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The impacts of climate and land use change on tick-related risks

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Key Messages

- Ticks can be found in any environment. They are most commonly found in wooded areas with leaf litter, tall grassy areas, and shrub layers as well as along forest edges, and/or within vegetated habitats under tree canopies.
- The number of places where ticks can survive and thrive in Canada is growing due to global warming, animal migration, and land fragmentation.
- Increasing ambient temperatures due to climate change are a primary driver of tick population changes, including increased maturation and decreased mortality.
- Elements of the built environment such as residential gardens, green spaces, playgrounds, and biodiversity conservation efforts can increase suitable habitats for tick populations. The many benefits of nature in the built environment need to be balanced with the increased potential for human exposure to tick species.
- Forest fragmentation (land fragmentation through deforestation and urbanization of natural continuous forests into smaller sections) can increase tick density as it creates easier movement opportunities for host populations.
- Municipal, provincial, and federal policies and land use practices must include evidence-based research and environmental health principles to minimize tick-related risks.

Introduction

It is widely accepted that the range of many tick species is expanding due to global warming, host-animal migration, and land fragmentation through deforestation and urbanization of natural continuous forests into smaller sections.[1-4] Climate projections show that ticks are increasing their range northwards by 35–55 km per year.[3] Tick species are known arthropod vectors, and can transmit a wide range of bacterial, viral, and protozoan pathogens to both humans and other animal species.[5,6] As the range of tick vectors increases across Canada, so does the potential for exposure to emerging tick-borne pathogens. The aim of this document is to review environmental factors that contribute to tick-related risks. This is the second document in a four-part series focussing on the risks of tick exposure in Canada. The first review entitled "A review of ticks in Canada and health risks from exposure" can be found here.

Literature search methodology

Scholarly research and grey literature were searched for information on ticks, climate change, land use change, forest fragmentation, and environmental ecology. Databases to identify relevant sources include Web of Science, PubMed, and Google Scholar. Grey literature and reports from academic institutions and governments were also reviewed. Relevant English language results were compiled. Although the search was primarily restricted to 2000–present, some earlier pivotal publications were included. Forward and backward chaining of initial results identified additional references.

Articles, reports, and websites were selected for review if they pertained to ticks and at least one of the following: climate change, land use change, forest fragmentation and/or environmental ecology. Both the common name and Latin name of pathogens and of known tick vectors were included in the search. The majority of the literature focussed on areas in the United States where ticks have been endemic for much longer time periods. Where possible, literature pertaining to Canada's provinces and territories was emphasized. The literature was also predominantly focussed on Lyme disease; however, the same environmental, land use, and climatic considerations would also apply to other tick-borne pathogens.

After selection, 85 items were included for review. All literature was analyzed and synthesized by one reviewer. A complete list of search terms and the full list of results are available upon request.

Results

Natural environments that increase the risk of tick exposures

The risk of human exposure to ticks, and potential tick-borne infections, is proportional to the amount of time an individual spends outdoors in habitats that support populations of ticks and/or their hosts. Ticks rely on host animals to survive and reproduce. While ticks are considered generalists and can feed on a broad range of species, evidence suggests that rodents, birds, and deer are common hosts for tick reproduction and movement in North America.[7-10] Any environment that is suitable for such hosts can therefore be considered tick habitat.

Different habitat types differentially increase or decrease one's risk to tick encounters. In North America, ticks are commonly found in wooded areas with leaf litter, tall grassy areas, and shrub layers as well as along forest edges, and/or within vegetated habitats under tree canopies.[11-16] Wooded areas are optimal habitats for ticks as they provide a suitable microclimate (small areas with different climatic features than neighbouring areas) of leaf litter, grasses, and shrubbery, protecting ticks from weather fluctuations and extreme weather events.[17] The duff layer (between the soil surface and leaf litter) in particular promotes tick survival over winter by protecting them from sub-zero temperatures.[18-22] While ticks can be found in both deciduous and coniferous woodland habitats (see Text Box 1), deciduous woodlands appear to carry a greater risk of exposure to ticks due to increased leaf litter.[23,24] Tree trunks and fallen logs in deciduous woodland habitats can also provide suitable habitats, especially *Ixodes pacificus*.[25] Ticks can also exist in small patches of forested areas, including those found in residential areas; they are frequently found in leaf litter and low-growing vegetation along forest ecotones (the transition zone between forested and non-forested habitats).[9,14,26] This transition between natural areas and built environments is also where people often recreate along trails.[9]

Other lesser-studied environments may also provide suitable habitats for ticks. For example, a recent study in California identified coastal areas with shrubs as a suitable habitat for hosts and identified ticks positive for *Borrelia* species.[27] This highlights the bias of researching tick-borne pathogens in more traditional woodland and grassland habitats, when in reality ticks may be present in any habitat that can support the host-vector relationship.[27] As the geographic range of ticks expands, it is feasible for ticks to establish themselves in new, previously unstudied habitats if the conditions are favourable. This can lead to unexpected tick exposures and highlights the need for surveillance across all landscapes.

Box 1: Deciduous versus coniferous habitats

Deciduous habitats *predominantly contain trees with leaves that fall off annually. The leaves on the trees are broad and flat and change colour in autumn from green to red, orange, and yellow, and then fall off. This creates leaf litter. Examples of trees found in such habitats include maple, oak, and birch trees.*[28]

Coniferous habitats*, also known as evergreen or needle-leaved trees, predominantly contain trees with cones and needles. These trees stay green year round. Examples include cedar, pine, spruce, and fir trees.*[28]

Built environment considerations that impact tick populations

Changing land use patterns are significant contributors to increasing zoonotic disease outbreaks worldwide.[29] Changes to the natural landscape can create suitable habitats for ticks and hosts, and are linked to increased tick activity and an increase in potential human encounters with ticks and tick-borne pathogens.[23,30-36] Tick density and movement are primarily impacted by changes to the built environment and forest fragmentation (change of natural continuous forests into smaller sections due to human development and urbanization).

Land use changes

While natural environments are the primary habitats for ticks, land use changes in urban, suburban, and rural areas where people live, work, and recreate are increasingly providing suitable habitats for ticks. Rapid development of housing in forested areas creates a network of forest patches (or islands) that can provide ecological connectivity to nearby natural habitats, facilitating tick movement into residential areas.[7] For example, landscaped areas with canopy cover provide both a suitable habitat for animal hosts and prevent desiccation of ticks, thereby facilitating survival and movement into residential areas and urban green spaces.[7] Log and brush piles in residential areas, ornamental plants, and larger properties also provide suitable habitats for ticks, thereby increasing potential tick encounters.[7,26] Ticks can also travel long distances on migratory birds and be dispersed into new urban and suburban settings.[23,37]

In Northeastern United States where *Ixodes scapularis* is endemic, the risk of encountering ticks and tick-borne infections in built environments containing green spaces with abundant vegetated walkways and associated nature preserves is equivalent to the highest reported incidences from natural environments across the country.[38] Yuan and colleagues (2020) found ticks positive for pathogens in school playgrounds and parks in New York State.[39] Such research highlights the diverse spread of ticks in endemic areas and the need for active surveillance programs in built environments as tick encounters become more frequent in Canada.

However, not all built environments promote ticks. Some landscape features and practices such as maintaining bare soil and short grass lawns surrounding parklands have been shown to reduce tick populations.[8,15,26,40,41]

There is also a tension between development and promoting urban biodiversity and greenspaces while minimizing risk of exposure to ticks.[42] It is clear that the built environment and landscape design have implications for tick populations in urban and suburban areas, especially with the push to increase green spaces, pollinator gardens, and movements towards rewilding. Such initiatives are important for pollinators, ecosystem services, and conservation efforts, and they support public health efforts encouraging time in nature and cardiovascular exercise.[34,40,43] However, they may also increase the risk of tick encounters and potential tick-borne infections.[44,45] This relationship is not well understood, and is likely non-linear and interconnected — highlighting the importance of an interdisciplinary One Health approach in examining the problem.[46] At a minimum, it warrants additional research especially as municipal, provincial, and federal governments increasingly prioritize parks and other green space development such as pollinator gardens.

Forest fragmentation

Land or forest fragmentation occurs through deforestation and urbanization of natural continuous forests into smaller sections.[35] Historically, the transition of forests to agricultural lands and for firewood collection in Northeastern United States led to a reduction in white-tailed deer and likely restricted the movement of tick species. This was followed by human population growth and the transition of agricultural areas to suburban areas. This land use change led to the development of residential areas and a network of reforested areas, followed by an increase in white-tailed deer due to the creation of suitable habitats. In turn, tick populations increased.[47,48]

The addition of roads and trails through forested areas creates a patchy network of landscapes, altering vector-host ecological dynamics and spatial patterns, and facilitating host movement along new pathways.[49,50] While forest fragmentation has many ecological impacts, when considering host ecology (such as deer and rodents), understanding the interaction of human and vector-host movement patterns is critical. Forest fragmentation can:

1. **Increase the density of deer populations**. Deer populations benefit from the edge habitats created by forest fragmentation due to the absence of predators and winter foraging opportunities.[51-53]
2. **Reduce species diversity**. Forest fragmentation leads to habit loss, thereby reducing species diversity. This in turn increases white-footed mice populations (a dominant host species in small forest patches and competent reservoir for tick-borne pathogens).[30,51,52,54,55] Interestingly, vertebrate host biodiversity has been shown to reduce nymph infection prevalence and may offer an opportunity to reduce tick-borne pathogens by supporting biodiversity preservation efforts.[55,56]
3. **Increase potential human exposure to ticks.** Forest fragmentation creates more opportunities for human engagement with forest habitats through residential properties and/or trails in edge habitats.[53]

While in general forest fragmentation is positively correlated to tick density and tick-infection prevalence,[30,57] research also shows lower Lyme disease incidence in fragmented areas despite higher tick densities, highlighting other contextual drivers of human exposure.[51] For example, small predator/prey ecological dynamics of the coyote and red fox have been shown to be a better predictor of Lyme disease in New York than deer abundance.[58] Additional research is warranted to tease apart the true relationship between forest fragmentation, host diversity, and tick-borne pathogens across different contexts.[51,54,57]

Tick populations and climate change

The influence of changing land use priorities on the expanding range of ticks in North America is, and will increasingly be, further complicated and amplified by climate change.[1,59] In the United States, the incidence of Lyme disease is expected to increase by 20% in the next 1–2 decades due to climate change.[60] In Canada, ticks are predicted to expand northwards 35–55 km per year.[3] Climate change is predicted to increase temperatures and change precipitation patterns, both of which could lead to extreme weather events such as floods and droughts.[18,34] The exact effect of the changing conditions on tick abundance will depend on the microclimate and geography of any given habitat, and is predicted to influence tick populations both directly and indirectly (i.e., through changes in host populations). Additional research and analysis is necessary to understand how such events will impact tick population establishment and re-establishment after extreme weather events across landscapes.

Direct environmental influences

Climate-change-driven shifts that have a direct influence on tick ranges include temperature, humidity, precipitation, and more frequent extreme weather events.

Temperature: Tick life cycle and mortality are influenced by temperature. Increasing temperatures in temperate and cold environments can lead to faster maturation of nymph ticks, shorter life cycles, increased tick abundance, and longer duration of tick activity.[1,34,61] Higher temperatures also increase the number of days per year and number of hours per day that ticks can seek and acquire a host.[18] Sustained temperature increases can also lead to the northward expansion and establishment of non-native tick species.[61-63] Conversely, rising temperatures in already arid environments can reduce tick activity and increase mortality through desiccation, and can lead to evolutionary changes.[18,24,34]

Species-specific responses to temperature changes are seen across tick vectors. *Dermacentor* species, *Amblyomma americannum* and *Haemaphysalis longicornis* ticks are more tolerant of environmental stresses and can survive in drier and hotter environments.[7,11] While these tick species are currently not established in Canada, they may become endemic with sustained climate warming. *Ixodes* ticks are more sensitive to environmental variability and prefer higher moisture areas, such as under leaf litter or forest canopy.[11] Tick species can behaviourally adapt to unfavourable environmental conditions by modifying their activity levels.[18] For example, the rate of mortality among some populations of the *Ixodes scapularis* has increased due to desiccation. This in turn has led ticks to reduce activity in hot and dry conditions and to shelter in the duff layer, below the leaf litter, to minimize the likelihood of desiccation.[18,21,64] This characteristic also protects ticks from cold temperatures, and reduces mortality, as ticks are able to seek insulated habitats (e.g., snow and duff layer) to facilitate overwintering.[18,22] Such behaviour changes can either increase or decrease tick-human pathogen transmission cycles, depending on the scenario.[64]

Humidity: High relative humidity can increase tick survival rates at higher temperatures.[65-67] This increases host-seeking activity, thereby increasing reproductive success, reducing mortality, and influencing total population density.[18,21,34,68] Areas with consistent high humidity levels allow for prolonged tick activity in a given day, as compared to more arid habitats.[24,68,69] Relative humidity is also highly variable based on the microclimate. This leads to spatial variability in the impact of humidity on tick populations.[68]

Precipitation: Increased precipitation can decrease tick activity levels and thereby slow down nymph development.[1,34] However, some predictions show that precipitation can facilitate the establishment of endemic tick populations.[3] Additional research is necessary to better understand the impact of total precipitation on tick populations.

Extreme weather events: Events such as flooding and droughts can decrease tick populations through direct mortality, reduction in host-seeking behaviour and/or by limiting the availability of hosts.[18,19,44,70-72] Flooding can cover tick habitats with silt, while temperatures above 30 degrees Celsius can cause ticks to reduce summer activity levels, leading to increased subsequent fall and winter activity levels.[44]

Shifts in weather and climate warming also have the potential to increase suitable habitats across Canadian landscapes as ticks move to higher latitudes and altitudes.[1,18,34,73,74] While there is some variability in how tick species and tick life stages react to climatic factors, increasing temperature is the most important predictor of tick population establishment and suitability as tick life cycle and mortality are predominantly influenced by temperature.[3,18] There is limited research on the dynamic between temperature, humidity, and precipitation across tick life stages.[75] For example, *Ixodes scapularis* will quest for hosts at lower heights in higher temperatures and low relative humidity.[76] Additional research is needed to further understand the interplay between climatic factors across population and ecological processes.

Indirect influences

Tick activity can also be indirectly influenced by climate change and resulting habitat changes, through impacts to their host species. Given that ticks rely on host species for their life cycle, the primary indirect influence is the availability and abundance of host populations, and alternation of predator-prey dynamics that may be linked to climate-change-driven habitat changes.[3,18,32,77,78] For example, the white-tailed deer (a known host for tick species) has been predominately concentrated along the southern border of Canada, but is expected to increase its range 100 km further north into the Albertan boreal forest, along river corridors, over the next 50 years due climate change.[77]

Sustained extreme weather events (e.g., flooding) may decrease suitable tick habitats (e.g., deposit silt on tick habitats, rendering them unfavourable), decrease tick activity, and increase tick mortality via predators.[18,32,77,79,80] It can also alter host population movement patterns. Such weather events may also alter land use changes and human behaviours in tick habitats (e.g., recreational activities, mushrooming, and picnics).[78]

The true impact of climate change is hard to determine given the many permutations of scale- and context-dependent variables that are influenced by specific microhabitats.[3] Research shows that the range of tick species is expanding, but that the changes in tick density and rate of infection with pathogens are not uniform.[81] Risk maps for specific tick species (*Ixodes scapularis*) in Canada suggest the establishment of endemic tick populations across southern parts of Canada, east of the Rocky Mountains, and northwards.[82-84] This provides a helpful narrative for public health initiatives. However, favourable changes in climate and habitat suitability will only increase the likelihood of the transmission of tick-borne infections.[1] As such, additional research is warranted to accurately predict the risk of ticks and tick-borne infections across Canada to better understand the spatial movement of hosts, the establishment of tick vectors across Canadian landscapes, and the complex ecological epidemiological relationship.[3,78,85]

Summary

Landscape changes, forest fragmentation, and climate change can increase tick populations and tick-related risks. The disease transmission cycle of tick-borne infections is part of a complex system that includes vectors, animal hosts, and humans. It is driven by many context dependent ecological and social factors. It is known that: 1) the geographic expansion of tick species into northern latitudes, and the potential of tick-borne infections, continues to pose a public health risk in Canada as ticks migrate north at a rate of 35–55 km per year in Canada; 2) climate change and land-use changes (including suburban development leading to forest fragmentation and landscaped built environments) will increase suitable habitats for tick species.[3] The greatest predictors of the establishment of tick populations in new geographical locations are climatic factors (particularly temperature) and the availability of host populations. Given that the tick life cycle relies on animal hosts to survive and reproduce, it is not surprising that tick geographic range is intrinsically tied to host ecology.

However, the relationships are complex and depend on a wide range of scale- and context-dependent ecological and social factors. Additional research, following an interdisciplinary or One Health approach, is warranted to tease apart the impact of climate change, land-use changes, and forest fragmentation on tick density and tick infection prevalence to better understand the spatial movement of hosts, the establishment of tick vectors across Canadian landscapes, and the complex ecological and epidemiological relationship. Specifically, research gaps include: 1) the synergies between climatic factors in the expansion and survival of tick species; 2) the impact of forest fragmentation on tick populations across ecological and social contexts; 3) the role of biodiversity, conservation, and rewilding efforts in establishing suitable tick habitats.

This review also reiterates the importance of surveillance programs in non-traditional tick habitats. In the absence of climate-change mitigation, it also reinforces the need for municipal, provincial, and federal governments to consider evidence-based research, environmental health, and tick-related risks in urban policy, urban greening efforts, land-use planning, and health communication. By understanding the environments and landscape features that are correlated with tick abundance, we can be better informed on how to plan and communicate public health messages to reduce the risk of tick encounters and burden of disease.

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