RECENT EXPANSION OF BLACK-LEGGED TICKS, *IXODES SCAPULARIS*, INTO THE THUNDER BAY REGION: IMPLICATIONS AND PUTATIVE ROLE OF CLIMATE CHANGE

by
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CAUTION TO THE READER

This H.B.E.M. thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management Lakehead University for the purpose of advancing the practice of professional and scientific forestry.

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ABSTRACT

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The distribution of *Ixodes scapularis* is increasing in Ontario, thereby increasing the risk of contracting Lyme disease. Climate change is a likely factor in the northward expansion of *I. scapularis* populations. Here, I explored published studies, interviewed professionals, and performed literature reviews to answer whether climate change is the primary cause of the expansion of *I. scapularis* populations in Ontario, and why they are now more frequently seen in Northwestern Ontario. Climate change was determined to be a cofactor in the expansion of *I. scapularis* range; mobile host species are increasing the rate at which black-legged ticks are expanding. *I. scapularis* is capable of surviving in new locations, provided there is suitable habitat and a sufficient number of hosts. It is predicted that *I. scapularis* will increase its range in Ontario by 46 km/year over the next decade. Increasing *I. scapularis* populations across Canada increases the percentage of black-legged ticks carrying the bacterium *Borrelia burgdorferi,* that causes Lyme disease. This will ultimately increase the risk of Lyme disease to all.

Keywords: *I.* scapularis, black-legged ticks, climate change, host species, Lyme disease, *Borrelia burgdorferi.*

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INTRODUCTION

Until the 1970s black-legged ticks (also known as deer ticks), *Ixodes scapularis,* were not reported in Canada (PHO, 2016). The first reports of *I. scapularis* in Canada came from Long Point Provincial Park, Ontario, along the northern shore of Lake Erie (PHO, 2016). Currently, *I. scapularis* is distributed primarily in the southern portions of Manitoba, Ontario, Quebec, New Brunswick and Nova Scotia.

The black-legged tick is a known vector of Lyme disease. Lyme disease is an infection caused by a spirochete bacterium, *Borrelia burgdorferi,* which is transmitted to humans through the bite of an infected black-legged tick (PHO, 2016). This disease was first reported in 1975, in several small towns in Connecticut, US. Lyme disease has been endemic to Canada since the early 1980s and t has been reported in British Columbia, Manitoba, Ontario, Quebec, New Brunswick, and Nova Scotia (GOC, 2018).

Black-legged ticks were first reported in Northwestern Ontario in the early 1990s (Schillberg *et al.,* 2018). This represents a significant northward expansion of *I. scapularis* in Ontario. There have been no confirmed cases of Lyme disease in the Thunder Bay region (TBDHU, 2018). However, the neighbouring districts of Kenora and Rainy River have been deemed Lyme-endemic (Schillberg *et al.,* 2018; TBDHU, 2018).

Here I describe the taxonomy, distribution and habitat, external morphology, and development of *I. scapularis,* and discuss the role of climate change, hosts, and Lyme disease in the expansion of black-legged ticks in Canada.

LITERATURE REVIEW

Taxonomy

Ticks comprise the suborder *Ixodida* of the order *Parasitiformes* and are blood feeding parasites of mammals, birds, amphibians, and reptiles around the world. *Ixodida* contains three families; *Ixodidae* (hard ticks)*, Argasidae* (soft ticks)*,* and *Nuttalliellidae* (Vredevoe, n.d)*.* The family *Ixodidae* is subdivided into *Prostriata*, which represents the single genus *Ixodes*, and the *Metastriata,* which includes 13 genera, and 650 species. *Nuttalliellidae* is represented by only one species, *Nuttalliella namaqua.* Ticks are classified with the class Arachnida, which contains spiders and scorpions. Within the family *Ixodidae*, the genus *Ixodes*, is the largest tick genus, containing approximately 235 species (Vredevoe, n.d; Anderson & Magnarelli, 2008). Within the genus *Ixodes* there are four species known as vectors of microbial agents to humans: the black-legged tick (*Ixodes scapularis*) in eastern North America; the castor bean tick*,* or sheep tick (*I. ricinus*) in Europe and western Asia; the taiga tick (*I. persulcatus*) in northeastern Europe and northern Asia; and the western black-legged tick (*I. pacificus*) in the far western United States (Anderson & Magnarelli, 2008).

Distribution and Habitat

Ixodes are widely distributed around the world, including Antarctica but they occur more commonly in temperate regions. *I. scapularis* prefer habitats that provide moist, humid, shaded habitat; such as wooded or forested areas. Forested habitat provides shade and suitable leaf litter which is essential cover for active ticks in the summer and winter months (Anderson & Magnarelli, 2008; PHO; 2016). Grasses and sedges on the edge habitat of forests provides ticks with the opportunity to attach to larger hosts.

External Morphology

Anderson & Magnarelli (2008) described the external morphology of adult black-legged ticks. Below is a summary of tick morphology. Adult ticks have flattened, ovoid or pear-shaped bodies. They are approximately 3 mm in length (this increases when they are fully engorged after feeding); females are almost always larger than males. Members of the genus *Ixodes* are easily identifiable by the distinctive anal groove which encloses the anus anteriorly. *I. scapularis*, unlike other ticks, lack festoons (ridges on the edge of the lower abdomen). Hard ticks have a sclerotized dorsal plate often referred to as the 'shield' or 'scutum', which is absent in soft ticks. The scutum is large and covers majority of the dorsal surface of the body in males, in females it is much smaller and only covers the anterior part of the body behind the capitulum. The capitulum, also referred to as the 'false head' is a beak-like structure that protrudes forwards beyond the body and contains the mouthparts. Ticks have eight legs (four pairs) each equipped with claws. Members of the genus *Ixodes* are easily identifiable by the distinctive anal groove which encloses the anus anteriorly. Female ticks have a black scutum and capitulum, and a dark red abdomen. Males are entirely black or dark brown in colour. Both sexes have black legs. Nymphs, ticks in the larval state, are approximately 1-2 mm in length. They are translucent with a dark head and have eight black legs.

Development

Ixodidae have a hemimetabolous lifecycle; there is an incomplete metamorphosis that involves a larval and a nymphal stage (Yuval & Spielman, 1990). Ticks have four stages to their lifecycle: egg, larva, nymph, and adult (Public Health Ontario, 2016; Yuval & Spielman, 1990). *Ixodid* ticks take at least one year to complete their lifecycle. The black-legged Tick, *Ixodes scapularis*, (also commonly known as the deer tick) requires three hosts at each stage of development to complete its lifecycle (CDC, 2018; Public Health Ontario, 2016). They complete their lifecycle in approximately 2-3 years. In *I. scapularis,* mating and courtship are regulated by pheromones. The release of pheromones causes members of both sexes to congregate on the ground, host, or vegetation. Adult *I. scapularis* is polygynous; females breed with one male and males breed with many females. After breeding, the male dies and females die after laying eggs (CDC, 2018; Public Health Ontario, 2016).

In the spring, eggs are deposited and hatch in early summer. Beginning in June, the deposited eggs hatch into tiny larvae. By August, the larvae are attaching to and feeding on a wide variety of mammals and birds; the primary host is the white-footed mouse, *Peromyscus leucopus (*referred now to as *P. leucopus*) (Watson & Anderson, 1976; Anderson & Magnarelli, 2008). Once attached, the larvae will feed for three to five days, and once fully engorged the larvae drop off of their first host onto the ground and will remain there throughout the winter. Engorged larval ticks molt over the winter and emerge in May as poppy seed-sized nymphs. Nymphs feed on an assortment of hosts, typically small mammals, for three to four days. Just as before, once engorged the nymph detaches from the host and drops to the ground where they molt into adults. By October, the new adult ticks become active (Watson & Anderson, 1976; Anderson & Magnarelli, 2008). Adult females feed upon their definitive host, the White-tailed Deer, *Odocoileus virginianus*, while the male rarely feeds. *I. scapularis* breeds upon its host, with the male dying shortly after copulation. Females remain active throughout the winter whenever the ground is not frozen. Blood-engorged females survive in the leaf litter on the forest floor and begin laying their eggs in late May, and the cycle begins again (Watson & Anderson, 1976; Anderson & Magnarelli, 2008).

Black-legged Tick Life Stages

In Ontario, Yuval & Spielman (1990) observed black-legged ticks were confined fields to determine how the length of various developmental stages survive in nature and to establish the interval between the blood feeding and ecdysis or oviposition as well as subsequent larval eclosion. Adult ticks that do not feed during their first season (fall through spring) of activity will die. Nymphs that do not feed survive through two seasons (May through August) of feeding activity – annual cohorts overlap. Nonfed larvae hatch toward the end of the summer and therefore survive less than one year – cohorts in this stage do not overlap. Larvae that feed before September and molt right after overwintering as nymphs; and those that feed later overwinter engorged and ecdyse the following spring. Nymphs that have fed do not survive the winter, and therefore must feed before late summer. Nymphs develop into the adult stage during the same year that they feed. Females lay eggs in the early summer regardless of the time they feed; the resulting larvae enclose later in the season at the same time. The lifecycle of the tick can be completed in two years; however, it may extend to four years when hosts are relatively limited. It appears that the seasonal inversion of larvae and nymphs is regulated by physiological mechanisms and host abundance (Yuval & Spielman, 1990).

Lindsay *et al.,* (1998) studied blood-fed females and unfed adults and nymphs of black-legged ticks kept in housings within four different habitats on Long Point, Ontario from November 1989 to April 1993, to evaluate the habitat effects on tick development. It was found that blood fed females within the maple forest had a greater survival rate (75.6%) than those within the cottonwood dunes (36.1%). In the two remaining habitats (oak savannah and white pine) 52.8-62.0% of blood fed females survived the winter. Eggs laid by females were proportionally similar and greater within the maple forest (90.3%), oak savannah (83.9%), and white pine habitats (78.4%) than in the cottonwood dune (53.8%). In each habitat, females began laying eggs during late April or early May during each year of the study. Egg deposition was consistent in time regardless of females feeding in November and overwintering, or feeding during April of the following year. There were significantly more eggs hatching in the maple forest (96.4%) and white pine forest (79.3%) than the other two habitats. Each year, eggs hatched in mid to late July. There was no significant difference in the winter survival rates of unfed adults among the four habitats. Habitat-specific differences such as the difference of seasonal extremes of vapor pressure deficits among the four different habitat types were likely responsible for the survival of black-legged ticks. The observations of captive black-legged ticks in this study suggest that the life cycle of this tick on Long Point is completed in 3-4 years.

Lindsay *et al.,* (1995) found that black-legged tick distributions are not clearly defined in Ontario. There is an endemic population on the Long Point peninsula, Lake Erie, Ontario, however, *I. scapularis* has also been collected from other areas in Ontario. This study was conducted from early December 1991 until May 1993; 35 fed females, 70 unfed adults, and 70 unfed nymphal black-legged ticks were held in containers within four natural habitats on Long Point and at northern localities near Ottawa, Hearst, and Kenora, Ontario, to test the hypothesis that distribution of the black-legged tick is limited by cold climatic extremes (Lindsay *et al.,* 1995). Blood fed females had a higher overwintering survival rate (84.8%) than unfed adults (30.5%). On Long Point, the fed females had a higher overwinter survival rate (56.4%) than unfed adults (23.6%). In northern localities the fed females and unfed adults had increased survival by >2 months when compared with Long Point; survival rates for unfed nymphs were the same at the northern sites and on Long Point. Within the four habitats on Long Point, and at Kenora and Ottawa, females laid eggs from late April to mid-May; eggs were deposited in late June at the Hearst site. On Long Point and at the Ottawa site, larvae emerged from eggs in late July or early August (Lindsay *et al.,* 1995). Larvae didn't emerge until early October at Kenora, and no larvae emerged at Hearst during 1992. The hatching rate was <10% at the northern sites during 1992-1993, some eggs that overwintered were viable (Lindsay *et al.,* 1995). Black-legged ticks introduced into regions of the province with seasonal degree-day accumulations lower than the ones observed on Long Point had an extended minimum duration of the lifecycle (Lindsay *et al.,* 1995). The lack of emergence and deposition of eggs at Hearst and Kenora were likely the result of insufficient accumulation of degree-days above threshold temperatures for development in 1992 (Lindsay *et al.,* 1995). Some eggs can overwinter successfully; it is suggested that latitude-related reduction in seasonal temperature may not limit the distribution of the black-legged tick in Ontario despite low hatchability (Lindsay *et al.,* 1995). This factor, combined with the natural incremental mortality at each instar, and other factors such as difficulty finding a mate and low density of medium to large mammal hosts for adults, may reduce the potential for establishment of black-legged ticks into certain northern regions (Lindsay *et al.,* 1995).

Climate Change

A deterministic model of the Lyme disease vector, *I. scapularis*, was developed (Wu *et al.,* 2013). The model was used to estimate a basic reproduction number for black-legged ticks under different climatic conditions. A map was developed for black-legged ticks in Canada, where this tick is emerging (Wu *et al.,* 2013). An estimation of basic reproduction numbers for black-legged ticks will assist public health responses to emerging Lyme disease.

A dynamic population model of black-legged tick (*Ixodes scapularis*) was developed by Ogden *et al.,* (2005) to simulate the effects of temperature on tick survival and seasonality. Through the use of mean monthly normal temperature data, the development rates of ticks were modelled as temperature-dependent time delays. Temperature was an influence in the host-finding success in the model. With the use of data from stations near endemic populations of black-legged ticks, the model reached repeatable stable, recurring equilibria with seasonal activity of different instars being very close to that observed in the field. Simulations were run using data from meteorological stations in central and eastern Canada; the further north the station was located the maximum equilibrium numbers of ticks declined, and simulated populations died out. The steady increase of mortality of all life stages and decreasing temperatures caused a tick die-out at northern latitudes. The study examined the mean annual numbers of degree-days >0 °C (DD>0 °C) as a readily mapped index of the temperature conditions at the meteorological stations providing temperature data for the linear regression model. There was a strong correlation between the maximum number of ticks at equilibrium and the mean DD>0 °C, when the province of origin of the meteorological station was accounted for. In the models, the intercepts provided the theoretical limits for the establishment of black-legged ticks in Canada. The maps provided evidence that there is a potential for tick populations to spread; the limits suggested that the potential range of southeast Canada is much greater than the existing distribution. The future applications of the model in investigating climate change effects on black-legged ticks are discussed.

Levi *et al.* (2005) determined a quantifiable relationship exists between climate change and tick phenology through the use of 19 years (1994-2012) of data on blacklegged ticks attached to small-mammal hosts. Evidence suggested that in warmer years, the months of May-August were associated with a nearly three-week advance in the phenology of nymphal and larval ticks in comparison to colder years. It is expected that the 2050s projected warming temperatures will advance the timing of average nymph and larva activity by 8-11 and 10-14 days. Climate warming should maintain or increase the transmission of pathogens if these trends continue.

Ogden *et al., (*2004) collected black-legged ticks from the field and held them in a laboratory at temperatures of 0 to 32°C at a constant day length to investigate the relationships between temperature and pre-oviposition, pre-eclosion, and premolt developmental periods for the tick. As temperatures increased the duration of the developmental periods decreased significantly. The findings suggested that temperature affects the duration of development of larvae from engorged adult females, and of nymphs from engorged larvae. The emergence of adult black-legged ticks from engorged nymphs may be dependent on independent diapause phenomena.

Environmental conditions that drive vector-borne disease outbreaks in real time is tracked through the use of remote-sensing and GIS methodologies (Ogden & Lindsay, 2016). This allows for the chance to improve warnings and risk assessments for the public. Bioinformatics analysis tools and genomics are validating modelling efforts and making it easier to identify and track vectors and vector-borne pathogens.

Hosts

Halsey & Miller, (2018) created and designed the first spatially explicit individual-based tick interaction model (SEIB-TIM) to examine the processes through which black-legged tick populations are examined from the perspective of the tick. The model was parameterized so that the black-legged tick infestation rates for white-footed mouse were within the range reported in field studies. Once the model accurately simulated the interactions between the wildlife hosts (white-tailed deer and white-footed mouse) and the environment, the robustness to parameter uncertainty was evaluated using both global and local sensitivity analyses. Life-history traits of the black-legged tick were implemented into model parameters and examined to understand how the model's changes affected the maintenance of black-legged tick populations. It is recommended that an effective management effort should be aimed at multiple stages in the black-legged ticks life cycle.

From May 9 to June 9, 1995, birds migrating northward across Lake Superior were captured when reaching landfall at Thunder Cape at the at the southwestern tip of the Sibley Peninsula, northwestern Ontario (Klinch *et al.,* 1996). Of the 530 birds examined, 21 of the birds had a total of 34 ticks; 6 of which were black-legged ticks (see Table 1) – the other 26 ticks found were the rabbit tick species, *Haemaphysalis leporispalustris* (Klinch *et al.,* 1996). The black-legged tick species has not been found on small mammals at Thunder Cape. Results showed that northward migrating birds are transporting black-legged tick larvae into areas where this species does not appear to have established in small animal populations – spring migrants may be more involved in the dispersal of black-legged ticks that previously thought (Klinch *et al.,* 1996).

Table 1. Number of tick species found on avian host species in Thunder Cape, Ontario.

Tick Species	**No. of Ticks**	**Avian Host Species**
Ixodes scapularis	4	American Robin, *Turdus migratorius*
	2	Chipping Sparrow, *Spizella passerina*
Haemaphysalis leporispalustris	1	American Robin, *Turdus migratorius*
	2	Swainson's Thrush, *Catharus ustulatus*
	1	White-throated Sparrow, *Zonotrichia alhicollis*
	1	Common Yellowthroat, *Geothlypis trichas*
	1	Blue Jay, *Cyanocitta cristata*
	12	Chipping Sparrow, *Spizella passerina*

From 1990-1992, black-legged tick populations were examined within 4 habitats on Long Point, Ontario to determine whether there was a correlation between the mouse population densities within the habitats and the immature black-legged tick populations (Lindsay *et al.,* 1999). Immature black-legged ticks were most prevalent on white-footed mice that were captured within the maple forest. There was no correlation between the number of mice captured within the four habitats and the number of black-legged tick larvae or nymphs infesting them (Lindsay *et al.,* 1999). Results suggest that factors other than the size of the mouse populations were responsible for the observed differences among the habitats.

Lyme Disease

Leighton *et al.,* (2012) developed a time-to-establishment model for tick populations across Canada to identify factors influencing the rate of distribution. The results suggest that the potential mechanisms for the long-distance dispersal of ticks are migratory birds and local dispersal by resident hosts. Climate warming may facilitate range expansion; environmental suitability for tick population establishment is directly associated with temperature (accumulated degree days; DD>0 °C). The model suggests that in the coming decade the rate of spread in black-legged tick ranges 46 km/year with climate warming expected to increase the rate of spread. With the expansion of black-legged tick populations, it is likely that there will be a substantial increase in human Lyme disease risk. Models support the theoretical range projections and provide an estimate of the rate of northward range expansion for black-legged ticks. These projections suggest immediate action is needed to prepare the Canadian public about the risks associated with black-legged ticks and Lyme disease.

Lyme disease is a vector-borne disease in the temperate zone caused by the bacterium *Borrelia burgdorferi* and transmitted via tick vectors (Ogden *et al.,* 2009). In the United States, there are more than 20 000 cases recorded annually. Early Lyme disease is most commonly characterized by a skin lesion, which resembles a bullseye, approximately >5 cm from the site of the tick bite (Ogden *et al.,* 2009; PHO, 2016). This disease can progress and cause adverse health complications if it is left untreated. *B. burgdorferi* is transmitted by ticks that feed on wildlife reservoir hosts of the pathogen, particularly rodents and birds. *Ixodes scapularis*, the black-legged tick, is the main vector in eastern and central North America. This species will feed on humans and can transmit pathogens from wildlife to humans (PHO, 2016).

Objectives

To understand why *I. scapularis* populations have expanded into the Thunder Bay region. Review possible reasons black-legged ticks are now more frequently seen in the Thunder Bay region by exploring published studies, interviewing professionals, and performing literature reviews.

Hypotheses

Ho: Black-legged tick populations are not showing up in the Thunder Bay region due to climate change.

Ha*:* Climate change is contributing to the expansion of black-legged ticks into northern areas, including the Thunder Bay region.

METHODS

The literature review was conducted with a topic search in multiple databases; ScienceDirect, Jstor, and Lakehead University Library, as well as within journals such as Journal of Medical Entomology. No time restriction was implemented. Literature was found by searching the common name, black-legged tick, and the scientific name, *Ixodes scapularis,* followed by climate change, distribution, host, vector, and Lyme disease. Each aspect was searched separately. Once articles were located, they were sorted into columns stating their titles and authors, management methods, and the principal conclusions. Publications focused on other tick species were excluded from this literature review.

RESULTS & DISCUSSION

In Canada, passive surveillance for the black-legged tick, *Ixodes scapularis*, has taken place since the early 1990s (Ogden *et al.,* 2006). Formerly, the distribution of *I. scapularis* in Canada was known to exist in isolated populations along the northern shores of Lake Ontario and Lake Erie, and the southeastern coast of Nova Scotia (Ogden *et al.,* 2006). Since 1990, Canada has seen an increase in the number of established and reproducing populations of *I. scapularis* (Clow *et al.,* 2017).

Ogden (2006) collected and analyzed data on *I. scapularis* ticks found in Canada by veterinarians, medical practitioners, wildlife specialists, and the general public. These ticks were identified and tested for the agent of Lyme borreliosis, *Borrelia burgdorferi.* From January 1990 to December 2003, a total 2319 (265 more ticks were submitted between 1993-1999) of *I. scapularis* were submitted, 2233 of which were adult females, 63 adult males, 22 nymphs, and one larva. These numbers may only represent a fraction of the number of ticks that may have been attached to humans and pets; as many can feed undetected. The majority (1725) of the submitted ticks were found on household pets. However, nearly 14% of ticks were found on humans. All of the submitted ticks were tested for *B. burgdorferi*. Some of the submitted ticks that were found on humans were infected with *B. burgdorferi* (Ogden *et al.,* 2006).

Each year, the number of ticks submitted from Ontario, Quebec, and the Atlantic provinces increased (Ogden *et al.,* 2006). This may have been due to increased public awareness; however, during this study period, there were increasing temperatures (Ogden *et al.,* 2006). This could indicate that established tick populations increased in abundance over the past few decades (Sonenshine, 2018). Clow *et al.,* (2017) detected *I. scapularis* at 17 of the 36 sites sampled; 5 of which had not previously documented ticks.

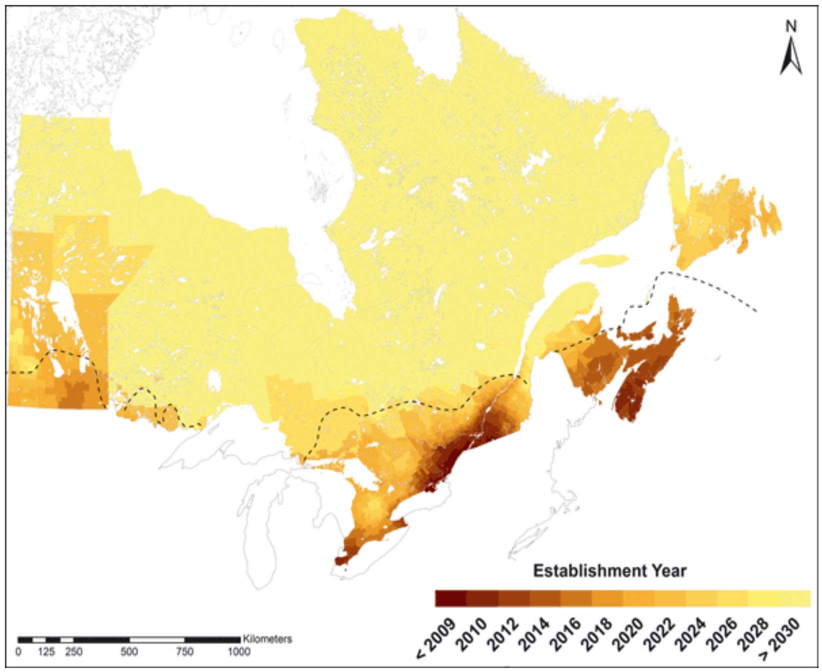


Figure 1. Projected range expansion of *Ixodes scapularis* ticks in eastern Canada (Leighton *et al*., 2012). The dashed line indicates the estimated limit of current temperature suitability for *I. scapularis* ticks projected by Ogden *et al*., 2005.

The geographic range of *I. scapularis* has expanded substantially, likely due to the above normal winter temperatures that have occurred over the past decade (Eisen *et al.,* 2016). Leighton *et al.,* (2012) predicted that the range of *I. scapularis* would expand 46 km per year over the next decade in Canada. Model projections suggested that, by the year 2020, the colonized areas of *I. scapularis* will have increased 14-fold to 317 000 km^2 (*see Figure 1)* (Leighton *et al.,* 2012).

In the next few decades, the range for *I. scapularis* is likely to increase substantially due to climate change (Ogden *et al*., 2006). The spread of tick populations across the potential new range ultimately relies on the ecological process of tick dispersal, which may be affected by the dispersal of multiple hosts which ultimately affects how fast and how far the ticks will disperse.

CLIMATE CHANGE

Climate influences the distribution of *I. scapularis*. Seasonal temperature patterns and relative humidity have an effect on the rate and success of development of *I. scapularis* (Ogden *et al*., 2005). A study conducted by Lindsay et al., (1995) from early December 1991 until May 1993 tested the hypothesis that the distribution of *I. scapularis* is limited by extreme cold climates. Seventy unfed adults, 35 fed females, and 70 unfed nymphal ticks were held in containers within four natural habitats on Long Point and at northern localities near Ottawa, Hearst, and Kenora, Ontario. It was observed that fed females had a higher overwinter survival rate (84.8%) than unfed adults (30.5%) at the northern sites. In comparison, the fed females had a higher overwinter survival rate (56.4%) than unfed adults (23.6%) at the Long Point site. The hatching rate was <10% at the northern sites during 1992-1993; a small proportion of eggs overwintered successfully. This suggests that lower temperatures in northern parts of Ontario may not limit the distribution of the black-legged tick despite having a low hatching rate. Adults survived the winter as long as they had fed before winter.

In more recent studies, temperature has been a good predictor of the abundance of *I. scapularis* at the northern limit of its range in Canada (Ogden *et al*., 2005). Tick activity and survival are inhibited below minimum temperature thresholds. Therefore, the length of time in which ticks search for hosts is directly affected by temperature, but may also be hindered by the availability and abundance of hosts. Over a 19-year study Levi *et al*., (2015) monitored the abundance of ticks on small-mammal hosts, it was found that in warmer years there was a nearly 3-week advance in the phenology of nymphal and larval ticks in comparison to colder years. This means that as the temperatures increase larval and nymphal ticks are seeking hosts earlier than they have in previous years which will only continue to increase. Ogden *et al*., (2004) conducted a study in the northern extent of the *I. scapularis* range. Black-legged

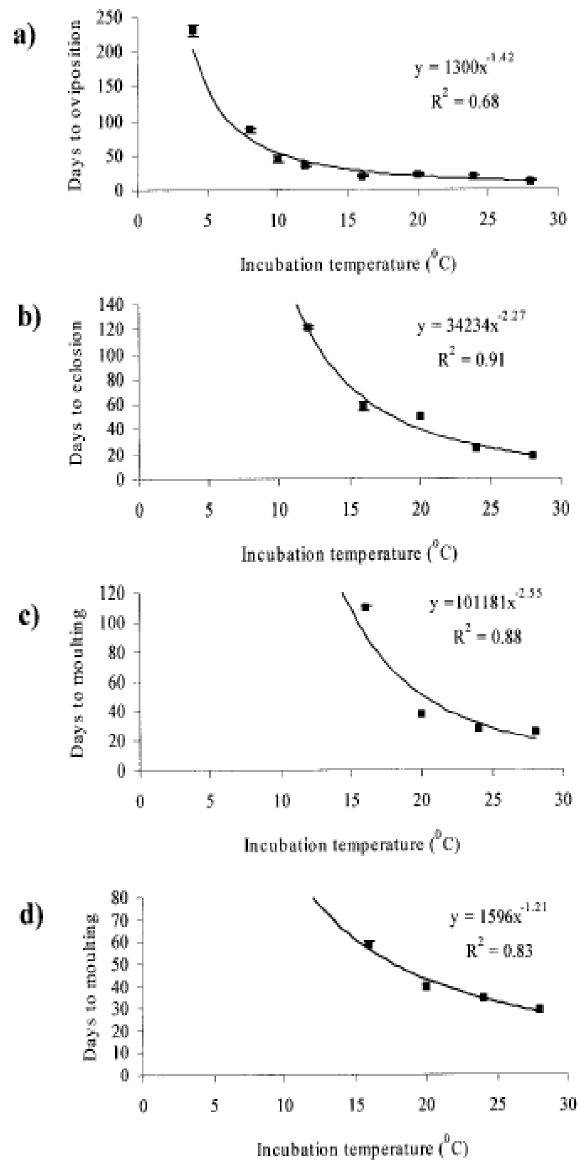


Figure 2. Ogden *et al*., (2004). Duration of development for *I. scapularis* ticks held at different temperatures in the laboratory. (a) Preoviposition period of engorged adult females. (b) Preeclosion period for egg masses. (c) Premolt period of engorged larvae. (d) Premolt period of engorged nymphs. The fitted curves, equations for the relationship between temperature and development (in days), and R^2 values are shown.

ticks were collected from the field in Long Point, Ontario and held in a laboratory at temperatures of 0 to 32°C at a constant day length. They investigated the relationship between temperature and the developmental periods (pre-oviposition, pre-eclosion, and premolt) for *I. scapularis*. All fully engorged adult female ticks held at -10°C died within 4 hours of the experiment. Adult female ticks held at a temperature of 0°C survived approximately 133 days in the cold but did not deposit eggs. Adult female ticks held at temperatures >0°C survived to lay eggs (69%). However, once temperatures reached 32°C the eggs that were deposited were misshapen and did not produce larvae. As temperatures increased, the duration of the developmental periods decreased significantly (*see Figure 2)*; these findings suggested that temperature affects the duration of the development of larvae from engorged adult females, and of nymphs from engorged larvae. This experiment observed that there is a temperature threshold within which ticks can produce viable eggs; they cannot survive in temperatures much cooler than -10°C and cannot produce viable eggs in temperatures >32°C. This could suggest that as temperatures continue to rise ticks may be migrating north in search of temperatures that are within an optimal range for development. With that in mind, there is, at this point, a limit to where they can expand their range due to the cold temperatures in the far north of Ontario. However, cold temperatures did not significantly affect the survivability of *I. scapularis* adults as long as there is suitable habitat that provides shelter from freezing temperatures. *I. scapularis* was able to survive overwintering in temperatures as cold as -30°C provided they were able to seek out a suitable duff layer (Lindsay *et al.*, 1995). Although they may be able to survive colder temperatures, low temperatures in the spring, summer, and autumn affects the duration of development of ticks from one life stage to the next, as development becomes too long and reduces the chances of survival of larval ticks (Simon *et al*., 2014).

Ticks cannot survive outside of certain ranges of temperature and rainfall because these conditions directly kill the ticks or inhibit them from seeking hosts (Ogden *et al*., 2004). The survivability of *I. scapularis* is likely to vary in different habitats depending on how well the litter layer prevents dehydration in the warmer months and freezing in the colder months. Ticks are found in deciduous woodland habitat; however, in Nova Scotia *I. scapularis* populations have become established in coniferous forest (Leighton *et al.,* 2012).

HOST

Although it is a very likely cause or cofactor, there is not enough evidence to solely link climate change to the observed changes in the distribution of ticks. Climate variability and the geographic distribution or local abundance of ticks may rely heavily on the distribution and abundance of hosts. Black-legged ticks are expanding into new areas by means of long-distance carriers, like migratory birds (Klich *et al.,* 1996); local non-human hosts, like deer or mice; suitable habitat for both the host and the ticks; and a minimum number of days with above-freezing temperatures to allow ticks to complete their life cycle (Ogden *et al.,* 2004).

Many ticks have well-defined geographic ranges, their adaptations to abiotic environmental factors such as climate (temperature, humidity, soil moisture) and biotic factors (host densities and habitat) limit the distribution of existing *I*. *scapularis* populations, and the establishment of new populations (Sonenshine, 2018; Ogden *et al.,* 2005). These factors influence the survival rates of ticks, the densities of endemic tick populations, and the maximum number of immigrating ticks needed to establish new populations (Sonenshine, 2018).

Increasing temperatures are likely to increase the range of *I. scapularis* through the northward migration of host species; ticks cannot move great distances without the aid of a mobile host species (Ogden *et al.,* 2006). Simon *et al*., (2014) conducted a study to determine whether climate and habitat change affected the distribution of the white-footed mouse, *P. leucopus,* and the black-legged tick. The range of *P. leucopus* was limited by the average temperature and length of the winter (Simon *et al*., 2014). Although the northern climates are still reducing the range expansion of *P. leucopus,* only slight increases in winter temperatures are required for *P. leucopus* to expand their range (Simon *et al*., 2014). The model by Simon et al., predicted that the distribution of *P. leucopus* is predicted to shift northward by approximately 250 km (Simon *et al*., 2014) and the distribution of *I. scapularis* is expected to shift northward by up to 300 km by the year 2050. The difference in the movement rates may be contributing to the dispersal of *I. scapularis* utilizing other hosts.

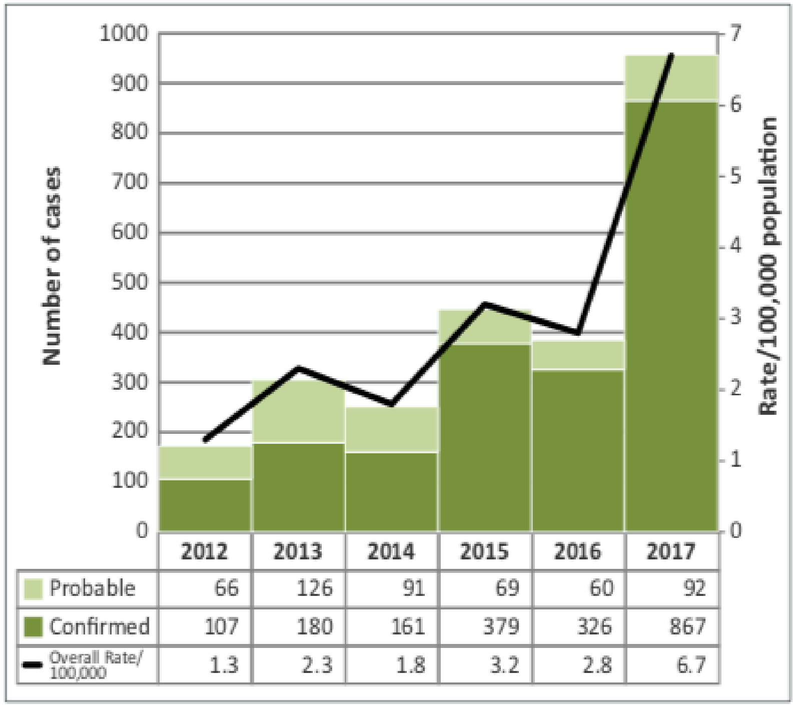
In Thunder Cape, Klich *et al.,* (1996), found that 21 of the 530 birds examined were carrying ticks; 6 of which were *I. scapularis*. This tick species was not found to be present on small mammals at Thunder Cape prior to this study. Results from this study prove that birds migrating north are transporting black-legged tick larvae into areas where there have not been seen before (Klich *et al.,* 1996). Similarly, Ogden *et al*., (2008) implied that migratory birds are significantly connected to the range expansion of *I. scapularis* by transporting an estimated 50 to 175 million *I. scapularis* ticks across Canada each spring.

If there were large enough congregations of migratory birds occurring in locations (perhaps due to inclement weather) that provided suitable habitat for *I. scapularis;* then it would be possible that at times they could be high enough to establish new populations of *I. scapularis* – providing that there were suitable host densities for *I. scapularis* to continue through developmental stages (Ogden *et al*., 2008). Migratory birds disperse *I. scapularis* into these new areas during the spring, at the peak of their activity in the nymphal stage. They then molt into adults where they feed on white-tailed deer. Deer have the greatest impact on the dispersal of ticks because they are the preferred host of adult ticks (Madhav *et al.,* 2004). Deer facilitate the dispersal of adult female ticks which essentially result in the dispersal of thousands of larvae (Schillberg *et al.,* 2018).

Although, the environmental conditions in these northern locations may inhibit *I. scapularis* from establishing reproducing populations presently, if the habitat is suitable for ticks to survive colder temperatures individuals may survive to establish reproducing populations in the future (Lindsay *et al.*, 1995). As climate change produces warmer winters, ticks may slowly begin to establish self-sustaining populations in these northern areas as long as there are sufficient host populations available at each life stage. In the Kenora and Rainy River districts of Northwestern, Ontario, there are known established *I. scapularis* populations, which provides proof that tick populations are capable of surviving in northern environments. Rising temperatures and the pressure from the expansion of urban areas has the potential for white-tailed deer populations to increase in Thunder Bay region, which will provide the adult black-legged ticks with their preferred host (Lindsay *et al*., 1995). These results have considerable public health significance because as populations of *I. scapularis* begin to expand across Canada, there is an increased risk of these ticks attaching to humans, ultimately, increasing the risk of people contracting Lyme disease.

LYME DISEASE

In 2017, there were 959 probable and confirmed cases of Lyme disease (*see Figure 3)*; which has tripled since the 5-year (2012-2016) average of 313 (Nelder *et al.,* 2017). In Ontario, the incidence rate was 6.7 cases per 100 000 population in 2017. This increase is associated with the range expansion of *I. scapularis* in Canada, including the northern regions of Ontario (Nelder *et al.,* 2017). Eastern Ontario had the greatest concentration of incidence rates, with Leeds-Grenville and Lanark District having the greatest incidence rate (128.8 cases per 100,000). In this part of the province, there are more black-legged tick populations and with a higher percentage of *B. burgdorferi* positive black-legged ticks (Public Health Ontario, 2017; Nelder *et al.,* 2014). Majority of the cases occurred from June through September, with July having the highest number of reported cases (369). Cases were most common among those aged 5-14 and 50-69 years; over half (59.8%) of the cases were among males (Nelder *et al.,* 2017).



	2012	2013	2014	2015	2016	2017
Probable	66	126	91	69	60	92
Confirmed	107	180	161	379	326	867
Overall Rate/ 100,000	1.3	2.3	1.8	3.2	2.8	6.7

Figure 3. Number of probable and confirmed Lyme disease cases by episode month in 2017, compared to 5-year averages (2012–2016): Ontario, Canada (Nelder *et al.,* 2017).

The Thunder Bay District Health Unit (TBDHU) reported 7% of the black-legged ticks submitted tested positive for *B. burgdorferi*. Thunder Bay has not yet had a case of Lyme disease reported (TBDHU, 2018), but this does not mean that it is not possible in the future. With the warming of the climate, the winter months are not rbecoming as cold as they have in the past, and *I. scapularis* can become active as soon as temperatures reach 4°C (TBDHU, 2018). Historically, Lyme carrying black-legged ticks were only found in Long Point Provincial Park, and now Lyme risk areas have increased exponentially (Clow *et al.,* 2017).

The Infectious Disease Society of America (IDSA) defines a Lyme-endemic area as one where the prevalence of *B. burgdorferi* in blacklegged ticks is greater than 20%. In northwestern Ontario, Kenora (and surrounding areas) and Rainy River (and surrounding areas) between 2011 and 2017 an average of 2 human Lyme disease cases was reported in the NWHU area (Schillberg *et al.,* 2018); and have therefore been deemed Lyme-endemic (TBDHU, 2018). Active tick surveillance in the Northwestern Health Unit (NWHU) catchment area has proven that there are emerging, self-sustaining, reproducing populations of *I. scapularis* (Schillberg *et al.,* 2018). Within the population, approximately 60% of the adult *I. scapularis* ticks were positive with *B. burgdorferi* (Schillberg *et al.,* 2018); this is similar to the established endemic populations of *I. scapularis* ticks across Michigan (Schillberg *et al.,* 2018; Hamer *et al.,* 2007). Studies have shown that Thunder Bay does not have a sufficient amount of degree-days for tick development (Lindsay *et al.,* 1995). However, as temperatures continue to become warmer, there is the potential for there to be a sufficient amount of degree-days in the future.

INTERVIEWS

Inquiries were made with the entomologist associated with the Thunder Bay District Health Unit; who was not willing to be interviewed. Many of the contacts made were not willing to share information on black-legged ticks. The Simcoe-Muskoka District Health Unit and the Thunder Bay District Health Unit directed and provided me with public information. This is an interesting result considering the potential risk that *I. scapularis* poses to human populations. Reasons for these responses may be political as in government authorities may be trying to prevent panic to the public or simply just an unwillingness to share data.

SUMMARY AND CONCLUSIONS

Ontario is seeing an increase in the presence of *I. scapularis* populations throughout the province (Clow *et al.,* 2017). Increasing temperatures are allowing more ticks to survive and establish populations where they have not been previously found (Sonenshine, 2018; Leighton *et al.,* 2012). The presence of all three stages of the tick is required to identify a reproducing population in a location (Ogden *et al.,* 2006).

Migratory birds aid in the dispersal of ticks over greater distances (Klich *et al.,* 1996), and the white-footed mouse is expanding its range as temperatures increase and are transporting black-legged ticks along with them (Simon *et al*., 2014). As long as there is suitable habitat and a sufficient number of hosts, *I. scapularis* is capable of surviving in new locations (Lindsay *et al., 1995*). It is expected that by the year 2080, Northwestern Ontario's average temperatures will increase by 7°C in the northern portion and 6.1°C in the south (McDermid, Fera, & Hogg, 2015). This trend is likely to continue and provide black-legged ticks and hosts the ability to expand their ranges northward.

As *I. scapularis* populations expand across Canada, it is expected that the percentage of black-legged ticks carrying *B. burgdorferi* may increase as well, ultimately increasing the risk of Lyme disease to all Canadians (Schillberg *et al.,* 2018; TBDHU, 2018; Clow *et al.,* 2017). Despite the lower population densities in northern Ontario, the increased risk of Lyme disease is a greater concern due to the limited access to public health and medical services for tick species identification and Lyme disease testing; especially for those in rural and remote communities (Schillberg *et al.,* 2018; TBDHU, 2018). Although Thunder Bay has not yet had a reported case of Lyme disease, there is the potential that cases may not have been reported, or public knowledge of Lyme disease symptoms are not known. Neighbouring municipalities (Kenora, Rainy River) have been deemed Lyme-endemic, which could potentially happen in Thunder Bay, as well.

Although, climate change alone is not responsible for the expansion of *I. scapularis*, its hosts do play an important role in the dispersal of these ticks. Without the assistance of a host species black-legged ticks would not be expanding at the rate they are projected to. Ongoing surveillance of tick and host distributions should be continued to provide up-to-date information on the current tick populations and distribution of black-legged tick populations in Ontario. Public and health care professionals should continue to report cases of Lyme disease and *B. burgdorferi*-positive ticks. Continued surveillance, public knowledge such as preventative strategies, early disease recognition and treatment will continue to minimize the impact of Lyme disease in Canada.

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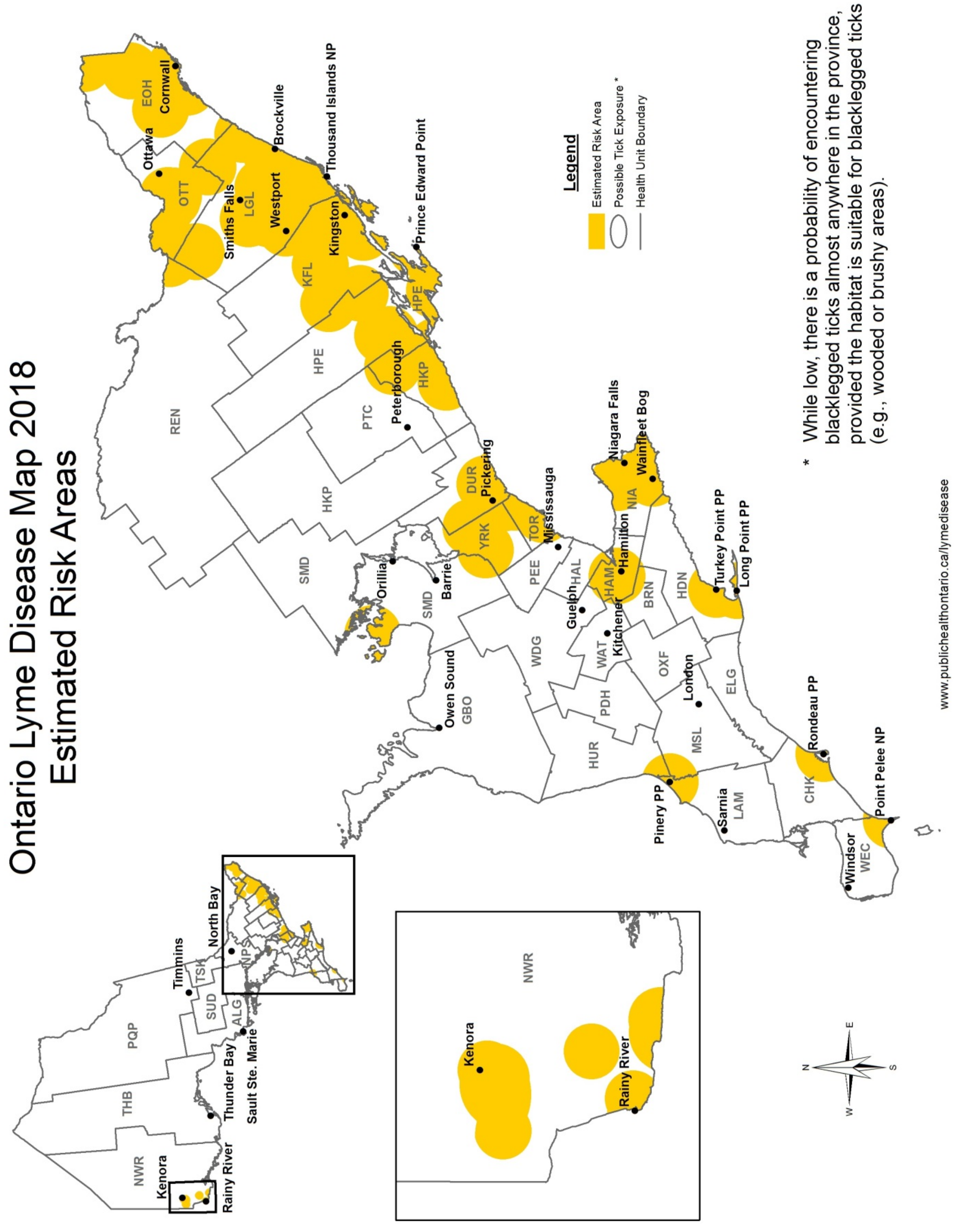
APPENDICES

Appendix A – Ontario Lyme Disease Map 2018 Estimated Risk Areas

Appendix B - Projected range expansion of *Ixodes scapularis* ticks in eastern Canada (Leighton *et al*., 2012).

APPENDIX A


Ontario Lyme Disease Map 2018
Estimated Risk Areas
Legend
Estimated Risk Area
Possible Tick Exposure *
Health Unit Boundary
* While low, there is a probability of encountering blacklegged ticks almost anywhere in the province, provided the habitat is suitable for blacklegged ticks (e.g., wooded or brushy areas).
www.publichealthontario.ca/lymedisease
EOH
Cornwall
Ottawa
OTT
Brockville
Thousand Islands NP
Smiths Falls
LGL
Westport
Kingston
Prince Edward Point
KFL
HPE
REN
HKP
Peterborough
PTC
DUR
Pickering
YRK
TOR
Mississauga
Niagara Falls
Wainfleet Bog
NIA
SMD
Orillia
Barrie
PEE
HAL
HAM
Hamilton
Guelph
Kitchener
BRN
HDN
Turkey Point PP
Long Point PP
WDG
WAT
OXF
London
ELG
Owen Sound
GBO
PDH
HUR
MSL
Rondeau PP
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LAM
CHK
Point Pelee NP
Windsor
WEC
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North Bay
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NWR
Kenora
Rainy River
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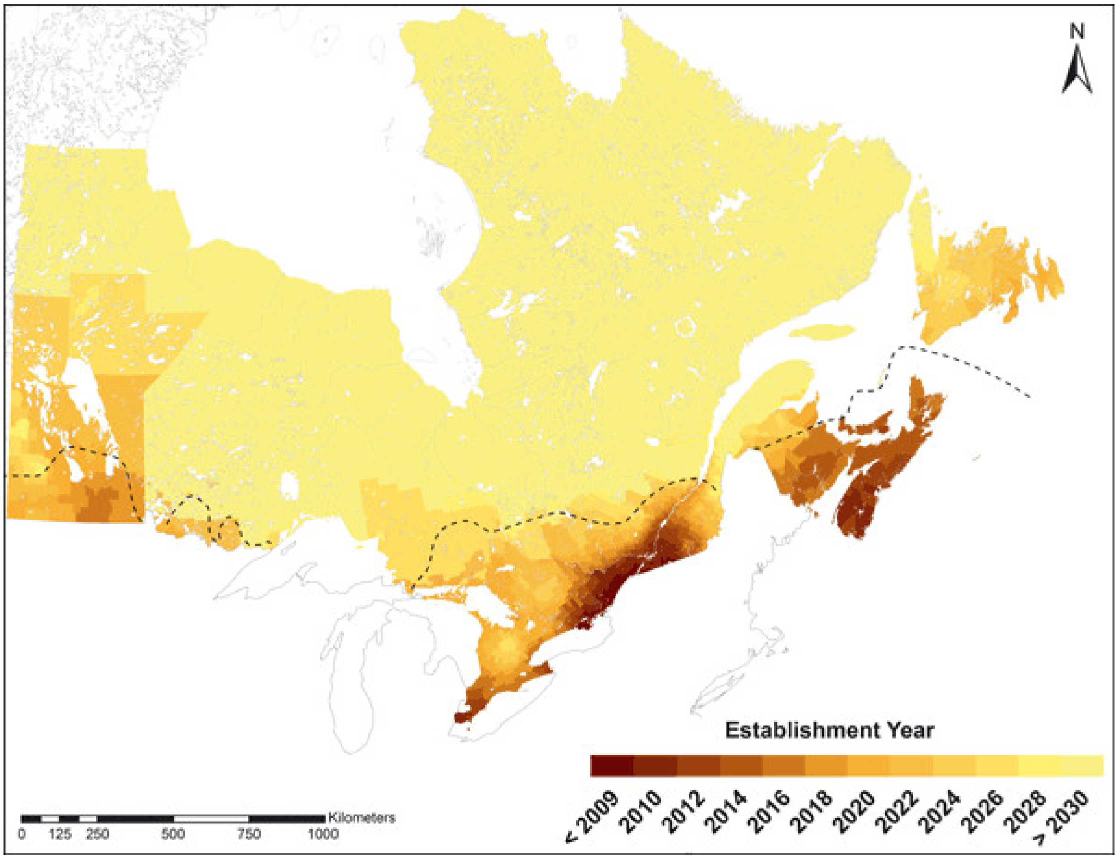
APPENDIX B



Projected range expansion of *Ixodes scapularis* ticks in eastern Canada. The dashed line shows the estimated limit of current temperature suitability for *I. scapularis* ticks (Ogden *et al*., 2005).