Ticks and Tick-borne Diseases xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ticks and Tick-borne Diseases

journal homepage: www.elsevier.com/locate/ttbdis

Original article

Combining public participatory surveillance and occupancy modelling to predict the distributional response of *Ixodes scapularis* to climate change

David J. Lieske[a,*], Vett K. Lloyd[b]

[a] *Department of Geography and Environment, Mount Allison University, 144 Main Street, Sackville, New Brunswick, E4L 1A7, Canada*
[b] *Department of Biology, Mount Allison University, 63B York Street, Sackville, New Brunswick, E4L 1G7, Canada*

ARTICLE INFO

Keywords:
Blacklegged tick
Ixodes scapularis
Species distribution modelling
Bioclimate modelling
Climate change
Range expansion
Borrelia burgdorferi sensu stricto
Lyme disease
Occupancy modelling

ABSTRACT

Ixodes scapularis, a known vector of *Borrelia burgdorferi* sensu stricto (Bbss), is undergoing range expansion in many parts of Canada. The province of New Brunswick, which borders jurisdictions with established populations of *I. scapularis*, constitutes a range expansion zone for this species. To better understand the current and potential future distribution of this tick under climate change projections, this study applied occupancy modelling to distributional records of adult ticks that successfully overwintered, obtained through passive surveillance. This study indicates that *I. scapularis* occurs throughout the southern-most portion of the province, in close proximity to coastlines and major waterways. Milder winter conditions, as indicated by the number of degree days < 0 °C, was determined to be a strong predictor of tick occurrence, as was, to a lesser degree, rising levels of annual precipitation, leading to a final model with a predictive accuracy of 0.845 (range: 0.828–0.893). Both RCP 4.5 and RCP 8.5 climate projections predict that a significant proportion of the province (roughly a quarter to a third) will be highly suitable for *I. scapularis* by the 2080s. Comparison with cases of canine infection show good spatial agreement with baseline model predictions, but the presence of canine Borrelia infections beyond the climate envelope, defined by the highest probabilities of tick occurrence, suggest the presence of Bbss-carrying ticks distributed by long-range dispersal events. This research demonstrates that predictive statistical modelling of multi-year surveillance information is an efficient way to identify areas where *I. scapularis* is most likely to occur, and can be used to guide subsequent active sampling efforts in order to better understand fine scale species distributional patterns.

1. Introduction

Under the influence of climate change, many species are expected to undergo extensive geographic shifts (Parmesan, 2006; Root et al., 2003; Sexton et al., 2009). Meta- analysis has demonstrated that climate change is currently driving organisms northward at an average rate of 6.1 ± 2.4 km per decade (Parmesan and Yohe, 2003). In the case of zoonotic diseases, changes in spatial distribution of vectors is a function of multiple biotic and abiotic processes (Lane et al., 1991), and can be characterized as part of a broader ecosystem response to pressures resulting from environmental change (Reeves et al., 1994; Rogers and Randolph, 2000). Prediction of the possible shifts in spatial patterns of organisms poses unique challenges for epidemiologists and ecologists due to the interaction of a wide range of environmental, biological and anthropogenic factors (Thuiller et al., 2008).

The blacklegged tick (*Ixodes scapularis*) is one such organism currently undergoing range expansion (Ogden et al., 2006b), and is of concern as a vector of the spirochaete *Borrelia burgdorferi* sensu stricto (referred to henceforth as Bbss) which belongs to the Lyme borreliosis group (Franke et al., 2013; Randolph, 2004; Sperling and Sperling, 2009). The macroscale environmental requirements of *I. scapularis* in Canada can be characterized as humid conditions at lower elevations where wind-driven desiccation can be avoided, and at microscales in areas which are heavily forested, bushy, and with extensive ecotonal ("edge") habitat (Falco and Fish, 1988; Lane et al., 1991). Recent work shows that *I. scapularis* is established in New England, portions of the

---

Abbreviations: AIC, Akaike Information Criterion; BROADLEAF, percent of total land cover which could be identified as broadleaf; DDLT0, degree days with temperature < 0 °C; ELEVMEAN, mean elevation (m); ELEVSD, standard deviation of elevation (m); EMT, extreme maximum temperature (°C); FFP, frost-free period; IPCC, Intergovernmental Panel on Climate Change; kNN, *k* nearest neighbour analysis; NEEDLELEAF, percent of total land cover which could be identified as needle leaf; NFI, National Forest Inventory; MAT, mean annual temperature (°C); MAP, mean annual precipitation (mm); PAS, precipitation as snow (mm); POPSIZE, human population numbers per grid cell; RIVDENSITY, density of river features (total length km^{-2}); STANDHGT, mean height (m) of the leading species; TREED, percent of total land cover consisting of trees; WATERAREA, total area of waterbodies (km^2); WETAREA, total area of wetlands (km^2)

[*] Corresponding author.

E-mail addresses: dlieske@mta.ca (D.J. Lieske), vlloyd@mta.ca (V.K. Lloyd).

https://doi.org/10.1016/j.ttbdis.2018.01.018
Received 2 August 2017; Received in revised form 26 January 2018; Accepted 28 January 2018

Please cite this article as: LIESKE, D.J., Ticks and Tick-borne Diseases (2018), https://doi.org/10.1016/j.ttbdis.2018.01.018

Great Lakes region, and the eastern seaboard of the United States (Hahn et al., 2016). In Canada, Ogden et al. (2008d) identified portions of southern Ontario and Nova Scotia as ‘high risk’ for occurrence of this species.

While surveillance studies for *I. scapularis* have been conducted at national scales (Estrada-Peña, 2002; Brownstein et al., 2003; Ogden et al., 2008d; Diuk-Wasser et al., 2010; Eisen et al., 2016; Hahn et al., 2016), detailed predictive models are missing at finer scales for many regions (Ogden et al., 2006b). The goal of this study, therefore, was to generate current and projected future bioclimatic envelopes (Guisan and Zimmermann, 2000; Heikkinen et al., 2006) of *I. scapularis* using new data gathered for the province of New Brunswick, Canada, to provide an “early warning” of the current and emerging patterns of this species’ geographic distribution. It is anticipated that such information could also be used to direct subsequent field-based sampling and monitoring. In addition to assessing and predicting future response of ticks to the changing environment, this research developed general techniques for constructing distribution models based on multi-year surveillance efforts that can be used to assess environmental suitability for other species. New Brunswick serves as a relevant case study given that it borders Nova Scotia and the U.S. State of Maine, both of which are jurisdictions with extensive and established tick populations (Rand et al., 2007; Ogden et al., 2014a,b). As a consequence of it being the adjacent and next more northerly jurisdiction, southern New Brunswick constitutes a territory that will continue to receive ticks dispersing from these southerly areas.

Ticks gathered by participating veterinary clinics and members of the general public, during the years 2014–16 were sent to Mount Allison University as part of a passive surveillance program. The tick data, which spanned the entire province, was combined with current (1981–2010) and projected climatic conditions under two IPCC5 scenarios (RCP 4.5 and RCP 8.5). Current and future bioclimatic envelopes were modelled for *I. scapularis* using state-of-the-art techniques, and predictions were compared to a sample of known canine *Borrelia* infections. Model predictions, under the two IPCC5 scenarios, were generated for the current (baseline) period, the 2020s, 2050s, and 2080s. Habitat factors may also be important environmental determinants of tick occurrence (Ogden et al., 2008a), therefore, forest land cover information was also compiled in order to improve understanding of areas vulnerable to colonization by this species as it undergoes northern range expansion. As pointed out previously (Ogden et al., 2008c; Piesman and Eisen, 2008), this knowledge is essential if regionally appropriate information is to be communicated to the public and to medical practitioners. We hope that future work will apply and extend these tools and innovations to study other vector species, or species of concern as invasive.

2. Methods

2.1. Passive tick surveillance data

As part of an ongoing passive tick surveillance program, members of participating veterinary clinics and the general public, submitted specimens to Mount Allison University. Adult *I. scapularis* gathered during only the March–June period of 2014–2016 were incorporated into the present study in order to concentrate on those individuals that could be assumed to have completed some portion of their life cycle within the province. All New Brunswick veterinary clinics received information on the project, guidelines for how to submit ticks, and a poster for public display. Presentations at the annual general meetings of the New Brunswick Veterinary Medical Association also detailed project goals and described how *I. scapularis* could be submitted to Mount Allison University. Thanks to extensive media coverage, members of the general public provided specimens, either directly or through their local veterinary clinics. All ticks were accompanied by completed information sheets providing information on the host, geographic location where the tick was encountered, host travel information, whether the tick was found attached or crawling, contact information of the tick donor and permission to test for Bbss and other infections (as described by Patterson et al., 2017). Specimens were excluded from this analysis if hosts were known to have travelled beyond the normal day-to-day activity distance within the previous two weeks. As humans were not the subject of the research, and no human participant information was collected other than contact information for specimens provided by the public, a human subjects protocol was not required by the institutional ethics review board. A CACC permission to sample invertebrates was in place.

Upon arrival in the laboratory, ticks were morphologically identified to species by the second author according to Keirans and Litwak (1989), photographed, then stored frozen at −20 °C for morphological and molecular analysis, and the associated metadata compiled. While cats tend to have home territories close to their homes, and dogs are often walked near to their owner’s place of residence, it is expected that uncertainty in the location of origin will remain, necessitating a spatial aggregation of records by 10-km hexagonal grid cell. Total tick counts were recoded to presence/absence (binary) data preparatory to occupancy modelling, which uses binary data (see Section 2.6).

2.2. Canine Borrelia seroprevalence data

To assess canine Bbss seroprevalence in New Brunswick, in the fall and spring tick seasons of 2013–2014 (November 2013–March 2014 and June–October 2014), canine serum samples were collected with the assistance of 21 veterinary hospitals throughout the province (Bjurman et al., 2016). One hundred samples, 50 in each of the spring and fall, were sought from each of the 7 health districts of the province, with 1–6 clinics participating per health region. Clinics were requested to select dogs without regard to health (i.e. consecutive surgeries), and generally, samples were collected over three to ten days during the course of blood collections associated with routine surgeries, as described previously (Bjurman et al., 2016). For those dogs not too old, small, ill, or aggressive for safe blood collection, at the time of collection, the owners completed a consent form and provided information on risk factors for tick exposure.

The owners of seropositive dogs were re-contacted to obtain detailed life histories of their dogs and seek permission to review the dogs’ complete veterinary medical records. Dogs were excluded from further analysis for any of the following reasons: (1) it was physically impossible for them to encounter ticks, i.e., were dogs that did not go outdoors, or lived only in concrete-floored kennels; (2) had been vaccinated against Lyme disease within the past year as they would not be “eligible” for infection, based on evidence that protection decreases after one year, making dogs with out-of-date vaccinations suitable as sentinels for infection; (3) had a travel history outside of their home community at any point in their lives, or had a lifetime travel history which was only partially verifiable, e.g., had been adopted from a shelter.

Serum collected from all clinics was stored frozen at −20 °C at veterinary hospitals and then sent frozen to Mount Allison University for testing. Serum samples were tested using the SNAP 4DxPlus® C6 ELISA (IDEXX Laboratories, Markham, Ontario), which detects antibodies to the C6 peptide of *Borrelia burgdorferi*, *Dirofilaria immitis*, *Anaplasma phagocytophilum/A. platys,* and *Ehrlichia canis/E. ewingii*. The IDEXX ELISA is based on the *B. garinii* C6 epitope and the manufacturer indicated sensitivity and specificity of 94.1% and 96.2%, respectively for *B. burgdorferi*. Studies with clinical canine populations report similar but slightly better values (Chandrashekar et al., 2010; Herrin et al., 2017). This test also detects *B. garinii* with high sensitivity (Krupka et al., 2009) but this *Borrelia* genospecies would not be expected to be prevalent in North America. The VlsE C6 epitope used in the SNAP 4DxPlus® C6 ELISA does not cross-react with the antibody response to commercial Lyme disease vaccines. Samples were tested according to