Check for updates

Received: 17 November 2023 | Revised: 12 March 2024 | Accepted: 3 May 2024

DOI: 10.1111/zph.13143

ORIGINAL ARTICLE

WILEY

Epidemiologic and tick exposure characteristics among people with reported Lyme disease – Minnesota, 2011–2019

Austin R. Earley[1] | Elizabeth K. Schiffman[2] | Karen K. Wong[3] | Alison F. Hinckley[1] | Kiersten J. Kugeler[1]

[1]Division of Vector-Borne Diseases, Centers for Disease Control and Prevention, Fort Collins, Colorado, USA

[2]Minnesota Department of Health, St. Paul, Minnesota, USA

[3]Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases, Atlanta, Georgia, USA

Correspondence
Kiersten J. Kugeler, Division of Vector-Borne Diseases, Centers for Disease Control and Prevention, Fort Collins, CO, USA.
Email: bio1@cdc.gov

Funding information
Centers for Disease Control and Prevention

Abstract

Aims and Methods: In the United States, blacklegged *Ixodes* spp. ticks are the primary vector of Lyme disease. Minnesota is among the states with the highest reported incidence of Lyme disease, having an average of 1857 cases reported annually during 2011–2019. In contrast to the Northeast and mid-Atlantic United States where exposure to ticks predominately occurs around the home, the circumstances regarding risk for exposure to blacklegged ticks in Minnesota are not well understood, and risk is thought to be highest in rural areas where people often participate in recreational activities (e.g. hiking, visiting cabins). We analysed enhanced surveillance data collected by the Minnesota Department of Health during 2011–2019 to describe epidemiologic and tick exposure characteristics among people with reported Lyme disease.

Results: We found that younger age, male gender, residence in a county with lower Lyme disease risk, residence in the Minneapolis-St. Paul metropolitan area, and an illness onset date later in the year were independently associated with higher odds of reporting tick exposures away from the home. We also describe the range of activities associated with tick exposure away from the home, including both recreational and occupational activities.

Conclusions: These findings refine our understanding of Lyme disease risk in Minnesota and highlight the need for heterogeneous public health prevention messaging, including an increased focus on peridomestic prevention measures among older individuals living in high-risk rural areas and recreational and occupational prevention measures among younger individuals living in the Minneapolis-St. Paul metropolitan area.

KEYWORDS
Ixodes, Lyme disease, Minnesota, tick bites, tick exposure

1 | INTRODUCTION

Blacklegged *Ixodes* spp. ticks are important disease vectors in the United States (Eisen & Eisen, 2018). The most common disease transmitted by these ticks is Lyme disease, caused by *Borrelia burgdorferi* sensu stricto and *Borrelia mayonii*. Lyme disease occurs focally, with most human disease reported from states in the Northeast, mid-Atlantic, and upper-Midwest, including Minnesota – where an average of 1857 confirmed and probable cases were reported annually during 2011–2019 (Mead, 2022;

© 2024 Wiley-VCH GmbH. Published by John Wiley & Sons Ltd. This article has been contributed to by U.S. Government employees and their work is in the public domain in the USA.

Schwartz et al., 2017). A majority of Minnesota counties have established blacklegged tick populations with the exception of the southwestern-most counties, which are dominated by agricultural rather than forested lands (Centers for Disease Control and Prevention, n.d.; Johnson et al., 2018; Robinson et al., 2015). Cases of Lyme disease are reported by county of residence (not exposure); nearly half of all cases in Minnesota are reported among residents of the seven-county Minneapolis-St. Paul metropolitan area alone (Minnesota Department of Health, 2023).

Several factors are known to be associated with risk for Lyme disease. It occurs more frequently among males and has a bimodal age distribution, with incidence peaking in both children and older adults (Kugeler et al., 2022). Geographic risk is dependent on both the distribution of infected ticks in a particular area, which is influenced by various ecological and environmental factors, and on how humans interact with their environment (Johnson et al., 2018; Orloski et al., 1998; Rand et al., 2003; Robinson et al., 2015). In the Northeast and mid-Atlantic United States, exposure to blacklegged ticks predominates in suburban areas in the peridomestic setting, largely due to the proximity of human development in or near wooded areas that provide ideal habitat for blacklegged ticks (Falco & Fish, 1988; Maupin et al., 1991; Mead et al., 2018; Moon et al., 2019; Smith et al., 2001). Evidence related to exposure risk in Minnesota is more limited; although infected blacklegged ticks are common in rural forested settings in the northern part of the state, more than half of the population resides further south in the Minneapolis-St. Paul metropolitan area, suggesting that recreational or other activities away from the home in these more northern areas may play a significant role in exposure risk (Mead, 2022; Neitzel & Kemperman, 2012).

During 2011–2019, the Minnesota Department of Health (MDH) conducted enhanced surveillance to obtain more detailed data on patients with Lyme disease and their tick exposure histories. Here, we summarize the epidemiologic and exposure patterns among reported Lyme disease cases in Minnesota.

Impacts

- Interview data from persons with reported Lyme disease in Minnesota improves understanding about geographic, seasonal, and demographic patterns of risk.
- Peridomestic risk predominates in non-metropolitan counties in Minnesota, similar to what has been observed in the Northeast and mid-Atlantic United States; in contrast, recreational or other non-peridomestic activities contribute to risk for a substantial portion of people living in the Minneapolis-St. Paul metropolitan area.
- Lyme disease prevention messaging in Minnesota tailored according to geography, seasonality, and age is warranted.

2 | METHODS

2.1 | Data collection

Reports from clinicians and laboratories of possible Lyme disease cases were transmitted to MDH during 2011–2019 in accordance with local disease reporting regulations. During this time, staff at MDH routinely followed-up on these to determine if the illness met criteria to be classified as a confirmed or probable case of Lyme disease (Centers for Disease Control and Prevention, n.d.). For enhanced surveillance activities, MDH staff also conducted patient interviews via telephone using a standardized interview form. Interviews for a particular calendar year generally began in October and continued through March of the following year. Contact was attempted up to seven times over the course of several weeks before deeming persons to be non-responders. Interviewees were asked about activities that occurred 3–30 days before onset of illness that may have been related to their exposure to infected ticks, and were classified as having home exposure, nonhome exposure, or both, based on their responses. Interviewees classified as having home exposure reported spending time in wooded or brushy areas around the home, recalling tick bites that occurred at home, and/or observing ticks on their property or inside their home. Interviewees classified as having nonhome exposure reported spending time in wooded or brushy areas away from home, including while visiting a private recreational property or cabin, performing common outdoor recreational activities like hiking or backpacking, or as part of their occupation. Interviewees reporting nonhome exposures were asked to further describe and provide the geographic location of those nonhome activities, which the interviewer recorded as free text. Questions included in the standardized questionnaire related to home and nonhome exposure histories can be found in Appendix S1.

An interviewed patient could have been included in the dataset for more than one occurrence of disease in a single year, and the exposure information for each occurrence of disease may not have been unique. For the purposes of this analysis, we retained only the first interview record for each person per year and considered subsequent interview entries in the same year to be duplicate records (Figure 1).

2.2 | Data analysis

We evaluated characteristics of patients with reported Lyme disease in Minnesota during 2011–2019. Among the subset of these patients who were interviewed, we describe demographic characteristics, as well as geographic and seasonal distributions of reported home and nonhome opportunities for exposure to tick habitat. The demographic characteristics of primary interest were age and gender. County of residence was categorized in two ways. First, we considered median Lyme disease incidence per county

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

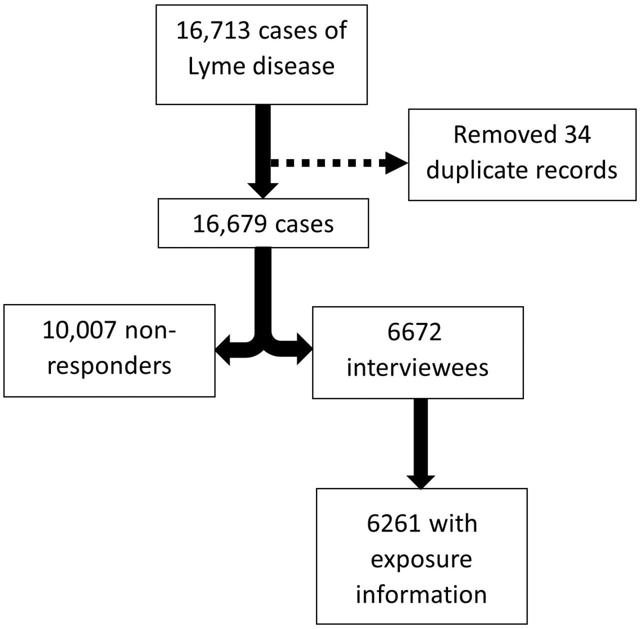

FIGURE 1 Subset of total reported Lyme disease cases with interview data available for analysis – Minnesota, 2011–2019.

during 2011–2019 as an indicator of risk in each county; we divided all counties into four categories (highest, high, medium, and low) based approximately on quartiles of median incidence. Second, we categorized the urbanicity of each county based on presence or absence in the Minneapolis-St. Paul metropolitan area, where more than half of the state population resides, referred to hereafter as 'metro' and 'nonmetro' respectively (Census.gov, n.d.). County classifications are found in Appendix S2.

Logistic regression was used to model the odds of reporting nonhome exposure among the subset of cases with a single exposure setting (e.g. home or nonhome). Variables included in the full multivariable model were purposefully selected based on univariate significance of the odds of reporting a nonhome exposure, epidemiologic relevance, and assessments of collinearity and model fit. Variables in the full model were gender, age, race and ethnicity, county risk category (treated as ordinal), county urbanicity, onset month, and year.

We also describe the breadth of activities in which people engaged away from home in the 3–30 days before their illness onset. Nonhome exposure activities recorded as free text were annotated with category labels. Because responses often listed multiple potential tick exposures, we pre-processed text by splitting on commas and analysing clauses as independent observations. After removing replicates, we used topic modelling to cluster observations by their semantic similarity using the uncased Simple Contrastive Learning of Sentence Embeddings (SimCSE) model, a sentence embedding model based on Bidirectional Encoder Representations from Transformers (BERT) that has been trained on sentences from English Wikipedia (Devlin et al., 2018; Gao et al., 2021). Using SimCSE, each text observation was converted to a numerical vector, where texts with similar meaning are closer together in the vector space. Cosine distance was calculated between embedding vectors to evaluate semantic similarity, and observations were clustered using the Farthest Point Algorithm. Clustered observations were manually reviewed and labelled, and each observation could have multiple labels.

A Wilcoxon rank-sum test was used to compare age distributions between interviewed and not interviewed patients. χ^2 tests and Cramer's V values were used to compare gender, race and ethnicity, and county of residence characteristics. A p-value <0.05 was considered statistically significant. We performed statistical analyses using SAS version 9.4 (SAS Institute, Cary, NC); nonhome exposure topic modelling was conducted using Python version 3.7.8 (Python Software Foundation, Delaware, USA) with the transformers package. This activity was reviewed by the Centers for Disease Control and Prevention (CDC), deemed not research, and was conducted consistent with applicable federal law and CDC policy.

3 | RESULTS

During 2011–2019, 16,713 confirmed and probable cases of Lyme disease were reported in Minnesota. After removing records for individuals with duplicative information ($n=34$), 16,679 cases were included in analysis (Figure 1). Supplemental information collected through patient interview was available for 6672 cases (40.0%); 6261 of these (93.8%) had information on location and activities related to possible infected blacklegged tick exposure (Figure 1).

3.1 | Representativeness of patient interview data

Characteristics of interviewed patients were generally similar to characteristics of reported cases overall. Median age of all patients was 46 years (range = 0–100, Table 1). Interviewed patients were slightly older than those not interviewed (median 48 years vs. median 44 years, respectively; $p=0.0008$). Most patients were male (61.6%), with a slightly higher proportion of females in the interviewed group compared to those not interviewed (39.9% vs. 37.0%, $p=0.0002$; Cramer's $V=0.0342$); however, the low Cramer's V value suggests that these proportions are likely comparable between the groups. White non-Hispanic people comprised a higher proportion of the interviewed group (93.8% vs. 59.9%, $p<0.0001$; Cramer's $V=0.411$); however, this is likely attributable to the substantial proportion of unknown race and ethnicity for persons who were not interviewed, as interviews are often how that information is obtained. Nonmetro residents made up a slightly smaller proportion of those interviewed compared to the not interviewed group (54.3% vs. 60.4%, $p<0.0001$; Cramer's $V=0.061$); however, the low Cramer's V suggests the groups to be comparable. A higher proportion of interviewed patients resided in counties in the high (37.8% interviewed vs. 33.3% not interviewed), medium (37.2% interviewed

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Characteristics of persons with reported Lyme disease according to enhanced surveillance interview status – Minnesota, 2011–2019.

	Not interviewed (n = 10,007)		Interviewed (n = 6672)		Total (n = 16,679)	
	n	%	*n*	%	*n*	%
Gender						
Male	6288	62.8	3988	59.8	10,276	61.6
Female	3700	37.0	2662	39.9	6362	38.1
Other	1	0.0	0	0.0	1	0.0
Unknown	18	0.2	22	0.3	40	0.3
Age (years)						
0–18	2816	28.1	1639	24.5	4455	26.7
19–44	2222	22.2	1441	21.6	3663	22.0
45–64	3031	30.3	2319	34.8	5350	32.1
65+	1938	19.4	1273	19.1	3211	19.2
Race/Ethnicity						
White, Non-Hispanic	5989	59.9	6261	93.8	12,250	73.5
Black, Non-Hispanic	64	0.6	8	0.1	72	0.4
Other, Non-Hispanic	289	2.9	161	2.4	450	2.7
Hispanic	83	0.8	70	1.1	153	0.9
2+ Races, Non-Hispanic	26	0.3	71	1.1	97	0.6
Unknown	3556	35.5	101	1.5	3657	21.9
County of residence risk level[a]						
Highest risk	3069	30.7	1487	22.3	4556	27.3
High risk	3334	33.3	2525	37.8	5859	35.1
Medium risk	3375	33.7	2484	37.2	5859	35.1
Low risk	227	2.3	176	2.7	403	2.5
Unknown	2	0.0	0	0.0	2	0.0
County of residence urbanicity[b]						
Metro	3965	39.6	3052	45.7	7017	42.1
Nonmetro	6042	60.4	3620	54.3	9662	57.9

[a]Risk categories for county of residence were determined using median Lyme disease incidence in the county between 2011 and 2019 as a proxy for Lyme disease risk. Appendix S2 provides a detailed breakdown of county of residence categories.

[b]Urbanicity category was based on a county's presence or absence in the Minneapolis-St. Paul metropolitan area. Metro includes seven counties in the greater Minneapolis-St. Paul metropolitan area, and nonmetro includes all other counties in Minnesota. Appendix S2 provides a detailed breakdown of county of residence categories.

vs. 33.7% not interviewed), and low (2.7% interviewed vs. 2.3% not interviewed) risk categories (p = <0.0001; Cramer's V = 0.09) compared to those not interviewed; however, these differences are unlikely to be meaningful based on the low Cramer's V value.

3.2 | Descriptive analysis

Among 6261 persons with available exposure history, 2650 (42.3%) reported both home and nonhome exposure in the 3–30 days before their illness onset, 1572 (25.1%) reported only home exposure, and 2039 (32.6%) reported only nonhome exposure (Table 2).

3.2.1 | Age and sex

People reporting only home exposure were older: 32.9% were ≥65 years old, whereas 12.9% of those reporting only nonhome exposure and 15.9% of those reporting both home and nonhome exposure were ≥65 years old (Table 2). Those reporting only nonhome exposure showed a more uniform age distribution than is typical for Lyme disease, while cases associated with only home exposure exhibited a classic bimodal age distribution with peaks in the very young and in older adults (Figure 2). Overall, a greater proportion of people reporting any nonhome exposure (including those with both home and nonhome exposure) were male (64.9% only nonhome

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 Frequency of exposure type by gender, age and county of residence among persons with reported Lyme disease and available exposure information – Minnesota, 2011–2019.

	Reported exposure type					
	Home (*n* = 1572)		Nonhome (*n* = 2039)		Both (*n* = 2650)	
	n	%	*n*	%	*n*	%
Gender						
Male	753	47.9	1323	64.9	1680	63.4
Female	816	51.9	708	34.7	962	36.3
Unknown	3	0.2	8	0.4	8	0.3
Age (years)						
0–18	326	20.7	493	24.2	711	26.8
19–44	185	11.8	645	31.6	520	19.6
45–64	544	34.6	638	31.3	999	37.7
65+	517	32.9	263	12.9	420	15.9
County of residence risk level[a]						
Highest incidence	594	37.8	124	6.1	676	25.5
High incidence	711	45.2	572	28.1	1097	41.4
Medium incidence	254	16.2	1257	61.6	809	30.5
Low incidence	13	0.8	86	4.2	68	2.6
County of residence urbanicity[b]						
Metro	434	27.6	1360	66.7	1067	40.3
Nonmetro	1138	72.4	679	33.3	1583	59.7

[a]Risk categories for county of residence were determined using median Lyme disease incidence in the county during 2011–2019 as a proxy for Lyme disease risk. Appendix S2 provides a detailed breakdown of county of residence categories.

[b]Urbanicity category was based on a county's presence or absence in the Minneapolis-St. Paul metropolitan area. 'Metro' includes seven counties in the greater Minneapolis-St. Paul metropolitan area, and 'nonmetro' includes all other counties in Minnesota. Appendix S2 provides a detailed breakdown of county of residence categories.

and 63.4% both) compared to those reporting only home exposure (47.9%, Table 2).

3.2.2 | County of residence

A majority (57.9%) of Lyme disease cases occurred among residents of counties outside the Minneapolis-St. Paul metropolitan area. Very few cases (2.5%) occurred among residents of counties in the lowest risk category, whereas frequency of reported cases was distributed more equally across counties in the other three risk categories (Table 1). Patients living in counties with relatively lower risk reported the highest frequency of nonhome exposure, whereas home exposure was more frequently reported in persons living in counties with higher risk (Table 2, Figure 3). Most patients reporting any home exposure lived in nonmetro area counties (72.4% only home and 59.7% both), while most patients reporting only nonhome exposure lived in metro area counties (66.7%, Table 2).

3.2.3 | Month of onset

Illness onset occurred in all months of the year. The peak month of illness onset for each exposure type was July; though, a larger proportion of those reporting only home exposure had an illness onset date in June (33.7%) compared to those reporting any nonhome exposure (25.6% only nonhome and 24.2% both, Figure 4).

3.2.4 | Reported nonhome exposure activities

In total, results from the analysis of free text interview fields containing descriptions of nonhome exposure activities show 4689 patients reported 6698 nonhome exposure activities in one or more of 19 exposure categories (Table 3). The most commonly reported activity was visiting a cabin or other property (42.3%) followed by recreational activities (25.0%) including hiking, biking, backpacking, walking and running. Camping, water-related activities (e.g. fishing at a lake or river) and occupational activities were also commonly reported (Table 3). Diverse occupational activities included forestry, logging, farming, and groundskeeping and landscaping, among many others.

Among 3402 geographic locations associated with reported nonhome exposure activities, 2694 (79.2%) occurred in nonmetro counties, primarily those in the northern half of the state (Figure 5). The counties in the Minneapolis-St. Paul metropolitan area where the greatest number of nonhome exposure activities were reported were Hennepin and Washington counties (Figure 5).

3.3 | Multivariable analysis

Although more than 40% of all persons reported engaging in both home and nonhome activities that put them at risk for Lyme disease in the month prior to their illness, we focused on the nearly 60% of patients who reported a single exposure type to explore differences in patient characteristics. After controlling for potential confounding effects among these variables and odds of nonhome exposure, the odds of reporting only nonhome exposure were higher in younger people (0–18 years old, adjusted odds ratio (aOR) = 1.53, 95% CI [1.21, 1.92]; 19–44 years old, aOR = 2.96, 95% CI [2.31, 3.79]) and lower in older people (65+ years, aOR = 0.45, 95% CI [0.36–0.57]) compared to those 45–64 years old (Table 4). Additionally, males were shown to have higher odds of only nonhome exposure compared to females (aOR = 1.54, 95% CI [1.29, 1.83]; Table 4). The odds of only nonhome exposure were substantially lower in counties with higher relative Lyme disease risk (aOR = 0.27, 95% CI [0.24, 0.31]),

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

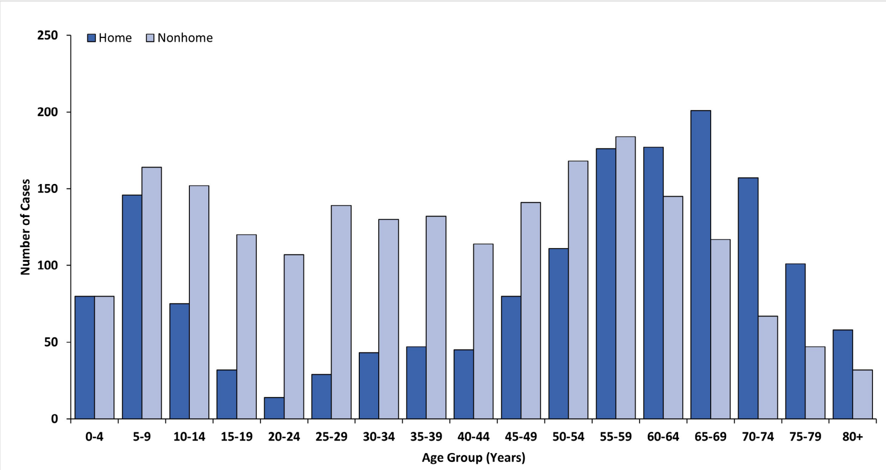

FIGURE 2 Age of patients with Lyme disease according to self-reported home or nonhome exposure to blacklegged ticks – Minnesota, 2011–2019.

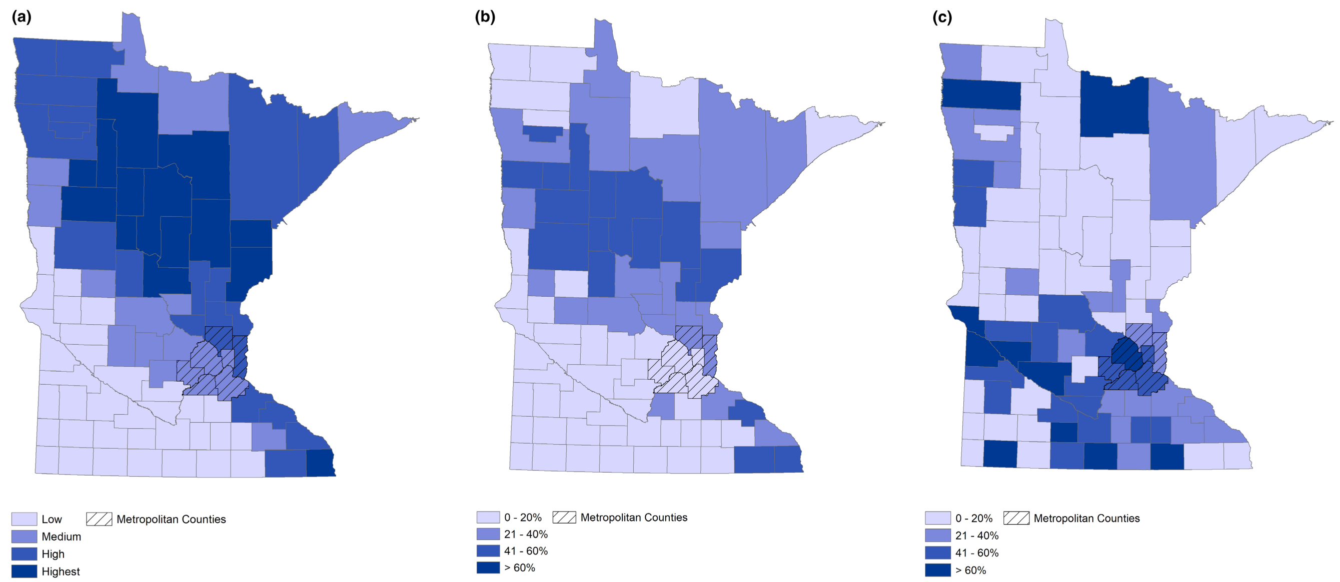

FIGURE 3 Minnesota counties categorized according to: (a) Lyme disease risk level based on median Lyme disease incidence during 2011–2019; (b) Percentage of exposures by county of residence that were reported as only home exposures; (c) Percentage of exposures by county of residence that were reported as only nonhome exposures.

and higher in those living in metro area counties (aOR = 2.25, 95% CI [1.86, 2.72]; Table 4). Patients with illness onset in July–October had higher odds of reporting only nonhome exposure compared to those with illness onset in June (Table 4).

4 | DISCUSSION

In Minnesota during 2011–2019, 40% of more than 16,500 patients with a reported case of Lyme disease were interviewed by health department staff to ascertain factors likely related to tick exposure. We examined these enhanced surveillance data to identify patterns in epidemiologic characteristics of patients and their associated self-reported exposure locations and activities. Younger age, male gender, residence in a county with lower Lyme disease risk, residence in the Minneapolis-St. Paul metropolitan area, and illness onset later in the year were all independently associated with higher odds of reporting only nonhome exposure to blacklegged ticks. These geographic, demographic and seasonal differences in exposure types broaden the understanding of Lyme disease risk in Minnesota and may be useful when refining public health education and other prevention strategies to target at-risk groups.

Geographic patterns in exposure types highlight that risk for exposure to infected blacklegged ticks in Minnesota is not one-dimensional, with both peridomestic and travel-associated risks. First, the counties where home exposure was more frequently reported are primarily in the northern half of Minnesota, where the density of ideal forested habitat for blacklegged ticks is greatest (Figures 3b and 5) (Johnson et al., 2018; Robinson et al., 2015). This relative geographic concentration of home exposure suggests that risk for exposure for residents in this part of the state may be similar to the northeastern and mid-Atlantic United States,

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

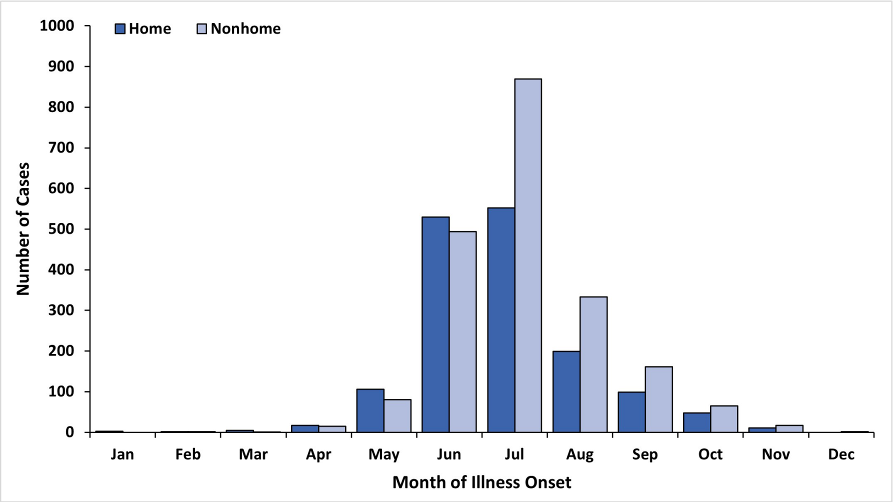

FIGURE 4 Number of home and nonhome exposures to blacklegged ticks by month of illness onset among cases of Lyme disease – Minnesota, 2011–2019.

TABLE 3 Frequency of nonhome tick exposures identified through free text analysis by exposure category among interviewed cases of Lyme disease – Minnesota, 2011–2019.

Nonhome exposure category	n[a]	%[b]
Visiting cabin/Family/Friends/Other property	1983	42.3
Hiking/backpacking/walking/running/biking	1173	25.0
Camping	986	21.0
Water-related recreational activities (e.g. fishing at lake/river)	534	11.4
General landscaping/gardening/brush clearing	330	7.0
Occupation	330	7.0
General outdoor activities/field sports/games	326	6.9
Hunting/Baiting/Trapping/Shooting	260	5.5
Miscellaneous/Unknown	209	4.5
Farm-related	172	3.7
Spending time in the woods	156	3.3
4-Wheeling	98	2.1
Picking fruits/vegetables	82	1.7
Activities with pets	66	1.4
Spending time at a park	63	1.3
Attending outdoor event (e.g. festival, concert)	45	1.0
School trip/Field trip	45	1.0
Hobbies in nature (e.g. wildlife photography)	42	0.9
Horseback riding	19	0.4

[a]A particular activity could have been included in multiple categories if it fit logically into more than one category. Thus, the total frequency reported in this table ($n=6919$) exceeds the number of activities associated with nonhome exposure ($n=6698$).

[b]Percent of patients with available exposure history who reported nonhome exposure, including those reporting both home and nonhome exposure ($n=4689$). Total adds to more than 100% due to patients reporting more than one exposure activity.

where risk is highest in peridomestic, forested, nonurban settings. Conversely, nonhome activities were most commonly reported by residents of the Minneapolis-St. Paul metropolitan area (Table 2, Figure 3c), most of whom reported being exposed in the same high-risk northern counties, highlighting the risk for travel-associated exposure (Figure 5). Open text descriptions of nonhome activities demonstrate the breadth of activities that can put people at risk for exposure to blacklegged ticks, from simply visiting family or friends to actively engaging in recreational activities to occupation (Table 3). In general, these geographic trends reflect what occurs

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

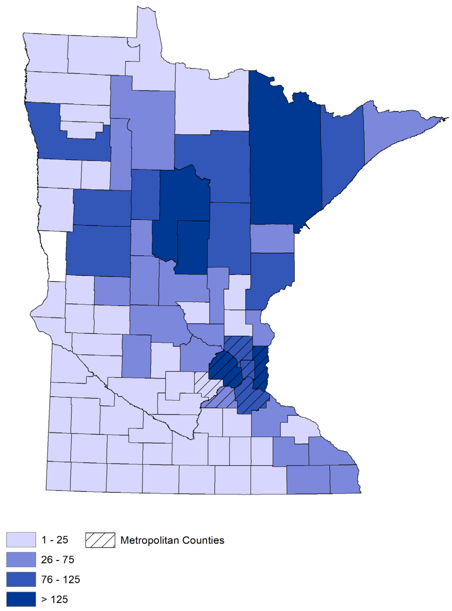

FIGURE 5 Frequency of activities associated with nonhome exposure to blacklegged ticks that occurred in each county – Minnesota, 2011–2019.

on the national scale in the United States: in lower-risk regions, cases of Lyme disease are more likely to be travel-associated, while locally acquired infection predominates among those who live in higher-risk settings (Forrester et al., 2015; Mead, 2022). It should be noted that many interviewed patients reported both home and nonhome opportunities for exposure to infected blacklegged ticks (Table 2, Appendix S3), so geographic location is not a strict determinant of exposure risk. However, 58% of interviewees reported a single exposure type (i.e. either home or nonhome), allowing us to identify clear patterns useful for informing targeted prevention messaging across the state.

Demographic differences between those reporting only home or nonhome opportunities for exposure may be attributable to different behaviours across groups. For example, younger adults may be more likely to participate in recreational activities associated with nonhome exposure (e.g. hiking), while older adults may more frequently engage in peridomestic activities such as gardening or landscaping. A study in Canada highlighted that risk factors such as working outside, doing outdoor activities, or travelling to a high-risk region were not distributed evenly across age groups; specifically, older adults were more likely to report working outside, while younger adults were more likely to visit a high-risk region, patterns that are similar to what we found in Minnesota (Aenishaenslin et al., 2017). Younger adults may also be more likely to have a physically demanding outdoor occupation that would put them at risk for exposure such as construction, logging, or forestry, each of which were reported by patients with nonhome exposure activities. Occupation may also partially explain the male predominance among those reporting nonhome exposure activities. Finally, the later peak of illness onset in patients reporting nonhome exposure suggests that travel-associated, recreational exposure risk may be higher later in the year. This later peak may be associated with weather patterns (e.g. colder temperatures, later snow melt) that affect accessibility or desire to visit recreational areas in northern Minnesota earlier in the season or could reflect that persons working around their home may do so earlier than recreational activities begin to occur with substantial frequency.

The results of this study are subject to several limitations. First, all interview information was self-reported by patients and interviews were not typically conducted during the peak of tick season. Therefore, patients may have been interviewed months after their initial exposure and illness onset, subjecting the results to recall bias. Furthermore, people often do not recall a bite by a blacklegged tick, limiting our ability to generalize about specific activities that place persons at higher risk for Lyme disease (Nadelman et al., 1996; Nigrovic et al., 2019). Nevertheless, we have no reason to suspect that recall of different exposure types (home vs. nonhome) may differ according to geography, patient age or gender, and thus believe that a non-differential misclassification may influence findings towards the null. Second, socioeconomic variables (e.g. employment status, education, income) that could drive how individuals interact with the environment around them were not assessed, but controlling for county of residence in multivariable models might minimize this effect on an ecological level. Third, county-level Lyme disease risk was measured on a relative scale using median incidence derived from traditional passive surveillance data. This measure is a proxy for true risk of acquiring the disease through exposure in that county. Given that cases reported through surveillance are based on county of residence and not county of exposure, these categories may not accurately reflect relative risk of acquiring Lyme disease in one county versus another. We treated this proxy as an ordinal rather than absolute measure to minimize overinterpretation. Fourth, interview data were available for less than half of all Lyme disease cases reported in Minnesota during 2011–2019. This and underreporting, which has been documented in high-incidence states including Minnesota (Schiffman et al., 2018; White et al., 2018), may limit the generalizability of these results to the entire state population. However, the comparable characteristics between the interviewed and not interviewed cases suggest the findings are not demonstrably impacted by any selection bias.

While substantial research has been devoted to understanding risk factors for Lyme disease in the Northeast and mid-Atlantic United States, far less is known about risk factors in the upper-Midwest. This summary highlights the nuance in who, where and when people in Minnesota are most at risk for exposure to infected blacklegged ticks and demonstrates potential need for targeted public health prevention messaging in different regions of the state. An increased emphasis on peridomestic prevention in high-risk areas may be especially warranted, as previous studies assessing attitudes and behaviours related to tickborne disease show that the use of peridomestic interventions is uncommon among residents of Minnesota

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 4 Univariate and multivariable (adjusted) logistic regression model estimating the odds of reporting nonhome exposure to blacklegged ticks according to patient demographic and geographic characteristics – Minnesota, 2011–2019.

Variable	Univariate		Multivariable (adjusted model)[a]	
	Odds ratio (95% CI)	*p*-value	Adjusted odds ratio (95% CI)	*p*-value
Gender				
Male	2.01 (1.75–2.30)	<0.0001	1.54 (1.29–1.83)	<0.0001
Female	Ref		Ref	
Age range (years)				
0–18	1.33 (1.11–1.59)	0.0023	1.53 (1.21–1.92)	0.0003
19–44	3.03 (2.48–3.71)	<0.0001	2.96 (2.31–3.79)	<0.0001
45–64	Ref		Ref	
65+	0.44 (0.37–0.54)	<0.0001	0.45 (0.36–0.57)	<0.0001
Race/Ethnicity				
White Non-Hispanic	1.36 (0.99–1.87)	0.0552	1.06 (0.70–1.60)	0.7807
Other	Ref		Ref	
County of residence risk level[b]	0.21 (0.19–0.23)	<0.0001	0.27 (0.24–0.31)	<0.0001
County of residence urbanicity[c]				
Metro	5.26 (4.55–6.08)	<0.0001	2.25 (1.86–2.72)	<0.0001
Nonmetro	Ref		Ref	
Onset month[d]				
Winter months	0.43 (0.14–1.39)	0.1606	1.64 (0.35–7.75)	0.5305
April	0.95 (0.46–1.97)	0.8882	1.06 (0.41–2.72)	0.9094
May	0.79 (0.57–1.08)	0.1424	0.74 (0.50–1.09)	0.1291
June	Ref		Ref	
July	1.71 (1.45–2.01)	<0.0001	1.86 (1.51–2.29)	<0.0001
August	1.83 (1.48–2.27)	<0.0001	2.32 (1.75–3.08)	<0.0001
September	1.82 (1.37–2.42)	<0.0001	2.13 (1.48–3.07)	<0.0001
October	1.48 (0.99–2.20)	0.0537	1.89 (1.14–3.13)	0.0132
November	1.68 (0.78–3.62)	0.0311	2.09 (0.79–5.58)	0.1385

[a]Variables included in the full model are gender, age, race/ethnicity, county of residence incidence category, county of residence urbanicity category, onset month, and year (not shown). Models include data from subset of interviewed persons with a single exposure type for which information was available for each variable included in the model ($n = 3548$).

[b]Risk categories for county of residence were determined using median Lyme disease incidence in the county between 2011 and 2019 as a proxy for Lyme disease risk. Risk categories were treated as ordinal and coded as a continuous variable in the regression models. Appendix S2 provides a detailed breakdown of county of residence categories.

[c]Geographic categories for county of residence were based on the urbanicity of the county. 'Metro' includes seven counties in the greater Minneapolis-St. Paul metropolitan area, and 'nonmetro' includes all other counties in Minnesota. Appendix S2 provides a detailed breakdown of county of residence categories.

[d]'Winter months' includes disease onset dates from December to March.

and other midwestern states (Beck et al., 2022; Bron et al., 2020). In contrast, targeting persons in the Minneapolis-St. Paul metropolitan area to highlight the importance of tick prevention during recreational and occupational activities in high-risk areas may reach the audience most likely to have nonhome exposure to infected blacklegged ticks. In conclusion, these observed geographic, demographic, and seasonal differences between patients reporting home and nonhome opportunities for infected blacklegged tick exposure will help local public health authorities better target individuals most at risk for Lyme disease and other blacklegged tick-transmitted diseases in Minnesota and may inform future research in other states in the Upper Midwest.

ACKNOWLEDGEMENTS

The authors acknowledge current and former vector-borne disease epidemiologists at the Minnesota Department of Health for their work collecting these data, as well as the many student workers who conducted the patient interviews.

FUNDING INFORMATION

U.S. Department of Health and Human Services: Centers for Disease Control and Prevention.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the U.S. Centers for Disease Control and Prevention.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Austin R. Earley https://orcid.org/0000-0002-1401-3350
Alison F. Hinckley https://orcid.org/0000-0003-2853-5165
Kiersten J. Kugeler https://orcid.org/0000-0002-5702-6688

REFERENCES

Aenishaenslin, C., Bouchard, C., Koffi, J. K., & Ogden, N. H. (2017). Exposure and preventive behaviours toward ticks and Lyme disease in Canada: Results from a first national survey. *Ticks and Tick-borne Diseases*, *8*(1), 112–118.

Beck, A., Bjork, J., Biggerstaff, B. J., Eisen, L., Eisen, R., Foster, E., Signs, K., Tsao, J. I., Kough, E., Peterson, M., Schiffman, E., Muganda, C. P., Osborn, R., Wozniak, R., Bron, G. M., Phaneuf, D., Smith, D., Bartholomay, L., Paskewitz, S., & Hinckley, A. F. (2022). Knowledge, attitudes, and behaviors regarding tick-borne disease prevention in Lyme disease-endemic areas of the upper Midwest, United States. *Ticks and Tick-borne Diseases*, *13*(3), 101925.

Bron, G. M., Fernandez, M. P., Larson, S. R., Maus, A., Gustafson, D., Tsao, J. I., Diuk-Wasser, M. A., Bartholomay, L. C., & Paskewitz, S. M. (2020). Context matters: Contrasting behavioral and residential risk factors for Lyme disease between high-incidence states in the northeastern and Midwestern United States. *Ticks and Tick-borne Diseases*, *11*(6), 101515.

Census.gov. (n.d.). U.S. Census Bureau. https://www.census.gov/library/stories/state-by-state/minnesota-population-change-between-census-decade.html

Centers for Disease Control and Prevention. (n.d.). Blacklegged tick (*Ixodes scapularis*) surveillance. https://www.cdc.gov/ticks/surveillance/BlackleggedTick.html

Centers for Disease Control and Prevention. (n.d.). Lyme disease (*Borrelia burgdorferi*) case definitions. https://ndc.services.cdc.gov/conditions/lyme-disease/

Devlin, J., Chang, M.-W., Lee, K., & Toutanova, K. (2018). BERT: Pre-training of deep bidirectional transformers for language understanding. *arXiv*.

Eisen, R. J., & Eisen, L. (2018). The blacklegged tick, *Ixodes scapularis*: An increasing public health concern. *Trends in Parasitology*, *34*(4), 295–309.

Falco, R. C., & Fish, D. (1988). Prevalence of Ixodes dammini near the homes of Lyme disease patients in Westchester County, New York. *American Journal of Epidemiology*, *127*(4), 826–830.

Forrester, J. D., Brett, M., Matthias, J., Stanek, D., Springs, C. B., Marsden-Haug, N., Oltean, H., Baker, J. D. S., Kugeler, K. J., Mead, P. S., & Hinckley, A. (2015). Epidemiology of Lyme disease in low-incidence states. *Ticks and Tick-borne Diseases*, *6*(6), 721–723.

Gao, T., Yao, X., & Chen, D. (2021). SimCSE: Simple contrastive learning of sentence embeddings. *arXiv*.

Johnson, T. L., Boegler, K. A., Clark, R. J., Delorey, M. J., Bjork, J. K. H., Dorr, F. M., Schiffman, E. K., Neitzel, D. F., Monaghan, A. J., & Eisen, R. J. (2018). An Acarological risk model predicting the density and distribution of host-seeking *Ixodes scapularis* nymphs in Minnesota. *The American Journal of Tropical Medicine and Hygiene*, *98*(6), 1671–1682.

Kugeler, K. J., Mead, P. S., Schwartz, A. M., & Hinckley, A. F. (2022). Changing trends in age and sex distributions of Lyme disease-United States, 1992-2016. *Public Health Reports*, *137*(4), 655–659.

Maupin, G. O., Fish, D., Zultowsky, J., Campos, E. G., & Piesman, J. (1991). Landscape ecology of Lyme disease in a residential area of Westchester County, New York. *American Journal of Epidemiology*, *133*(11), 1105–1113.

Mead, P. (2022). Epidemiology of Lyme disease. *Infectious Disease Clinics of North America*, *36*(3), 495–521.

Mead, P., Hook, S., Niesobecki, S., Ray, J., Meek, J., Delorey, M., Prue, C., & Hinckley, A. (2018). Risk factors for tick exposure in suburban settings in the northeastern United States. *Ticks and Tick-borne Diseases*, *9*(2), 319–324.

Minnesota Department of Health. (2023). *Annual Summary of Communicable Diseases Reported to the Minnesota Department of Health, 2021. Minnesota Department of Health Disease Control Newsletter*. p. 1–28.

Moon, K. A., Pollak, J., Poulsen, M. N., Hirsch, A. G., DeWalle, J., Heaney, C. D., Aucott, J. N., & Schwartz, B. S. (2019). Peridomestic and community-wide landscape risk factors for Lyme disease across a range of community contexts in Pennsylvania. *Environmental Research*, *178*, 108649.

Nadelman, R. B., Nowakowski, J., Forseter, G., Goldberg, N. S., Bittker, S., Cooper, D., Aguero-Rosenfeld, M., & Wormser, G. P. (1996). The clinical spectrum of early Lyme borreliosis in patients with culture-confirmed erythema migrans. *The American Journal of Medicine*, *100*(5), 502–508.

Neitzel, D. F., & Kemperman, M. M. (2012). Tick-borne diseases in Minnesota: An update. *Minnesota medicine*, *95*(8), 41–44.

Nigrovic, L. E., Neville, D. N., Balamuth, F., Bennett, J. E., Levas, M. N., Garro, A. C., & for Pedi Lyme Net. (2019). A minority of children diagnosed with Lyme disease recall a preceding tick bite. *Ticks and Tick-borne Diseases*, *10*(3), 694–696.

Orloski, K. A., Campbell, G. L., Genese, C. A., Beckley, J. W., Schriefer, M. E., Spitalny, K. C., & Dennis, D. T. (1998). Emergence of Lyme disease in Hunterdon County, New Jersey, 1993: A case-control study of risk factors and evaluation of reporting patterns. *American Journal of Epidemiology*, *147*(4), 391–397.

Rand, P. W., Lubelczyk, C., Lavigne, G. R., Elias, S., Holman, M. S., Lacombe, E. H., & Smith, R. P. (2003). Deer density and the abundance of *Ixodes scapularis* (Acari: Ixodidae). *Journal of Medical Entomology*, *40*(2), 179–184.

Robinson, S. J., Neitzel, D. F., Moen, R. A., Craft, M. E., Hamilton, K. E., Johnson, L. B., Mulla, D. J., Munderloh, U. G., Redig, P. T., Smith, K. E., Turner, C. L., Umber, J. K., & Pelican, K. M. (2015). Disease risk in a dynamic environment: The spread of tick-borne pathogens in Minnesota, USA. *EcoHealth*, *12*(1), 152–163.

Schiffman, E. K., McLaughlin, C., Ray, J. A. E., Kemperman, M. M., Hinckley, A. F., Friedlander, H. G., & Neitzel, D. F. (2018). Underreporting of Lyme and other tick-borne diseases in residents of a high-Incidence County, Minnesota, 2009. *Zoonoses and Public Health*, *65*(2), 230–237.

Schwartz, A. M., Hinckley, A. F., Mead, P. S., Hook, S. A., & Kugeler, K. J. (2017). Surveillance for Lyme disease - United States, 2008-2015. *MMWR Surveillance Summaries*, *66*(22), 1–12.

Smith, G., Wileyto, E. P., Hopkins, R. B., Cherry, B. R., & Maher, J. P. (2001). Risk factors for Lyme disease in Chester County, Pennsylvania. *Public Health Reports*, *116*(Suppl 1), 146–156.

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

White, J., Noonan-Toly, C., Lukacik, G., Thomas, N., Hinckley, A., Hook, S., & Backenson, P. B. (2018). Lyme disease surveillance in New York state: An assessment of case underreporting. *Zoonoses and Public Health*, *65*(2), 238–246.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Earley, A. R., Schiffman, E. K., Wong, K. K., Hinckley, A. F., & Kugeler, K. J. (2024). Epidemiologic and tick exposure characteristics among people with reported Lyme disease – Minnesota, 2011–2019. *Zoonoses and Public Health*, *00*, 1–11. https://doi.org/10.1111/zph.13143

18632378, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13143 by The Wikipedia Library, Wiley Online Library on [30/05/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License