Saskatchewan (SVMA), and Manitoba (MVMA) by inclusion in their weekly E-Newsletters so that private practice veterinarians were included in the conversation. The SurveyMonkey platform was used to create, disseminate and record survey data. The survey remained open from October 5 to November 2, 2020.

3.3.3 Designing Survey

Survey questions were formulated with the intent to score and rank 51 canine pathogens of possible public health significance within the Prairie Provinces using expert opinion. Based on final scores, a top 3-5 canine pathogen list would become the basis for a companion animal

surveillance initiative. Identifying 3-5 high priority pathogens was deemed a feasible starting point for the surveillance initiative by investigators. The main objective in survey question design was to identify which canine pathogens experts in the field (veterinary medicine, epidemiology, and public health) within the region of interest (the Prairie Provinces) would be interested in seeing in a companion animal surveillance system. The survey was piloted by 5 veterinary epidemiology colleagues prior to dissemination. Any recommendations or suggestions for the survey design were considered and adjusted accordingly.

The final survey consisted of 11 questions, including 3 initial questions related to respondent demographics (Appendix G). The demographic questions required participants to specify occupation, his/her primary location by province, and experience in canine zoonoses specifically. The remainder of the survey asked participants to choose a top 10 from the list of 51 canine pathogens and then rank those choices from 1 to 10, with 1 being the most important pathogen in his/her opinion from a public health perspective. Participants were also required to elaborate on his or her reasoning for pathogen selections. In addition, survey respondents were asked to select 5 bottom canine pathogens from the list and elaborate on why these pathogens were selected as unimportant from a public health perspective.

Participants were also given the opportunity to comment on importance of pathogens from a taxonomical standpoint, if any zoonotic canine pathogens were missing from the initial list, and if there were any additional non-zoonotic canine pathogens that should be included in a companion animal surveillance program from an animal health perspective. To aid in the selection process, participants were provided with a supplementary chart that could be referred to for pathogen information if needed (Appendix H). The supplemental chart included background information on each pathogen, how dogs are involved in human infection, severity in dogs and humans

(including if the pathogen is fatal in humans), and treatments if applicable. If the pathogen was considered common or rare this was also stated.

3.3.4 Data Analysis

3.3.4.1 *Pathogen Scoring: A Semi-Quantitative Approach*

Final pathogen scores were generated using a point-system, culminating in a total sum of points for each pathogen. Each time a pathogen was ranked as a participant's top pathogen it received 10 points. Pathogens ranked second position received 9 points, pathogens ranked third position received 8 points, and this point-system continued up to the tenth ranking position upon which a pathogen received only 1 point (Table 3.1). Additionally, every time a pathogen was placed in a participant's "bottom 5" it received negative 1 point, irrespective of rank. A pathogen's final score was the summation of all points accumulated. Pathogens were then ranked relative to each other from highest to lowest score.

3.3.4.2 *Stratification*

Pathogen selections were also stratified by demographic variables (province, occupation, and experience level) with re-calculation of scores based on these categories. The purpose of stratification was to assess whether the highest priority pathogens changed depending on the experts' demographics.

3.3.4.3 *Open-Ended Questions*

All open-ended questions were analyzed by grouping repeated or similar answers into themes regardless of respondent demographics. In addition, open-ended responses were compared between public health participants and animal health participants (veterinarians in research/academia, government, or private practice) to assess whether themes were similar or different between the two stakeholder groups. Open-ended responses were also compared between

provinces to assess whether location altered answers. Repeated themes from the open-ended responses for why pathogens were placed in a participant's top 10 or bottom 5 were further assessed against the overall "top 5" and "bottom 5" ranking pathogens. This was to establish whether prominent themes for pathogen selections coincided with which pathogens ultimately scored the highest and lowest.

3.4 Results

3.4.1 Demographic Data

A total of 36 completed surveys were collected; any incomplete surveys were discarded resulting in a 65% (36/55) completion rate for survey participation. Of the 36 usable surveys, 42% (15/36) of participants were from Alberta, 28% (10/36) were from Saskatchewan, 19% (7/36) were from Manitoba, and11% (4/36) were from "other" (Table 3.2).

Occupational data revealed that 14% (5/36) of participants worked in the public health sector through government or laboratory settings while 6% (2/36) worked within the government as veterinarians. Additionally, 11% (4/36) of participants identified as working in veterinary medicine within research/academia. The largest group of participants were companion animal veterinarians at 44% (16/36), while 25% (9/36) of participants classified themselves as mixed animal veterinarians. No large animal veterinarians participated in the survey (Table 3.2). Participants were also arranged into two larger stakeholder groups: public health participants versus animal health participants regardless of more specific occupational descriptions. This revealed that 14% (5/36) of individuals were from the public health sector and 86% (31/36) of individuals were from the animal health sector.

In terms of experience related to canine zoonoses specifically, 0 participants said they had no experience, 22% (8/36) of participants claimed to have minimal experience, 67% (24/36) of

participants had moderate experience, and only 11% (4/36) of participants felt they had significant experience (Table 3.2).

3.4.2 Pathogen Scoring

Each of the 51 canine pathogens received a final score during the prioritization exercise ranging from 221 to -14 (Table 3.3). A natural break in final scores provided a rational overall "top 5". The top 5 highest scoring pathogens in descending order were *Echinococcus spp.* (*granulosus, multilocularis*), methicillin-resistant *Staphylococcus aureus* (MRSA), *Salmonella enterica*, methicillin-resistant *Staphylococcus pseudintermedius* (MRSP), and *Borrelia burgdorferi senso stricto*. *Escherichia coli* (*E. coli*), dog-bite pathogens and *Campylobacter spp.* also had notable scores. The 5 lowest scoring pathogens in descending order included *Alaria spp., Cryptocotyle lingua, Dirofilaria immitis, Acanthocheilonema reconditum,* and *Malassezia pachydermatis*. There was a single participant who ranked a pathogen (*Bordetella bronchiseptica)* in both the top 10 (ranked #10) and bottom 5. Therefore, the score for *B. bronchiseptica* from this participant was not included. This did not happen with any of the remaining 35 survey responses.

3.4.3 Stratification

Scores for pathogens stratified by province, occupation and level of experience in canine zoonoses showed minor variations between the top 5 scoring pathogens (Table 3.4). Both *Echinococcus spp.* and MRSA remained consistently in the top 5 list of pathogens regardless of demographic input. *Salmonella enterica* was also repeated in several top 5 stratified groups. *Echinococcus spp.* remained in either the first or second position regardless of a respondent's occupation or level of experience in canine zoonoses. The largest discrepancies in the top 5 pathogens selected were seen when pathogens were stratified by province, where participants from provinces outside of the Prairie Provinces had the most distinct top 5.

3.4.4 Open-Ended Questions

Several responses to the open-ended questions were common in terms of reasoning for why a canine pathogen was placed in an individual's top 10 regardless of demographics. Repeated responses included: prevalent in the prairies, severity of disease in humans, fatal in humans, lack of treatment, high transmission or exposure from dogs to humans, high risk in the immunocompromised, lack of public awareness, and the pathogen is emerging (Table 3.5). These responses were repeated regardless of stakeholder interests (individuals from public health versus animal health) or province of origin. Perceived prevalence in the prairies was particularly common for practicing veterinarians if they had personally diagnosed the pathogen in a clinic setting (n=15). Unique responses of note included an interest in pathogens where the dog acts as a sentinel, or pathogens as they may relate to public health decision making. One respondent from the public health group selected pathogens "that have an unclear epidemiology". An additional notable response from a public health official suggested pathogen selection be based on surveillance systems already in place that would provide compliments to a companion animal surveillance system in the Prairie Provinces, such as PulseNet Canada and FoodNet for enteric pathogens. Public health stakeholders were more likely to comment on pathogens of importance from a reservoir, common-source exposure, or sentinel perspective. Three respondents within the animal health stakeholder group expressed that concern for zoonoses surrounding raw food diets contributed to their choices.

Common reasons experts placed canine pathogens in the bottom 5 included: the respondent has never diagnosed the pathogen, perceived low prevalence in the prairies or that the pathogen is rare, low severity of disease (in dogs and humans), the pathogen wasn't recognized by the participant, it is easily treatable, and the pathogen is perceived to have low transmission potential

from dogs to humans (Table 3.5). Having never diagnosed the pathogen or being unfamiliar with the pathogen was a particularly common answer from private veterinarians (n=11). One respondent's rationale from the public health sector was the "practicality" of monitoring certain pathogens in a companion animal surveillance system.

Thirty-nine percent (14/36) of respondents placed equal weight on all taxonomical categories, and this did not affect whether or not a pathogen was selected in his or her top 10. Common rationale from participants was that pathogens from several categories could have serious consequences to humans. Of the individuals who placed higher importance on some taxonomical categories over others, "bacteria" was the most popular choice (11/36). Even more specifically, 6 respondents emphasized antimicrobial resistance (AMR) as a primary concern. In addition, a concern for AMR pathogens was expressed by at least one individual in each stakeholder group (public health and animal health) and within each province. There were 3 participants (from both stakeholder groups) who specified particular concern for viruses due to severity of disease, the possibility for direct transmission from dogs to humans, and difficulties in treating viral diseases. In terms of taxonomical categories that experts felt were less important, 12 individuals specified ectoparasites. Comments for why ectoparasites were perceived as a less important category included that preventatives exist, they are easily treatable, and severity of disease in people is low.

The greatest variability in open-ended responses occurred from participants who placed variable importance on taxonomical categories. Although there were several repeated answers (bacteria as more important, ectoparasites as less important), there were several contradictions for particular taxonomical categories like helminths, and fungi for why one group may or may not be important. For example, one individual placed more importance on helminths because of poor deworming compliance and lack of public awareness, while another participant placed helminths

as less important because standard hygienic practices and preventatives help reduce the risk of infection in humans. Aside from ectoparasites being a common choice, there were many variations in which additional taxonomical categories were perceived as less important in participants who placed different weights on each category.

When asked if any canine zoonotic pathogens were missing from the prioritization exercise, 81% (29/36) of respondents did not have any additional pathogens to add. There were 2 participants who specified *Sars-CoV-2* and 2 participants requested canine influenza. Additionally, 1 participant included toxoplasmosis and 2 respondents requested rabies. For the inclusion of non-zoonotic canine pathogens to a companion animal surveillance program, 61% (22/36) of respondents did not have any additional pathogens to add. Repeated answers from those with suggestions included parvovirus, distemper, and canine influenza. A few non-communicable examples were also suggested including allergic skin disease, transitional cell carcinoma, and dental malocclusions. The majority of pathogen suggestions came from the animal health stakeholder group (n = 13).

Repeated themes (responses) from open-ended questions on why a pathogen was placed in a participant's top 10 or bottom 5 (Table 3.5) were examined against the overall top 5 highest scoring pathogens and bottom 5 lowest scoring pathogens. The final ranking was both agreeable with the common themes for top 10 selections and bottom 5 selections. Several participants felt echinococcosis was "on the rise", particularly in wild canid populations making it a more emerging concern in domestic dog and human populations. Additionally, the disease is severe in humans and participants perceived an overall lack of public awareness. For MRSA/MRSP severity of disease in humans is high, treatment options are limited, and disease risk is even greater in those who are immunocompromised. Salmonellosis can have a high transmission rate from dogs to

humans as a result of raw food diets. Furthermore, there is lack of treatment in resistant and emerging strains. For Lyme disease, severity of disease in humans is high and prevalence of the disease is prominent in certain regions. There is also an increased chance of exposure to humans because dogs may bring infected ticks into a shared environment. The lowest scoring pathogens (*M. pachydermatis, A. reconditum, D. immitis, C. lingua, Alaria spp.*) are all either extremely rare in the prairies, easily treatable/preventable, and transmission from dogs to humans is considered low. It is important to note that the supplemental chart provided to experts included some of the above details for pathogens included in the exercise.

3.5 Discussion

Based on simple summation of final pathogen scores, the top 5 collective canine pathogens selected by veterinary and public health experts in the Prairie Provinces and other parts of Canada were: (1) *Echinococcus spp.* (*granulosus, multilocularis*), (2) MRSA, (3) *Salmonella enterica*, (4) MRSP, and (5) *Borrelia burgdorferi senso stricto*. These pathogens were selected from a public health perspective for the possible inclusion in a companion animal surveillance system. In addition, several non-zoonotic canine pathogens were of interest for inclusion in a companion animal surveillance initiative including parvovirus, distemper, and canine influenza.

Stratification of pathogen scores based on location, occupation and level of experience in canine zoonoses revealed only minor variations in the top 5 canine pathogens selected. Of particular note, the top 5 pathogens did not change substantially regardless of a respondent's area of interest (occupation). For example, it would be expected that a researcher may have very different motivations for companion animal surveillance than a private practitioner. Contrary to this perception, the top 3 pathogens (*Echinococcus spp.,* MRSA, and *Salmonella enterica*) were always present in the top 5 groupings regardless of occupation. The greatest differences in the

stratified top 5 pathogen lists were seen from respondents living in British Columbia and Ontario, which were not the primary locations of interest in this study.

It is also important to consider how surveillance data would be obtained for these pathogens of interest. Based on pathogen scoring, including stratified scores, a strong consideration is to group certain pathogens together for the purposes of surveillance. For example, several enteric pathogens (*Salmonella enterica, E. coli, Campylobacter spp.*) scored high during the prioritization exercise and were repeated in stratified scores regardless of demographic data. For the intent of surveillance, "enteric pathogens" as a group could be a consideration. Additionally, diagnostic testing for enteric diseases in dogs often tests for multiple pathogens. Therefore, if a dog presents for gastrointestinal illness and a full diarrhea panel is being submitted, then reporting would occur for any of the zoonotic pathogens *Salmonella spp., E. coli,* and *Campylobacter spp.* Similarly, vector-borne diseases are another grouping to be considered. *B. burgdorferi* was included as a final top 5 pathogen. A common test used to diagnose Lyme disease in dogs is the IDEXX SNAP 4Dx Test (IDEXX Laboratories, Inc.). *Anaplasma spp., Ehrlichia spp.,* and heartworm are included in this test and could therefore also be considered in a surveillance program[11–13]. Concern regarding AMR in general (including but not limited to MRSA and MRSP) was a recurring topic throughout the prioritization exercise in both pathogen scoring and open-ended responses.

With these considerations in mind, the following 4 groups of canine pathogens for a companion animal surveillance initiative in the Prairie Provinces are recommended: (1) *Echinococcus spp.,* (2) AMR pathogens (ex. MRSA/MRSP), (3) enteric pathogens (*Salmonella spp., E. coli, Campylobacter spp.*), and (4) vector-borne pathogens (*B. burgdorferi, Anaplasma spp., Ehrlichia spp., D. immitis*). The use of data from veterinary clinics for a companion animal

surveillance program and the development of case definitions for canine pathogens of interest will be examined in a follow-up study.

"Dog bite pathogens" scored relatively high in general and was repeated in several stratified top 5 groups. The majority of dog bite pathogens are commensals of the canine mouth or human skin, leading to polymicrobial infections following a bite[14,15]. In addition, because of high contamination in dog bite wounds, cultures are very rarely performed as they may not be representative of true infection, and therefore the true etiological agent is never determined[16,17]. For these reasons, monitoring of such pathogens from a surveillance perspective is meaningless. While it may not be feasible or useful to retain surveillance data on individual dog bite pathogens, there is currently limited surveillance data within Canada on the frequency of dog bites[15]. The high ranking of "dog bite pathogens" during this prioritization exercise highlights an interest for a centralized database on dog bite prevalence, which could be addressed within our public health sector.

Responses from open-ended questions on why a pathogen was included in a participant's top 10 mimicked the criteria that are commonly used in more quantitative prioritization exercises. Common criteria reported in the literature include: burden of disease (incidence, prevalence in humans, mortality), case-fatality rate, transmissibility, disease emergence potential, public perception, and treatment and preventative options[18]. Prior examples focus heavily on communicable diseases in humans, including some zoonoses, and food-borne diseases[6,18,19]. Very few animal specific examples are described, particularly companion animal examples[9]. In this study, participants emphasized their perceived prevalence of a pathogen in the dog population, severity of disease in dogs and humans, if it is fatal to humans, transmissibility from dogs to humans, public awareness, and emergence potential. The final top scoring pathogens and bottom

scoring pathogens appeared to correlate with these common criteria based on available or perceived information. Once a companion animal surveillance system is established, more concrete data on prevalence, incidence, mortality-rates and transmissibility of these pathogens as they relate to the dog will be available. Pathogens included in the surveillance program can then be prioritized from a quantitative perspective using specific criteria to ensure that relevant pathogens continue to be monitored.

A few open-ended responses requested the inclusion of *Sars-CoV-2* in a companion animal surveillance system within the Prairie Provinces. Given the current situation at the time of this writing, although COVD-19 research is incredibly relevant, there is no evidence at this time that dogs play a role in the transmission of *Sars-CoV-2* to humans, nor do they maintain the virus in the environment as a reservoir host[20,21]. In addition, because dogs do not exhibit clinical signs of disease when infected with *Sars-CoV-2,* they are poor sentinels for the pathogen[22,23]. Because of this current knowledge, *Sars-CoV-2* did not move on to the final pathogen short list described in the preceding study and was not provided to experts for the prioritization exercise[10].

In addition, rabies was mentioned on two occasions by respondents for inclusion in a companion animal surveillance system. Because surveillance data already exists for rabies both provincially and federally in Canada, it was not included in this exercise. Although this was stated in the survey introduction, it is likely that this information was missed by some participants. Several feline focused pathogens were also recommended by participants for companion animal surveillance including toxoplasmosis and panleukopenia. While not the focus of this study, feline pathogens will also eventually be explored for a companion animal surveillance initiative in the prairies. Although there is currently no evidence that canine influenza is zoonotic[24], this pathogen

was of interest to many participants during the exercise and could be considered as a non-zoonotic pathogen for canine surveillance efforts.

The lowest scoring pathogens identified during the prioritization exercise were *Alaria spp., C. lingua, D. immitis, A. reconditum*, and *M. pachydermatis*. Reasons for placing a pathogen in a participant's bottom 5 included a perceived low prevalence of the pathogen in his/her region, low severity of disease, as well as easily treatable. Additionally, if respondents didn't recognize the pathogen this was a common reason for a low ranking. It was important that pathogens of minimal importance to those contributing to a surveillance program also be established. This is in part to help motivate veterinarians to participate in a surveillance system. It is worth noting that just because a pathogen is rare, does not mean it should not be considered in a companion animal surveillance program if severity of disease is high. Rabies is increasingly rare due to vaccination programs, but its fatal nature makes it a high priority for surveillance within Canada[2]. Furthermore, rare but dangerous canine pathogens may be present in the Prairie Provinces, but lack of surveillance data simply means researchers are unaware of true distributions. In addition, canine pathogens that seem relatively benign in pathogenicity can still have profound consequences in the immunocompromised. Although *M. pachydermatis* was the lowest scoring pathogen from the prioritization exercise (score of -14), there is at least one report in the literature of an outbreak in a neonatal intensive care unit that was traced back to a nurse and her infected pet dog[25].

This study would have benefited from a larger sample size. Because the majority of this exercise did not utilize more quantitative methods there is a degree of subjectivity and bias in the results. Ng et al. argue that regardless of the approach used, there is always some level of subjectivity[26]. The methodological approach used was based on the minimal information available

from companion animals, especially within Canada[9,27]. An alternative qualitative method to the study described here would be to prioritize pathogens using a focus group.

The breadth of participation by various stakeholders was deemed important by the primary researchers. Since the focus was on pathogens of importance to public health, including stakeholders with a background in public health was essential. More representation from the public health stakeholder group in both study size and diversity of occupations within the public health sector could be beneficial in future prioritization exercises. It was also critical that practicing veterinarians be involved in the conversation as they would be the source of surveillance data. Without their input into pathogens of concern, there is a greater chance that veterinarians will not be interested in participating in a surveillance program. The general public was not involved in the ranking exercise as a level of scientific and clinical knowledge was required to contribute opinions on canine zoonotic pathogens. Contrary to this, other study authors have reported meaningful results from the general public during prioritization exercises on human communicable diseases[28,29].

"Weighing" the participant scores was considered during data analysis. For example, weights could be applied to scores from individuals who classified themselves as "experienced" in canine zoonoses so that their choices would have a greater impact on final pathogen scores. Since there were only 4 respondents in the current survey who classified themselves as "experienced" and because this is a subjective classification, these responses were not weighted more heavily than other participants. Future exercises may benefit from doing so if a larger and broader sample size is utilized. Additionally, the author acknowledges that the supplemental chart provided to experts on an as needed basis had the potential to bias a participant's responses. This is why only basic and consistent information across all pathogens was included to provide

supplemental material if a pathogen was unfamiliar to the respondent. During the pilot phase of this study the supplemental chart was deemed a necessary component by pilot participants; however, there is no way to tell who in the survey used the chart and who did not. It is possible that the supplemental chart provided a level plane of knowledge for all those participating in the study, experienced as compared to unexperienced with reliance on the chart.

3.6 Conclusion

In conclusion, based on the following prioritization exercise using experts from both veterinary and public health disciplines, the following groups of canine pathogens are recommended for a companion animal surveillance initiative in the Prairie Provinces of Canada from a public health perspective: (1) *Echinococcus spp.,* (2) AMR pathogens (including MRSA/MRSP), (3) enteric pathogens (*Salmonella spp., E. coli, Campylobacter spp.*), and (4) vector-borne diseases (*B. burgdorferi, Anaplasma spp., Ehrlichia spp., D. immitis*). Several non-zoonotic canine pathogens including parvovirus, distemper, and canine influenza are further recommendations for inclusion in the surveillance program from an animal health perspective. A companion animal surveillance program within the Prairie Provinces should be evaluated at regular intervals and prioritization exercises should be repeated as necessary to ensure that relevant pathogens are continually monitored and updated accordingly.

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Table 3.1. Point-system used for pathogen scoring

Ranking Position	Associated Score
#1	*10 points*
#2	*9 points*
#3	*8 points*
#4	*7 points*
#5	*6 points*
#6	*5 points*
#7	*4 points*
#8	*3 points*
#9	*2 points*
#10	*1 point*

Table 3.2. Demographic data for survey respondents, including count and % total of respondents

	Survey Respondents (n=36)	% Total respondents
Province		
Alberta	15	42
Saskatchewan	10	28
Manitoba	7	19
Other[a]	4	11
Occupation		
Public Health Government[b]	5	14
Veterinary Medicine Government	2	6
Veterinary Medicine Research/Academia	4	11
Veterinary Medicine Companion Animal	16	44
Veterinary Medicine Mixed Animal	9	25
Experience Level		
None	0	0
Minimal	8	22
Moderate	24	67
Experience	4	11

[a] 2 respondents were from BC and 2 respondents were from Ontario
[b] One individual classified themselves as working in a public health laboratory

Table 3.3. Final scores in descending order for each pathogen from prioritization exercise

Pathogen	Score
Echinococcus spp. (granulosus, multilocularis)	221
Methicillin-resistant *Staphylococcus aureus*	199
Salmonella enterica (enteritidis, typhimurium)	143
Methicillin-resistant *Staphylococcus pseudintermedius*	133
Borrelia burgdorferi senso stricto	119
Escherichia coli	109
Dog bite pathogens	108
Campylobacter spp. (coli, jejuni, upsaliensis)	103
Leptospira interrogans	84
Toxocara canis	78
Baylisascaris procyonis	68
Giardia duodenalis (assemblage A1, assemblage B)	65
Dermatophytes (*Microsporum canis, Trichophyton spp.*)	57
Clostridium spp. (difficile, perfringens)	52
Brucella canis	39
Bartonella spp. (henselae, vinsonii subsp. berkhoffii)	29
Cryptosporidium canis	29
Pseudomonas aeruginosa	28
Blastomyces dermatitidis	27
Anaplasma phagocytophilum	26
Enterococcus spp. (faecium; VRE*)*	22
Taenia spp. (serialis)	22
Mites *(Cheyletiella yasguri, Sarcoptes scabiei var canis)*	20
Rickettsia rickettsii	17
Yersinia spp. (enterocolitica, pestis)	16
Cryptococcus gattii	13
Klebsiella spp.	9
Francisella tularensis	8
Leishmania infantum	7
Histoplasma capsulatum	6
Dipylidium caninum	5
Coxiella burnetii	5
Helicobacter heilmannii	4
Ehrlichia canis	4
Trypanosoma cruzi	4
Bordetella bronchiseptica	2
Streptococcus canis	2
Unicaria stenocephala	1
Diphyllobothrium spp.	-1
Fleas (*Ctenocephalides canis, C. felis, Pulex irritans*)	-2
Nanophyetus salmincola	-3
Mesocestoides spp.	-3
Paragonimus kellicotti	-4
Sporothrix schenckii	-5
Apophallus donicus	-5
Metorchis conjunctus	-6
Alaria spp. (alata, americana, canis, marcianae)	-8
Cryptocotyle lingua	-9
Dirofilaria immitis	-12
Acanthocheilonema reconditum	-12
Malassezia pachydermatis	-14

Table 3.4. Top 5 pathogens when stratified by province, occupation and experience

Stratified Demographic Data	Top 5 Pathogens	Score
Province		
Alberta (n=15)	*Echinococcus spp. (granulosus, multilocularis)*	127
	Salmonella enterica (enteritidis, typhimurium)	69
	Methicillin-resistant *Staphylococcus aureus*	64
	Dog bite pathogens	59
	Leptospira interrogans	48
Saskatchewan (n=10)	Methicillin-resistant *Staphylococcus aureus*	75
	Methicillin-resistant *Staphylococcus pseudintermedius*	58
	Echinococcus spp. (granulosus, multilocularis)	48
	Borrelia burgdorferi senso stricto	44
	Salmonella enterica (enteritidis, typhimurium)	40
Manitoba (n=7)	Methicillin-resistant *Staphylococcus aureus*	45
	Echinococcus spp. (granulosus, multilocularis)	42
	Escherichia coli	30
	Campylobacter spp. (coli, jejuni, upsaliensis)	25
	Methicillin-resistant *Staphylococcus pseudintermedius*	24
	Borrelia burgdorferi senso stricto	24
Other[a] (n=4)	*Campylobacter spp. (coli, jejuni, upsaliensis)*	25
	Leptospira interrogans	22
	Borrelia burgdorferi senso stricto	18
	Escherichia coli	18
	Methicillin-resistant *Staphylococcus aureus*	15
	Methicillin-resistant *Staphylococcus pseudintermedius*	15
Occupation		
Public Health Government (n=5)	*Echinococcus spp. (granulosus, multilocularis)*	33
	Borrelia burgdorferi senso stricto	26
	Methicillin-resistant *Staphylococcus aureus*	23
	Salmonella enterica (enteritidis, typhimurium)	22
	Anaplasma phagocytophilum	16
Veterinary Medicine Government (n=2)	Methicillin-resistant *Staphylococcus aureus*	18
	Echinococcus spp. (granulosus, multilocularis)	14
	Salmonella enterica (enteritidis, typhimurium)	11
	Campylobacter spp. (coli, jejuni, upsaliensis)	11
	Methicillin-resistant *Staphylococcus pseudintermedius*	9
	Baylisascaris procyonis	9
Veterinary Medicine Research/Academia (n=4)	*Echinococcus spp. (granulosus, multilocularis)*	26
	Methicillin-resistant *Staphylococcus pseudintermedius*	25
	Methicillin-resistant *Staphylococcus aureus*	24
	Salmonella enterica (enteritidis, typhimurium)	18
	Dog bite pathogens	17
Veterinary Medicine Companion Animal (n=16)	Methicillin-resistant *Staphylococcus aureus*	93
	Echinococcus spp. (granulosus, multilocularis)	84
	Dog bite pathogens	68
	Methicillin-resistant *Staphylococcus pseudintermedius*	64
	Salmonella enterica (enteritidis, typhimurium)	58
	Escherichia coli	58
Veterinary Medicine Mixed Animal (n=9)	*Echinococcus spp. (granulosus, multilocularis)*	64
	Methicillin-resistant *Staphylococcus aureus*	41
	Borrelia burgdorferi senso stricto	38
	Campylobacter spp. (coli, jejuni, upsaliensis)	37
	Salmonella enterica (enteritidis, typhimurium)	34

Experience Level		
Minimal (n=8)	*Echinococcus spp. (granulosus, multilocularis)*	51
	Methicillin-resistant *Staphylococcus aureus*	46
	Salmonella enterica (enteritidis, typhimurium)	39
	Escherichia coli	38
	Campylobacter spp. (coli, jejuni, upsaliensis)	30
Moderate (n=24)	*Echinococcus spp. (granulosus, multilocularis)*	142
	Methicillin-resistant *Staphylococcus aureus*	137
	Methicillin-resistant *Staphylococcus pseudintermedius*	95
	Salmonella enterica (enteritidis, typhimurium)	82
	Borrelia burgdorferi senso stricto	73
Experienced (n=4)	*Echinococcus spp. (granulosus, multilocularis)*	28
	Salmonella enterica (enteritidis, typhimurium)	22
	Borrelia burgdorferi senso stricto	18
	Dog bite pathogens	17
	Methicillin-resistant *Staphylococcus aureus*	16

[a] 2 respondents were from BC and 2 respondents were from Ontario

Table 3.5. Themes from open-ended responses for why a pathogen was placed in a participant's top 10 or bottom 5

Top 10 Themes	Bottom 5 Themes
• Prevalent in the prairies	• Respondent has never diagnosed the pathogen
• Severity of disease in humans	• Low prevalence in the prairies/rare
• Fatal in humans	• Low severity of disease
• Lack of treatment	• Pathogen wasn't recognized by the participant
• High transmission from dogs to humans	• Easily treatable
• High risk in the immunocompromised	• Low transmission risk from dogs to humans
• Lack of public awareness	
• Pathogen is emerging	

CHAPTER 4: INVESTIGATING THE ROLE OF CLINICAL VETERINARIANS IN A COMPANION ANIMAL SURVEILLANCE PROGRAM

4.1 Abstract

Online surveys were disseminated to clinical veterinarians across the provinces of Alberta, Saskatchewan and Manitoba to investigate the role of veterinarians/veterinary clinics in a companion animal surveillance initiative specific to the Prairie Provinces of Canada and to develop case definitions for several canine pathogens of public health concern. The utility of domestic dogs as sentinels using Lyme disease as an example was also explored. Survey data revealed a moderate interest (median = 7.5/10) from veterinarians to participate in a companion animal surveillance program. Furthermore, the number of cases reported by veterinarians for several canine zoonotic pathogens including *Echinococcus spp.,* MRSA/MRSP, *Salmonella spp.,* and *Borrelia burgdorferi* were recorded. Preliminary case definitions for these pathogens were also formulated as a foundational step in the creation of a companion animal surveillance program. In addition, veterinary data provided evidence to support domestic dogs as sentinels for assessing Lyme disease risk in humans. Overall, this study emphasized the importance of collaborating with clinical veterinarians in a companion animal surveillance program.

4.2 Introduction

The World Health Organization (WHO) defines surveillance as "the process of systematic collection, collation and analysis of data with prompt dissemination to those who need to know, for relevant action to be taken"[1]. While surveillance systems are well established for human, production animal, and wildlife diseases in Canada and worldwide, surveillance data on companion animal diseases, including diseases of public health significance, is extremely limited[2–4]. Because of the increasing intimacy people have with companion animals and because several

pathogens companion animals harbour are zoonotic, it is important to obtain surveillance data on this population to address both animal health and public health concerns.

Because of finite resources, surveillance systems generally focus on predetermined pathogens of interest based on the objectives of the surveillance program[5]. These objectives will vary based on stakeholder groups involved in the project. While there are several methods for selecting pathogens upon which surveillance will be conducted, including pathogen prioritization exercises[6], once a group of pathogens is selected for a surveillance program, creating uniform case definitions for each pathogen is an essential step. By doing so, a level of standardization for what constitutes a "case" is established for reporting[5,7]. Typically, only confirmed cases are reported based on clinical, laboratory or epidemiological indicators; however, both "confirmed" and "probable" (where probable refers to a lack of diagnostic confirmation) case definitions may be created for a particular pathogen or disease[7]. As surveillance systems and the response to pathogens of interest evolve with time, case definitions need to be periodically reviewed and updated[8].

To obtain surveillance data on any companion animal population, practicing veterinarians and veterinary clinics are a potential source of surveillance data. The use of veterinary clinics in companion animal surveillance programming has been previously explored[2,8–11]. In particular, extracting data from electronic medical records (EMR) has been heavily researched[8–12]. While possible to obtain valuable data from EMR for the purposes of surveillance, one major limitation includes a lack of standardization with medical record keeping and nomenclature that would allow for seamless data extraction regarding symptoms and/or clinical diagnoses[8,11–13]. This means that data may not be properly captured by extraction software if there are inconsistencies in nomenclature between medical records or if records are incomplete. Other possible surveillance

methods using veterinary clinics include interactive web-based systems or periodic dissemination of clinic questionnaires[2,11,14–16]. While these methods avoid the limitations surrounding a lack of standardized medical record keeping, they require a larger time commitment from participating clinics and compliance or response rates may be low[14,15]. Regardless of the method used, surveillance data acquired from companion animal veterinary clinics will not be representative of the entire domestic animal population, but only of those receiving veterinary services.

Companion animals seen at veterinary clinics also offer a unique opportunity for sentinel surveillance[17,18]. For several zoonotic pathogens, companion animals may serve as an early warning system for disease risk in humans[2,19]. In particular, dogs have served as sentinels for both human and wildlife populations[18,20]; specifically, dogs have been described as good sentinels for vector-borne diseases[2,10,19,21]. This is because dogs tend to be at greater risk of vector exposure (particularly ticks) and can serve as an early indicator for vector-borne disease prevalence and therefore human risk in a given area[10,21].

The primary objectives of this study were (1) to investigate the role of veterinarians and veterinary clinics in a companion animal surveillance system specific to the Prairie Provinces of Canada, and (2) to use veterinarians to develop case definitions for several canine pathogens of public health interest. Establishing general interest from practicing veterinarians and associated veterinary clinics on their willingness to contribute companion animal surveillance data is a crucial step in the development of a surveillance program[15,22]. In addition, a third objective was to explore the role of the dog as a sentinel of zoonotic disease risk in humans using Lyme Disease as an example. The region of interest for this study was specific to the Prairie Provinces because this region of Canada has extremely limited companion animal surveillance data.

4.3 Materials and Methods

4.3.1 Designing Survey

The investigators chose to disseminate an online survey to clinical veterinarians in order to investigate the role veterinarians and veterinary clinics may play in a companion animal surveillance initiative. The main objectives in survey question design were: (1) to identify the role practicing veterinarians may play in a companion animal surveillance program through willingness to participate, (2) to establish case definitions for several canine zoonotic diseases of public health interest, and (3) to explore the role of domestic dogs as sentinels using Lyme disease as an example. The primary canine diseases of public health interest upon which case definitions would be formulated were based on results of a previously performed prioritization exercise and were echinococcosis, methicillin-resistant staphylococcal infections MRSA and MRSP, salmonellosis, and Lyme disease. Survey questions were formulated through discussions by the investigators. In addition, the survey was piloted by 5 clinical veterinary colleagues across Alberta (AB), Saskatchewan (SK) and Manitoba (MB) prior to dissemination. Any recommendations or suggestions for the survey design were considered and adjusted accordingly.

The final survey consisted of 35 questions, including 4 initial questions related to respondent demographics (Appendix I). The demographic questions required participants to specify his/her clinic location, practice region, species treating, and experience in companion animal zoonoses (canine and feline) specifically. The remainder of the survey was divided into 3 main sections including: (1) overall interest and willingness to participate in a surveillance program, (2) knowledge and experience with several canine diseases of public health interest to aid in the development of case definitions, and (3) clinical experience with Lyme disease to create a more complete case definition and to assess the use of domestic dogs as sentinels.

The intent of questions related to knowledge and experience with several canine diseases was to establish a baseline for whether practicing veterinarians are currently diagnosing serious canine zoonoses in the prairies. It was also to quantify different sources of clinical data (such as results from in-clinic testing), for which there is no current surveillance platform to record this information. These pathogens included *Echinococcus spp*. (*granulosus, multilocularis*), AMR pathogens (including MRSA/MRSP), enteric pathogens *Salmonella spp., Campylobacter spp*., and *Escherichia coli* (*E.coli*), and vector-borne pathogens including *Borrelia burgdorferi, Anaplasma spp*., and *Ehrlichia spp*. These pathogens were selected based on prior results from a prioritization exercise using experts in the field of veterinary medicine, public health and epidemiology, and similar pathogens were grouped together for the purposes of surveillance.

Respondents were also given a final opportunity to comment their 'final thoughts' at the conclusion of the survey. It was stated here that additional non-zoonotic canine pathogens such as parvovirus, distemper and canine influenza would also be considered in a companion animal surveillance program from an animal health perspective.

4.3.2 Survey Dissemination

Only veterinarians residing in AB, SK or MB were eligible to participate in the survey to obtain data exclusive to the Prairie Provinces. This was because surveillance data on companion animal zoonoses is limited in this region, and relevant pathogens are expected to be similar across the prairies due to comparable climate, temperatures and other environmental factors. Survey invitations were provided through each of the three veterinary medical associations in Alberta (ABVMA), Saskatchewan (SVMA), and Manitoba (MVMA) by inclusion in their weekly E-Newsletters and participation was completely voluntary. In addition, the survey was also disseminated by the Calgary Academy of Veterinary Medicine (CAVM) to its online members.

The SurveyMonkey platform was used to create, disseminate and record survey data, and the survey remained open from March 3 to March 31, 2021.

Two weeks following this initial survey invitation, a reminder email for survey participation was sent directly to clinics throughout AB, SK and MB. A list of clinics across the prairies was randomly compiled to include general practitioners in both companion animal and mixed animal practice, as well as small animal referral centers and emergency clinics. This was to encourage a broad range of participating veterinarians. Only clinics with an active email address were contacted. The final compiled list included 79 randomly selected clinics (28 from SK, 30 from AB, and 21 from MB). The email included the survey invitation, survey introduction, intent of study, and ethics approval.

4.3.3 Data Analysis

4.3.3.1 *Statistical Analysis of Survey Data*

Descriptive statistics were performed for all demographic data, information on surveillance interest, and clinical experience with several canine diseases of public health concern. This included all data contributed regarding Lyme disease. Data on an individual's willingness to participate in a surveillance program was further analyzed through stratification by province, practice region, and experience in companion animal zoonoses to assess whether a respondent's demographics altered their interest in a surveillance program. Furthermore, data specific to echinococcosis and Lyme disease were compared by province to examine possible differences in disease behaviour and management between regions.

4.3.3.2 *Open-Ended Questions*

All open-ended questions were analyzed by grouping repeated or similar responses together regardless of respondent demographics. The main goals of the open-ended questions were

to identify: (1) what would motivate participation in a surveillance system and what would deter participation, (2) where surveillance data may be lacking from laboratory sources if participants are not submitting samples for laboratory testing, (3) common symptoms related to canine pathogens of interest to aid in the development of case definitions, and (4) additional preventatives such as vaccination that may inhibit the utility of dogs as sentinels for Lyme disease. Participants were also given the opportunity to comment any final thoughts on a companion animal surveillance program.

4.3.3.3 *Case Definitions*

Using survey data collected on *Echinococcus spp.,* MRSA/MRSP, *Salmonella spp.,* and Lyme disease, preliminary case definitions for the purposes of surveillance were created. Because more detailed data was gathered on Lyme disease, a more complete case definition incorporating specific clinical and diagnostic information was possible. Further data on the remaining canine pathogens of interest may be required to establish complete case definitions for the purposes of surveillance; however, given the nature of testing to definitively diagnose echinococcosis, MRSA/MRSP and salmonellosis, collaboration with laboratories will be necessary. Therefore, in-clinic information gathered through the present survey served as a general starting point in exploring case definitions for these remaining pathogens.

4.3.3.4 *Assessing Domestic Dogs as Sentinels for Lyme Disease*

Using survey data collected on Lyme disease, responses on observable canine symptoms and preventative measures used (such as ectoparasitic treatment and/or Lyme vaccination) were examined to assess the utility of domestic dogs as sentinels for Lyme disease risk in humans. This was done using the following requirements: that a sentinel must be susceptible to the disease in question (Lyme disease), survive the disease, be readily exposed to the risk factor (tick exposure),

and mount a response to the disease that can be readily detected through either observable clinical signs or diagnostic testing.

4.4 Results

4.4.1 Demographic Data

A total of 76 participants engaged in the survey at a 79% completion rate (60/76). Any incomplete surveys were discarded. Of the 60 usable surveys, the largest proportion of participants were from AB at 55% (33/60), 17% (10/60) were from SK, and 28% (17/60) were from MB (Table 4.1). Responses pertaining to practice region revealed that 55% (33/60) of participants worked in an urban setting, 33% (22/60) worked in rural practice, and 12% (7/50) split their time between both urban and rural practice (Table 4.1).

When respondents were asked to specify their experience with companion animal zoonoses (canine and feline) specifically, 9% (5/59) claimed to have minimal experience, 64% (38/59) claimed to have moderate experience, and 27% (16/59) claimed to be experienced . There were 0 participants who felt they had no experience with companion animal zoonoses (Table 4.1). When asked to report on time spent with individual species in practice, 100% (60/60) of participants saw canine and feline patients in some capacity with an average time of 55% spent with dogs and 34% spent with cats (Table 4.2).

4.4.2 Surveillance Interest

On a scale from 1 to 10 with 10 being most likely to and 1 being least likely to, the median willingness to participate in a companion animal surveillance program specific to the Prairie Provinces was 7.5/10 (Table 4.3). Responses ranged from 2/10 to 10/10. In terms of a respondent's willingness to participate in a surveillance program if he/she had to input data into an online database or have a staff member do so, the median was 7/10 (range of 2/10 to 10/10).

When ratings were stratified by province, participants from AB or MB had the highest scores for willingness to participate in a surveillance program at medians of 8/10 (Table 4.3). When stratified by practice region and experience in companion animal zoonoses, individuals who split their time between urban and rural settings and individuals who felt they had minimal experience or were greatly experienced in companion animal zoonoses had the highest scores for willingness to participate at a median of 9/10. Individuals who split their time in terms of practice region and those experienced in companion animal zoonoses also had the highest scores for willingness to input data themselves at a median of 8/10 (Table 4.3).

When asked to rank his/her preferred frequency for contributing surveillance data, the top choice from participants was 'monthly' reporting with the majority of participants (41%) rating this as their number 1 choice (Table 4.4). The bottom choice was 'annual' reporting with 51% of participants ranking this option as their least preferred choice. When asked to rank his/her preferred frequency for reports coming out of the surveillance program the top choice was 'monthly' reports with 66% of participants ranking this option as their number 1 choice. The majority of participants at 65% ranked updates 'in real-time' as their lowest choice (Table 4.4).

Participants were also given the opportunity to elaborate on why they would or would not be willing to participate in a companion animal surveillance program. Repeated responses for why an individual would participate included feeling a professional responsibility, to establish local relevance and prevalence of diseases in the prairies, to assess risk in both patients from an animal health perspective and clients from a public health perspective, because it would be beneficial for evidence-based medicine, that it would aid in client education, and that practitioners are the first line of defence from a One Health perspective. A recurring theme was also a general interest in surveillance and the overall importance of companion animal zoonoses and surveillance. One

participant acknowledged that there is currently no place to report concerning companion animal zoonoses. In addition, 2 participants emphasized that surveillance data would provide them an opportunity to learn. The most common response for why participants were not willing to participate in a companion animal surveillance program was time commitment and increased workload (n=13). Only one participate had cost concerns and felt compensation was necessary. In addition, anonymity concerns and ease of data input were specified by one individual.

4.4.3 Canine Pathogens of Interest

Survey responses provided baseline data for the proportion of veterinarians having seen previously identified canine pathogens of public health interest specific to the Prairie Provinces within the past 5 years (Table 4.5).

4.4.3.1 *Echinococcosis*

Overall, 16.7% (10/60) of respondents reported diagnosing at least one case of *Echinococcus spp*. (*granulosus, multilocularis*) within the past 5 years (Table 4.5). Of particular note, 70% (7/10) of these respondents were from AB while the remaining 30% (3/10) were from MB. No respondents from SK reported cases of *Echinococcus spp*. within the last 5 years. The participants who reported diagnosing *Echinococcus spp*. did not need to specify number of cases seen or testing used to definitively diagnose the parasite, only that they did or did not diagnose at least one case of *Echinococcus spp*. (*granulosus, multilocularis*) within the past 5 years.

The most common method for diagnosing tapeworms and other enteric helminths was by fecal floatation at 80% (48/60) (Table 4.6). Of the participants who specified using fecal floatation to diagnoses helminths, 31% (15/48) performed the test in-clinic, 25% (12/48) only submitted fecal floatation through a laboratory, and 44% (21/48) used both in-clinic fecal floatation and laboratory submissions. This means that 75% (36/48) of the individuals who use fecal floatation as a method

to diagnose helminths (including tapeworms) are performing the test in-clinic; therefore, this is data that is not currently captured through any type of surveillance programming.

Of the individuals using laboratory testing for fecal floatation, 43% (14/33) specified using Prairie Diagnostic Services (PDS), 70% (23/33) specified using IDEXX Laboratories, and 21% (7/33) specified 'other' which included Antech (4/7) and Manitoba Veterinary Diagnostic Services (3/7). Respondents were able to choose all laboratories that applied if they were submitting to multiple laboratories. The most common reasons that prevented participants from submitting samples for laboratory testing were cost (n=27) and poor owner compliance (n=19). Six individuals specified that they do not submit laboratory testing for helminths in particular because treatment trials are a simple and cost-effective solution. There were 9 respondents who said they don't have any reasons that prevent them from submitting laboratory tests.

Only 2 respondents did not prescribe any dewormer (Table 4.7) because they worked outside of clinical practice and it was not applicable. Interceptor Plus was the most common deworming choice of participants at 68% (41/60). The majority of participants (66%) specified that frequency of deworming was case dependent (Table 4.7).

When provided with the opportunity for additional commentary on echinococcosis, several participants stated that it is likely more common than realized and a frustrating disease, and that guidance on prevalence, testing and treatment would be beneficial. One individual specified that this is a disease they discuss with owners. Additional unique comments included that promotion from the medical profession is lacking, and that surveillance maps on human, domestic animal, and wildlife cases would be valuable.

4.4.3.2 *AMR Pathogens (MRSA/MRSP)*

The majority of participants at 55% (33/60) did not report diagnosing any AMR pathogens within the past 5 years. The percentage of individuals who had diagnosed AMR pathogens were reported at 23% (14/60) for MRSA and 22% (13/60) for MRSP (Table 4.5). Respondents were not given the opportunity to specify the number of cases seen, only if he/she had diagnosed at least one case in the past 5 years for any AMR pathogens including MRSA/MRSP. In addition to a large proportion of participants reporting MRSA/MRSP cases, when given the opportunity to specify any other AMR pathogens diagnosed in the past 5 years, responses included *Bordetella bronchiseptica, Pseudomonas spp., Enterococcus spp., Enterobacter spp.,* and *Proteus spp*.

Of the 22 respondents who reported diagnosing MRSA and/or MRSP in the past 5 years, 23% (5/22) specified using PDS for definitive diagnosis (culture and sensitivity testing) while the majority of respondents at 73% (16/22) specified using IDEXX. In addition, 3 participants used Antech and 1 participant used Manitoba Veterinary Diagnostic Laboratories. Participants were able to choose all laboratories that applied if they were submitting to multiple laboratories.

The most common symptom associated with a diagnosis of MRSA/MRSP was dermatitis (n=20); which included 2 respondents who specified otitis externa. Additional but less common symptoms were reported to include unresolving urinary tract infections, and eye infections. One respondent specified a positive culture related to an orthopedic implant while another respondent specified an incisional complication. When given the opportunity to comment further on MRSA/MRSP, respondents discussed breed predispositions in Bulldogs and Pit Bulls. In addition, the possible relationship to allergic skin disease, and the relationship to trauma such as bite wounds were discussed. One respondent also discussed a correlation between positive canine patients who were owned by hospital personnel.

4.4.3.3 *Enteric Pathogens (Salmonellosis)*

Of participants diagnosing enteric pathogens within the past 5 years, the largest proportion, 52% (31/60), specified *E. coli* (Table 4.5); likewise, 42% (25/60) of participants specified diagnosing *Campylobacter spp.,* and 18% (11/60) specified *Salmonella spp*. Forty percent of participants hadn't diagnosed any of the 3 enteric bacteria listed. Participants did not need to specify the number of cases diagnosed for these pathogens, only that they had diagnosed them within the past 5 years and participants could select all pathogens that applied.

Of the respondents who commented on symptoms observed in positive cases of canine salmonellosis, the most common clinical sign was diarrhea (n=9). Additional but less common clinical signs included vomiting and urinary signs. One respondent specified that history of a raw food diet pertained to his/her positive case(s). The most common tests used for a definitive diagnosis of salmonellosis, were fecal PCR testing and/or fecal culture and sensitivity testing. Urine culture was also described by one participant. Of the participants who specified which diagnostic laboratories they used for a definitive diagnosis of salmonellosis (n=10), the majority of respondents used IDEXX at 70% (7/10). Only one individual specified each of the following: PDS, Antech and Manitoba Veterinary Diagnostic Laboratories.

4.4.3.4 *Vector-Borne Diseases*

For the proportion of vector-borne diseases seen by respondents within the past 5 years, 40% (24/60) specified Lyme disease, 42% (25/60) specified *Ehrlichia spp*., and 35% (21/60) specified *Anaplasma spp*. (Table 4.5). A total of 42% (25/60) of individuals had not diagnosed any of the vector-borne diseases listed or specified other vector-borne diseases. Respondents did not have to specify the number of cases seen for any of the listed pathogens and could select all

pathogens that applied. When given the opportunity to comment on any other vector-borne diseases diagnosed in the past 5 years, additional responses included *D. immitis* and *Babesia spp*.

4.4.4 Lyme Disease Data

The majority of participants at 60% (36/60) had not diagnosed Lyme disease within the past 2 years (Table 4.8). Twenty-three percent (14/60) of individuals reported diagnosing 1-10 cases within the last 2 years while only 5% (3/60) and 12% (7/60) reported diagnosing 11-30 and >30 cases of Lyme disease in the past 2 years respectively. Participants diagnosing 1-10 cases resided in all 3 provinces. Only participants from MB reported seeing 11-30 or >30 cases in the past 2 years. Furthermore, all respondents from MB reported seeing at least 1-10 cases of Lyme disease in the past 2 years (Table 4.8).

The most common reason for Lyme disease testing was 'if the dog is exhibiting symptoms', at 68% (41/60) across all three provinces (Table 4.8). Only 8% (5/60) of participants tested 'as part of every wellness visit'. Alternatively, 8% (5/60) of participants admitted to 'never' testing for Lyme disease. Four of these respondents were from AB and 1 respondent was from MB. Having a travel related history was a more likely reason for Lyme disease testing in AB and SK than in MB. The most common response for 'other' reasons to test for Lyme disease was when it was performed in conjunction with annual or bi-annual 4Dx screening protocols (ex. for heartworm monitoring) (n=12) (Table 4.8).

Of the participants who diagnosed at least 1 case of Lyme disease in the past 2 years, 58% (14/24) described canine patients as being 'asymptomatic' (Table 4.8). Of the 2 SK participants who reported diagnosing Lyme disease, only asymptomatic cases were observed. In clinical cases, the most common observable clinicals signs were lameness/joint pain/joint swelling or other arthritic changes (67%) and pyrexia (54%). Of the participants reporting Lyme disease cases in

AB and MB, a variety of less common symptoms were also described including anorexia, lethargy, renal symptoms, weight loss, immune mediate thrombocytopenia (ITP), lymphadenopathy, and polyuria/polydipsia (PU/PD) (Table 4.8).

When respondents were asked to specify which tests they used to screen for Lyme disease a resounding 70% specified the in-clinic IDEXX SNAP 4Dx Test (IDEXX Laboratories, Inc.) (Table 4.9). This represents a large proportion of testing data that is not reported to any type of surveillance programming (such as is the case with veterinary laboratory databases). When asked to report on frequency of Lyme vaccination, the majority of participants (58%) specified 'only if the history of the pet warrants vaccination'. A large proportion of participants (35%) also specified 'never' using the Lyme vaccine as a preventative measure (Table 4.9). The most common reason for not vaccinating against Lyme disease included low prevalence in the participant's region (n=14). Five participants also specified that using a tick preventative was their preference over the Lyme vaccine. Less common reasons for not vaccinating against Lyme disease included side effects of the vaccine, questionable vaccine efficacy, lack of owner interest, cost, and low severity of disease in dogs.

The majority of respondents claimed to 'always' recommend tick prevention to clients, regardless of compliance, at 62% (37/60) (Table 4.9). Of the available ectoparasitic treatments used, the most popular choices were Bravecto at 71% (41/58) and/or Nexguard at 67% (39/58). Respondents were able to choose as many ectoparasitic treatments that were applicable to them.

4.4.5 Case Definitions

Using statistical data from survey responses and commentary from open-ended questions, proposed case definitions for *Echinococcus spp*. (*granulosus, multilocularis*), MRSA/MRSP, salmonellosis, and Lyme disease were created (Table 4.10). Because data collected was more

extensive for Lyme disease specifically, a more comprehensive case definition was possible. For the remaining pathogens, diagnosis through veterinary laboratory services would be required because definitive in-clinic testing does not currently exist for these pathogens.

4.4.6 Dogs as Sentinels for Lyme Disease

Dogs were assessed as sentinels based on the requirements that the sentinel must be susceptible to Lyme disease, survive the disease, be readily exposed to the risk factor (tick exposure), and mount a response to the disease that can be detected through clinical signs or diagnostic testing. Therefore, even though participants established that many dogs are asymptomatic for Lyme disease, because the testing is quick, inexpensive, and non-invasive, dogs can still be good sentinels for assessing disease risk of Lyme disease in humans. They are also good sentinels for Lyme disease because they are readily exposed to the risk factor (tick exposure). Despite preventatives being recommended by most vets, positive cases are still reported. Not every owner is going to comply with recommendations (requesting a tick preventative but also administrating the medication appropriately); therefore, there is still a population of dogs that are or could test positive, serving as sentinels to assess disease risk for Lyme disease in humans.

4.4.7 Open-Ended Questions: Final Thoughts

When given the opportunity to provide any final thoughts on a companion animal surveillance program in the Prairie Provinces, responses varied. Two respondents commented on compensation for time or some other incentive for participation in the surveillance program. In addition, one respondent emphasized that anonymity must be ensured. Several participants also expressed additional zoonotic diseases for inclusion such as rabies, giardiasis, leptospirosis, brucellosis, ringworm, blastomycosis, sarcoptic mange, and several feline pathogens including lungworm and trichomoniasis. There were 3 respondents who also recommended collaboration

with other surveillance programs such as laboratory surveillance. One respondent specified collaboration with larger surveillance programs such as the Companion Animal Parasite Council (CAPC) in the United States.

4.5 Discussion

In the present study, the role of veterinarians and veterinary clinics in a companion animal surveillance program was successfully explored. The contribution of veterinarians and in-clinic data is vital for the success of a companion animal surveillance initiative in the Prairie Provinces of Canada. In addition to highlighting the value practicing veterinarians bring to companion animal surveillance, this study identified the willingness of veterinarians to participate in a surveillance program, captured baseline reporting data on several canine pathogens of public health concern, created preliminary case definitions for canine pathogens that may be included in the surveillance initiative, and assessed domestic dogs as sentinels using Lyme disease as an example.

Veterinarians across all 3 provinces expressed moderate interest in participating in a companion animal surveillance program. Survey data also promoted the importance of all practice regions being involved in companion animal surveillance as every participant, regardless of his/her background in practice region or species treating, saw dogs and cats in some capacity. The greatest variability in surveillance interest was related to the frequency with which clinical data and surveillance data would be reported to and from the program. While the overall consensus was 'monthly' reporting in either direction, frequency of reporting may be adjusted at the discretion of primary stakeholders and veterinary clinics enrolled in the program. More favorable reporting frequency may become evident as the surveillance program evolves.

The most common reason for hesitation to participate in a companion animal surveillance program was time commitment. In addition, compensation or incentivization was suggested by some participants. The investigators propose that incentives take the form of information sharing and targeted research as a direct result of surveillance data in lieu of monetary compensation. This method of incentivization offers longer sustainability of the program. While prior research has demonstrated the benefit of monetary compensation for cooperation by veterinarians, it still does not guarantee adequate participation in a surveillance program[23]. Research on compliance and sustainability within animal health surveillance systems has explored monetary incentives through covered testing costs, but ultimately identified that "ease of data collection" was a primary reason for high compliance and long-term participation by veterinarians enrolled in the program[24].

Results from this survey provided a baseline for the proportion of veterinarians reporting several canine pathogens of public health interest in the Prairie Provinces including *Echinococcus spp.* (*granulosus, multilocularis*), MRSA/MRSP, *Salmonella spp., Campylobacter spp., E. coli, B. burgdorferi, Ehrlichia spp.,* and *Anaplasma spp.* Though this information is not a true reflection of prevalence, it acts as an estimate for the number of veterinarians/veterinary clinics diagnosing these canine zoonoses in the prairies. The data to come out of a companion animal surveillance program would provide more concrete data on prevalence for these canine zoonotic pathogens of public health concern.

Exploring the utility of veterinary clinics in providing surveillance data on serious canine zoonoses such as *Echinococcus spp.* (*granulosus, multilocularis*) was examined. *Echinococcus spp.* was the overall highest scoring pathogen from a previously conducted prioritization exercise that used experts in the field of veterinary medicine, public health, and epidemiology. A large interest in this pathogen was related to concerns in increasing parasite distribution and severity of

disease in both animals and humans. Although a keen interest in this pathogen from possible stakeholders was well established, the utility of surveillance data from veterinary clinics as a means to assess disease risk in humans for echinococcosis from domestic dogs required further exploration. The present survey identified that a small proportion of veterinarians reach for endoparasitic treatment in lieu of definitively testing for helminths, due to ease of treatment and cost of treating versus testing. Therefore, domestic dogs may not be a good representation of *Echinococcus spp*. prevalence from a surveillance perspective because of low testing and common deworming practices. However, due to the high severity of disease in dogs and people, there is still value in reporting any positive canine cases to a surveillance program when/if echinococcosis is identified.

From a public health perspective, dogs are only a source of infection to humans through fecal shedding of *Echinococcus spp*. eggs[25], therefore definitive fecal analysis is the best way to accurately assess the transmission risk of *Echinococcus spp*. from dogs to humans in the prairies. Jenkins emphasized the need for an in-clinic veterinary test capable of detecting *Echinococcus spp*. antigens or DNA in canine feces for more timely and cost-effective diagnosis[26]. Such a rapid in-clinic test would be extremely beneficial for the purposes of *Echinococcus spp*. surveillance in domestic dogs. As definitive fecal testing for *Echinococcus spp*. currently stands (through fecal PCR or fecal coproantigen ELISA[26]), only laboratory confirmed cases can be utilized for companion animal surveillance from a public health perspective when considering only direct transmission risk from domestic dogs.

This survey highlighted that a large proportion of clinical veterinary data could be better utilized for surveillance purposes. Of particular note, 70% of all respondents used the IDEXX SNAP 4Dx Test in-clinic to screen and diagnose Lyme disease. Similarly, 60% of all respondents

performed in-clinic fecal floatation at some capacity. Although fecal floatation alone cannot distinguish between several tapeworm species[26], this represents another example of in-clinic diagnostic testing for possible zoonotic pathogens that is not recorded in any type of surveillance database. In addition to recording in-clinic data to a companion animal surveillance program that would otherwise be lost, collaboration with veterinary laboratory services could be a valuable addition to a companion animal surveillance program in the prairies[23,27]. Several veterinary diagnostic laboratories were highlighted in this survey including PDS, IDEXX, Antech and Manitoba Veterinary Diagnostic Services. Currently there is no formal reporting from veterinary laboratories in place. Where reporting occurs, at the level of the veterinarian or at the level of the diagnostic laboratory, would need to be explicit for surveillance purposes to avoid duplicate reporting of cases. In addition, lack of communication between these various laboratory groups will remain a challenge for streamlining possible companion animal surveillance data from veterinary diagnostic laboratories across the prairies.

For the purposes of companion animal surveillance in collaboration with veterinary clinics, grouping certain canine pathogens of public health interest may be considered. For example, since several other vector-borne diseases are included on the IDEXX SNAP 4Dx Test[28] commonly performed in-clinic, reporting could include *Ehrlichia spp., Anaplasma spp.,* and *D. immitis* in addition to Lyme disease if positive results occurred for any of these pathogens. Similarly, several canine enteric pathogens of public health concern are tested for collectively through veterinary laboratory testing. Therefore, reporting could occur for *Salmonella spp., Campylobacter spp.,* and/or *E. coli* as these pathogens received high scores from experts in a previously conducted prioritization exercise. For enteric pathogens specifically, several studies have explored syndromic surveillance using dogs with gastrointestinal symptoms as indicators for possible

human health risks[29,30]. In the instance of syndromic surveillance, determining the etiological agent is less important than clinical signs alerting to a possible outbreak or public health concern. The utility of syndromic surveillance in this companion animal surveillance initiative requires further exploration. Lastly, because of the growing concerns surrounding AMR, any resistant bacterial pathogen, particularly multi-drug resistant (MDR) pathogens (including but not limited to MRSA/MRSP) could be reported to a companion animal surveillance program.

Case definitions will vary greatly when used for diagnostic, outbreak, or surveillance purposes. The goal of this study was to create a case definition for Lyme disease from a surveillance perspective and to start formulating case definitions for several other canine zoonotic pathogens of public health concern for the inclusion in a surveillance program. In the instance of Lyme disease, for the purposes of surveillance, having a positive diagnostic test was deemed important regardless of clinical signs, since the majority of dogs are asymptomatic. Alternatively, using only clinical signs as the case definition (without a positive test result) was deemed meaningless, because many other canine diseases can cause similar clinical symptoms. For the pathogens *Echinococcus spp*., MRSA/MRSP, and *Salmonella spp*., definitive diagnoses through laboratory testing would be required for confirmed cases. If in-clinic testing capabilities continue to evolve, then more definitive clinical testing options can be included in these case definitions. As a companion animal surveillance program matures over time, case definitions should be periodically updated[7].

Based on survey data from the present study, the investigators propose the use of dogs as sentinels for assessing Lyme disease risk in humans. This conclusion is based on the following principles: that an ideal sentinel is susceptible to the disease of interest, survives the disease, is readily exposed to the risk factor, and mounts an easily detectable response to the disease through

clinical signs or diagnostic testing[18,19]. Although many dogs are asymptomatic, testing for Lyme disease is quick, inexpensive and non-invasive. Furthermore, there were a variety of reasons that veterinarians screened for Lyme disease across all 3 provinces, including non-endemic regions; therefore, testing for Lyme disease is already a popular choice among practicing veterinarians. From a surveillance perspective, this is data that is readily accessible but is not being collected or used for public health advancement.

Despite a high proportion of veterinarians endorsing tick prevention, positive cases of canine Lyme disease were still reported within the past 2 years across the prairies. As tick prevention increases in popularity (with veterinarians and owners) a decrease in the incidence of canine Lyme disease may be observed over time, making them unsuitable sentinels; however, without ongoing surveillance monitoring, these trends in canine Lyme disease cannot be observed or adequately responded to. Furthermore, if a decline in incidence of canine Lyme disease was not observed, then educational programs on tick prevention may be an appropriate reaction to the surveillance data. Administration of the Lyme vaccine appears to be low at this time and is unlikely to inhibit the use of dogs as sentinels for Lyme disease. While Lyme disease was used as a primary example in this study for the utility of domestic dogs as sentinels, dogs have also been proposed sentinels for many other zoonotic pathogens, particularly vector-borne[19] and parasitic pathogens[26,31].

Several open-ended responses to a participant's 'final thoughts' on a companion animal surveillance program in the Prairie Provinces highlighted an overall communication gap in information sharing between research and/or government groups and practicing veterinarians. This was observed when several statements regarding more information on certain pathogens, such as rabies, were suggested. Surveillance programs for rabies are currently well-established both

provincially and federally in Canada[32,33]. Thus, a surveillance program could also provide a direct communication channel to share information more easily with practicing veterinarians. In addition, several participants suggested other canine pathogens for the surveillance program that were previously excluded from the initiative based on results from the prioritization exercise. Because of finite resources, only a select group of high priority pathogens can be included in any surveillance program[5]. In addition to canine pathogens of public health concern, feline zoonotic pathogens will also be assessed for this companion animal surveillance program in the future.

Prior research has identified limitations with data extraction from EMR for the purposes of surveillance. This is largely due to a lack of standardization in nomenclature and medical record keeping by veterinary professionals[8,9]. While such technology would provide little time commitment from participating veterinary clinics, these gaps in medical record keeping can cause incomplete or inaccurate data capture. Other studies have explored the utility of web-based surveillance systems that require veterinarians to directly input surveillance data[14]. In the present study, it was important to identify the willingness of veterinarians to input surveillance data into a proposed online database. This type of surveillance programming can be particularly favorable for real-time dissemination of surveillance data[2]. The largest limitation of this surveillance design is compliance from participating clinics due to an increased time commitment[14,15]. Although an overall willingness to participate in a companion animal surveillance program using a web-based approach was moderate, incorporating some form of incentivization (including nonmonetary options) and ease of data entry will be crucial for the success of the program[23,24].

The present study would have benefited from a larger sample size to obtain a wider variety of veterinary practitioners throughout the Prairie Provinces. Based on 2015 published data[34], there are approximately 398 companion animal servicing veterinarians/veterinary clinics in AB, 96 in

SK, and 101 in MB. Therefore, the investigators acknowledge low survey participation when compared to number of practices within the region of interest. Prior research also reports low response rates with web-based survey methods[35,36]. Additionally, non-response bias[34,37] exists in the present study. Those veterinarians most interested in surveillance were more likely to participate in this survey and contribute data. Therefore, results from the present survey are more likely to be representative of individuals already interested in a surveillance initiative. Despite these limitations, there is still value in the baseline data gathered from this survey to gauge surveillance interest. Furthermore, response rate and non-response bias did not impact the development of case definitions or assessment of dogs as sentinels for Lyme disease.

Because only current practice location was recorded for each participant, the investigators could not rule out that a participant moved or practiced in multiple provinces within the past 5 years. This may have affected the accuracy of where reported cases actually occurred if participants recalled a case seen within the past 5 years in a different province to their current practice location. Because this surveillance program will include data from all 3 prairie provinces, minor discrepancies in location of cases was not a primary concern. A limitation of the surveillance program itself is that data gathered from veterinary clinics will not be representative of the entire domestic animal population[11]. Rather, it will only provide data on the proportion of companion animals that receive veterinary care and diagnostic testing. Regardless of this limitation with any surveillance system, such programming is still a means to gather data on a population of animals we currently have little to no information on.

4.6 Conclusion

In conclusion, it was identified that in-clinic veterinary data, particularly from in-clinic 4DX SNAP testing, can be utilized for the purposes of companion animal surveillance. It was also

established that veterinarians are a useful tool in the development of case definitions for companion animal diseases intended for surveillance. Furthermore, it was concluded that domestic dogs may serve as good sentinels for assessing Lyme disease risk in humans.

The use and cooperation of veterinarians and veterinary clinics for a companion animal surveillance program in the Prairie Provinces is essential to the success of such programming. Although surveillance data collected from participating veterinarians and veterinary clinics will not be representative of the entire companion animal population, it will provide baseline prevalence and disease trends in animals that pose a public health risk to humans. In addition, collaboration with veterinary diagnostic laboratory services and better communication channels between laboratory groups will need to be addressed for retaining, sharing, and utilizing companion animal surveillance data across the prairies.

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Table 4.1. Demographic data for survey respondents, including count and % total of respondents

	Survey Respondents (n=60)	% Total respondents
Province		
Alberta	33/60	55
Saskatchewan	10/60	17
Manitoba	17/60	28
Other	0/60	0
Practice region		
Urban (city or suburb; densely populated)	33/60	55
Rural (countryside, town; low population density)	20/60	33
Both (split time between urban and rural)	7/60	12
Experience in companion animal zoonoses*		
None	0/59	0
Minimal	5/59	9
Moderate	38/59	64
Experienced	16/59	27

*One participant skipped question (n=59)

Table 4.2. Summary of species veterinarians see in practice and percentage of time spent with each

Species	No. of respondents seeing species (n=60)	% of respondents seeing species	Average % of time spent with species between all respondents	Max individual % of time spent with species	Min individual % of time spent with species
Canines	60/60	100	55	80	10
Felines	60/60	100	33.9	50	1
Pocket Pets*	16/60	26.6	2.4	70	1
Reptiles	4/60	6.7	0.1	3	1
Pet Birds	6/60	10	0.2	5	1
Equines	9/60	15	1.0	15	2
Beef Cattle	11/60	18.3	3.8	60	2
Dairy Cattle	7/60	11.7	2.5	60	1
Poultry	2/60	3.3	0.1	7	1
Swine	2/60	3.3	0.1	5	1
Small Ruminants	6/60	10	0.6	20	1
Wildlife	3/60	5	0.2	5	2
Game Cervids	0/60	0	0	0	0
Other	0/60	0	0	0	0

*small mammals

Table 4.3. Willingness to participate in a companion animal surveillance program on a scale of 1 to 10 specific to the Prairie Provinces

	Willingness to participate in a companion animal surveillance program			Willingness to participate if inputting information yourself (or by a staff member) into an online database with a login code		
	Median	**Min**	**Max**	**Median**	**Min**	**Max**
Stratified by province						
Alberta	8.0	2	10	7.0	2	10
Saskatchewan	7.0	4	10	5.5	2	10
Manitoba	8.0	3	10	7.0	2	10
Stratified by practice region						
Urban	8.0	3	10	7.0	2	10
Rural	7.0	2	10	5.5	2	10
Both	9.0	7	10	8.0	7	10
Stratified by experience						
Minimal	9.0	5	10	7.6	5	10
Moderate	7.0	2	10	7.0	2	10
Experienced	9.0	4	10	8.0	2	10
Total	**7.5**	**2**	**10**	**7.0**	**2**	**10**

Table 4.4. Preferred frequencies of surveillance reporting from participants

	With what frequency are you willing to report surveillance data?			With what frequency would you like to see updates from a companion animal surveillance system?		
Rank	**Frequency**	**No. of participants (majority) selecting ranking position***	**% of participants selecting ranking position**	**Frequency**	**No. of participants (majority) selecting ranking position***	**% of participants selecting ranking position**
1st	Monthly	24/59	41%	Monthly	39/59	66%
2nd	Weekly	22/54	41%	Annually	22/55	37%
3rd	In real-time	15/54	28%	Weekly	28/54	52%
4th	Annually	28/55	51%	In real-time	36/55	65%

*'n' varies as a result of participants who contributed only partial rankings; this question was skipped entirely by one participant

Table 4.5. Proportion of respondents reporting several canine pathogens of interest in the past 5 years within the Prairie Provinces

Pathogen	**Proportion of respondents reporting (n = 60)**	**% of all respondents**
Echinococcus spp.	10/60*	16.7
MRSA	14/60	23.3
MRSP	16/60	21.7
Salmonella spp.	11/60	18.3
Campylobacter spp.	25/60	41.7
Escherichia coli	31/60	51.7
Borrelia burgdorferi	24/60	40.0
Ehrlichia spp.	25/60	41.7
Anaplasma spp.	21/60	35.0

*7/10 respondents (70%) were from AB and 3/10 respondents were from MB (30%); no respondents from SK reported diagnosing at least one case of canine echinococcosis in the last 5 years.

Table 4.6. Most common methods for diagnosing tapeworms

Test	No. of respondents using the test (n=60)	% of respondents using the test
Fecal floatation (n=48)	48/60	80
In-clinic	15/48	31
Laboratory	12/48	25
Both[a]	21/48	44
Fecal wet mount	21/60	35
ELISA/CELISA	19/60	32
PCR	26/60	43
Doesn't test	7/60	12
Other	5/60	12
Histology	1/60	2
Visual Exam	2/60	3
FAT	1/60	2
Treatment trial	1/60	2

[a]Individuals selecting 'both' are separate from individuals choosing 'in-clinic' or 'laboratory' only

Table 4.7. Tapeworm preventative used and frequency of deworming protocols

	No. of respondents	% of respondents
Preventative used (n=60)		
Drontal Plus	26/60	43
Dolpac	20/60	33
Interceptor Plus	41/60	68
Other[a]	2/60	3
N/A[b]	2/60	3
Frequency of deworming (n=58)*		
Monthly	8/58	14
Every 3 months	6/58	10
Every 6 months	1/58	2
Annually	5/58	9
Case dependent	38/58	66

[a]2 respondents specified Droncit

[b]2 participants worked outside of clinical practice and therefore prescribing dewormer is 'not applicable'

*n=58 because prescribing dewormer is not applicable for two participants

Table 4.8. Lyme disease cases, frequency of testing and symptoms associated with positive cases specified by province and total number of participants

Lyme Disease Information	AB Respondents (n=33)	SK Respondents (n=10)	MB Respondents (n=17)	Total (n=60)
Canine cases diagnosed in past 2y				
0	28/33 (85%)	8/10 (80%)	0/17 (0)	36/60 (60%)
1-10	5/33 (15%)	2/10 (20%)	7/17 (41%)	14/60 (23%)
11-30	0/33 (0)	0/10 (0)	3/17 18%)	3/60 (5%)
>30	0/33 (0)	0/10 (0)	7/17 (41%)	7/60 (12%)
Frequency of testing				
As part of routine wellness	1/33 (3%)	0/10 (0)	4/17 (24%)	5/60 (8%)
At request of owner	8/33 (24%)	1/10 (10%)	8/17 (47%)	17/60 (28%)
If dog is exhibiting symptoms	20/33 (60%)	9/10 (90%)	12/17 (70%)	41/60 (68%)
If travel related history	20/33 (60%)	6/10 (60%)	5/17 (29%)	31/60 (52%)
Never	4/33 (12%)	0/10 (0)	1/17 (6%)[a]	5/60 (8%)
Other	6/33 (18%)[b]	1/10 (10%)[c]	10/17 (59%)[d]	17/60 (28%)
Symptoms with positive cases*	**(n=5)**	**(n=2)**	**(n=17)**	**(n=24)**
Asymptomatic	2/5 (40%)	2/2 (100%)	10/17 (59%)	14/24 (58%)
Lameness/joint pain/swelling	3/5 (60%)	0/2 (0)	13/17 (76%)	16/24 (67%)
Fever	1/5 (20%)	0/2 (0)	12/17 (71%)	13/24 (54%)
Anorexia	1/5 (20%)	0/2 (0)	3/17(18%)	4/24 (17%)
Lethargy	2/5 (40%)	0/2 (0)	6/17 (35%)	8/24 (33%)
Other	1/5 (40%)[e]	0/2 (0)	8/17 (47%)[f]	9/24 (38%)

[a]Not applicable for 1 respondent who worked outside of clinical practice
[b]4 respondents specified if history of tick; 2 respondents specified with 4Dx screening as part of annual exam or regular heartworm testing
*'n' corresponds with no. of respondents who identified diagnosing Lyme cases
[c]1 respondent specified prior to administering the Lyme vaccine
[d]10 respondents specified with 4Dx screening as part of annual exam or regular heartworm testing
[e]1 respondent specified immune mediated thrombocytopenia (ITP)
[f]5 respondents specified renal signs; 1 respondent specified weight loss; 1 respondent specified lymphadenopathy; 1 respondent specified PU/PD

Table 4.9. Summary of Lyme disease data: Testing, vaccination, frequency and type of tick prevention

Lyme Disease Information	No. of respondents (n=60)	% of respondents
Type of test used		
IDEXX SNAP 4Dx Test (in-clinic)	42/60	70
Other[a]	20/60	33
N/A[b]	5/60	8
Frequency of Lyme vaccination		
Never	21/60	35
Only if the history of the pet warrants vaccination	35/60	58
Every patient gets vaccinated for Lyme disease	1/60	2
Other[c]	3/60	5
Frequency of tick prevention recommendation		
Always	37/60	62
Usually	16/60	27
Sometimes	2/60	3
Rarely	0/60	0
N/A[d]	2/60	3
Other[e]	3/60	5
Type of prevention used (n=58)*		
Bravecto	41/58	71
Nexguard[f]	39/58	67
Simparica[g]	24/58	41
Revolution	16/58	28
Advantix	24/58	41
Other[h]	2/58	3

[a]14 respondents specified using PDS, Antech or IDEXX laboratories for send out SNAP testing; 4 respondents specified using the Lyme Quant C6 Test from IDEXX; 1 respondent specified PCR testing and 1 respondent specified treatment trial
[b]Represents the 5 participants who never test for Lyme disease
[c]2 respondents specified they only rarely recommend; 1 respondent specified that they always recommend but compliance is varied
[d]Two participants work outside of clinical practice and therefore recommending tick prevention is not applicable
[e]3 respondents specified based on risk/lifestyle
*n=58 because recommending tick prevention is not applicable for two participants
[f]Including Nexguard Spectra
[g]Including Simparica Trio
[h]2 respondents specified Credlio

Table 4.10. Proposed case definitions for several canine pathogens/diseases of public health concern based on information obtained from clinical veterinarians for the purposes of surveillance in the Prairie Provinces

Pathogen/Disease	Confirmed Case Definition	Additional Comments
Echinococcus spp. (multilocularis, granulosus)	Any urban, rural or free-roaming dog residing in the provinces of AB, SK, or MB with a positive fecal coproantigen ELISA or PCR test result for *Echinococcus multilocularis* or *E. granulosus*	Requires access to laboratory testing; only interested in transmission risk from dogs to humans (shedding of worm segments or eggs in feces)
MRSA/MRSP	Any urban, rural or free-roaming dog residing in the provinces of AB, SK, or MB with a positive MRSA/MRSP result on culture and sensitivity testing with resistance to one or more antibiotic(s) regardless of clinic signs	Requires laboratory testing; consider the addition of any AMR and MDR pathogen(s)
Enteric pathogens (*Salmonella spp. Campylobacter spp., E.coli)*	Any urban, rural or free-roaming dog residing in the provinces of AB, SK, or MB with a positive PCR test or fecal culture for *Salmonella spp., Campylobacter spp.,* and/or *E.coli* regardless of clinical signs	Requires laboratory testing; consider the addition of other enteric pathogens
Lyme disease	Any urban, rural or free-roaming dog residing in the provinces of AB, SK, or MB with a positive in-clinic 4Dx SNAP test or laboratory confirmed positive for Lyme disease regardless of clinical signs	Including laboratory positives requires access to laboratory testing

CHAPTER 5: GENERAL DISCUSSION AND CONCLUSION

5.1 Introduction

The concept of One Health seeks to bridge the gap between human, animal, environmental, and ecosystem health by collectively assessing these drivers of disease spread[1]. This is because the transmission of many diseases involves all four components. Companion animals, including but not limited to cats and dogs, are an important population of animals that pose a risk of disease transmission to humans when considering the One Health paradigm[2,3]. Currently, there is minimal information on disease trends in companion animals from either an animal health or public health perspective, particularly in Canada[2,4]. Pathogen prioritization and disease surveillance are two epidemiologic methodologies that can incorporate a One Health approach to understanding disease distribution and determinants. With the rising popularity of domestic animal ownership, the potential zoonotic risk these animals pose to humans deserves greater attention.

There is a clear need for further research on companion animal surveillance and pathogen prioritization for companion animal diseases in Canada. Currently, The OAHN in Ontario is the only formal surveillance program in Canada to include companion animal health trends and diseases[5]. The Prairie Provinces became the primary region of interest for this research because surveillance data on companion animal diseases is extremely limited in this region. Similar climate, environments, socioeconomic factors, and anticipated pathogens of concern from a public health perspective also make the 3 Prairie Provinces a rational combined region for a companion animal surveillance initiative.

This thesis sought to accomplish 3 main objectives. The first objective was to create a comprehensive list of canine pathogens ever reported in the domestic dog and to condense this list to include only those pathogens of public health interest, where the dog is involved in how humans

acquire the disease, specific to Canada and the prairies. The second objective was to then prioritize these pathogens using experts in the field of veterinary medicine, public health and epidemiology to identify the top 5 highest priority pathogens that would become the focus of a companion animal surveillance initiative. Finally, the third objective was to explore the role of clinical veterinarians and veterinary clinics in a companion animal surveillance system, to develop case definitions for the canine pathogens of public health significance established in prior chapters for the purposes of surveillance, and to assess domestic dogs as sentinels for human health risk using Lyme disease as an example. Data obtained from a companion animal surveillance program in the Prairie Provinces would be of benefit to both animal health and human health, however, the primary focus of this research was exploring canine zoonotic pathogens and companion animal surveillance from a public health perspective.

5.2 Key Findings

In Chapter 2, a comprehensive list of pathogens historically reported in the domestic dog (n=594) was recorded. Using a stepwise approach formulated by the primary researchers, this list was pared down to include only those pathogens of public health interest, and where the dog plays a role in human disease, that were relevant to Canada and the prairies. In total, 84 canine pathogens met these criteria and comprised the final canine pathogen shortlist. Additionally, supplementary groups of pathogens were highlighted for their possible importance in future companion animal surveillance programming in Canada due to constantly changing environmental and social drivers.

In Chapter 3, a prioritization exercise using experts in the field of veterinary medicine, public health, and epidemiology was performed to establish the top 5 highest priority pathogens from the initial shortlist developed in Chapter 2 upon which to focus a companion animal surveillance program in the Prairie Provinces. The top 5 highest scoring pathogens were

Echinococcus spp. (granulosus, multilocularis), MRSA, *Salmonella spp.,* MRSP, and *B. burgdorferi*. From a surveillance perspective and the realities of diagnostic testing for many of these high priority pathogens, the following groups of canine pathogens were proposed for consideration in a companion animal surveillance program from a public health perspective: (1) *Echinococcus spp.,* (2) AMR pathogens (including MRSA/MRSP), (3) enteric pathogens (*Salmonella spp., E. coli, Campylobacter spp.*), and (4) vector-borne diseases (*B. burgdorferi, Anaplasma spp., Ehrlichia spp., D. immitis*). In addition, several non-zoonotic canine pathogens including parvovirus, distemper, and canine influenza were identified as significant pathogens for inclusion in the surveillance program from an animal health perspective.

Finally, in Chapter 4, the utility of clinical veterinarians and veterinary clinics in a companion animal surveillance initiative was thoroughly examined. The use and cooperation of veterinarians and veterinary clinics from all practice regions was deemed essential to the success of a companion animal surveillance program in the prairies. This study also established that clinical veterinarians provide valuable sources of information needed for the development of case definitions for canine diseases intended for surveillance. In addition, it was identified that in-clinic veterinary data, such as in-clinic IDEXX SNAP 4DX testing or results from in-house fecal testing, are under-utilized for the purposes of surveillance. Finally, domestic dogs were identified as appropriate sentinels for assessing Lyme disease risk in humans in the prairies and may serve as sentinels for several other canine zoonotic diseases of interest, particularly vector-borne[6] and parasitic diseases[7,8].

5.3 Limitations of Research

Several limitations were acknowledged throughout the course of this research. In Chapter 2, the potential to miss rare or emerging pathogens while formulating the initial comprehensive

list was possible. In fact, during the course of this research *Sars-CoV-2* emerged and was subsequently added to the list. In addition, it is important to recognize that the exhaustive canine pathogen list was pared down by only two investigators; therefore, pathogen categorization was the result of specific definitions determined by these individuals. These definitions may change slightly depending on the investigator and stakeholder interests. The final shortlist is therefore not definitive but is unlikely to change substantially if replicated. If time and resources allow it, double-blinded methods for paring down the comprehensive canine list will decrease subjectivity.

A primary limitation from Chapter 3 was the small sample size. Increased participation, particularly from public health stakeholders, would have been beneficial for pathogen scoring by a diverse range of experts. In addition, this study was limited to a semi-quantitative prioritization approach due to a lack of pre-existing companion animal disease data[9,10]. This created some level of subjectivity and bias in the results[9,11]. Furthermore, additional considerations during data analysis for this research chapter included "weighing" participant scores. For example, weights could be applied to scores from participants who classified themselves as "experienced" in canine zoonoses. As a result, these participants would have a greater impact on final pathogen scores and therefore overall ranking. Because only 4 respondents classified themselves as "experienced" and because this is a subjective consideration, their scores were not weighted more heavily. Future exercises may benefit from weighing scores if a larger and more diverse sample size is achieved. Lastly, the supplemental chart provided to experts had the potential to bias a participant's top 10 pathogen selections. To reduce this bias, only simple and consistent information was provided for each pathogen to aid the experts if a particular pathogen was unfamiliar to them. Similarly, a larger sample size in Chapter 4 would have provided data from a wider range of veterinary practitioners throughout the Prairie Provinces and decreased non-response bias. In addition to this,

because only current practice location was recorded for each participant, it could not be ruled out that a participant moved or practiced in multiple provinces within the past 5 years. This could have affected the location of cases that were reported in the survey.

A significant limitation of any companion animal surveillance program is that data gathered from veterinary clinics is not representative of the entire domestic animal population[12]. Data captured from companion animal surveillance will only provide information on those domestic animals that receive veterinary care and diagnostic testing. In other words, companion animal surveillance data can only be collected from those animals that receive standard veterinary services, and additionally, owners must be willing to pursue diagnostic testing (to definitively diagnose the pathogens included in a surveillance initiative). In particular, remote communities with limited access to veterinary services will be underrepresented in such a surveillance strategy. Alternative and more direct ongoing surveillance efforts on zoonoses from domestic cats and dogs will need to be established in remote regions throughout the prairies, including Indigenous communities[13–15]. Despite these limitations, companion animal surveillance data collected from participating veterinarians and veterinary clinics will provide valuable baseline information on disease trends in a population of animals that can pose serious public health risks to humans.

5.4 Future Investigations

This thesis focused primarily on the domestic dog. Other companion animal species such as cats, exotic pets, small mammals, and domestic birds should also be considered for future research. In particular, domestic feline pathogens will be the next group of pathogens assessed for this companion animal surveillance initiative. The author also recognizes that several of the zoonotic pathogens identified over the course of this research are relevant to wild canids within Canada[16–19]. Surveillance of wild canids in the prairies is an additional area to be explored for

provincial surveillance programs. The methods applied in all three research chapters can be adapted for any of the above-mentioned species.

In addition to participation from veterinary clinics, collaboration with veterinary diagnostic laboratory services, as well as better communication between various laboratory groups needs to be examined in order to retain, share, and act on companion animal surveillance data across the prairies. Although there is currently no formal reporting in place for veterinary laboratory services, population based data has been previously reported on in North America, primarily from an animal health perpective[20]. In Canada, the use of veterinary laboratory data has been examined for the purposes of syndromic surveillance in a retrospective study[21]. Further research on incentivization (including nonmonetary strategies), compliance, and sustainability of veterinary clinics in surveillance also needs further attention[22,23].

As with any surveillance program, pathogen prioritization, case definitions, and the surveillance program itself will need to be evaluated at regular intervals[9,11,24,25] to ensure relevant companion animal pathogens are monitored in the program due to ever-changing environmental and social climates. In addition, evaluations of the program will provide feedback from stakeholders and adjustments to improve the program can be made throughout its evolution.

5.5 Conclusions

There is an evident need in both the animal health and public health sector for companion animal surveillance in the Prairie Provinces. This thesis provided the foundation for such a companion animal surveillance initiative and the following outcomes were accomplished: canine pathogens upon which to focus surveillance were identified, a proportion of in-clinic veterinary data that is not currently captured for the purposes of surveillance was exposed, the willingness of clinical veterinarians to participate in a surveillance program was determined, case definitions for

several canine pathogens to be included in surveillance were proposed, and dogs were assessed as sentinels for pathogens of public health importance using Lyme disease as an example. Overall, this thesis highlighted significant gaps in companion animal zoonotic disease and surveillance research within Canada and the prairies. It should ignite the conversation that there is more work to be done to truly achieve One Health within the Prairie Provinces and that companion animal diseases warrant greater attention.

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APPENDIX A

Complete list of 594 pathogens identified in canines categorized by the following taxonomical groups: bacteria, ectoparasites, fungi, helminths, protozoa, rickettsia and viruses. Pathogens categorized as zoonotic/sapronotic/anthroponotic have been **bolded**; sapronoses are specifically denoted by a ❖. If the dog is involved in transmission, maintenance or detection of the pathogen it has been further underlined. Of these, if the pathogen is reported in dogs in Canada (Tier 1) it has been denoted by an *. If the pathogen is reported in Canada but canine-specific reports are lacking (Tier 2) it is marked with a [C] (see also Appendix C). Finally, if the pathogen has the potential to occur in Canada (Tier 3) it is marked by a [D] (see also Appendix D).

Bacteria

Acholeplasma laidlawii
Acinetobacter baumannii
Actinobacillus actinomycetemcomitans [C]
Actinobacillus lignieresii
Actinomyces bovis
Actinomyces bowdenii
Actinomyces canis
Actinomyces catuli
Actinomyces coleocanis
Actinomyces hordeovulneris
Actinomyces hyovaginalis
Actinomyces israelii
Actinomyces naeslundii
Actinomyces neuii subsp. anitratus [C]
Actinomyces odontolyticus
Actinomyces turicensis
Actinomyces urogenitalis
Actinomyces viscosus*
Actinomyces weissii
Aliarcobacter butzleri [C]
Aliarcobacter cryaerophilus [C]
Anaerobiospirillum succiniciproducens [C]
Anaerobiospirillum thomasii [D]
Archanobacterium pyogenes
Bacillus anthracis [C]
Bacillus circulans [C]
Bacillus subtilis [D]
Bacteroides spp. [C]
Bartonella clarridgeiae
Bartonella elizabethae
Bartonella henselae*
Bartonella koehlerae
Bartonella quintana
Bartonella rochalimae
Bartonella vinsonii subsp. berkhoffii*
Bartonella washoensis
Bergeyella zoohelcum [C]
Bordetella bronchiseptica*
Bordetella pertussis
Borrelia afzelii senso lato
Borrelia burgdorferi senso stricto*
Borrelia garinii senso lato
Borrelia turicatae
Brachyspira alvinipulli-like
Brachyspira canis
Brachyspira intermedia
Brachyspira pilosicoli [C]
Brachyspira pulli
Brevibacterium spp. [C]
Brucella abortus
Brucella canis*
Brucella suis
Burkholderia mallei
Burkholderia pseudomallei ❖
Campylobacter coli*
Campylobacter gracilis
Campylobacter helveticus
Campylobacter jejuni*
Campylobacter lari
Campylobacter upsaliensis*
Candidatus Mycoplasma haematoparvum
Capnocytophaga canimorsus*
Capnocytophaga cynodegmi [C]
Chlamydia abortus
Chlamydia caviae
Chlamydophila felis
Chlamydophila psittaci
Chromobacterium spp. ❖ [D]
Chromobacterium violaceum ❖
Citrobacter diversus
Citrobacter freundii [C]
Citrobacter spp. [D]
Clostridium botulinum type C
Clostridium botulinum type D
Clostridium difficile*
Clostridium perfringens*
Clostridium piliforme
Clostridium spp. [C]
Clostridium tetani [C]
Corynebacterium auriscanis [D]
Corynebacterium canis [C]
Corynebacterium freiburgense [C]
Corynebacterium spp. [D]
Corynebacterium ulcerans [C]
Corynebacterium urealyticum
Coxiella burnetii*
Cytobacillus firmus [C]
Dermabacter hominis [C]
Dermatophilus congolensis
Eikenella corrodens [C]
Enterobacter cloacae [C]
Enterococcus avium [C]
Enterococcus canintestini
Enterococcus casseliflavus
Enterococcus faecalis [C]
Enterococcus faecium*
Enterococcus gallinarum
Enterococcus hirae
Enterococcus malodoratus [D]
Enterococcus spp.*
Erysipelothrix rhusiopathiae [C]
Erysipelothrix tonsillarum serovar 7
Escherichia coli (EHEC, EPEC, AIEC, UPEC, NTEC, ETEC)*
Eubacterium plautii [D]
Eubacterium spp. [C]
Flavobacterium spp. [D]
Francisella philomiragia
Francisella tularensis*
Fusobacterium spp.*
Gemella morbillorum [C]
Haemophilus aphrophilus [C]
Helicobacter bilis
Helicobacter bizzozeronii
Helicobacter canis [D]
Helicobacter cinaedi
Helicobacter cynogastricus
Helicobacter felis [D]
Helicobacter fennelliae
Helicobacter heilmannii*
Helicobacter rappini
Helicobacter salomonis
Klebsiella spp.*
Lactobacillus spp. [C]
Lawsonia intracellularis
***Leptospira interrogans* serovar australis** [C]
Leptospira interrogans* serovar autumnalis
***Leptospira interrogans* serovar bataviae** [D]
Leptospira interrogans* serovar bratislava
Leptospira interrogans* serovar canicola
Leptospira interrogans* serovar grippotyphosa
Leptospira interrogans* serovar hardjo
Leptospira interrogans* serovar icterohaemorrhagiae

Leptospira interrogans* serovar pomona
***Leptospira interrogans* serovar zanoni** [D]
Leptotrichia buccalis [C]
Listeria monocytogenes
Mesomycoplasma molare
Metamycoplasma gateae
Metamycoplasma spumans
Methicillin resistant *CoNS strains* (MRSS)
Methicillin resistant *Staph aureus* (MRSA)*
Methicillin resistant *Staph pseudintermedius* (MRSP)*
Micrococcus lylae [D]
Micrococcus spp. [C]
Moraxella spp.*
***Mycobacterium avium subsp paratuberculosis*❖**
***Mycobacterium avium-intracellulare complex*❖**
Mycobacterium bovis
Mycobacterium chelonae-abscessus group [C]
Mycobacterium fortuitum group [C]
***Mycobacterium genavense*❖**
***Mycobacterium goodii*❖**
Mycobacterium kansasii [C]
Mycobacterium microti
***Mycobacterium smegmatis group*❖**
Mycobacterium Canine Leproid Granulomas
Mycobacterium tuberculosis
Mycoplasma arginini
Mycoplasma bovigenitalium
Mycoplasma canis
Mycoplasma cynos
Mycoplasma edwardii [C]
Mycoplasma feliminutum
Mycoplasma felis
Mycoplasma haemocanis
Mycoplasma maculosum
Mycoplasma opalescens
Mycoplasma ovis
Neisseria animaloris [C]
Neisseria canis [C]
Neisseria dentiae [D]
Neisseria spp. [C]
Neisseria weaveri*
Neisseria zoodegmatis [C]
Nocardia brasiliensis [C]
Nocardia farcinica [C]
Nocardia nova [C]
Nocardia otitidiscaviarum [C]
Oerskovia spp. [D]
Pasteurella canis*
Pasteurella multocida*
Pasteurella spp.*
Pediococcus spp. [D]
Peptostreptococcus spp. [C]
Plesiomonas shigelloides [C]
Porphyromonas spp. [D]
Prevotella spp. [C]
Propionibacterium spp. [C]
Proteus mirabilis [C]
Proteus vulgaris [C]
Providencia alcalifaciens
Providencia stuartii
Pseudomonas aeruginosa*
Pseudomonas oryzihabitans [D]
Pseudomonas spp. [C]
***Ralstonia pickettii*❖**
Rhodococcus equi
Riemerella anatipestifer [C]
Salmonella enterica (enteriditis, typhimurium)*
Serratia spp.
Shigella spp.
Staphylococcus aureus*
Staphylococcus epidermidis [C]
Staphylococcus pseudintermedius*
Staphylococcus schleiferi coagulans
Staphylococcus schleiferi schleiferi
Staphylococcus sciuri
Staphylococcus spp. [D]
Staphylococcus xylosus [C]
Stenotrophomonas maltophilia [C]
Stomatococcus mucilaginosus [C]
Streptobacillus moniliformis [C]
Streptococcus agalactiae
Streptococcus canis (Group G)*
Streptococcus dysgalactiae dysgalactiae
Streptococcus dysgalactiae equisimilis
Streptococcus equi subsp. equi
Streptococcus equi subsp. zooepidemicus [C]
Streptococcus Group D commensals
Streptococcus Group E
Streptococcus Group L
Streptococcus Group M
Streptococcus intermedius
Streptococcus mitis (α-streptococcus) [C]
Streptococcus pneumoniae
Streptococcus pyogenes (α-streptococcus) [C]
Streptococcus spp.*
Streptococcus suis
Tannerella forsythia [D]
Ureaplasma canigenitalum
Veillonella spp. [C]
Wolbachia pipientis [D]
Yersinia enterocolitica*
Yersinia pestis*
Yersinia pseudotuberculosis [C]

Ectoparasites

Cheyletiella parasitovorax [D]
Cheyletiella yasguri*
Ctenocephalides canis*
Ctenocephalides felis*
Demodex canis
Echidnophaga gallinacea [C]
Notoedres cati
Otodectes cynotis
Pneumonyssoides caninum
Pulex irritans*
Pulex simulans
Sarcoptes scabiei var canis*
Tunga penetrans
Xenopsylla cheopis [C]

Fungi

***Absidia spp.*❖**
***Acremonium hyalinulum*❖**
***Acremonium kiliense*❖**
***Alternaria spp.*❖**
***Aspergillus deflectus*❖**
***Aspergillus flavipes*❖**
***Aspergillus flavus*❖**
***Aspergillus fumigatus*❖**
***Aspergillus nidulans*❖**
***Aspergillus niger*❖**
***Aspergillus terreus*❖**
***Basidiobolus spp.*❖**
***Bipolaris spp.*❖**
Blastomyces dermatitidis*
Candida albicans
Candida famata
Candida glabrata
Candida guilliermondii
Candida krusei
Candida parapsilosis
Candida rugosa
Candida tropicalis
***Chlorella spp.*❖**
***Chrysosporium spp.*❖**
***Cladophialophora bantiana*❖**
***Cladophialophora spp.*❖**
***Cladosporium xylohypha*❖**
Coccidioides immitis
Coccidioides posadasii
***Conidiobolus spp.*❖**
***Cryptococcus albidus*❖**

Cryptococcus gattii ❖*
Cryptococcus laurentii ❖
Cryptococcus neoformans ❖
Curvularia spp. ❖
Emmonsia parva ❖
Encephalitozoon cuniculi
Encephalitozoon hellem
Encephalitozoon intestinalis
Enterocytozoon bieneusi
Epidermophyton spp.
Fonsecaea spp. ❖
Fusarium spp. ❖
Geomyces spp. ❖
Geosmithia argillacea ❖
Geotrichum candidum ❖
Histoplasma capsulatum ❖*
Lagenidium spp. ❖
Madurella spp. ❖
Malassezia pachydermatis*
Microsporum canis*
Microsporum gypseum C
Monocillium indicum ❖
Mucor spp. ❖
Ochronconis spp. ❖
Paecilomyces fumorsoroseus ❖
Paecilomyces lilacinus ❖ C
Paecilomyces variotii ❖
Paracoccidioides brasiliensis ❖
Penicillium spp. ❖
Phialemonium spp. ❖
Phialophora spp. ❖
Pneumocystis carinii ❖
Pneumocystis wakefieldae ❖
Prototheca spp. ❖
Pseudallescheria boydii ❖
Pseudomicrodochium spp. ❖
Pythium insidiosum ❖
Rhinosporidium seeberi ❖
Rhizomucor spp. ❖
Rhizopus spp. ❖
Rhodotorula glutinis ❖
Rhodotorula mucilaginosa ❖
Saksenaea spp. ❖
Schizophyllum commune ❖
Sporothrix schenckii*
Trichoderma spp. ❖
Trichophyton spp.*
Trichosporon cutaneum ❖

Helminths

Acanthocheilonema reconditum*
Alaria alata*
Alaria americana*
Alaria canis*
Alaria marcianae*
Alaria nasuae
Amphimerus pseudofelineus D
Ancylostoma braziliense
Ancylostoma caninum
Ancylostoma ceylanicum
Angiostrongylus vasorum
Apophallus donicus*
Ascaris lumbricoides
Baylisascaris procyonis*
Brugia malayi
Brugia pahangi
Capillaria aerophila
Centrocestus armatus
Centrocestus formosanus
Clonorchis sinensis
Cryptocotyle lingua*
Dicrocoelium dendriticum
Dioctophyma renale
Diphyllobothrium spp.*
Dipylidium caninum*
Dirofilaria immitis*
Dirofilaria repens D
Dracunculus insignis
Dracunculus medinensis
Echinochasmus fujianensis
Echinochasmus japonicus
Echinochasmus liliputanus
Echinochasmus perfoliatus
Echinococcus granulosus*
Echinococcus multilocularis*
Echinococcus vogeli D
Echinostoma cinetorchus
Echinostoma hortense
Echinostoma ilocanum
Echinostoma spp.
Episthmium caninum
Filaroides hirthi
Gnathostoma spinigerum
Haplorchis pumilio
Haplorchis taichui
Haplorchis yokogawai
Heterobilharzia americana
Heterophyes dispar
Heterophyes heterophyes
Heterophyopsis continua
Macracanthorhynchus hirudinaceus D
Macracanthorhynchus ingens C
Mesocestoides spp.*
Metagonimus yokogawai
Metorchis albidus
Metorchis conjunctus*
Nanophyetus salmincola*
Ollulanus tricuspis
Onchocerca lupi
Oncicola canis
Opisthorchis felineus
Opisthorchis noverca
Opisthorchis viverrini
Oslerus osleri
Paragonimus africanus
Paragonimus heterotremus
Paragonimus hueit'ungensis
Paragonimus kellicotti*
Paragonimus mexicanus
Paragonimus spp.
Paragonimus westermani
Phagicola longa C
Phaneropsolus bonnei
Physaloptera rara
Plagiorchis muris
Prohemistomum vivax
Prosthodendrium glandulosum
Prosthodendrium obtusum
Pseudamphistomum truncatum
Pygidiopsis summa
Schistosoma incognitum
Schistosoma japonicum
Schistosoma mansoni
Schistosoma mekongi
Schistosoma rodhaini
Spirocerca lupi
Spirometra mansoni
Stellantchasmus falcatus
Stellantchasmus pseudocirratus
Stictodora fuscata
Strongyloides stercoralis C
Taenia brauni D
Taenia crassiceps C
Taenia hydatigena
Taenia krabbei
Taenia multiceps C
Taenia ovis
Taenia pisiformis
Taenia serialis*
Taenia solium
Taenia spp.*
Taenia taeniaeformis
Thelazia californiensis D
Thelazia callipaeda D
Toxascaris leonina
Toxocara canis*
Trichinella spiralis
Trichuris vulpis
Uncinaria stenocephala*

Protozoa

Acanthamoeba castellanii ❖
Acanthamoeba culbertsoni ❖
Acanthamoeba genotype T1 ❖
Babesia caballi
Babesia canis canis
Babesia canis rossi
Babesia canis vogeli
Babesia conradae
Babesia gibsoni
Babesia microti-like *(Babesia annae)*

Balamuthia mandrillaris ❖ [C]
Balantidium coli [C]
Blastocystis hominis
Blastocystis spp.
Caryospora bigentica-like
Cryptosporidium canis*
Cryptosporidium muris
Cryptosporidium parvum
Cyclospora cayetanensis
Cystoisospora canis
Cystoisospora ohioensis
Entamoeba histolytica
Giardia duodenalis (assemblage A1)*
Giardia duodenalis (assemblage B)*
Giardia duodenalis assemblage C
Giardia duodenalis assemblage D
Hammondia heydorni
Hepatozoon americanum
Hepatozoon canis
Intrahepatic biliary coccidiosis
Intrapulmonary coccidiosis
Isospora burrowsi
Isospora neorivolta
Leishmania amazonensis
Leishmania braziliensis
Leishmania donovani
Leishmania infantum*
Leishmania major
Leishmania panamensis
Leishmania peruviana
Leishmania tropica
Neospora caninum
Pentatrichomonas hominis
Sarcocystis aucheniae
Sarcocystis canis
Sarcocystis capracanis
Sarcocystis cruzi
Sarcocystis fayeri
Sarcocystis hircicanis
Sarcocystis meischeriana
Sarcocystis neurona
Theileria annulata
Theileria equi
Toxoplasma gondii
Tritrichomonas foetus
Trypanosoma brucei brucei
Trypanosoma brucei gambiense
Trypanosoma brucei rhodesiense
Trypanosoma caninum
Trypanosoma congolense
Trypanosoma cruzi*
Trypanosoma evansi

Rickettsia

Anaplasma phagocytophilum*
Anaplasma platys
Ehrlichia canis*
Ehrlichia chaffeensis
Ehrlichia ewingii
Ehrlichia ruminantium
Neorickettsia elokominica
Neorickettsia helminthoeca
Neorickettsia risticii
Neorickettsia risticii subsp. atypicalis
Orientia tsutsugamushi
Rickettsia akari
Rickettsia australis
Rickettsia conorii subsp. conorii
Rickettsia felis [C]
Rickettsia japonica
Rickettsia prowazekii
Rickettsia rickettsii*
Stellanchasmus falcatus

Viruses

African Horse Sickness
Astrovirus
Australian bat virus
Barmah Forest virus
Bluetongue virus
Borna Disease virus
Canine Acidophil Cell Hepatitis
Canine Adenovirus 1
Canine Adenovirus 2
Canine Calicivirus (strain 48)
Canine Coronavirus group 1 type 1
Canine Coronavirus group 1 type 2 (pantropic biotype)
Canine Coronavirus group 1 type 2 (subtype a and b)
Canine Distemper virus
Canine Herpesvirus 1
Canine Influenza virus (H3N8)
Canine Norovirus
Canine Oral Papillomavirus
Canine Papillomavirus type 2
Canine Papillomavirus type 3
Canine Papillomavirus type 6
Canine Papillomavirus type 7
Canine Parainfluenza virus (respiratory)
Canine Parainfluenza virus 5 variant (non-respiratory)
Canine Parvovirus 1
Canine Parvovirus 2
Canine Pneumovirus
Canine respiratory coronavirus group 2 (subtype a)
Canine rotavirus group A (G3P[3], G3P[8]) [D]
Cowpox
Coxsackievirus A9, A20
Coxsackievirus B1
Coxsackievirus B3
Coxsackievirus B5
Eastern equine encephalitis
Ebola virus
Echovirus 6
Echovirus 7
Encephalomyocarditis virus
European bat virus
Foot and Mouth Disease
Hendra virus
Hepatitis E virus
Influenza virus A (Human; subtypes H1N1, H3N2, H5N1)
Influenza virus B (Human)
Influenza virus C (Human)
Irkut virus
Japanese encephalitis virus
Kobuvirus
La Crosse virus
Lagos bat virus
Louping ill
Lymphocytic Choriomeningitis virus
Mokola virus
Mumps virus
Nipah virus
Poliovirus 1
Porcine Herpesvirus 1
Powassan virus
Rabies (genotype 1 phylogroup 1 subtype 1)*
Reovirus MRV (Mammalian Reovirus) serotype 1
Reovirus MRV (Mammalian Reovirus) serotype 2
Reovirus MRV (Mammalian Reovirus) serotype 3
Rift Valley Fever
Ross River virus
Sapovirus
Sars-CoV-2 **(Covid-19)**
Sin Nombre virus
St. Louis encephalitis
Tenshaw (Tensaw) virus infection
Tick borne encephalitis
Unclassified enteroviruses
Venezuelan equine encephalitis
Vesicular exanthema
West Nile virus
Western equine encephalitis

APPENDIX B

The following list represents 29 zoonotic/anthroponotic pathogens denoted as *Grey-Zone Pathogens*. These represent any pathogen where there is some evidence the dog is involved in transmission, maintenance or detection of the pathogen as it relates to human infection, but current research has not definitively proven the dog's role at the time of this study. There were no sapronoses in this group. Of these pathogens, those that have been reported in Canada are marked with a [1]. Those pathogens that have the potential to occur in Canada but have not yet been reported are marked with a [2].

Bacteria

Acinetobacter baumannii [1]
Borrelia turicatae [1]
Campylobacter gracilis [1]
Campylobacter lari [1]
Helicobacter bizzozeronii [2]
Mycoplasma canis [2]
Mycoplasma maculosum [2]
Rhodococcus equi [1]
Staphylococcus schleiferi coagulans [1]

Fungi

Encephalitozoon cuniculi [1]
Encephalitozoon intestinalis [2]
Enterocytozoon bieneusi [2]

Helminths

Ascaris lumbricoides [1]
Trichinella spiralis [1]
Trichuris vulpis [1]

Protozoa

Babesia canis canis
Babesia canis rossi
Babesia canis vogeli [1]
Blastocystis hominis [1]
Blastocystis spp. [1]
Cryptosporidium parvum [1]
Leishmania donovani

Rickettsia

Anaplasma platys [1]
Ehrlichia chaffeensis [2]
Ehrlichia ewingii [2]

Viruses

Reovirus MRV (Mammalian Reovirus) serotype 1 [1]
Reovirus MRV (Mammalian Reovirus) serotype 2 [1]
Reovirus MRV (Mammalian Reovirus) serotype 3 [1]
West Nile virus [1]

APPENDIX C

The following list represents 74 zoonotic/sapronotic pathogens where the dog is involved in transmission, maintenance, or detection of the pathogen and the pathogen has been reported to have historically occurred in Canada, however, Canadian canine-specific reports are lacking (Tier 2). Sapronoses are specifically denoted by ❖.

Bacteria

Actinobacillus actinomycetemcomitans
Actinomyces neuii subsp. anitratus
Aliarcobacter butzleri
Aliarcobacter cryaerophilus
Anaerobiospirillum succiniciproducens
Bacillus anthracis
Bacillus circulans
Bacteroides spp.
Bergeyella zoohelcum
Brachyspira pilosicoli
Brevibacterium spp.
Capnocytophaga cynodegmi
Citrobacter freundii
Clostridium spp.
Clostridium tetani
Corynebacterium canis
Corynebacterium freiburgense
Corynebacterium ulcerans
Cytobacillus firmus
Dermabacter hominis
Eikenella corrodens
Enterobacter cloacae
Enterococcus avium
Enterococcus faecalis
Erysipelothrix rhusiopathiae
Eubacterium spp.
Gemella morbillorum
Haemophilus aphrophilus
Lactobacillus spp.
Leptospira interrogans serovar australis
Leptotrichia buccalis
Micrococcus spp.
Mycobacterium chelonae-abscessus group (RGM)
Mycobacterium fortuitum group (RGM)
Mycobacterium kansasii (slow growing)
Mycoplasma edwardii
Neisseria animaloris
Neisseria canis
Neisseria spp.
Neisseria zoodegmatis
Nocardia brasiliensis
Nocardia farcinica
Nocardia nova
Nocardia otitidiscaviarum
Peptostreptococcus spp.
Plesiomonas shigelloides
Prevotella spp.
Propionibacterium spp.
Proteus mirabilis
Proteus vulgaris
Pseudomonas spp.
Reimerella anatipestifer
Staphylococcus epidermidis
Staphylococcus xylosus
Stenotrophomonas maltophila
Stomatococcus mucilaginosus
Streptobacillus moniliformis
Streptococcus equi subsp. zooepidemicus
Streptococcus mitis (α-streptococcus)
Streptococcus pyogenes (α-streptococcus)
Veillonella spp.
Yersinia pseudotuberculosis

Ectoparasites

Echidnophaga gallinacea
Xenopsylla cheopis

Fungi

Microsporum gypseum
Paecilomyces lilacinus ❖

Helminths

Macracanthorhynchus ingens
Phagicola longa
Strongyloides stercoralis
Taenia crassiceps
Taenia multiceps

Protozoa

Balamuthia mandrillaris ❖
Balantidium coli

Rickettsia

Rickettsia felis

APPENDIX D

The following list represents 31 zoonotic pathogens where the dog is involved in transmission, maintenance or detection of the pathogen that have the potential to occur in Canada, however, no definitive Canadian reports were identified at the time of this study (Tier 3). There were no sapronoses in this group.

Bacteria

Anaerobiospirillum thomasii
Bacillus subtilis
Chromobacterium spp.
Citrobacter spp.
Corynebacterium auriscanis
Corynebacterium spp.
Enterococcus malodoratus
Eubacterium plautii
Flavobacterium spp.
Helicobacter canis
Helicobacter felis
Leptospira interrogans serovar bataviae
Leptospira interrogans serovar zanoni
Micrococcus lylae
Neisseria dentiae
Oerskovia spp.
Pediococcus spp.
Porphyromonas spp.
Pseudomonas oryzihabitans
Staphylococcus spp. (warneri, cohnii, coagulase negative*, hominis, auricularis)*
Tannerella forsythia
Wolbachia pipientis

Ectoparasites

Cheyletiella parasitovorax

Helminths

Amphimerus pseudofelineus
Dirofilaria repens
Echinococcus vogeli
Macracanthorhynchus hirudinaceus
Taenia brauni
Thelazia californiensis
Thelazia callipaeda

Viruses

Canine rotavirus group A (G3P[3], G3P[8])

APPENDIX E

In alphabetical order, complete list of 594 pathogens identified in dogs and associated reference(s) used to determine whether a pathogen advanced to a subsequent step. When a reference is not listed it means one was not found during literature search and thus the answer was deemed "no" or "maybe" due to lack of evidence or reporting.

Pathogen	Is the pathogen zoonotic/sapronotic/ anthroponotic?	Is the dog involved in transmission, maintenance or detection of the pathogen?	Is there a level of risk for occurrence of the pathogen in Canada?	Has a dog-specific example been documented in Canada?
Absidia spp.	Yes[1]	No[1]	--	--
Acanthamoeba castellanii	Yes[1]	No[1]	--	--
Acanthamoeba culbertsoni	Yes[1]	No[1]	--	--
Acanthamoeba genotype T1	Yes[1]	No[1]	--	--
Acanthocheilonema reconditum	Yes[1–3]	Yes[3,4]	Yes[5,6]	Yes[5,6]
Acholeplasma laidlawii	No[1,2]	--	--	--
Acinetobacter baumannii	Yes[1]	Maybe[1,7]	Yes[8]	--
Acremonium hyalinulum	Yes[1]	No[1]	--	--
Acremonium kiliense	Yes[1]	No[1]	--	--
Actinobacillus actinomycetemcomitans	Yes[1]	Yes[1]	Yes[9]	No
Actinobacillus lignieresii	Yes[2,10]	No[11,12]	--	--
Actinomyces bovis	Yes[1,4]	No[4]	--	--
Actinomyces bowdenii	No[1,2]	--	--	--
Actinomyces canis	No[1,2]	--	--	--
Actinomyces catuli	No[1]	--	--	--
Actinomyces coleocanis	No[1]	--	--	--
Actinomyces hordeovulneris	No[1,2]	--	--	--
Actinomyces hyovaginalis	No[1,2]	--	--	--
Actinomyces israelii	Yes[2,4,13]	No[4]	--	--
Actinomyces naeslundii	Yes[2,13]	No	--	--
Actinomyces neuii subsp. anitratus	Yes[1]	Yes[1,14]	Yes[15]	No
Actinomyces odontolyticus	Yes[2,13]	No[1]	--	--
Actinomyces turicensis	Yes[16]	No	--	--
Actinomyces urogenitalis	Yes[17,18]	No	--	--
Actinomyces viscosus	Yes[1,13,19]	Yes[14,19,20]	Yes[21]	Yes[20]
Actinomyces weissii	No[22]	--	--	--
African Horse Sickness	No[1]	--	--	--
Alaria alata	Yes[4]	Yes[4]	Yes[23]	Yes[23]
Alaria americana	Yes[23]	Yes[23]	Yes[23]	Yes[23]
Alaria canis	Yes[4]	Yes[4]	Yes[24]	Yes[24]
Alaria marcianae	Yes[23]	Yes[23]	Yes[23]	Yes[23]
Alaria nasuae	No[23]	--	--	--
Aliarcobacter butzleri	Yes[1,2,25]	Yes[25]	Yes[26]	No
Aliarcobacter cryaerophilus	Yes[1,2]	Yes[25]	Yes[26,27]	No
Alternaria spp.	Yes[1]	No[1]	--	--
Amphimerus pseudofelineus	Yes[23]	Yes[23]	Maybe[28,29]	--
Anaerobiospirillum succiniciproducens	Yes[1]	Yes[1]	Yes[21]	No
Anaerobiospirillum thomasii	Yes[1]	Yes[1]	Maybe	--
Anaplasma phagocytophilum	Yes[1]	Yes[1]	Yes[1,30,31]	Yes[30–32]
Anaplasma platys	Yes[33]	Maybe[1,33]	Yes[34,35]	--
Ancylostoma braziliense	Yes[4]	Yes[4,23]	No[4,23]	--
Ancylostoma caninum	Yes[4]	Yes[23,24]	No[4,36]	--
Ancylostoma ceylanicum	Yes[4]	Yes[23]	No[37]	--
Angiostrongylus vasorum	No[4]	--	--	--
Apophallus donicus	Yes[38]	Yes[38]	Yes[23]	Yes[39]
Archanobacterium pyogenes	Yes[2,40]	No[14]	--	--
Ascaris lumbricoides	Yes[4]	Maybe[41]	Yes[42]	--
Aspergillus deflectus	Yes[1]	No[43]	--	--
Aspergillus flavipes	Yes[1]	No[43]	--	--
Aspergillus flavus	Yes[1,2]	No[43]	--	--
Aspergillus fumigatus	Yes[1,2]	No[43]	--	--

Aspergillus nidulans	Yes[1,2]	No[43]	--	--
Aspergillus niger	Yes[1,2]	No[43]	--	--
Aspergillus terreus	Yes[1,2]	No[43]	--	--
Astrovirus	No[19,44,45]	--	--	--
Australian Bat virus	Yes[1]	No[46]	--	--
Babesia caballi	No[1,4]	--	--	--
Babesia canis canis	Yes[1,4]	Maybe[47,48]	No[1,49]	--
Babesia canis rossi	Yes[1,4]	Maybe[48,50]	No[1,51]	--
Babesia canis vogeli	Yes[1,4]	Maybe[48,50]	Yes[34]	--
Babesia conradae	No[1,4]	--	--	--
Babesia gibsoni	No[1,4]	--	--	--
Babesia microti-like *(Babesia annae)*	No[1,52]	--	--	--
Bacillus anthracis	Yes[1,4]	Yes[1,43,53,54,55]	Yes[56]	No
Bacillus circulans	Yes[1]	Yes[1]	Yes[57]	No
Bacillus subtilis	Yes[1]	Yes[1,58]	Maybe	--
Bacteroides spp.	Yes[1]	Yes[1]	Yes[21]	No
Balamuthia mandrillaris	Yes[1]	Yes[1]	Yes[59,60]	No
Balantidium coli	Yes[1]	Yes[1]	Yes[61,62]	No
Barmah Forest virus	Yes[1]	No[1]	--	--
Bartonella clarridgeiae	Yes[1]	No[1,43]	--	--
Bartonella elizabethae	Yes[1]	No[1,14]	--	--
Bartonella henselae	Yes[1]	Yes[1,43]	Yes[63,64]	Yes[65]
Bartonella koehlerae	Yes[1]	No[1,14]	--	--
Bartonella quintana	Yes[1]	No[1,14]	--	--
Bartonella rochalimae	Yes[1]	No[1,14]	--	--
Bartonella vinsonii subsp. berkhoffii	Yes[1]	Yes[1,14,43,66]	Yes	Yes[66]
Bartonella washoensis	Yes[1]	No[1,14]	--	--
Basidiobolus spp.	Yes[1,2]	No[1]	--	--
Baylisascaris procyonis	Yes[4]	Yes[43,67]	Yes[67,68]	Yes[69]
Bergeyella zoohelcum	Yes[1]	Yes[43]	Yes[59]	No
Bipolaris spp.	Yes[1,2]	No[1]	--	--
Blastocystis hominis	Yes[1,2]	Maybe[1]	Yes[70]	--
Blastocystis spp.	Yes[1,2]	Maybe[1,71,72]	Yes[70]	--
Blastomyces dermatitidis	Yes[1,4,19]	Yes[1,19]	Yes[1,73]	Yes[74]
Bluetongue virus	No[1]	--	--	--
Bordetella bronchiseptica	Yes[1]	Yes[1,43]	Yes[64]	Yes[75]
Bordetella pertussis	Yes[19]	No[19]	--	--
Borna Disease virus	Yes[1]	No[1]	--	--
Borrelia afzelii senso lato	Yes[1,4]	No[1,4,76,77]	--	--
Borrelia burgdorferi senso stricto	Yes[1]	Yes[1,14]	Yes[64]	Yes[78]
Borrelia garinii senso lato	Yes[1,4]	No[1,4,76]	--	--
Borrelia turicatae	Yes[1,2,4]	Maybe[79,80]	Yes[81]	--
Brachyspira alvinipulli-like	No[1]	--	--	--
Brachyspira canis	No[1]	--	--	--
Brachyspira intermedia	No[14]	--	--	--
Brachyspira pilosicoli	Yes[1]	Yes[82,83]	Yes[83]	No
Brachyspira pulli	No[14]	--	--	--
Brevibacterium spp.	Yes[1]	Yes[1,84]	Yes[85]	No
Brucella abortus	Yes[1]	No[14]	--	--
Brucella canis	Yes[1]	Yes[1,,86]	Yes[64]	Yes[87]
Brucella suis	Yes[1]	No[14,88]	--	--
Brugia malayi	Yes[23]	No[23]	--	--
Brugia pahangi	No[23]	--	--	--
Burkholderia mallei	Yes[1]	No[1]	--	--
Burkholderia pseudomallei	Yes[1]	No[1]	--	--
Campylobacter coli	Yes[1,19]	Yes[4,19]	Yes[89]	Yes[90]
Campylobacter gracilis	Yes[43]	Maybe[91]	Yes[21]	--
Campylobacter helveticus	No[1,14,92]	--	--	--
Campylobacter jejuni	Yes[1]	Yes[1,4]	Yes[89]	Yes[93]
Campylobacter lari	Yes[1,2,94]	Maybe[14,43]	Yes[95]	--
Campylobacter upsaliensis	Yes[1]	Yes[1,43]	Yes[93]	Yes[93]
Candida albicans	Yes[2,96]	No[96]	--	--
Candida famata	Yes[97]	No[1]	--	--

Candida glabrata	Yes[1,2,96]	No[1]	--	--
Candida guilliermondii	Yes[2,96]	No[1]	--	--
Candida krusei	Yes[2,96]	No[1]	--	--
Candida parapsilosis	Yes[1,2,96]	No[1,98]	--	--
Candida rugosa	Yes[1]	No[1]	--	--
Candida tropicalis	Yes[2,96]	No[1]	--	--
Candidatus Mycoplasma haematoparvum	Yes[99]	No [99]	--	--
Canine Acidophil Cell Hepatitis	No[1]	--	--	--
Canine Adenovirus 1	No[1]	--	--	--
Canine Adenovirus 2	No[1,19]	--	--	--
Canine Calicivirus	No[1,100,101]	--	--	--
Canine Coronavirus group 1 type 1	No[1,19]	--	--	--
Canine Coronavirus group 1 type 2 (pantropic biotype)	No[1,19]	--	--	--
Canine Coronavirus group 1 type 2 (subtype a and b)	No[1,19]	--	--	--
Canine Distemper Virus	No[1,19,102]	--	--	--
Canine Herpesvirus 1	No[1]	--	--	--
Canine Influenza virus (H3N8)	No[1,19,103,104]	--	--	--
Canine Norovirus	No[19,105–107]	--	--	--
Canine Oral Papillomavirus	No[1]	--	--	--
Canine Papillomavirus types 2	No[1]	--	--	--
Canine Papillomavirus types 3	No[1]	--	--	--
Canine Papillomavirus types 6	No[1]	--	--	--
Canine Papillomavirus types 7	No[1]	--	--	--
Canine Parainfluenza virus (respiratory)	No[19]	--	--	--
Canine Parainfluenza virus virus 5 variant (non-respiratory)	No[1,19,108]	--	--	--
Canine Parvovirus 1	No[1]	--	--	--
Canine Parvovirus 2	No[1,19]	--	--	--
Canine Pneumovirus	No[1,4]	--	--	--
Canine respiratory coronavirus group 2 subtype a	No[1,19]	--	--	--
Canine rotavirus group A	Yes[1]	Yes[1,109]	Maybe[26,110,111]	--
Capillaria aerophila	Yes[4]	No[23]	--	--
Capnocytophaga canimorsus	Yes[1]	Yes[43,112]	Yes[43,64,113]	Yes[114]
Capnocytophaga cynodegmi	Yes[1]	Yes[43,115,116]	Yes[59]	No
Caryospora bigentica-like	No[1]	--	--	--
Centrocestus armatus	Yes[23]	Yes[23]	No[23,117,118]	--
Centrocestus formosanus	Yes[23]	Yes[23]	No[23,119,120]	--
Cheyletiella parasitovorax	Yes[4]	Yes[121]	Maybe[4]	--
Cheyletiella yasguri	Yes[4]	Yes[122,123]	Yes[124]	Yes[124]
Chlamydia abortus	Yes[4]	No[4]	--	--
Chlamydia caviae	No[1,19]	--	--	--
Chlamydophila felis	Yes[1,19]	No[1,19,43]	--	--
Chlamydophila psittaci	Yes[1,4,19]	No[1,4,19,43]	--	--
Chlorella spp.	Yes[1,125]	No[1,125]	--	--
Chromobacterium spp.	Yes[1]	Yes[1,58]	Maybe	--
Chromobacterium violaceum	Yes[1]	No[1]	--	--
Chrysosporium spp.	Yes[1]	No[1]	--	--
Citrobacter diversus	Yes[126]	No	--	--
Citrobacter freundii	Yes[2,126]	Yes[127,128]	Yes[129]	No
Citrobacter spp.	Yes[19,128]	Yes[19,128]	Maybe[128,129]	--
Cladophialophora bantiana	Yes[1]	No[1]	--	--

Cladophialophora spp.	Yes[1]	No[1]	--	--
Cladosprorium xylohypha	Yes[1]	No[1]	--	--
Clonorchis sinensis	Yes[4]	Yes[4,23]	No[23,118,130]	--
Clostridium botulinum C	Yes[1]	No[1,4,14,19]	--	--
Clostridium botulinum D	Yes[1]	No[1,4,14,19]	--	--
Clostridium difficile	Yes[1]	Yes[43]	Yes[64,131]	Yes[132,133]
Clostridium perfringens	Yes[1]	Yes[43,128,134,135]	Yes[131]	Yes[136]
Clostridium piliforme	Yes[1]	No[14]	--	--
Clostridium spp.	Yes[1,43,137]	Yes[43]	Yes[131]	No
Clostridium tetani	Yes[1,19]	Yes[19]	Yes[138]	No
Coccidioides immitis	Yes[1,139,140]	Yes[1,141]	No[1]	--
Coccidioides posadasii	Yes[1,139]	Yes[1,141]	No[1]	--
Conidiobolus spp.	Yes[1]	No[1]	--	--
Corynebacterium auriscanis	Yes[1]	Yes[1]	Maybe	--
Corynebacterium canis	Yes[1]	Yes[1]	Yes[59]	No
Corynebacterium freiburgense	Yes[1]	Yes[1]	Yes[59]	No
Corynebacterium spp.	Yes[1]	Yes[1]	Maybe	--
Corynebacterium ulcerans	Yes[1]	Yes[43]	Yes[142,143]	No
Corynebacterium urealyticum	Yes[143]	No[143]	--	--
Cowpox	Yes[1]	No[1]	--	--
Coxiella burnetii	Yes[1]	Yes[43]	Yes[43,64]	Yes[145]
Coxsackievirus A9, A20	Yes[1]	No[1]	--	--
Coxsackievirus B1	Yes[1]	No[1]	--	--
Coxsackievirus B3	Yes[1]	No[1]	--	--
Coxsackievirus B5	Yes[1]	No[1]	--	--
Cryptococcus albidus	Yes[1]	No[1,43]	--	--
Cryptococcus gattii	Yes[1]	Yes[146,147]	Yes[146]	Yes[146]
Cryptococcus laurentii	Yes[1]	No[1,43]	--	--
Cryptococcus neoformans	Yes[1]	No[1,43]	--	--
Cryptocotyle lingua	Yes[2,4,148]	Yes[23]	Yes[4,149]	Yes[150]
Cryptosporidium canis	Yes[1,4]	Yes[43]	Yes[151]	Yes[152, 153]
Cryptosporidium muris	Yes[4]	No[43]	--	--
Cryptosporidium parvum	Yes[43,154]	Maybe[43,155]	Yes[64,156]	--
Ctenocephalides canis	Yes[23]	Yes[23]	Yes[157]	Yes[157]
Ctenocephalides felis	Yes[4,23]	Yes[43]	Yes[157]	Yes[157]
Curvularia spp.	Yes[1]	No[1]	--	--
Cyclospora cayetanensis	Yes[1]	No[1]	--	--
Cytobacillus firmus	Yes[1]	Yes[1,58]	Yes[158]	No
Cystoisospora canis	No[1]	--	--	--
Cystoisospora ohioensis	No[1]	--	--	--
Demodex canis	No[1,4]	--	--	--
Dermabacter hominis	Yes[19,127,128,159]	Yes[19,127,128,159]	Yes[160]	No
Dermatophilus congolensis	Yes[1]	No[1,14]	--	--
Dicrocoelium dendriticum	Yes[23]	No[23]	--	--
Dioctophyma renale	Yes[23]	No[23]	--	--
Diphyllobothrium spp.	Yes[4,23]	Yes[23]	Yes[161]	Yes[150]
Dipylidium caninum	Yes[4]	Yes[4,23]	Yes[150]	Yes[162]
Dirofilaria immitis	Yes[1,4]	Yes[23,43]	Yes[32]	Yes[32]
Dirofilaria repens	Yes[1,4]	Yes[23]	Maybe	--
Dracunculus insignis	Yes[23]	No[23]	--	--
Dracunculus medinensis	Yes[23]	No[23]	--	--
Eastern equine encephalitis	Yes[1]	No[1]	--	--
Ebola virus	Yes[1]	No[1,163]	--	--
Echidnophaga gallinacea	Yes[4,164]	Yes[162]	Yes[165]	No
Echinochasmus fujianensis	Yes[23]	Yes[23]	No[118,119,166]	--
Echinochasmus japonicus	Yes[4]	Yes[23]	No[4,23,118]	--
Echinochasmus liliputanus	Yes[23]	Yes[23]	No[23,118,119]	--
Echinochasmus perfoliatus	Yes[23]	Yes[23]	No[119,167]	--
Echinococcus granulosus	Yes[4]	Yes[4,43]	Yes[69]	Yes[168]
Echinococcus multilocularis	Yes[4]	Yes[4,43]	Yes[168]	Yes[168]
Echinococcus vogeli	Yes[4]	Yes[4,43]	Maybe	--
Echinostoma cinetorchus	Yes[23]	Yes[23,38]	No[23,38,118,169]	--
Echinostoma hortense	Yes[4]	Yes[23]	No[38,118]	--
Echinostoma ilocanum	Yes[4]	Yes[23]	No[23,119]	--

Echinostoma spp.	Yes[4]	Yes[23]	No[23,119]	--
Echovirus 6	Yes[1]	No[1]	--	--
Echovirus 7	Yes[1]	No[1]	--	--
Ehrlichia canis	Yes[1]	Yes[43]	Yes[32]	Yes[32]
Ehrlichia chaffeensis	Yes[1]	Maybe[1,43]	Maybe[170]	--
Ehrlichia ewingii	Yes[1]	Maybe[1,43]	Maybe[34,171]	--
Ehrlichia ruminantium	No[1,172,173]	--	--	--
Eikenella corrodens	Yes[1]	Yes[1,174]	Yes[175]	No
Emmonsia parva	Yes[2,176]	No[1,176]	--	--
Encephalitozoon cuniculi	Yes[1,4]	Maybe[1,43]	Yes[177]	--
Encephalitozoon hellem	Yes[1,4]	No[1,43]	--	--
Encephalitozoon intestinalis	Yes[1,4,154]	Maybe[178,179]	Maybe	--
Encephalomyocarditis virus	Yes[4]	No[1,4]	--	--
Entamoeba histolytica	Yes[1]	No[1]	--	--
Enterobacter cloacae	Yes[1,2,180]	Yes[1]	Yes[85,181]	No
Enterococcus avium	Yes[1,2]	Yes[1]	Yes[182,183]	No
Enterococcus canintestini	Yes[184]	No[184]	--	--
Enterococcus casseliflavus	Yes[185]	No[186]	--	--
Enterococcus faecalis	Yes[1,2,19]	Yes[43,187]	Yes[182,188]	No
Enterococcus faecium	Yes[1,2,189]	Yes[43,187]	Yes[182,190]	Yes[191]
Enterococcus gallinarum	Yes[185]	No[186]	--	--
Enterococcus hirae	Yes[2,184]	No[14]	--	--
Enterococcus malodoratus	Yes[1]	Yes[1]	Maybe[128]	--
Enterococcus spp.	Yes[1,2]	Yes[1,43,189]	Yes[192,193]	Yes[192,193]
Enterocytozoon bieneusi	Yes[1,4]	Maybe[43]	Maybe[43]	--
Epidermophyton spp.	Yes[1]	No[1,4,194]	--	--
Episthmium caninum	Yes[23]	Yes[23]	No[23,119]	--
Erysipelothrix rhusiopathiae	Yes[1]	Yes[1]	Yes[59,195]	No
Erysipelothrix tonsillarum serovar 7	Yes[1]	No[1]	--	--
Escherichia coli	Yes[1,4,19]	Yes[1]	Yes[196]	Yes[196]
Eubacterium plautii	Yes[1]	Yes[1]	Maybe[128]	--
Eubacterium spp.	Yes[19]	Yes[19]	Yes[21]	No
European bat virus	Yes[1,43]	No[1,197]	--	--
Filaroides hirthi	No[2,4]	--	--	--
Flavobacterium spp.	Yes[1]	Yes[1]	Maybe[128]	--
Fonsecaea spp.	Yes[1]	No[1]	--	--
Foot and Mouth Disease	Yes[4]	No[1]	--	--
Francisella philomiragia	Yes[198]	No[1,198]	--	--
Francisella tularensis	Yes[1]	Yes[1]	Yes[64]	Yes[63]
Fusarium spp.	Yes[1]	No[1]	--	--
Fusobacterium spp.	Yes[1,19]	Yes[1,14,19]	Yes[64]	Yes[64,199]
Gemella morbillorum	Yes[1]	Yes[1]	Yes[200]	No
Geomyces spp.	Yes[1]	No[1,2]	--	--
Geosmithia argillacea	Yes[1]	No[1,2]	--	--
Geotrichum candidum	Yes[1]	No[1,2]	--	--
Giardia duodenalis assemblage A1	Yes[1]	Yes[201–203]	Yes[204]	Yes[204]
Giardia duodenalis assemblage B	Yes[1]	Yes[201–203]	Yes[204]	Yes[204,153]
Giardia duodenalis assemblage C	Yes[205]	No[43,203,205]	--	--
Giardia duodenalis assemblage D	No[1,205]	--	--	--
Gnathostoma spinigerum	Yes[23]	Yes[23]	No[119,206–208]	--
Haemophilus aphrophilus	Yes[1]	Yes[1,209–211]	Yes[212]	No
Hammondia heydorni	No[1]	--	--	--
Haplorchis pumilio	Yes[23]	Yes[23,119]	No[23,119,213]	--
Haplorchis taichui	Yes[23]	Yes[23,119]	No[23,119,213,214]	--
Haplorchis yokogawai	Yes[23]	Yes[23,119]	No[23,119]	--
Helicobacter bilis	Yes[215]	No[14,215]	--	--
Helicobacter bizzozeronii	Yes[1,19]	Maybe[4,215–217]	Maybe	--
Helicobacter canis	Yes[19,218,219]	Yes[14]	Maybe[19]	--
Helicobacter cinaedi	Yes[1,19,220]	No[19,215,221]	--	--
Helicobacter cynogastricus	No[19,215,217]	--	--	--

Helicobacter felis	Yes[1,19]	Yes[217,222]	Maybe[19]	--
Helicobacter fennelliae	Yes[215,220]	No[215]	--	--
Helicobacter heilmannii	Yes[1]	Yes[1,215]	Yes[223,224]	Yes[224]
Helicobacter rappini	Yes[14,220]	No	--	--
Helicobacter salomonis	Yes[19,217]	No[217]	--	--
Hendra virus	Yes[1,4]	No[1,4]	--	--
Hepatitis E virus	Yes[1]	No[1]	--	--
Hepatozoon americanum	No[1]	--	--	--
Hepatozoon canis	No[1]	--	--	--
Heterobilharzia americana	Yes[2,23]	Yes[4,23]	No[23,225–228]	--
Heterophyes dispar	Yes[23]	Yes[23]	No[23,213,229]	--
Heterophyes heterophyes	Yes[23]	Yes[23]	No[23,119,229]	--
Heterophyopsis continua	Yes[23]	Yes[23]	No[23,213]	--
Histoplasma capsulatum	Yes[1,2]	Yes[141,230]	Yes[1,231,232]	Yes[233]
Influenza virus A (Human; H1N1, H3N2, H5N1)	Yes[1,19]	No[103]	--	--
Influenza virus B (Human)	Yes[1,2]	No[1]	--	--
Influenza virus C (Human)	Yes[1,2]	No[1]	--	--
Intrahepatic biliary coccidiosis	No[1]	--	--	--
Intrapulmonary coccidiosis	No[1]	--	--	--
Irkut virus	Yes[1,19]	No[1,234]	--	--
Isospora burrowsi	No[1]	--	--	--
Isospora neorivolta	No[1]	--	--	--
Japanese encephalitis virus	Yes[1]	No[1]	--	--
Klebsiella spp.	Yes[1,19]	Yes[19,235]	Yes[85,193]	Yes[192]
Kobuvirus	No[19]	--	--	--
La Crosse virus	Yes[4]	No[1,4]	--	--
Lactobacillus spp.	Yes[1]	Yes[1]	Yes[21]	No
Lagenidium spp.	Yes[1]	No[1]	--	--
Lagos bat virus	Yes[1,19]	No[1]	--	--
Lawsonia intracellularis	No[1,236]	--	--	--
Leishmania amazonensis	Yes[2]	No[43]	--	--
Leishmania braziliensis	Yes[1]	No[1,19]	--	--
Leishmania donovani	Yes[2]	Maybe[237]	No[238,239]	--
Leishmania infantum	Yes[1]	Yes[1,4,43]	Yes[240]	Yes[240,241]
Leishmania major	Yes[23]	No[43]	--	--
Leishmania panamensis	Yes[2]	No[43]	--	--
Leishmania peruviana	Yes[1]	No[43]	--	--
Leishmania tropica	Yes[2]	No[43]	--	--
Leptospira interrogans serovar australis	Yes[1]	Yes[1]	Yes[242]	No
Leptospira interrogans serovar autumnalis	Yes[1]	Yes[1]	Yes[43]	Yes[243]
Leptospira interrogans serovar bataviae	Yes[1]	Yes[1]	Maybe	--
Leptospira interrogans serovar bratislava	Yes[1]	Yes[1]	Yes[43]	Yes[243]
Leptospira interrogans serovar canicola	Yes[1]	Yes[1,43]	Yes[43]	Yes[243]
Leptospira interrogans serovar grippotyphosa	Yes[1]	Yes[1,43]	Yes[43]	Yes[243]
Leptospira interrogans serovar hardjo	Yes[1]	Yes[1]	Yes[242]	Yes[244]
Leptospira interrogans serovar icterohaemorrhagiae	Yes[1]	Yes[1]	Yes[43]	Yes[243]
Leptospira interrogans serovar pomona	Yes[1]	Yes[1]	Yes[245]	Yes[243]
Leptospira interrogans serovar zanoni	Yes[1]	Yes[1]	Maybe	--
Leptotrichia buccalis	Yes[1]	Yes[1]	Yes[21]	No
Listeria monocytogenes	Yes[1]	No[43]	--	--
Louping ill	Yes[1]	No[1]	--	--
Lymphocytic Choriomeningitis virus	Yes[1]	No[1]	--	--
Macracanthorhynchus hirudinaceus	Yes[4]	Yes[4,246]	Maybe[4,246]	--

Macracanthorhynchus ingens	Yes[246]	Yes[246]	Yes[247]	No
Madurella spp.	Yes[1]	No[1]	--	--
Malassezia pachydermatis	Yes[1]	Yes[1]	Yes[248]	Yes[248]
Mesocestoides spp.	Yes[2,23]	Yes[4,23]	Yes[249,250]	Yes[249]
Mesomycoplasma molare	No[251]	--	--	--
Metagonimus yokogawai	Yes[2,23]	Yes[23]	No[23,118,119]	--
Metamycoplasma gateae	No[251]	--	--	--
Metamycoplasma spumans	No[251]	--	--	--
Methicillin resistant infections CoNS strains	Yes[1,252]	No[1,252]	--	--
Methicillin resistant Staphylococcus aureus	Yes[1]	Yes[1]	Yes[253]	Yes[133,253]
Methicillin resistant Staphylococcus pseudintermedius	Yes[1]	Yes[1]	Yes[253]	Yes[253–255]
Metorchis albidus	Yes[23]	Yes[23]	No[23,118]	--
Metorchis conjunctus	Yes[4,23]	Yes[23]	Yes[256]	Yes[256]
Micrococcus lylae	Yes[19]	Yes[19,58]	Maybe	--
Micrococcus spp.	Yes[1]	Yes[19,58]	Yes[85,257]	No
Microsporum canis	Yes[1]	Yes[1]	Yes[258,259]	Yes[64]
Microsporum gypseum	Yes[1]	Yes[1]	Yes[258]	No
Mokola virus	Yes[1,19]	No[1,260,261]	--	--
Monocillium indicum	Yes[1]	No[1]	--	--
Moraxella spp.	Yes[1,19]	Yes[19,64,262]	Yes[64]	Yes[64]
Mucor spp.	Yes[1]	No[1]	--	--
Mumps virus	Yes[1]	No[1]	--	--
Mycobacterium avium subsp paratuberculosis	Yes[1]	No[1]	--	--
Mycobacterium avium-intracellulare complex	Yes[1]	No[1,4]	--	--
Mycobacterium bovis	Yes[1,4]	No[43]	--	--
Mycobacterium chelonae-abscessus group	Yes[1]	Yes[1]	Yes[263,264]	No
Mycobacterium fortuitum group	Yes[1]	Yes[1]	Yes[263,264]	No
Mycobacterium genavense	Yes[1]	No[1]	--	--
Mycobacterium goodii	Yes[1,265,266]	No[1]	--	--
Mycobacterium kansasii	Yes[1]	Yes[1]	Yes[263,264]	No
Mycobacterium microti	Yes[1]	No[1]	--	--
Mycobacterium smegmatis group	Yes[2,267]	No[1]	--	--
Mycobacterium Canine Leproid Granulomas	No[1]	--	--	--
Mycobacterium tuberculosis	Yes[1]	No[1, 43]	--	--
Mycoplasma arginini	Yes[268,269]	No[268]	--	--
Mycoplasma bovigenitalium	No[251]	--	--	--
Mycoplasma canis	Yes[1,251]	Maybe[251,269,270]	Maybe	--
Mycoplasma cynos	No[251]	--	--	--
Mycoplasma edwardii	Yes[271]	Yes[271]	Yes[272]	No
Mycoplasma feliminutum	No[251]	--	--	--
Mycoplasma felis	Yes[251]	No[251,273]	--	--
Mycoplasma haemocanis	No[251]	--	--	--
Mycoplasma maculosum	Yes[1]	Maybe[274]	Maybe	--
Mycoplasma opalescens	No[251]	--	--	--
Mycoplasma ovis	Yes[1]	No[19]	--	--
Nanophyetus salmincola	Yes[4]	Yes[4,23]	Yes[4]	Yes[275]
Neisseria animaloris	Yes[1]	Yes[1]	Yes[59]	No
Neisseria canis	Yes[1]	Yes[1]	Yes[59]	No
Neisseria dentiae	Yes[1]	Yes[1]	Maybe	--
Neisseria spp.	Yes[1,19]	Yes[1,19]	Yes[59]	No
Neisseria weaveri	Yes[1,19]	Yes[1,19]	Yes[59]	Yes[276]
Neisseria zoodegmatis	Yes[1]	Yes[1]	Yes[59,277]	No
Neorickettsia elokominica	No[4,278,279]	--	--	--
Neorickettsia helminthoeca	No[4,278,279]	--	--	--
Neorickettsia risticii	No[1,4,278,279]	--	--	--

Neorickettsia risticii subsp atypicalis	No[1,4,278,279]	--	--	--
Neospora caninum	No[1,280–282]	--	--	--
Nipah Virus	Yes[1,4]	No[1,4,43]	--	--
Nocardia brasiliensis	Yes[1,2]	Yes[4]	Yes[283]	No
Nocardia farcinica	Yes[1,2]	Yes[4]	Yes[283]	No
Nocardia nova	Yes[1,2,284]	Yes[4]	Yes[283]	No[19]
Nocardia otitidiscaviarum	Yes[1,2]	Yes[4]	Yes[283]	No
Notoedres cati	Yes[4]	No[4,285]	--	--
Ochronconis spp.	Yes[1,2]	No[1]	--	--
Oerskovia spp.	Yes[19]	Yes[19]	Maybe	--
Ollulanus tricuspis	No[4]	--	--	--
Onchocerca lupi	Yes[286–288]	No[287,288]	--	--
Oncicola canis	No[4]	--	--	--
Opisthorchis felineus	Yes[4]	Yes[4,23]	No[23,118,289]	--
Opisthorchis noverca	Yes[23]	Yes[23,289]	No[23]	--
Opisthorchis viverrini	Yes[4]	Yes[4,23]	No[23,118,289]	--
Orientia tsutsugamushi	Yes[1]	No[1]	--	--
Oslerus osleri	No[4]	--	--	--
Otodectes cynotis	Yes[43,290]	No[43]	--	--
Paecilomyces fumorsoroseus	Yes[1,2]	No[1]	--	--
Paecilomyces lilacinus	Yes[1,2,19]	Yes[19]	Yes[291]	No
Paecilomyces variotii	Yes[1]	No[1]	--	--
Paracoccidiodes brasiliensis	Yes[1,2]	No[1]	--	--
Paragonimus africanus	Yes[23]	Yes[4,23]	No[23,292]	--
Paragonimus heterotremus	Yes[23]	Yes[4,23]	No[23]	--
Paragonimus hueit'ungensis	Yes[23]	Yes[23]	No[23,293,294]	--
Paragonimus kellicotti	Yes[23]	Yes[4,23]	Yes[295]	Yes[296]
Paragonimus mexicanus	Yes[23]	Yes[4,23]	No[23,297,298]	--
Paragonimus spp.	Yes[23]	Yes[23]	No[23]	--
Paragonimus westermani	Yes[4]	Yes[4,23]	No[23,297]	--
Pasteurella canis	Yes[19]	Yes[19]	Yes[248]	Yes[248]
Pasteurella multocida	Yes[1]	Yes[1]	Yes[248]	Yes[248]
Pasteurella spp.	Yes[1]	Yes[1]	Yes[64]	Yes[64]
Pediococcus spp.	Yes[19]	Yes[19,127]	Maybe[128]	--
Penicillium spp.	Yes[1]	No[1]	--	--
Pentatrichomonas hominis	Yes[2,23,299]	No[23,299]	--	--
Peptostreptococcus spp.	Yes[1]	Yes[1]	Yes[21]	No
Phagicola longa	Yes[23]	Yes[23]	Yes[119]	No
Phaneropsolus bonnei	Yes[23]	No[23]	--	--
Phialemonium spp.	Yes[1,2]	No[1]	--	--
Phialophora spp.	Yes[1]	No[1]	--	--
Physaloptera rara	No[4]	--	--	--
Plagiorchis muris	Yes[23]	Yes[23]	No[23,118,119]	--
Plesiomonas shigelloides	Yes[1]	Yes[1]	Yes[59,300]	No
Pneumocystis carinii	Yes[1,2]	No[1]	--	--
Pneumocystis wakefieldae	Yes[1,2]	No[1]	--	--
Pneumonyssoides caninum	No[4]	--	--	--
Poliovirus 1	Yes[1]	No[1]	--	--
Porcine herpesvirus 1	No[1]	--	--	--
Porphyromonas spp.	Yes[1,19]	Yes[1,19,174]	Maybe	--
Powassan virus	Yes[1]	No[1,301]	--	--
Prevotella spp.	Yes[1,19]	Yes[1,19,174]	Yes[59,302]	No
Prohemistomum vivax	Yes[23]	No[23]	--	--
Propionibacterium spp.	Yes[1,19]	Yes[1,19,174]	Yes[21]	No
Prosthodendrium glandulosum	Yes[23]	No[23]	--	--
Prosthodendrium obtusum	Yes[23]	No[23]	--	--
Proteus mirabilis	Yes[1,2]	Yes[1,174]	Yes[85]	No
Proteus vulgaris	Yes[1,2]	Yes[303]	Yes[304]	No
Prototheca spp.	Yes[1,305]	No[1]	--	--
Providencia alcalifaciens	Yes[1,2]	No[1]	--	--
Providencia stuartii	Yes[2]	No[306]	--	--
Pseudallescheria boydii	Yes[1,2]	No[1]	--	--

Pseudamphistomum truncatum	Yes[23]	Yes[23]	No[23,118,307,308]	--
Pseudomicrodochium spp.	Yes[1,2]	No[1]	--	--
Pseudomonas aeruginosa	Yes[1]	Yes[1]	Yes[248,304]	Yes[192]
Pseudomonas oryzihabitans	Yes[1]	Yes[1,84]	Maybe	--
Pseudomonas spp.	Yes[1,19]	Yes[1,19]	Yes[85,304,309]	No
Pulex irritans	Yes[310]	Yes[310,311]	Yes[312]	Yes[312]
Pulex simulans	No[4,246]	--	--	--
Pygidiopsis summa	Yes[23]	Yes[23]	No[23,119,213]	--
Pythium insidiosum	Yes[1]	No[1]	--	--
Rabies	Yes[1]	Yes[1]	Yes[313]	Yes[313]
Ralstonia pickettii	Yes[1]	No[1]	--	--
Reovirus (Mammalian Reovirus) serotype 1	Yes[1,19,314]	Maybe[1,19]	Yes[315]	--
Reovirus (Mammalian Reovirus) serotype 2	Yes[1,19,316]	Maybe[1,19]	Yes[315,316]	--
Reovirus (Mammalian Reovirus) serotype 3	Yes[1,19,317]	Maybe[1,19]	Yes[315,318]	--
Rhinosporidium seeberi	Yes[1,2]	No[1]	--	--
Rhizomucor spp.	Yes[1]	No[1]	--	--
Rhizopus spp.	Yes[1]	No[1]	--	--
Rhodococcus equi	Yes[1]	Maybe[1,319,320]	Yes[321]	--
Rhodotorula glutinis	Yes[1]	No[1]	--	--
Rhodotorula mucilaginosa	Yes[1,2]	No[1]	--	--
Rickettsia akari	Yes[4]	No[4]	--	--
Rickettsia australis	Yes[4]	No[1,4]	--	--
Rickettsia conorii subsp. conorii	Yes[4]	Yes[23]	No[23,322]	--
Rickettsia felis	Yes[1,4]	Yes[1,43]	Yes[323]	No
Rickettsia japonica	Yes[4]	No[1]	--	--
Rickettsia prowazekii	Yes[4]	No[4]	--	--
Rickettsia rickettsii	Yes[4]	Yes[23]	Yes[23]	Yes[63–65]
Riemerella anatipestifer	Yes[1]	Yes[1]	Yes[324]	No
Rift Valley Fever	Yes[4]	No[1]	--	--
Ross River virus	Yes[4]	No[1]	--	--
Saksenaea spp.	Yes[1]	No[1]	--	--
Salmonella enterica (enteriditis, typhimurium)	Yes[1]	Yes[1,4,43,325]	Yes[196,326,327]	Yes[196,328,329]
Sapovirus	No[19,105]	--	--	--
Sarcocystis aucheniae	No[1,4]	--	--	--
Sarcocystis canis	No[1]	--	--	--
Sarcocystis capracanis	No[1,4]	--	--	--
Sarcocystis cruzi	No[1,4,330,331]	--	--	--
Sarcocystis fayeri	No[1,4]	--	--	--
Sarcocystis hircicanis	No[1,4]	--	--	--
Sarcocystis meischeriana	No[1,4]	--	--	--
Sarcocystis neurona	No[1]	--	--	--
Sarcoptes scabiei var canis	Yes[4]	Yes[4]	Yes[64,332]	Yes[64,332]
Sars-CoV-2 (Covid-19)	Yes[333]	No[334,335]	--	--
Schistosoma incognitum	Yes[23]	Yes[23,336]	No[23,118]	--
Schistosoma japonicum	Yes[23]	Yes[23]	No[23,118]	--
Schistosoma mansoni	Yes[23]	No[23]	--	--
Schistosoma mekongi	Yes[23]	Yes[23]	No[23,118,337]	--
Schistosoma rodhaini	Yes[23]	No[23,338]	--	--
Schizophyllum commune	Yes[1]	No[1]	--	--
Serratia spp.	Yes[1,339]	No[1,127,137]	--	--
Shigella spp.	Yes[1]	No[1]	--	--
Sin Nombre virus	Yes[1]	No[1]	--	--
Spirocerca lupi	No[4]	--	--	--
Spirometra mansoni	Yes[23]	Yes[23]	No[23,340]	--
Sporothrix schenckii	Yes[1]	Yes[1,43,209,341]	Yes[342]	Yes[343]
St. Louis encephalitis	Yes[1]	No[1]	--	--
Staphylococcus aureus	Yes[1,19]	Yes[1,19,43,344,345]	Yes[74,346]	Yes[347]
Staphylococcus epidermidis	Yes[1]	Yes[1]	Yes[85]	No
Staphylococcus pseudintermedius	Yes[1,19]	Yes[1,19,345]	Yes[348]	Yes[348]

Staphylococcus schleiferi coagulans	Yes[1]	Maybe[1,43]	Yes[254]	--
Staphylococcus schleiferi schleiferi	Yes[43]	No[43]	--	--
Staphylococcus sciuri	Yes[1]	No[1,43]	--	--
Staphylococcus spp.	Yes[1]	Yes[1]	Maybe	--
Staphylococcus xylosus	Yes[1]	Yes[1]	Yes[349]	No
Stellanchasmus falcatus	No[278,350]	--	--	--
Stellantchasmus falcatus	Yes[23,119]	Yes[23,119]	No[23,119]	--
Stellantchasmus pseudocirratus	Yes[38]	Yes[38,351]	No[351–353]	--
Stenotrophomonas maltophilia	Yes[1]	Yes[1]	Yes[85]	No
Stictodora fuscata	Yes[23,119]	Yes[23]	No[23,119]	--
Stomatococcus mucilaginosus	Yes[19]	Yes[19,84]	Yes[354]	No
Streptobacillus moniliformis	Yes[1]	Yes[1]	Yes[21]	No
Streptococcus agalactiae	Yes[1]	No[1,14]	--	--
Streptococcus canis	Yes[19]	Yes[1,19,43,355]	Yes[356]	Yes[356]
Streptococcus dysgalactiae dysgalactiae	Yes [14, 357]	No[1, 4, 14]	--	--
Streptococcus dysgalactiae equisimilis	Yes[14,358]	No[4,358]	--	--
Streptococcus equi subsp. zooepidemicus	Yes[1,4]	Yes[1,43,359]	Yes[360]	No
Streptococcus equi subsp. equi	Yes[1,361]	No[4,43]	--	--
Streptococcus Group D commensals	Yes[362, 363]	No[1]	--	--
Streptococcus Group E	No[1]	--	--	--
Streptococcus Group L	Yes[364]	No[1,364]	--	--
Streptococcus Group M	No[1,365]	--	--	--
Streptococcus intermedius	Yes[1,2]	No[1,366,367]	--	--
Streptococcus mitis	Yes[19]	Yes[19]	Yes[368]	No
Streptococcus pneumoniae	Yes[1,2]	No[1]	--	--
Streptococcus pyogenes	Yes[19]	Yes[19,84]	Yes[85]	No
Streptococcus spp.	Yes[1]	Yes[1,64]	Yes[64]	Yes[64]
Streptococcus suis	Yes[1,4]	No[1,4]	--	--
Strongyloides stercoralis	Yes[4]	Yes[43]	Yes[369–371]	No
Taenia brauni	Yes[4]	Yes[43]	Maybe[4,23,43]	--
Taenia crassiceps	Yes[4]	Yes[43]	Yes[4,372–374]	No
Taenia hydatigena	No[4]	--	--	--
Taenia krabbei	No[4]	--	--	--
Taenia multiceps	Yes[4]	Yes[4,43]	Yes[375]	No
Taenia ovis	No[4]	--	--	--
Taenia pisiformis	No[4]	--	--	--
Taenia serialis	Yes[4]	Yes[4, 43]	Yes[376]	Yes[162]
Taenia solium	Yes[4]	No[43]	--	--
Taenia spp.	Yes[4]	Yes[43]	Yes[69]	Yes[69]
Taenia taeniaeformis	Yes[2,377]	No[43]	--	--
Tannerella forsythia	Yes[19]	Yes[19,378]	Maybe	--
[4,379,380]*Tenshaw virus*	No[1]	--	--	--
Theileria annulata	No[4]	--	--	--
Theileria equi	No[381]	--	--	--
Thelazia californiensis	Yes[23]	Yes[23]	Maybe[4, 23]	--
Thelazia callipaeda	Yes[23]	Yes[4, 23]	Maybe[382]	--
Tick borne encephalitis	Yes[1]	Yes[4,379,380]	No[1,383]	--
Toxascaris leonina	Yes[2,384]	No[23,43]	--	--
Toxocara canis	Yes[4]	Yes[43]	Yes[69]	Yes[69]
Toxoplasma gondii	Yes[1]	No[43]	--	--
Trichinella spiralis	Yes[4]	Maybe[385]	Yes[386]	--
Trichoderma spp.	Yes[387]	No[194]	--	--
Trichophyton spp.	Yes[1]	Yes[1]	Yes[258]	Yes[329,388]
Trichosporon cutaneum	Yes[1,2]	No[1]	--	--
Trichuris vulpis	Yes[4]	Maybe[43]	Yes[372]	--
Tritrichomonas foetus	Yes[1]	No[1,43]	--	--
Trypanosoma brucei brucei	Yes[389]	No[389]	--	--

Trypanosoma brucei gambiense	Yes[1,4]	Yes[1]	No[4,390]	--
Trypanosoma brucei rhodesiense	Yes[1]	Yes[1]	No[4,390]	--
Trypanosoma caninum	No[19]	--	--	--
Trypanosoma congolense	No[19,391]	--	--	--
Trypanosoma cruzi	Yes[1,4]	Yes[1,43]	Yes[390,392,393]	Yes[240]
Trypanosoma evansi	Yes[394]	No[394]	--	--
Tunga penetrans	Yes[4]	Yes[395]	No[4]	--
Uncinaria stenocephala	Yes[4]	Yes[43]	Yes[43,376]	Yes[152,162,396]
Unclassified enteroviruses	Yes[1]	No[1]	--	--
Ureaplasma canigenitalum	No[1,2]	--	--	--
Veillonella spp.	Yes[1]	Yes[1,128,174]	Yes[21]	No
Venezuelan equine encephalitis	Yes[1]	Yes[1]	No[1,141]	--
Vesicular exanthema	No[2,4]	--	--	--
West Nile Virus	Yes[1]	Maybe[1,397,398,141]	Yes[399]	--
Western equine encephalitis	Yes[1]	No[1]	--	--
Wolbachia pipientis	Yes[1]	Yes[1]	Maybe[400]	--
Xenopsylla cheopis	Yes[246,310]	Yes[401]	Yes[157,402]	No
Yersinia enterocolitica	Yes[1,4]	Yes[43]	Yes[327]	Yes[59]
Yersinia pestis	Yes[4]	Yes[43]	Yes[63,64]	Yes[63,64]
Yersinia pseudotuberculosis	Yes[1,4]	Yes[43]	Yes[64,195]	No

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APPENDIX F

List of 51 individual canine pathogens or pathogen/parasitic groups provided to experts for the pathogen prioritization exercise listed in alphabetical order.

1. *Acanthocheilonema reconditum*
2. *Alaria spp. (alata, americana, canis, marcianae)*
3. *Anaplasma phagocytophilum*
4. *Apophallus donicus*
5. *Bartonella spp. (henselae, vinsonii subsp. berkhoffii)*
6. *Baylisascaris procyonis*
7. *Blastomyces dermatitidis*
8. *Bordetella bronchiseptica*
9. *Borrelia burgdorferi senso stricto*
10. *Brucella canis*
11. *Campylobacter spp. (coli, jejuni, upsaliensis)*
12. *Clostridium spp. (difficile, perfringens)*
13. *Coxiella burnettii*
14. *Cryptococcus gattii*
15. *Cryptocotyle lingua*
16. *Cryptosporidium canis*
17. Dermatophytes (*Microsporum canis, Trichophyton spp.*)
18. *Diphyllobothrium spp.*
19. *Dipylidium caninum*
20. *Dirofilaria immitis*
21. Dog bite pathogens [*Actinomyces viscosus, Capnocytophaga canimorsus, Fusobacterium spp., Moraxella spp, Neisseria weaveri, Pasteurella spp. (canis, multocida), Staphylococcus spp. (aureus, pseudintermedius), Streptococcus spp.*]
22. *Echinococcus spp. (granulosus, multilocularis)*
23. *Ehrlichia canis*
24. *Enterococcus spp. (faecium;* VRE)
25. *Escherichia coli*
26. Fleas *(Ctenocephalides canis, C. felis, Pulex irritans)*
27. *Francisella tularensis*
28. *Giardia duodenalis* (assemblages A1, B)
29. *Helicobacter heilmannii*
30. *Histoplasma capsulatum*
31. *Klebsiella spp.*
32. *Leishmania infantum*
33. *Leptospira interrogans (*serovars autumnalis, bratislava, canicola, grippotyphosa, hardjo, icterohaemorrhagiae, pomona*)*
34. *Malassezia pachydermatis*
35. *Mesocestoides spp.*
36. Methicillin-resistant *Staphylococcus aureus*
37. Methicillin-resistant *Staphylococcus pseudintermedius*
38. *Metorchis conjunctus*
39. Mites *(Cheyletiella yasguri, Sarcoptes scabiei var canis)*
40. *Nanophyetus salmincola*
41. *Paragonimus kellicotti*
42. *Pseudomonas aeruginosa*
43. *Rickettsia rickettsia*
44. *Salmonella enterica (enteritidis, typhimurium)*
45. *Sporothrix schenckii*
46. *Streptococcus canis*
47. *Taenia spp. (serialis)*
48. *Toxocara canis*
49. *Trypanosoma cruzi*
50. *Unicaria stenocephala*
51. *Yersinia spp. (enterocolitica, pestis*

APPENDIX G

Survey questions provided to experts for prioritization exercise using the platform SurveyMonkey.

1) Which of the following best describes your current occupation?
    a. Public Health: Government (provincial or federal)
    b. Public Health: Research/Academia
    c. Veterinary Medicine: Government (provincial or federal)
    d. Veterinary Medicine: Research/Academia
    e. Veterinary Medicine: General or specialty practice companion animal
    f. Veterinary Medicine: General or specialty practice mixed animal
    g. Veterinary Medicine: General or specialty practice: Large animal
    h. Other (please specify):

2) How would you classify your level of knowledge regarding *canine* zoonoses specifically?
    a. None
    b. Minimal
    c. Moderate
    d. Experienced

3) Where do you primarily work or reside?
    a. Alberta
    b. Saskatchewan
    c. Manitoba
    d. Other (please specify):

4) Given the following list of 51 canine zoonotic/sapronotic/anthroponotic pathogens, please select your **top 10** pathogens from a public health perspective (you will be asked to rank your choices from 1-10 in the next question). See attached table for supplementary information on each pathogen if needed.

5) Please rank your selected pathogens from 1-10 with #1 being the MOST important from a public health perspective.

6) Please describe what made you place a pathogen in your top 10 and deem it as an important canine pathogen in the Prairie Provinces from a public health perspective:

7) Given the same list of 51 canine zoonotic/sapronotic/anthroponotic pathogens, please select your **bottom 5** pathogens from the entire list, ie. those canine pathogens you are the least concerned about from a public health perspective. These do not need to be ranked in a particular order. See attached table for supplementary information on each pathogen if needed.

8) Please describe what made you place a pathogen in your bottom 5 and deem it as an unimportant canine pathogen in the Prairie Provinces from a public health perspective:

9) For the taxonomical categories (bacteria, ectoparasites, fungi, helminths, rickettsia, viruses), do you:
    a. Place more weight on one or more categories in terms of importance? If yes, elaborate on which and why:
    b. Place one or more category as least important? If yes, elaborate on which and why:
    c. Place the same weight on all categories (no preference in terms of importance). If yes, elaborate on why:

10) Are there any canine zoonotic pathogens not included on the previous list that you would like to see in a companion animal surveillance system in the Prairie Provinces? If so, which pathogen(s) would you include? Provide a short reason for including the pathogen(s):

11) Are there any canine specific (non-zoonotic) diseases that you would like to see included in a companion animal surveillance system within the Prairie Provinces? If yes, please list up to five canine disease below:

APPENDIX H

The following table was provided to experts to use at his/her discretion and represents the list of 51 canine pathogens that are (1) zoonotic/sapronotic/anthroponotic, (2) involve the dog in transmission to humans either directly, through maintenance of the pathogen in the environment, or through detection of the pathogen as a sentinel for human exposure, and (3) have been reported in the canine population in Canada.

Pathogen	Additional Information
Acanthocheilonema reconditum	- Non-pathogenic subcutaneous filarial nematode of dogs; *C. felis* serves as intermediate host - Only one human case report of subconjunctival infection; source of infection presumed to be a flea - Historically reported in dogs in Canada through veterinary surveys - Largely controlled through heartworm medication[1–4]
Alaria spp. (alata, americana, canis, marcianae)	- Generally non-pathogenic trematode of dogs, rare in humans - Dogs act as definitive host and shed eggs in environment - Human infection occurs following ingestion of undercooked intermediate hosts (ex. wild boar) - Fatal human case has been reported in Canada after ingestion of infected frog legs; larva can penetrate stomach wall an migrate through various tissues[1,5]
Anaplasma phagocytophilum	- Transmitted to humans via Ixodes ticks (including *Ixodes scapularis*) - Dogs act as sentinels for human risk, not direct transmission - Non-specific clinical signs in dogs, low pathogenicity - Often self-limiting in humans[6]
Apophallus donicus	- Intestinal fluke; non-pathogenic in dogs; uncommon - Dogs act as a reservoir host - Human infection occurs from ingestion of raw or undercooked fish[1,5,7]
Bartonella spp. (henselae, vinsonii subsp. berkhoffii)	- Vector, bite or scratch transmission possible; handling of blood can also lead to human infection - Main reservoir host in *B. henselae* (cat scratch fever) is the cat; dog acts as incidental host; - Main reservoir host in *B. vinosonii berkhoffii* is the dog - Fever and lymphadenopathy in humans is most common, but other manifestations possible[2,6]
Baylisascaris procyonis	- Roundworm; causes visceral larva migrans and ocular larva migrans in humans, especially children - Racoons are the most common definitive host; dogs can act as both a definitive and intermediate host - Transmission to humans is from ingestion of parasitic eggs; dogs can shed eggs in environment or carry eggs on their coat - Disease is severe (eosinophilic meningoencephalitis, chorioretinitis, optic neuritis and atrophy, and blindness) and can be fatal[1,2,8]
Blastomyces dermatitidis	- Commonly known as blastomycosis; fungal infection - Shared environmental exposure; rare dog bite pathogen - Humans acquire infection from inhalation or from the soil; endemic areas where canine infection is also occurring - dogs act primarily as sentinels - Cutaneous and systemic infection in humans is possible[2,6,9]
Bordetella bronchiseptica	- Human infection in immunocompromised individuals has been reported - Commonly known as kennel cough; can be directly transmitted to humans from dogs - Diseases in humans range from upper and lower respiratory tract infections including sinusitis, bronchitis and pneumonia[2,6]
Borrelia burgdorferi senso stricto	- Causative agent of Lyme Disease; transmitted by Ixodes ticks (*Ixodes scapularis, Ixodes pacificus*) - Dogs and humans are incidental hosts; dogs serve as sentinels for human exposure - Positive dogs have experimentally re-infected ticks and could serve as a reservoir host - Dogs can introduce ticks into the household[6]
Brucella canis	- Human acquired infections most common through direct contact with aborting bitches - Reproductive tissue, fluids, urine - Poses greatest risk to the immunocompromised - Severe disease in immunocompetent humans is uncommon[2,6]
Campylobacter spp. (coli, jejuni, upsaliensis)	- Causes enteric disease in humans - Oral-fecal direct transmission from dogs; food and water-borne sources also common - Has been identified as a dog bite isolate[1,2]
Clostridium spp. (difficile, perfringens)	- Commensal GI bacteria in dogs that can cause enteric disease in humans; direct transmission

	- *C. difficile* is an important nocosomial and antimicrobial-associated cause of diarrhea in humans; reverse zoonosis (human to dog) also possible - *C. perfringens* has been isolated from dog bites; can be transmitted to humans through wound contamination in addition to ingestion[2,6,10]
Coxiella burnetii	- Agent of Q-fever; dogs are a less common source for human infection than other animals but still reported - Animals are usually non-clinical; severity of disease in humans is related to degree of exposure and results in flu-like illness; pneumonia and hepatitis is common - Arthropod (tick) and direct transmission through ingestion or inhalation possible; can be shed in feces, urine, milk, placenta and reproductive fluids[2,6]
Cryptococcus gattii	- Sapronotic fungus; environmental exposure leads to human infection - Inhalation most common source of infection, but transmission from ingestion and wound contamination are also reported - Dogs act as sentinels; common-source infection - Clinical illness most common in immunocompromised individuals and includes meningitis and systemic infections; granulomatous intracranial lesions and pulmonary nodules called cryptoccomas[2,6]
Cryptocotyle lingua	- Rare intestinal fluke; only one confirmed human case – diarrhea was a possible clinical sign (coinfection common in study participants); infection in humans can occur from ingesting undercooked or raw fish - Non-pathogenic in dogs; dogs act as a definitive host[1,5,11,12]
Cryptosporidium canis	- Fecal-oral transmission most common; contaminated food/water and inhalation also possible - Infection is often subclinical in dogs and immunocompotent individuals - More serious infections in immunocompromised individuals possible; enteric disease[1,2]
Dermatophytes (*Microsporum canis, Trichophyton spp.*)	- Causative agents of ringworm (fungal infection) - Dermal lesions in humans, often pruritic, result from direct contact with clinically affected or asymptomatic animals as well as contaminated environments[1,6]
Diphyllobothrium spp.	- Intestinal tapeworm; dogs act as definitive host and shed eggs into environment - Humans are infected from eating undercooked or raw fish - Human infection is usually asymptomatic; rare clinical signs include obstruction, diarrhea, abdominal pain and anemia[1,5]
Dipylidium caninum	- Common intestinal tapeworm; dogs are the definitive host and fleas are the intermediate host - Human infection is most common in children and occurs following ingestion of fleas - Adult tapeworms are generally non-pathogenic in dogs and humans but may cause peri-anal pruritis[1,5]
Dirofilaria immitis	- Agent of heartworm disease in dogs - Rare cause of human illness; granulomatous pulmonary nodules possible - Transmitted to humans from mosquito bites; humans act as a dead end host[1,2,6]
Dog bite pathogens [*Actinomyces viscosus, Capnocytophaga canimorsus, Fusobacterium spp., Moraxella spp., Neisseria weaveri, Pasteurella spp. (canis, multocida), Staphylococcus spp. (aureus, pseudintermedius), Streptococcus spp.*]	- Direct transmission; part of normal canine oral flora or skin and other mucosal surfaces - *C. canimorsus* can cause fatal septicemia in humans; bites, licking ulcers; veterinarians have also been infected during dental procedures - *P. canis* is one of the most common species isolated from dog bites; *S. aureus* is the most common Staphylococcal species isolated from dog bites[2,6,13,14,15,16,17,18,19,20]
Echinococcus spp. (granulosus, multilocularis)	- Dogs act as definitive host of this tapeworm; transmission to humans is through fecal-oral ingestion of parasitic eggs - *E. granulosus* causes space occupying cysts in the lungs and liver of humans (hydatid cyst disease) - *E. multilocularis* causes masses most commonly in the liver of humans (alveolar cyst disease)[1,2]
Ehrlichia canis	- Transmitted to humans through tick bites (*Rhipicephalus sanguineus*) - Dogs act as reservoir hosts - A subspecies of *E. canis* is suspected as the cause of Venezuelan human ehrlichiosis; flu-like symptoms[2,6,21]
Enterococcus spp. (faecium; VRE)	- Endogenous, normal flora of GI tract in dogs; becomes opportunistic infection - Highly resistant; important cause of nosocomial infections in humans - Dogs can shed in urine and feces as source of human infection; has also been recovered from dog food

	- Also reported in dog bites[2,6,22]
Escherichia coli	- Opportunistic pathogen; shed in canine feces - Source of human infection by direct transmission; food, water-borne and dog bite transmission also possible - Multi-drug resistant strains[1,6]
Fleas *(Ctenocephalides canis, C. felis, Pulex irritans)*	- Direct contact with dogs; can serve as vectors for transmission of several other zoonotic pathogens - Clinical signs in humans results from flea bites and include erythema, pruritis and dermatitis[5,23]
Francisella tularensis	- Agent of Tularemia in humans; highly infectious - Transmission to humans through ticks; licking, scratches and dog bites also possible transmission routes - Clinical signs in humans range from fever, anorexia, skin lesions, lymphadenopathy, conjunctivitis and pneumonia[2,6]
Giardia duodenalis (assemblage A1, assemblage B)	- Surface water contamination is the most common source for human infection - Transmission from dogs to humans (uncommon) is likely to be indirect through environmental contamination - Dogs shed cysts in their feces which can survive in the environment for prolonged periods - Asymptomatic and self-limiting in most individuals but can cause enteric disease[2,5,6]
Helicobacter heilmannii	- Oral to oral transmission from dogs to humans; gastric Helicobacter species - Only rarely transmitted from pets; causes gastritis in humans[6]
Histoplasma capsulatum	- Sapronotic; environmental exposure leads to human infection via inhalation of soil-borne fungus - Dogs act as sentinels; common-source infection - Clinical illness in humans most common in immunocompromised individuals; pulmonary and systemic[2,6]
Klebsiella spp.	- Opportunistic pathogen; nasopharynx, GI, genitourinary and systemic infections possible - Cause of nosocomial infections in humans; has also been isolated as a dog bite pathogen - Canine multi-drug resistant urinary isolate[6,14,24]
Leishmania infantum	- Dogs act as main reservoir host for human infection; increased prevalence in canine populations correlates with increases in human infection (poor socioeconomics is an important risk factor) - Vector-transmission through sandfly bites; fox hound prevalence study in Ontario could not find source of infection suggesting other transmission routes likely possible - Potentially fatal in both dogs and humans[1,2,6,25]
*Leptospira interrogans (*serovars autumnalis, bratislava, canicola, grippotyphosa, hardjo, icterohaemorrhagiae, pomona*)*	- Transmission through both direct and indirect contact; infected canine urine most common - Contaminated water, soil and food; dogs can excrete the pathogen for up to several months following infection (serovar *canicola* can be shed life-long in some cases but is a less common serovar) - Humans are incidental hosts; dogs may act as incidental or reservoir hosts - Disease in humans can range from mild signs to fatal[2,6]
Malassezia pachydermatis	- Commensal yeast of skin and mucous membranes in dogs; transmitted to humans through direct contact - Clinical signs most common in the immunocompromised or young children; skin lesions, dermatitis[6]
Mesocestoides spp.	- Tapeworm; dogs can serve as secondary intermediate host and definitive host - Human infection occurs from ingestion of uncooked blood/organ tonics of snakes and turtles; rare in Canada - Clinical signs in humans include diarrhea, abdominal pain and hunger[1,5]
Methicillin-resistant *Staphylococcus aureus*	- Opportunistic pathogen; transmission occurs through direct contact - Zoonotic transmission from dogs and reverse zoonotic transmission also suspected - Antimicrobial resistant pathogen; hospital acquired infections important in human medicine[2,6]
Methicillin-resistant *Staphylococcus pseudintermedius*	- Commensal bacteria that leads to opportunistic infections in dogs - Uncommon cause of clinical disease in humans but still possible - Transmission from dogs most likely associated with bites[2,6]
Metorchis conjunctus	- Non-pathogenic liver fluke in dogs; dogs are definitive hosts - Human infection is rare; transmission occurs from ingestion of raw fish - Can cause fever, abdominal pain and eosinophilia in humans[1,5]
Mites (*Cheyletiella yasguri, Sarcoptes scabiei var canis)*	- Transmission to humans from dogs is through direct contact or contaminated fomites - Causes pruritic skin lesions in humans - Humans rarely require any treatment once effected animals are treated[1,5]

Nanophyetus salmincola	- Intestinal fluke responsible for transmission of rickettsial "salmon poisoning" agent that infects dogs - Dogs shed eggs in feces in environment; humans are infected from ingestion of undercooked or raw fish - Causes mild gastritis in humans[1]
Paragonimus kellicotti	- Lung fluke of dogs; humans affected only rarely - Humans infected from ingestion of undercooked crayfish or crab - Clinical illness in humans usually includes pulmonary signs[1,5]
Pseudomonas aeruginosa	- Opportunistic pathogen; has been isolated from dog bites - Nosocomial infections in human hospitals - Multi-drug resistant canine urinary isolate that can be shed into shared environments with humans[6,26,27]
Rickettsia rickettsii	- Agent of Rocky Mountain Spotted Fever; transmitted to humans through tick bites (*Dermacentor variabilus, D. andersoni* most common; *Amblyomma americanum* and *R. sanguineus* also possible) - Dogs and humans act as incidental hosts; dogs can serve as sentinels and also expose humans to ticks - Clinical signs in humans include upper respiratory, skin lesions, cardiac, and neurological signs; can be fatal[2]
Salmonella enterica (enteritidis, typhimurium)	- Foodborne infections common; fecal-oral transmission from dogs to humans - Handling of raw food diets and shedding in canine feces - Multi-drug resistant strains emerging[2,28]
Sporothrix schenckii	- Fungus; widely distributed in the soil; dogs become infected from penetrating wounds - Direct transmission to humans through bites and scratches or by direct contact with contaminated wounds - Human illness manifests as cutaneous lesions and systemic spread[2,6,29]
Streptococcus canis	- Direct transmission through dog bites or contact with open wounds on human skin - Has been reported to cause septicemia in humans; was also reported as the cause of endocarditis in a human (close contact with an infected dog, no bite history)[2,6]
Taenia spp. (serialis)	- Tapeworm; dogs are definitive hosts; infection rare in domestic dogs, more common in feral and shelter dogs - Fecal-oral transmission; human ingestion of eggs by contaminated water, soil and vegetation - Can lead to cystic disease in humans (subcutaneous tissue, muscle, eyes, and CNS)[1,2]
Toxocara canis	- Common canine roundworm; dogs shed eggs in feces; fecal-oral transmission - Visceral and ocular larva migrans possible in humans; most common in children[1,2]
Trypanosoma cruzi	- Causative agent of Chagas disease; "kissing bug" vector transmits pathogen to humans through contaminated bites; dogs act as a reservoir for the vector as well as the pathogen - Can act as sentinels for disease risk in humans; risk factor in developing countries is dogs in the home - Varying degrees of severity in humans; curable if treated early in infection, otherwise symptomatic treatment only and potentially life-long effects[6,30]
Unicaria stenocephala	- Canine hookworm; dogs shed eggs in feces; transmission to humans through L3 larva penetrating the skin - Can cause cutaneous larva migrans in humans; most common in children[1,2]
Yersinia spp. (enterocolitica, pestis)	- Dogs are a rare source of *Y. enterocolitica* infection; dogs can excrete in feces after ingestion of contaminated pork; causes gastroenteritis in humans - *Y. pestis* is the agent of Plague; transmitted to humans from flea bites, inhalation, bites/scratches or direct contact with open wounds; dogs are source of flea exposure to humans, but dogs can also become infected from ingestion of wildlife and harbor bacteria in the oropharynx and transmit directly - Flu-like syndrome in humans, lymphadenitis, pneumonia and sepsis; fatal if left untreated[1,2]

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APPENDIX I

Survey questions provided to private veterinarians using the platform SurveyMonkey.

DEMOGRAPHICS

1) In which province is your current clinic located?
    a. Alberta
    b. Saskatchewan
    c. Manitoba
    d. Other *(disqualified from survey)*
2) How would you describe your current practice region?
    a. Urban (city or suburb; densely populated)
    b. Rural (countryside, town; low population density)
    c. Both (split time between both urban and rural)
    d. Other (please specify):
3) What percentage of time do you spend with the following animals on a weekly basis? (Should add up to 100%)
    a. Canines
    b. Felines
    c. Pocket pets (small mammals)
    d. Reptiles
    e. Pet birds
    f. Beef Cattle
    g. Dairy Cattle
    h. Equine
    i. Poultry
    j. Swine
    k. Small ruminants
    l. Game cervids
    m. Wildlife
    n. Other (please specify):
4) How would you classify your knowledge of companion animal (canine and feline) zoonoses specifically?
    a. None
    b. Minimal
    c. Moderate
    d. Experienced

SURVEILLANCE PARTICIPATION

Veterinary clinics are key to obtaining data concerning diseases in dogs and cats. Thus, surveillance for pathogens or events of interest will require the participation of veterinary clinics across the Prairie Provinces. Surveillance has not been a part of Companion Animal Practice in Canada; therefore, it is essential that we get a sense of willingness to participate. Answers to these questions are merely hypothetical and in no way commit you to participate in any future surveillance initiative. The purpose here is to design a feasible system by gauging the best methods to encourage participation.

1) On a scale of 1-10 how would you rate your/your clinic's willingness to participate in a provincial companion animal surveillance program with 1 being no interest to participate and 10 being a strong interest to participate?
2) On a scale of 1-10, how likely would you/your clinic be willing to participate in a companion animal surveillance program if you were required to input information yourself (or by a staff member), for example, into an online database with a login code?
3) Why are you willing (or not willing) to participate in a companion animal surveillance system?
4) With what frequency would you/your clinic be willing to report surveillance data? Please rank the following from 1 being your most favorable option to 4 being your least favorable option.

a. In real time (daily/at time of diagnosis)
b. Weekly
c. Monthly
d. Annually

5) With what frequency would you/your clinic want to see updates from a companion animal surveillance system? Please rank the following from 1 being your most favorable option to 4 being your least favorable option.
    a. In real time (daily)
    b. Weekly reports
    c. Monthly reports
    d. Annual reports

CANINE PATHOGENS OF INTEREST

Our prior research identified the following zoonotic diseases as being of interest to veterinarians and public health experts for consideration in a companion animal surveillance program in the Prairie Provinces: echinococcosis, antimicrobial resistance (MRSA/MRSP), salmonellosis, and Lyme disease. Therefore, this companion animal surveillance initiative may involve such pathogens. The following questions relate to these diseases specifically.

1) Have you diagnosed a dog in the past 5 years with *Echinococcus spp. (granulosus, multilocularis)*?
    a. Yes
    b. No
2) What testing do you use to diagnose gastrointestinal parasites, such as tapeworms, roundworms or other helminths (choose all that apply)?
    a. Fecal flotation
    b. Fecal wet mount
    c. ELISA/CELISA
    d. PCR
    e. Other (please specify):
    f. None (I don't test for helminths)
3) What reasons would prevent you from submitting laboratory samples if any?
4) Do you perform fecal flotations in clinic or send your sample(s) to a third party (external to your clinic) laboratory for fecal flotation? *(only prompted to this Q if selected 'fecal flotation' above)*
    g. In clinic
    h. Laboratory
    i. Both (case dependent)
5) What third party (external to your clinic) diagnostic laboratories do you/your clinic use for these sample submissions? (choose all that apply) *(only prompted to this Q if selected 'laboratory' or 'both' above)*
    j. Prairie Diagnostic Services (PDS)
    k. IDEXX Laboratories
    l. Other (specify):
6) What canine preventatives do you promote for tapeworms? (choose all that apply)
    m. Drontal Plus
    n. Dolpac
    o. Interceptor Plus
    p. Other (please specify):
    q. None
7) How often are you recommending deworming medication? *(Q is skipped if 'none' selected above)*
    r. Monthly
    s. Every 3 months
    t. Every 6 months
    u. Annually
    v. Case dependent (specify):
8) Are there any other important pieces of information about echinococcosis you would like to mention here?

CANINE PATHOGENS OF INTEREST CONT'D (AMR)

1) Please indicate whether you have personally diagnosed a dog in the past 5 years with any of the following pathogens: (choose all that apply)
    a. MRSA
    b. MRSP
    c. Other antimicrobial resistant pathogens (specify):
    d. None of the above

MRSA/MRSP *(this page will only appear if MRSA or MRSP was selected above)*
The following questions are in regard to your previous selection for a diagnosis of MRSA or MRSP in a canine patient within the last 5 years.

1) What symptoms did the dog(s) present to your clinic with if any?
2) What diagnostic laboratories do you/your clinic use for culture and sensitivity testing? (choose all that apply)
    a. Prairie Diagnostic Services (PDS)
    b. IDEXX Laboratories
    c. Other (specify):
3) Are there any other important pieces of information about MRSA/MRSP you would like to mention here?

CANINE PATHOGENS OF INTEREST CONT'D (GI PATHOGENS)

1) Please indicate whether you have personally diagnosed a dog in the past 5 years with any of the following pathogens: (choose all that apply)
    a. Salmonella spp.
    b. Campylobacter spp.
    c. Escherichia coli
    d. None of the above

SALMONELLOSIS *(this page will only appear if 'Salmonella spp.' was selected above)*
The following questions are in regard to your previous selection for a diagnosis of salmonellosis in a canine patient within the last 5 years.

1) What symptoms did the dog(s) present to your clinic with if any?
2) What diagnostic test(s) did you use to diagnose the dog(s) with salmonellosis?
3) What third party (external to your clinic) diagnostic laboratories do you/your clinic use for these sample submissions? (choose all that apply)
    a. Prairie Diagnostic Services (PDS)
    b. IDEXX Laboratories
    c. Other (specify):

CANINE PATHOGENS OF INTEREST CONT'D (VECTOR-BORNE)

1) Please indicate whether you have personally diagnosed a dog in the past 5 years with any of the following pathogens: (choose all that apply)
    a. *Borrelia burgdorferi* (Lyme disease)
    b. *Ehrlichia* spp.
    c. *Anaplasma* spp.
    d. Other vector-borne diseases (please specify):
    e. None of the above

LYME DISEASE
Your answers to the following questions will be used as an exercise to help establish a case definition for Lyme disease based on what veterinarians in private practice are seeing and use to prevent, diagnose, and treat Lyme

disease. Answers to the following questions will also allow us to assess the use of domestic dogs as sentinels for Lyme disease.

1) Approximately how many canine patients have you diagnosed with Lyme disease in the past 2 years?
    a. 0
    b. 1-10
    c. 11-30
    d. >30
2) How often are you testing dogs for Lyme disease? (choose all that apply)
    a. As part of routine wellness appointment
    b. At request of owner
    c. If dog is exhibiting symptoms
    d. If there is travel related history
    e. Never
    f. Other (please specify):
3) If you are testing for Lyme disease, what test(s) are you using? (choose all that apply)
    a. IDEXX SNAP 4Dx Test (in-clinic)
    b. Other (please specify):
    c. N/A
4) What symptoms do you see in your canine patients who do test positive for Lyme disease? If you typically see asymptomatic cases, please specify this: (*this Q will only appear for individuals who responded with >0 cases of Lyme in the past 5 years above*)
5) How often are you vaccinating dogs against Lyme disease?
    a. Never
    b. Only if the history of the pet warrants vaccination (example: travel history, owner request etc.)
    c. Every patient gets vaccinated for Lyme disease
    d. Other (please specify):
6) What are your reasons for not vaccinating against Lyme disease? *(this question will only appear if individuals selected 'never' above)*
7) How often are you recommending tick prevention to your clients during tick season (regardless of whether or not the client complies)?
    a. Always
    b. Usually
    c. Sometimes
    d. Rarely
    e. Never
    f. Other (please specify)
8) What canine tick prevention are you using in your clinic? (choose all that apply): (*Q is skipped if 'never' selected above)*
    a. Bravecto
    b. Nexguard (or Nexguard Spectra)
    c. Simparica
    d. Revolution
    e. Advantix
    f. Other (please specify):

FINAL THOUGHTS

Note: Additionally, some canine specific pathogens (non-zoonotic) may be added to the surveillance program, such as parvovirus, canine distemper, and canine influenza. Feline pathogens will also be explored and included in the future.

1) Do you have any additional comments to add regarding a companion animal surveillance program specific to the Prairie Provinces of Canada?