Ixodes Scapularis: A Trailblazer for Vector Borne Pathogens in eastern United States and southeast Canada

Christina Yoka | INTH 401, 4.16.2024

Daniel Defoe's classic literary work "A Journal of the Plague Year," shares the intense story of a City under the siege of the "Plague." He recounts the stories of walking through the city streets and seeing individuals falling dead, mass graves, the Bills of the Parishes documenting growing numbers of lives lost, and the extreme measures individuals will take when faced with these circumstances. He recounts the response by government agencies to keep individuals out of their communities to insulate them from the "dreadful," as well as the steps taken to keep individuals "in" that are suffering from the illness and isolated from the rest of the population [1]. Despite being 300-years after JPL was written, many parallels can be drawn to modern society's experience with the COVID-19 pandemic. The COVID-19 pandemic resulted in an extreme loss of life that was televised daily by the numbers of deaths scrolling on news channels; individuals were isolated from their loved ones while hospitalized; proof of vaccination was required for international travel; and public health orders were issued to reduce the spread of the disease.

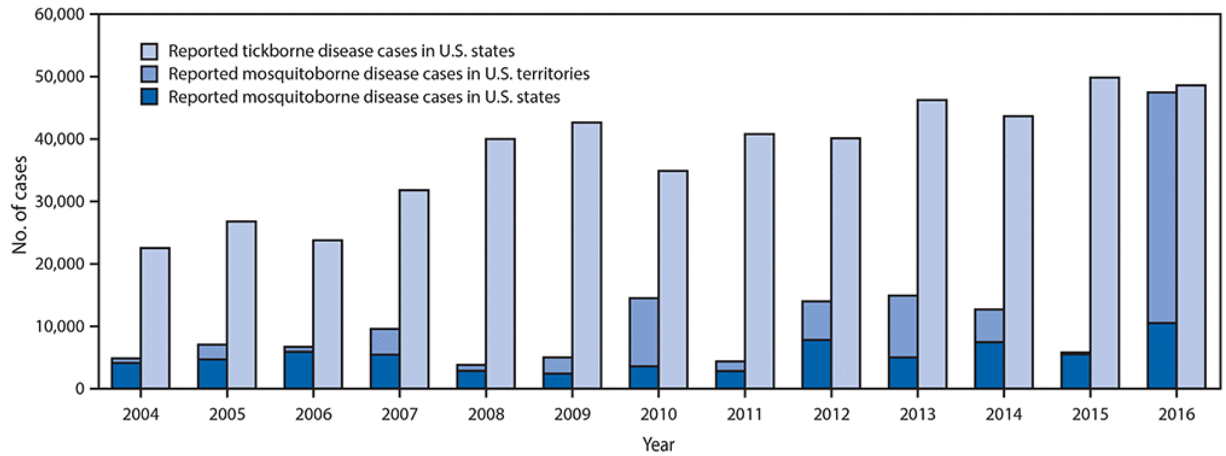
The similarities in experiences between two very different time periods are not without reason. Both diseases are zoonotic in origin, meaning that a pathogen was transmitted from animals to humans. However, a major difference in the disease pathogen transmission is that the Bubonic Plague was transmitted by a vector, the flea, whereas SARS-CoV-2 was a disease that made the jump from animal to human. Zoonotic diseases are spread through direct contact with the bodily fluids of an infected animal, indirect contact where the person came in to contact with a surface touched by the animal, and by vector, food or water [2]. Vector-borne zoonotic diseases include mosquitos, ticks and fleas. Vector-borne diseases have been increasing in the number of cases and emerging in new or expanded territories. The increase in cases and in geographic range have been attributed to a variety of factors including land use changes, increased travel and trade, and climate change [3].

Regardless of the type of zoonotic disease, the transmission of animal carried pathogens to humans are a global health concern that should be monitored since conditions can change in very short period. The following statement was made in a 2012 review article that acknowledged various zoonotic diseases that had to potential to spread but were controlled through public health measures: "*Some of these zoonoses, such as HIV, have become established as substantial new human pathogens that circulate persistently without repeat animal-to-person transmission. SARS could have established, but was contained by rapid global response to its emergence* [4]." Given the uncertainty over the future and how quickly public health emergencies can arise, it is important for public health professionals to stay vigilant on emerging threats. For that reason, this paper will examine the effectiveness of the hard-bodied tick species, *Ixodes scapularis,* as a disease vector in United States and Canada from the perspectives of infectious disease, spatial epidemiology, and environmental sciences. The primary pathogen examined will be the causative agent of Lyme Disease, *Borrelia burgdorferi* with a secondary focus on one of the causative agents of Babesiosis, *Babesiosis microti*. Physical and biological variables that influence the geographic distribution of *I. scapularis* will be examined from the spatial epidemiology perspective. Finally, this paper will examine how changing environmental conditions, primarily climate change, impact risk for contracting diseases carried by *I. scapularis*.

Section 1
Infectious Disease: *Ixodes Scapularis* as an effective vector

Zoonotic vector-borne diseases (VBD) occur by the transfer of a pathogen from an animal host to a human. This is a complex relationship that involves natural life cycles of pathogens, the vector, a reservoir host, and humans. The pathogen can be a microparasite (helminths and arthropods) or microparasites (viruses, bacteria, or protozoa). Ticks and mosquitos are examples of arbovirus vectors, or those transmitted by arthropods (insects). The reservoir host is a species critical to the pathogen's life cycle and a carrier of the disease. A vector will feed on the reservoir host and transfer the pathogen to a human. If humans are not necessary for the completion of the pathogen's life cycle, they are referred to as incidental hosts. There are many factors that influence how easily a pathogen can be transmitted to a human. Each component of the vector transmission cycle is susceptible to their own reproductive and survivability pressures that result in a Basic Reproductive Value (R_0). For example, when a reservoir host population changes, the pathogen R_0 value may decrease/increase in response. This relationship has been further complicated by human activities, including but not limited to deforestation/reforestation, domestication of animals, recreational activities, increased travel and trade, and antibiotics [4].

The National Notifiable Disease Surveillance System (NNDSS) is a database tracking cases of sixteen vector-borne diseases reported by health departments. In an analysis of data from 2004–2016, there were 642,602 cases of vector–borne diseases reported that were transmitted by ticks, mosquitos, and fleas. Although mosquitos accounted for the greatest variety of disease types (9 of the 16), ticks accounted for 77% of all cases from a total of 6 different diseases reported. Of the tickborne diseases, the greatest number of cases were Lyme Disease (82%) followed by Anaplasmosis/Ehrlichiosis (8%). Babesiosis became a reportable disease in for the first time in 2011 and accounted for 2% of cases. The NNDSS dataset likely underreports the actual number of vector-borne cases that occur each year since it is reliant on people seeking care. There are estimates that cases of Lyme Disease alone are closer to 300,000 to 476,000 annually. It is important to note that the case definition for Lyme Disease was expanded in 2022, which also accounts for a portion of the increased cases [5]. The number of cases associated with tickborne diseases have been steadily increasing over recent years and represent a growing



public health concern [3, 6].

Figure 1: Reported nationally notified mosquitoborne, tickborne, and fleaborne diseas cases
Source: CDC National Notifiable Disease Surveillance System,
https://www.cdc.gov/mmwr/volumes/67/wr/mm6717e1.htm

The hard bodied tick *Ixodes scapularis* is the primary tick responsible for VBD in the mid-eastern states of the U.S. and in southern Canada. *I. scapularis* is a vector for seven primary pathogens: *Borrelia burgdorferi/B. mayonii (Lyme Disease), B. miyamotoi* (Relapsing Fever), *Anaplasma phagocytophilum* (Anaplasmosis), *Ehrlichiosis chaffeensis/E. muris*, *Babesia microti* (Babesisios), and *Powassan* (Powassan Virus Disease). *B. burgdorferi* and *Ba. microti* share very similar transmission pathways for human infection. The tick life cycle consists of 3-stages: larva, nymph, and adult. During the larva and nymph stages, the ticks engage in blood meals of small mammals and birds. The white-footed mouse, *Peromyscus leucopus*, has been described as the "most important" reservoir host carrying *B. burgdorferi* and it is also a reservoir for *Ba. microti.* Ticks will become infected with the pathogen while feeding on *P. leucopus* during the larva or nymph stage. Humans are typically infected by the nymph stage. After the nymph molts to an adult tick, it will seek out a larger mammal as a host. White tailed deer (*Odocoileus virginanus*) serves as an important part of the tick life cycle because that is where adult ticks will mate and lay eggs. Humans are incidental hosts in this process. However, due to the shared reservoir host, humans can be infected with multiple pathogens at the same time [6].

As demonstrated, Lyme Disease has a high incidence, and this has increased over recent years. Symptoms of Lyme Disease appear between 3 to 30 days after the tick bite and some symptoms include fever, chills, headache, fatigue, and joint ache. The classic sign of Lyme Disease is the erythema migrans (EM) rash, otherwise known as a bulls-eye rash. The rash presents in about 70-80% of cases and can grow to 12 inches in diameter. Lyme disease can be diagnosed through a serological test. However, tests results may be negative for the first couple of weeks following the infection. Diagnosis should include a review of symptoms as and not depend solely on the serological test. Antibiotics can be used in the treatment of Lyme Disease. If not treated, symptoms can increase in severity and lead to additional EM rashes, severe pain, facial palsy, and arthritis and may become chronic in 5-10% of cases [7]. Babesiosis symptoms typically begin about one week after infection and some symptoms include fever, chills, headaches, and body aches. Individuals that do not have a spleen, are immunocompromised, elderly or have other serious health conditions are more susceptible to severe symptoms. Babesiosis can be diagnosed by a review of symptoms, observing a blood culture under a microscope and identifying the parasite, and through laboratory analysis. Medical treatments are available and include antibiotics. Unlike Lyme Disease, Babesiosis can also be transmitted through blood transfusions [8].

Although Babesiosis has a lower incidence than Lyme Disease, the symptoms tend to be more severe (particularly in the elderly or immunocompromised) when the individual presents with symptoms. Data were obtained from the National Inpatient Sample (NIS) database which represents commercial insurance claims for 25 million U.S. residents. The study compared hospitalizations associated with Lyme Disease and Babesiosis and found that Babesiosis patients experience more severe cases and longer hospital stays. The overall mortality rate for both Lyme Disease and Babesiosis was low (less than 1%) in the general populations. Older individuals and individuals that were immunocompromised was between 4% - 27%. The study also found that 23.7% of Babesiosis cases had coinfections with Lyme Disease [9]. Coinfections of vector borne diseases caused by *I. scapularis* can occur when a single tick that is infected my multiple pathogens feeds on a host, or if multiple ticks infected with different pathogens feed on the same host. A tick may feed on a host for 3-12 days, and it has been documented that the longer it feeds, the more likely a pathogen will be transmitted. The prevalence of infected reservoir hosts will correlate with the prevalence of infected ticks, with one study demonstrating 42% of rodents were infected with *B. burdorferi*, 21% were infected with *Ba. microti*, and 35% had coinfections. In cases of coinfection of *I. scapularis*, *B. burgdorferi* is almost always present. *B. burgdorferi* and *Ba. microti* has a 12.5% prevalence, while *B. burgdorferi* and *Anaplasma phagocytophilium* has a 10% prevalence [10].

Some studies suggest that *B. burgdorferi* amplifies the ability of *Ba. microti* to colonize a geographic region. *B. burgdorferi* always precedes the establishment of *Ba. microti* [11]. In a laboratory setting, researchers demonstrated that *Ba. microti* were better able to colonize in *P. leucopus* when the mouse was infected with *B. burgdorferi* first. The timing of the tick feeding was also important in that there had to be a period in between the initial infection of *B. burgdorferi* before the Ba*. microti* infection. When these two conditions were present, the basic reproductive value of the *Ba. microti* increased [12]. The *B. burgdorferi* bacteria is a member of the spirochete classification and have periplasmic flagella that are used for motion. To be successful in reproduction, the bacteria must be able to move through the bodies of the tick and host. This is achieved through a swim-like motion that is propelled by the flagella [13]. Laboratory studies have demonstrated that when an infected mouse is bitten by a tick, a chemical signal is released that attracts the bacteria to the bite site. The bacteria colonize the tick within 48-hours of attachment. Laboratory tests have demonstrated that other spirochete bacteria do not respond to this chemical signal [14]. As an infectious disease, B. burgdorferi is an effective pathogen and it is likely due to the biological nature of the organism. These factors have led to the high prevalence of Lyme Disease in the United States and in southern Canada.

Section 2

Spatial Epidemiology: The shifting geographic range of *Ixodes scapularis*

The geographic range of *Ixodes scapularis* in the United States and Canada has shifted multiple times through the 500,000 years of the species existence. These shifts have been due to natural climatic changes and human induced land changes. Modeling and genetic analysis indicates that the tick species used to be ubiquitous across the United States. The most recent geographic distribution change of *I. scapularis* has occurred in the past century and is from the southern United States to the North. As the U.S. was colonized by Europeans, significant deforestation occurred, and the white-tailed deer population was almost depleted. As a necessary host in the *I. scapularis* life cycle, the tick species' basic reproductive value was decreased in relation to the decreased deer population. Reforestation started to occur in the 1900's, which has enabled the tick population to expand its geographic range in the United States once again [15]. In a 2017 state and county analysis, the geographic distribution of *I. scapularis* was reported in 37 U.S. States. The distribution was compared for two time periods (pre-1996 and as of 2015) and the analysis distinguished between "reported" and "established" presence. In 1996, 12.7% of U.S. counties had "established" populations of *I. scapularis* and *I. pacificus* (also a vector for Lyme Disease).

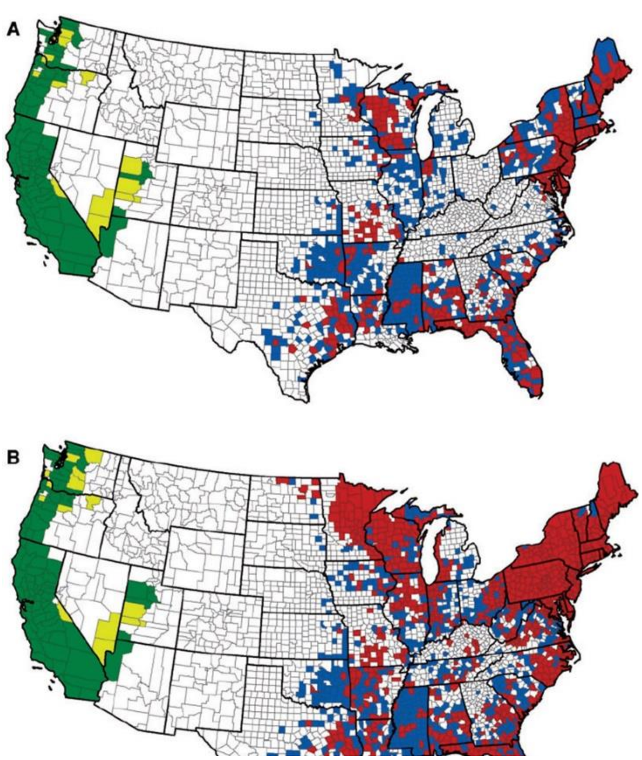


Figure 2:Distribution by county of recorded presence of I. scapuarlis and I. pacificus. A: 1907 – 1996 and B: 1907-2015: Source: [16]

By 2015, 27.1% of counties had established populations of either *I. scapularis* or *I. pacificus [16]*.

The geographic range of *I. scapularis*, *B. burgdorferi*, and consequently human risk of infection of VBDs are dependent on complex variables at each stage of infection. Habitat suitability at the macro level such as the type of ecological division (temperature deciduous forest verses coniferous forest) and at the micro level (temperature, humidity) interact to form the broad geographic range of that *I. scapularis* has the potential to inhabit. At the macroscale, habitats that are deciduous trees (maples, oaks) are more likely to be suitable habitat for the tick versus forested areas that are predominantly coniferous trees (pines) or areas that are predominantly grasslands. The type of forested area influences the type of soil and tree litter that is produced, which is an essential component of the tick life cycle when transitioning between stages [17]. North American land type has been categorized as Ecoregions, or broad geographic areas that share similar physical and biological characteristics. There are four levels with Level 1 Ecoregions having the broadest similarities and Level IV Ecoregions having the finest spatial similarities [18]. When comparing tick distribution from 2017 tick population analysis [16] to Level I Ecoregions (Appendix 1), all but four of the states with reported or established tick populations would fall in region 8, characterized as Eastern Temperate Forests. The four states that fall outside of region 8 are in region 9 and are characterized as Great Plains (North Dakota, South Dakota, Nebraska, and Kansas). Additionally, region 8 extends north into southern Canada where *I. scapularis* has been observed[1].

Fine-scale evaluations of regions with established or emerging *I. scapularis* populations have been conducted to better understand how micro-conditions (as compared to the broad Level I Ecoregion) may impact habitat suitability. In Quebec, Canada researchers analyzed how host availability (rodents and deer), microclimates, and habitat characteristics interact to produce conditions that impact tick density. The researchers used various tick-trapping methods to collect tick samples and classify by life stage at 32 sample sites in Mont Saint-Bruno, National Park. The researchers used three types of spatial analysis to determine correlations between tick density and location, including global clustering with Moran's I statistic, variograms and Monte Carlo simulations. The researchers conclude that differences in microclimates (temperature and relative humidity) and microhabitats (soil drainage) lead to variation in tick density [19]. This fine-scale analysis can help with future assessments of how tick populations are distributed at higher level Ecoregions. Higher level ecoregions provide a more detailed approach to analyzing the differences in smaller geographic regions. This type of fine scale

---

[1] This assessment of Ecoregion and tick populations was based on a visual observation taken from the tick distribution map in the Eisen article and the Level I Ecoregion map. A more accurate analysis would include mapping tick locations and densities over the ecological regions and conducting a statistical analysis to determine associations. However, that level of statistical analysis was outside the scope of this review article.

analysis when trying to determine risk within states or event at specific areas within the state, such as national parks or other recreational areas.

The Center for Disease Control and Prevention categorizes states as High Risk and Low Risk for contracting Lyme Disease. The US States that have are considered "High Risk" that are in the *I. scapularis* geographic range remain in the northeast and Midwest states (New York, Pennsylvania, and Wisconsin have the highest incidence). Many of the U.S. States that considered "Low Risk" and are within the *I. scapularis* range are in the southern area (Florida, Georgia, Arkansas). There are also states in the more central region (Kentucky or Tennessee) that are categorized as low incidence States [20]. There are similar geospatial trends for cases of Babesiosis. Since 2011, Babesiosis incidence has increased significantly in northeastern States. In Vermont, cases increased by 1,602% (from 2-34 cases) and 1,422% in Maine (from 9 to 138 cases) [21]. As stated in the previous section, *B. burdorferi* typically precedes establishment of *Ba. microti*. Therefore, as a greater number of states become high risk for Lyme Disease, they are also likely to experience higher incidence of Babesiosis.

Despite the expanded geographic range, not all US States are seeing the same level of increased incidence of Lyme Disease. Studies have indicated that this may be a result of differences in tick behavior between the northern and southern states. Zooprophylaxis is an ecological process where the vector itself may be diverting the pathogen away from humans. Two hypotheses were tested to assess what might be occurring in southern states that have high populations of *I. scapularis*, but low incidence of contracting Lyme disease. The vectors may either be diluting or buffering the pathogen from encountering humans and transmitting the pathogen. Dilution would occur if there were a wide variety of species to act as hosts. This may result in ticks attaching to hosts that are not competent hosts. Buffering occurs when the vector's behavior selectively chooses a host that is a less competent reservoir host. Researchers tested *I. scapularis* from multiple states to determine prevalence of B. burgdorferi infection. The state with the highest prevalence was Wisconsin (.35) where they collected a total of 730 adult ticks. The state with the second highest number of ticks collected was Florida (528), which had a prevalence of .1 infections. The researchers also analyzed availability and type of hosts. They found that I. scapularis preferred small rodents (such as *P. leucopus*) in the North, whereas in the south small lizards were frequently the hosts. Lizards are not a competent reservoir host for *B. burgdorferi*, limiting the likelihood of infected ticks. Lastly, ticks in the north tend to "climb" vegetation, which would put them in closer proximity to people. In the south, ticks tend to avoid climbing and the researchers conclude that this behavior is to avoid desiccation that would be caused by the increased heat [22].

Section 3
Environmental Sciences: Climate Change and Future Impacts of Tickborne Diseases

The expanded geographic range of *I. scapularis* has been attributed to land use changes that resulted in increased deer populations, which provided an opportunity for a higher basic reproductive value [3, 6, 15]. In addition to reforestation, the increase in the expanded geographic range may be due to climate change. As already discussed, vector borne disease transmission cycles are complex interactions between the pathogen, vector, reservoir host and transmission to humans. Each component of this cycle is acted upon by external factors that can alter survivability of each. Climate change, described as the long term change in the average weather patterns that have come to define Earth's local, regional, and global climates [23], will likely influence distribution of vector borne diseases as well. As weather patterns change, the suitable habitat for vectors and reservoir hosts will respond. A variety of vector borne diseases have either already experienced changes or are predicted to do so in the coming decades [24]. The U.S. EPA has identified key indicators for climate change, and West Nile Virus and Lyme Disease are included in the indicators. Examples of additional indicators include heat-related deaths or illnesses [25].

Climate change is the long-term alteration to weather patterns, some of which is natural and some is caused by human behavior (or anthropogenic). Climate change is generally assessed over the course of 30-years. One of the main forms of anthropogenic climate change is caused by the increasing quantities of gases (air pollution) into the atmosphere, which results in the greenhouse gas effect. Examples of anthropogenic sources include energy generation, industry and transportation, which are mostly produced from the burning of fossil fuels. The greenhouse gas effect is the process of gases trapping temperature close to the Earth and thereby reducing the ability of thermal energy to dissipate. This is a necessary process for life as we know it to be sustained on Earth. Otherwise, the Earth's temperature would likely be -19 degrees Celsius [26]. However, the pace at which this is occurring has increased substantially over the past century. Since 1960, the mean annual temperature has increased by 1 degree Celsius (Figure 3). Correspondingly, atmospheric Carbon Dioxide concentrations, have increased from 320 parts per million in 1960 to over 420 parts per million today, (Figure 4) [23].

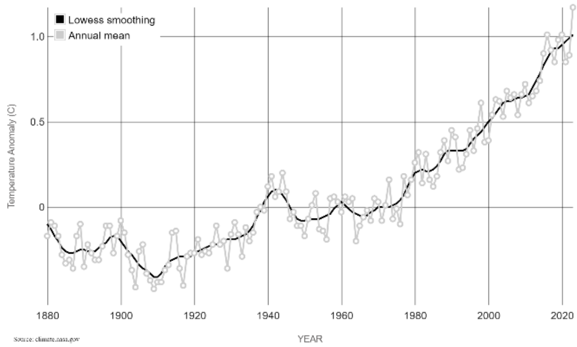


Figure 3: Annual Temperature Mean, Source [23]

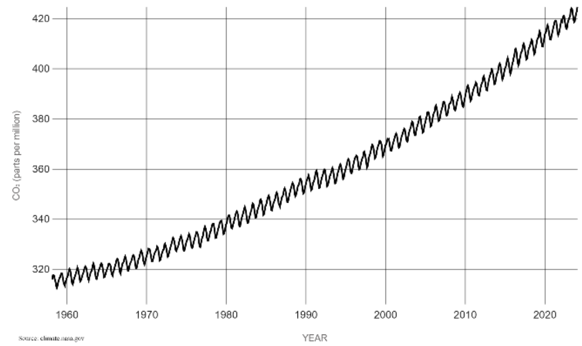


Figure 4: Annual Carbon Dioxide Emissions, Source [23]

The U.S. Global Change Research Program produced the Climate and Health Assessment, which identifies how changes in global climate will affect human health. The report identifies. several areas that will be impacted by climate change and pose a risk to human health including Temperature-Related Death and Illness, Air Quality Impacts, Vector-Borne Disease, and Water-Related Illness. Vector-borne disease is projected to be impacted in four ways including 1) changing distribution of the vector 2) earlier tick activity and northward range expansion 3) changing mosquito borne disease dynamics and 4) emergence of new vector-borne pathogens [27]. Malaria, dengue, West Nile Virus are mosquito borne diseases that will likely experience changes in distribution or activity. West Nile Virus, which is also a climate change indicator according to the U.S. EPA, can be carried by 300 different bird species and is the leading mosquito borne disease in the U.S. In Columbia and in Ethiopia, a .2 degrees Celsius change in temperature has been associated with a wider distribution *I. scapularis*. However, in some countries, climate change is expected to result in drought, which would decrease overall distribution of a variety of vectors [24].

The way that vector activity changes in response to temperature is determined by the species itself. Ticks in the *Ixodes* genus prefer habitats that exceed 85% relative humidity and 7 degrees Celsius [28]. As already described, the geographic distribution of *I. scapularis* has already been expanding northwards in the United States and incidences of Lyme Disease have been steadily increasing [6, 15, 17, 28]. Similarly, the range of *Ba. microti* and resultant Babesiosis cases have increased in incidence and have expanded north from the U.S. to southern Canada [11]. In addition to reforestation, these changes may be associated with warmer temperatures. An analysis of the *I. scapularis* basic reproductive value was conducted using data from 1971 – 2010 in 30 Canadian sites and two U.S. sites. The selected locations were chosen for temperature variability impact on host-seeking behavior at different stages of the tick life cycle. Temperature data included the overall survival range (maximum and minimum) for *I. scapularis*. The researchers concluded that there is the potential for an increase in *I. scapulari's* geographic range by 2 -5 times in Canada and 1.5 to 2 times in the U.S, and that the tick life cycle may be shortened. The two year life cycle of the tick makes it more tolerant to individual weather events but more susceptible to longer term climatic changes [29].

In addition to analyzing samples of collected ticks to determine observed range, models can be applied to predict future geographic distribution. The Maximum Entropy Method (MaxEnt) is used to determine habitat suitability of a species given specific environmental variables. A species fundamental niche (or potential area a species can occupy that meets its basic survival needs) and realized niche (area the species occupies) can be compared. The modeling parameters must be appropriate for the scale that is being modeled. An Ecoregion of Level I, for example, would be considered meso-scale region as it is larger than individual weather events and would have similar topographic features. The MaxEnt method calculates the probability of distribution of a species given the environmental parameters entered [30]. This method was applied to model future global distribution of *I. scapularis*. The researchers analyzed data of collected tick samples from the Global Biodiversity Information Facility, which includes latitude and longitude of the sample that was collected. The environmental parameters considered were historical temperature (minimum and maximum), total monthly precipitation, and elevation. Future climatic conditions were considered based on Shared Socioeconomic Pathways (SSPs) models developed by the Intergovernmental Panel on Climate Change. These data produced estimates of geographic regions that would be classified based on their degree of suitability to serve as a fundamental niche (high suitability to low suitability) for multiple periods of time leading up to the year 2100. Overall, the models predict a continued northern shift until 2081 and then a decreased range as a result of too high temperatures and drought [31].

The effect that climate change will have on reservoir hosts and the pathogens themselves remains inconclusive. The impact that climate change will have on *Ba. microti*, for example, is mostly attributed to changes to the vector (*I. scapularis*). The predicted changes to Babesiosis cases are mostly due to change in tick populations. There are some indications that there may be changes in the reservoir host in response to warming temperatures, but increases in cases or expansion of geographic range are mostly attributed to expanded range of the vector [32].

Conclusions

The complex vector-host-pathogen relationship that influence vector-borne infectious diseases make this public health concern an interesting, albeit difficult, one to address. Many factors outside of the public health professional's control will influence how much of a risk a specific infectious disease may be. These external factors include but are not limited to land use changes and climate change. However, by paying attention to ecological trends, the public health professional can better plan for future risk. *I. scapularis* acts as a trailblazer by foraging new territories through its ability to expand its' geographic range and as an indicator of what has the potential to be a future risk. As demonstrated, the number of counties in the United States that have established or reported *I. scapularis* populations increased from 12.7% to 27% in a matter of twenty years. Additionally, the data presented in that study were up to 2015 and did not include the expanded territory into southern Canada. If those trends have continued, the number of counties with established *I. scapularis* populations are likely even higher.

The U.S. EPA has identified Lyme Disease cases as an indicator of climate change based on studies that suggest the expanded geographic range of *I. scapularis* is partly due to more suitable habitats caused by warming temperatures. Lyme Disease is among 50 indicators that are believed to be an outcome of changing environmental conditions. However, just as important as serving as an indicator for climate change, the presence of *B. burgdorferi* can serve as an indicator of current or future risk for other vector borne infectious diseases. As an effective pathogen, *B. burgdorferi* populations always precede the establishment of *Ba. microti*. Although not addressed in this article to the same level as Babesiosis, the association of established *B. burgdorferi* colonies ahead of other tickborne diseases have also been observed. If multiple pathogens transmitted by I. scapularis become established, there is a higher risk of patients experiencing co-infections. Individuals that experience coinfections also present with more sever symptoms. Additionally, the establishment of *B. burgdorferi* can indicate the future presence of different pathogens that have more sever impact on the patient, such as Anaplasmosis.

The overall trend of an expanded *I. scapularis* population followed by an established *B. burgdorferi* population, then additional pathogens have implications for the public health professional and in clinical settings.   From a public health perspective, professionals can develop surveillance programs that are consistent with the expected population trends of the pathogens and the vector. They can follow published ecological surveys that report on newly identified populations of ticks. Based off the public health professionals geography, the risk for Lyme Disease can also be estimated. As discussed, *B. burgdorferi* infections are less common in ticks in that inhabit Southern states. However, in areas that *B. burgdorferi* have higher likelihoods of establishing, public health and medical providers should prepare for the potential of additional infectious diseases that are presented as either coinfections or independent infections. Either way, public health and clinical professionals should be aware of how Lyme Disease can serve as either a predictor or indicator of other health concerns. Spatial epidemiology serves as a good tool to identify where this risk might be the highest by tracking where the tick population is expanding to, followed by Lyme Disease incidence and subsequent pathogen establishment.

Finally, the impact of climate change on influencing the range of vector borne diseases by changing habitats is likely. Studies have shown changes in temperature and precipitation have likely contributed to the northward expansion of *I. scapularis*. Modeling based on physical samples collected, existing environmental conditions, and climate projections indicate that the geographic range of *I. scapularis* will continue to change. In addition to expansion, some models predict that certain areas will experience a reduction in range because of increased temperature and drought. Climate change will have a unique impact on each ecosystem and although models can provide a good estimate of what is likely to occur, nothing is definitive. There are a multitude of external factors that can disrupt these models such as socio-economic, political or natural disasters.

Given how much of an impact zoonotic disease can have on human populations, it is important to continue to monitor and assess emerging risks associated with vector-borne diseases. Vector-borne diseases are global health concerns that can have catastrophic impacts on human life and the quality of life, and these changes can occur in a very short period. Public health professionals should continue to engage in cross disciplinary collaborations to monitor for emerging diseases that have the potential to become uncontrollable.

References

1. Defoe D. A Journal of the Plague Year. London: Penguin Books, **1722**
2. Zoonotic Diseases Available at: https://www.cdc.gov/onehealth/basics/zoonotic-diseases.html. Accessed 4/4 2024.
3. Kilpatrick AM, Randolph SE. Drivers, dynamics, and control of emerging vector-borne zoonotic diseases. Lancet **2012**; 380:1946-55.
4. Karesh WB, Dobson A, Lloyd-Smith JO, et al. Ecology of zoonoses: natural and unnatural histories. Lancet **2012**; 380:1936-45.
5. Rosenberg R LN, Fischer M, Gregory C, Hinkley A, Mead P, Paz-Bailey G, Waterman S, Drexler N, Kersh G, Hooks H, Partridge S, Visser S, Beard C, Petersen L. Vital Signs: Trends in Reported Vectorborne Disease Cases - United States and Terriroties, 2004 - 2016. Morbidity and Mortality Weekly Report. Vol. 67: U.S Department of Health and Human Services, **2018**:496-501.
6. Eisen RJ, Eisen L. The Blacklegged Tick, Ixodes scapularis: An Increasing Public Health Concern. Trends Parasitol **2018**; 34:295-309.
7. Lyme Disease Available at: https://www.cdc.gov/lyme/index.html. Accessed 3/30/2024 2024.
8. Parasites - Babesiosis Available at: https://www.cdc.gov/parasites/babesiosis/. Accessed 03/30 2024.
9. Bloch EM, Zhu X, Krause PJ, et al. Comparing the Epidemiology and Health Burden of Lyme Disease and Babesiosis Hospitalizations in the United States. Open Forum Infect Dis **2022**; 9:ofac597.

10. Rocha SC, Velásquez CV, Aquib A, Al-Nazal A, Parveen N. Transmission Cycle of Tick-Borne Infections and Co-Infections, Animal Models and Diseases. Pathogens **2022**; 11:1309.
11. Kumar A, O'Bryan J, Krause PJ. The Global Emergence of Human Babesiosis. Pathogens **2021**; 10.
12. Dunn JM, Krause PJ, Davis S, et al. Borrelia burgdorferi promotes the establishment of Babesia microti in the northeastern United States. PLoS One **2014**; 9:e115494.
13. Sultan S MA, Stewart P, Bestor A, Rosa P, Charon N, Motaleb M. . Motility is Crucial for the Infectious Life Cycle of Borrelia burgdorferi. Infection and Immunity **2012**; 81:2012-21.
14. Radolf JD, Caimano MJ, Stevenson B, Hu LT. Of ticks, mice and men: understanding the dual-host lifestyle of Lyme disease spirochaetes. Nat Rev Microbiol **2012**; 10:87-99.
15. Eisen L ER. Changes in the geographic distribution of the blacklegged tick, Ixodes scapularis, in the United States Tick and Tick-borne Diseases **2023**; 14.
16. Eisen RJ, Eisen L, Beard CB. County-Scale Distribution of Ixodes scapularis and Ixodes pacificus (Acari: Ixodidae) in the Continental United States. J Med Entomol **2016**; 53:349-86.
17. Guerra M, Walker E, Jones C, et al. Predicting the risk of Lyme disease: habitat suitability for Ixodes scapularis in the north central United States. Emerg Infect Dis **2002**; 8:289-97.
18. Ecosystem Research. Available at: https://www.epa.gov/eco-research/ecoregions-north-america. Accessed 4/2 2024.
19. Dumas A, Bouchard C, Lindsay LR, Ogden NH, Leighton PA. Fine-scale determinants of the spatiotemporal distribution of Ixodes scapularis in Quebec (Canada). Ticks Tick Borne Dis **2022**; 13:101833.
20. K Kugeler EA, Mead P, Hinckley A. Surveillance for Lyme Disease After Implementation of a Revised Case Definition — United States, 2022. Morbidity and Mortality Weekly Report. Vol. 73, **2024**.
21. Swanson M PA, Willimanson J, Montgomery S. Trends in Reported Babesiosis Cases - Unites States, 2011-2019. Morbidity and Mortality Weekly Report Vol. 72: Center for Disease Control and Prevention, **2023**:273-7.
22. Ginsberg HS, Hickling GJ, Burke RL, et al. Why Lyme disease is common in the northern US, but rare in the south: The roles of host choice, host-seeking behavior, and tick density. PLoS Biol **2021**; 19:e3001066.
23. What is Climate Change? . Available at: https://science.nasa.gov/climate-change/what-is-climate-change/. Accessed 3/30 2024.
24. Thomson MC, Stanberry LR. Climate Change and Vectorborne Diseases. N Engl J Med **2022**; 387:1969-78.
25. Climate Change Indicators Available at: https://www.epa.gov/climate-indicators. Accessed 4/4 2024.
26. VijayaVenkataRaman S, Iniyan S, Goic R. A review of climate change, mitigation and adaptation. Renewable and Sustainable Energy Reviews **2012**; 16:878-97.
27. Program USGCR. Climate Health Assessment: About this Report. . Accessed April 5 2024.

28. Beard C ER, Barker C, et al. . The Impacts of Climate Change on Human Health: Vector Borne Diseases, **2016**:129-55.
29. Ogden NH, Radojevic M, Wu X, Duvvuri VR, Leighton PA, Wu J. Estimated effects of projected climate change on the basic reproductive number of the Lyme disease vector Ixodes scapularis. Environ Health Perspect **2014**; 122:631-8.
30. Phillips S, Anderson R, Schapire R. Phillips SJ, Anderson RP, Schapire RE.. Maximum entropy modeling of species geographic distribution. Ecol Model 19: 231-259. Ecological Modelling **2013**; 190:231-59.
31. Zhang L, Ma D, Li C, Zhou R, Wang J, Liu Q. Projecting the Potential Distribution Areas of Ixodes scapularis (Acari: Ixodidae) Driven by Climate Change. Biology **2022**; 11:107.
32. Gray JS, Ogden NH. Ticks, Human Babesiosis and Climate Change. Pathogens **2021**; 10.

Appendix 1: Level I Ecoregion