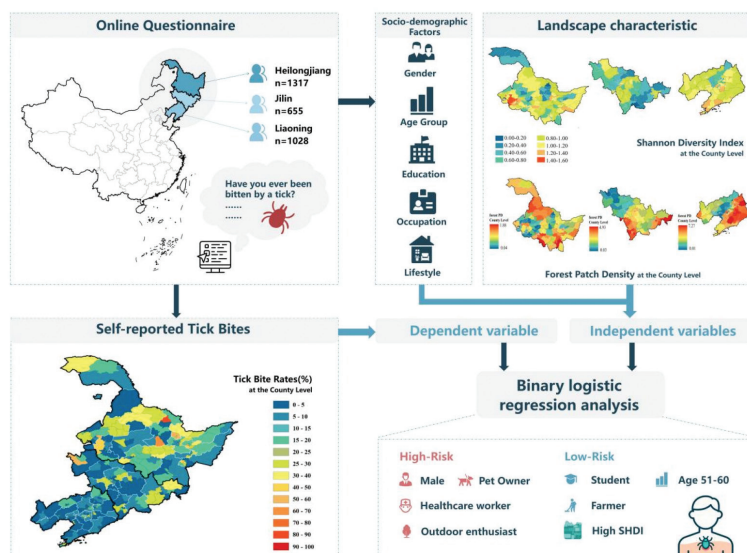




ORIGINAL ARTICLE

Tick Exposure Patterns and Associated Risk Factors in Northeastern China

Graphical abstract



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Brief statement

This study examined tick bite risk and prevention methods in northeastern China, where tick-borne diseases pose a significant public health challenge. Data were collected through an online survey of 3000 people and a landscape analysis. About 21% of participants reported tick bites, and the risk was influenced by specific demographic factors. Areas with low land-use diversity showed higher tick bite rates. These findings highlight the combined effects of human and environmental factors and support integrated prevention through public awareness, personal protection, and environmental management.

Highlights

- This study integrates socio-demographic, behavioral, and satellite-derived landscape data to assess tick bite risk in northeastern China.
- It identifies low land-use diversity as a key factor associated with higher tick exposure.
- Protective measures, particularly among individuals with prior exposure, are shown to effectively reduce risk.
- The findings support a targeted prevention framework that combines awareness, behavioral change, and environmental management.

Tick Exposure Patterns and Associated Risk Factors in Northeastern China

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Abstract

Background: In northeastern China, tick-borne diseases pose a major public health challenge, which is exacerbated by environmental and anthropogenic changes. This study was aimed at assessing the risk of tick bites and the effectiveness of protective measures in an endemic region, and investigating the influences of socio-demographic, behavioral, and landscape factors.

Methods: A comprehensive online survey was conducted among 3000 participants from Heilongjiang, Liaoning, and Jilin provinces between July and August 2022. Data on self-reported tick bites, protective measures, and associated socio-demographic characteristics were gathered. Landscape analysis was conducted with satellite imagery, and the Shannon diversity index (SHDI) and forest patch density (PD) were selected to quantify landscape factors. Factors influencing tick bite incidence were identified with a logistic regression model, and linkages between landscape characteristics and exposure risk were assessed with spatial statistics.

Results: Twenty-one percent of respondents reported experiencing tick bites, primarily during the active tick season (May to October). The self-reported incidence of tick-borne diseases (e.g., tick-borne encephalitis (TBE), Lyme disease (LD), and severe fever with thrombocytopenia syndrome (SFTS)) varied across provinces, and notable socio-demographic factors (e.g., age, gender, occupation, and lifestyle) associated with tick exposure were identified. Adoption of protective measures was high (80.3%) among the surveyed population, particularly among those who had previously experienced tick bites. Landscape analysis revealed an inverse relationship between land use diversity and tick bite incidence, thus suggesting that areas with lower land use diversity might have higher tick bite risk.

Conclusions: The study highlights the multifaceted nature of tick-borne disease risk in northeastern China and the importance of integrated strategies encompassing awareness, behavioral change, and environmental management to decrease tick exposure and prevent disease transmission. These insights might assist public health authorities in developing targeted interventions to combat the spread of tick-borne diseases in the region.

Key words: Tick Exposure, Protective Measures, Northeastern China, Land Use Diversity, Socio-Demographic Factors

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BACKGROUND

Ticks, a type of hematophagous arthropod, are prevalent in various regions worldwide. They can carry viruses, bacteria, and protozoa [1], and are considered the second most important vector after mosquitoes in the transmission of

pathogens affecting human and animal health [2].

The causative agents of TBE, LD, and SFTS have been increasingly detected in ticks across northeastern China in recent years [3]. TBE, a viral infection affecting the central nervous system [4], is an endemic infectious disease in northeastern

China that is naturally transmitted through tick bites. TBE is caused by the tick-borne encephalitis virus, which has multiple sub-types and poses a serious threat to global public health. The first recorded case of TBE occurred in China in 1942 [5,6]. From 2007 to 2017, the China Infectious Disease Epidemic Reporting System documented 3364 TBE cases. Most cases (89.9%) were concentrated in the densely forested regions of Daxing'anling, Xiaoxing'anling, and Changbai Mountain in northeastern China [7]. With a mortality rate of approximately 2%, TBE can lead to long-term morbidity, thus potentially affecting people's daily lives and leading to chronic complications [8]. Additionally, tick-borne diseases such as LD and SFTS are prevalent, and emerging tick-borne pathogens, such as Alongshan virus, have been identified in northeastern China [9–11]. Given the presence of 21 tick species across seven genera and two families in 96 counties of China's three northeastern provinces [12], research on ticks and their associated diseases is important to protect public health, safeguard agriculture and livestock, respond to environmental changes, and strengthen international cooperation and disease surveillance.

Recent studies in Europe have revealed that the risk of tick exposure extends beyond professional outdoor workers, such as forest rangers and farmers, and includes a wider urban and rural population [13–15]. The growing demand for urban and rural land for construction purposes leads to urban sprawl, which encroaches on green spaces and forests. Consequently, intensified fragmentation at urban outskirts might displace tick-carrying wildlife and force them to migrate from their natural habitats into human settlements, thus ultimately leading to increased tick bites [16–18] and facilitating the transmission of tick-borne diseases to humans [19]. Furthermore, with the development of ecotourism and urbanization, the public has increasing access to nature through the creation of urban green spaces, such as parks and gardens, and increased outdoor recreational amenities in suburban areas. These changes also markedly increase the risk of tick exposure among urban and rural populations. Consequently, tick exposure is no longer confined to rural landscapes and occupational settings but is increasingly becoming a common issue faced by both urban and rural residents.

Because of a lack of targeted treatments [20], control of tick-borne diseases relies on risk management strategies at the individual, family, and societal levels. These strategies involve increasing knowledge regarding tick-borne diseases and promoting proactive measures to avoid tick exposure. Several studies have revealed that certain individual behaviors can effectively decrease tick bites and tick-borne infections. These behaviors include using tick repellents before entering tick habitats [21], wearing long sleeves and pants [22], regularly inspecting clothing and skin for ticks [23], and, when necessary, wearing protective clothing [24]. Scientific evidence also indicates that prompt bathing after outdoor activities can effectively decrease LD risk [25]. However, many individuals or

households do not use adequate protective measures in their daily lives, because of various factors, such as limited awareness of the risks associated with tick bites and related diseases; practical obstacles such as the discomfort of wearing protective clothing in summer; a lack of belief in the efficacy and safety of protective measures, such as uncertainty regarding the effectiveness and potential toxicity of insect repellents; and personal behavioral habits and economic constraints [26,27].

Given the ongoing changes in land use, severe habitat fragmentation, increasing public interaction with green spaces, and insufficient use of protective measures, studying the risk of tick exposure among a broad spectrum of populations in northeastern China is essential for controlling existing tick-borne diseases, responding to emerging threats, and safeguarding regional public health. In this context, the main objectives of this study were: (i) to determine self-reported tick bites in northeastern China through an online questionnaire, and (ii) to explore the associations among protective measures, landscape risk factors, and tick exposure. This study provides novel empirical data for risk assessment of tick-borne diseases in high-prevalence areas of China. Our findings might serve as a foundation for public health strategies for prevention of tick-borne diseases.

MATERIALS AND METHODS

Study area

The survey area in this study includes Heilongjiang, Jilin, and Liaoning, the three province-level administrative regions in northeastern China (Fig 1). The population distribution across the region is uneven: higher population densities are found in the central and southern parts, whereas much lower densities are found in the northern and eastern areas. By the end of 2024, the permanent resident populations of each province comprised 30.29 million, 23.17 million, and 41.55 million people, respectively. The study area of 808400 km² extends from 118°E to 135°E longitude and from 38°N to 53°N latitude. Heilongjiang and Jilin primarily comprise the Xiaoxing'anling and Changbai mountain ranges, which support coniferous and broadleaf mixed forests, whereas Liaoning has a diverse landscape featuring small mountains, hills, the fertile Liao River Plain, and increasingly urbanized coastal areas. The region's heterogeneous land-use pattern encompasses forests, agricultural fields, grasslands, and expanding urban areas. The average forest coverage rate across the three provinces is 39.6%, a value exceeding the national average rate of 16.6%. Northeastern China is recognized as a high-risk zone for tick-borne diseases [28,29] because of its unique combination of biodiversity, climate-sensitive tick populations, and growing human activity in natural habitats. Therefore, it is a critical region for understanding how environmental and socio-behavioral factors interact in driving disease transmission.

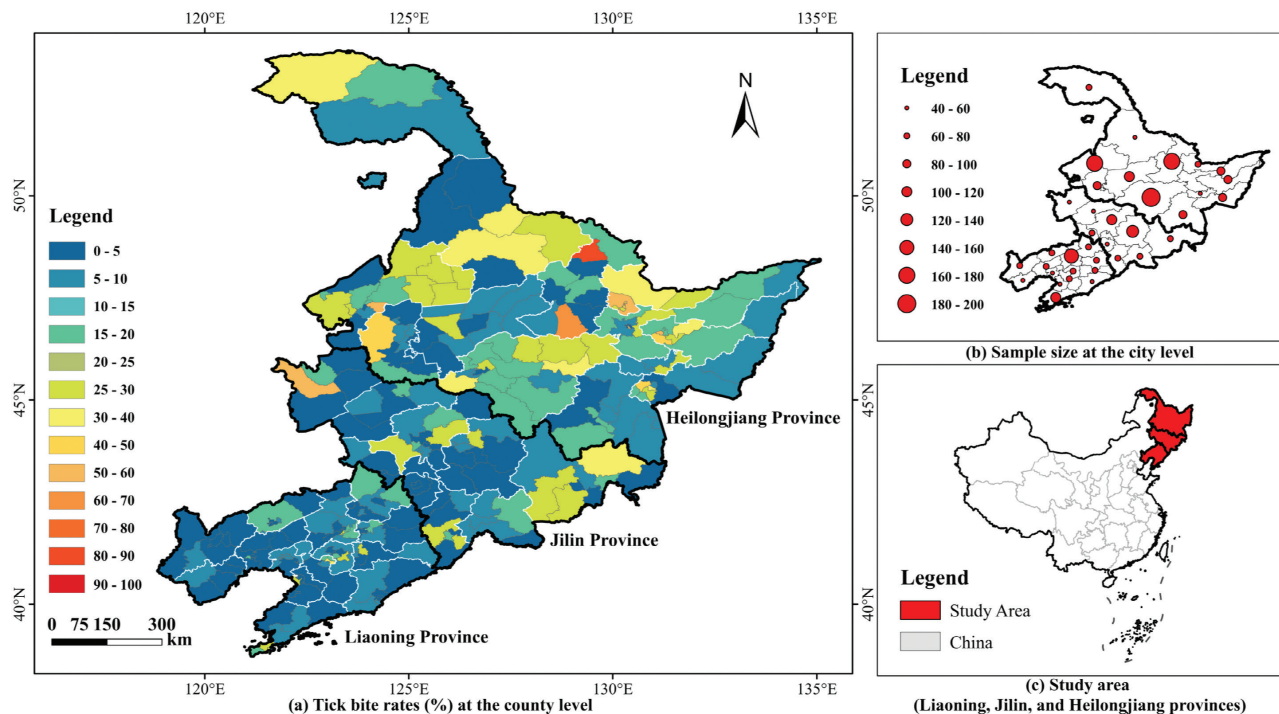


FIGURE 1 | Study area, sample size, and self-reported tick bite rates in Heilongjiang, Jilin, and Liaoning provinces, from a July–August 2022 survey covering the preceding 24 months. (a) Tick bite rates (%) at the county level. (b) Sample size at the city level. (c) Study area (Liaoning, Jilin, and Heilongjiang provinces).

Note: All intervals are defined as left-inclusive and right-exclusive (e.g., 0–5% denotes values $\geq 0\%$ and $< 5\%$).

Survey delivery and quality control

Questionnaire distribution and collection were conducted by Zhongyan Technology Company. The company specializes in market research, data analysis, and questionnaire design services, and owns Wenjuanxing, a well-known online questionnaire platform in China. The questionnaire was distributed online between July and August 2022 via the company's own community, Aidiaoyan (<https://www.idiaoyan.com>), targeting individuals 18 years or older residing in the three designated study areas. The online community comprises more than 10.43 million users and more than 3.92 million active users. It covers all major, medium, and small cities, as well as some rural towns in China, and can accurately locate users' cities. The platform follows standard procedures for data collection and respondent management, and fully adheres to principles of safety and fairness. The research content of this study posed no harm or risk to the respondents. All participants were voluntarily registered users who provided informed consent before participating and were able to opt out at any time without any consequences. To protect participant privacy, the study did not collect any personally identifiable information, such as names, home addresses, or contact details. All questionnaire data were processed anonymously and kept strictly confidential. The research content and findings are free from any conflicts of interest. Additional details are provided in the ethical statement. Any participant compensation was

managed solely by Zhongyan Technology Company and was not disclosed to the research team.

A total of 3000 responses were collected. Within each provincial-level division, county-level districts served as the primary sampling units. To ensure adequate representation and mitigate regional bias, at least ten individuals were sampled from each district, and each respondent could complete the questionnaire only once. This multi-stage sampling strategy helped minimize sampling errors. To further ensure data quality and reliability, the company used a comprehensive quality control process, including both pre-survey and post-survey controls, such as verification of user uniqueness, monitoring of response times, logical consistency checks, sample validation, data cleaning, and other procedures. Collectively, these measures enhanced the accuracy, robustness, and reliability of the survey data.

Questionnaire design

The questionnaire was developed in alignment with the research objectives and was administered in Chinese. The questionnaire required approximately 5 minutes to complete and comprised five main sections: 1) basic knowledge regarding ticks; 2) experience with tick bites within the past 5 years and 24 months; 3) perception of risk, assessed through participants' responses to several statements pertaining to ticks, with answer options of "I agree," "I disagree," or "I don't know"; 4) frequency of

use of protective measures, including checking the body for ticks and promptly removing them after outdoor activities, wearing long sleeves and pants, tucking pants into socks, applying insect repellents, avoiding tall trees and shrubs, inspecting pets for ticks, and showering after spending time in forest or grassy areas, with frequency options of “never,” “occasionally,” “often,” or “always”; and 5) socio-demographic characteristics, such as gender, age, place of residence, education level, occupation and lifestyle. Pets were defined as common outdoor animals such as dogs and cats that are susceptible to tick exposure. Most items were single-choice, but some multiple-choice questions were also included, particularly those assessing knowledge of ticks and tick-borne diseases. In addition, several questions on tick bites (e.g., number of bites, months of occurrence, bite settings, affected body parts, and geographic locations) were presented in a semi-structured, open-ended format, designed to guide respondents toward a limited range of expected responses. For example, the number of tick bites was expected to be reported as a numeric value, and locations were expected to be names of recognizable places. Some questions used conditional branching logic; therefore, whether they were displayed depended on responses to previous items. The approach was aimed at decreasing unnecessary response burden and minimizing potential sources of measurement error.

Several steps were taken to minimize the potential influence of common method bias. First, all survey items were carefully constructed to ensure clarity and avoid ambiguity, thus allowing respondents to interpret and answer questions accurately. Second, independent variables (e.g., lifestyle) and dependent variables (tick bite experiences) were intentionally separated into different sections of the questionnaire and phrased distinctly. This design was aimed at decreasing the respondents’ cognitive linking of different constructs, thereby mitigating the risk of biased responses because of perceived associations. Third, participants were explicitly informed that the survey was anonymous, and their responses would be kept strictly confidential; these measures helped decrease social desirability effects and encourage honest reporting.

Landscape variable preparation

The SHDI and forest PD were used to quantify the extent of landscape diversity and fragmentation in the study area. The study area included seven types of land cover: water surface, woodland, grassland, cropland, built area, bare land, and shrub. SHDI, a composite index that accounts for both the richness and evenness of land cover types, is widely used in landscape-scale biodiversity studies [30]. The SHDI is calculated with the formula $H = -\sum P_i \ln P_i$, where H represents the SHDI, and P_i denotes the proportional abundance of the i^{th} land cover type (i.e., the area of each patch type divided by the total area).

Forest fragmentation was assessed with PD, which was calculated from woodland cover data within the study area. Forest fragmentation refers to the breaking of continuous forest into smaller, isolated patches, through either natural processes or anthropogenic activities, and is considered a specific form of habitat fragmentation [31]. PD reflects the number of landscape patches per unit area, thereby indicating the heterogeneity and fragmentation of the forest landscape [32]. The formula for PD is

$PD = \frac{n_i}{A} \times 10000 \times 100$, where n_i is the number of patches in the landscape of patch type (class) i , and A is the total landscape area in square meters. The area is converted to units of 100 hectares by multiplying by 10000 and then by 100. The units of PD are number/100 hectares. In this study, PD refers specifically to forest patches. Therefore, n_i denotes the number of forest landscape patches.

Land cover data for 2021 were derived from Sentinel-2 satellite imagery with a 10-meter resolution, available through the ESRI platform.

Data analytical steps

First, we conducted a descriptive analysis of the questionnaire data. Data from the past 5 years were used primarily to analyze long-term patterns in tick-borne disease incidence. Data from the past 24 months captured the number and circumstances of recent tick bites, which were used to calculate tick bite rates. These datasets served different analytical purposes and were analyzed independently.

To systematically investigate associations among individual behaviors, lifestyle factors, landscape characteristics, and tick bites, we constructed binary logistic regression models. The dependent variable was defined as the presence or absence of tick bite experience (yes = 1, no = 0). Independent variables were selected according to prior empirical evidence or theories regarding tick exposure risk, by drawing on the literature describing demographic, behavioral, and environmental determinants. The independent variables included gender, age, education, occupation, lifestyle, and two landscape factors (SHDI and PD). The specific factors of the first five independent variables are shown in Table 1. Gender and lifestyle variables were treated as binary variables and included directly in the model. Age and education, both of which were multi-category variables, were converted into sets of dummy variables before model inclusion. The first category of each variable served as the reference group for interpretation. For the original occupation variable, which comprised 12 subcategories, direct inclusion posed challenges arising from sparse data, limited statistical interpretability, and potential multicollinearity. Because the study was aimed at assessing the specific effects of certain occupations, we used a two-step approach. First, univariate logistic regression analyses were conducted for each of the 12 original occupation categories, controlling for covariates such as

TABLE 1 | Demographic characteristics of 3000 respondents.

Variable	N (%)
Gender	
Men	1628 (54.2)
Women	1372 (45.7)
Age group	
18–30 yr	870 (29.0)
31–40 yr	1380 (46.0)
41–50 yr	564 (18.8)
51–60 yr	141 (4.7)
61–70 yr	27 (0.9)
71+ yr	18 (0.6)
Education	
Primary school or below	69 (2.3)
Completed junior high school	360 (12.0)
Completed high school	1030 (34.3)
Undergraduate degree	1468 (48.9)
Postgraduate or higher degree	73 (2.4)
Habitation	
Heilongjiang province	1317 (43.9)
Jilin province	655 (21.8)
Liaoning province	1028 (34.2)
Occupation	
Work in government/institutions or civil servant	138 (4.6)
Professional staff (teacher/lawyer/journalist)	191 (6.4)
Healthcare worker	118 (3.9)
General staff	1138 (37.9)
Enterprise owner/boss	153 (5.1)
Senior or middle-level management	233 (7.8)
Freelancer	473 (15.8)
Student	239 (8.0)
Farmer	184 (6.1)
Full-time parent	37 (1.2)
Retiree	66 (2.2)
Other	30 (1.0)
Lifestyle	
Keep pets	1745 (58.1)
Enjoy outdoor sports	2121 (70.7)
Frequently engaged in leisure activities in rural areas	2060 (68.6)

gender, age, and education. To rigorously account for the elevated risk of type I error (false positives) arising from these multiple univariate comparisons, we selected the

Bonferroni correction method to conservatively ensure that only robustly significant associations were carried forward. Associations for four occupational categories (healthcare worker, farmer, student, and general staff) remained statistically significant after this adjustment. These categories were subsequently included in the multi-variate model as independent binary variables (1 = yes, 0 = no) indicating whether each participant belonged to a specific occupational category. Landscape factors, specifically county-level SHDI and PD, were included as continuous variables. Ultimately, the final binary logistic regression model included gender, age (as dummy variables), education (as dummy variables), the four selected binary occupation variables (general staff, healthcare worker, farmer, and student), and the continuous landscape factors (SHDI and PD) as independent variables.

To ensure statistical robustness, we evaluated the adequacy of the sample size with the events-per-variable (EPV) criterion. The EPV is a key metric for determining the statistical power and reliability of a logistic regression model. Among the 3000 respondents, 630 reported at least one tick bite. For the final model with 14 independent variables, the EPV was 45 (630/14), exceeding the commonly recommended minimum of 10 EPV [33]. Therefore, the power was sufficient to detect moderate effect sizes (e.g., odds ratio ≥ 1.5) under standard assumptions ($\alpha = 0.05$, power = 0.80), thereby supporting the statistical validity of the findings.

To examine potential bias, we applied Harman's single-factor test to assess common method variance. An initial commonality below 40% suggests an absence of significant common method bias [34]. To further evaluate the validity of the model, we conducted multicollinearity diagnostics among the variables with the variance inflation factor; values < 10 indicated negligible collinearity [35]. Whereas Harman's test indicates whether a single factor accounts for a large proportion of the variance, variance inflation factor analysis ensures that predictors are not highly correlated. Together, these steps confirmed the independence of variables and the validity of the regression analysis.

The model was refined through a backward stepwise-conditional approach, and likelihood ratio tests were applied to progressively eliminate non-significant variables until all remaining covariates met the 0.05 significance threshold. The fit of the final logistic regression model was evaluated with the Hosmer–Lemeshow test, for which a value > 0.05 supports the model's adequacy. Receiver operating characteristic (ROC) curve analysis was used to assess the predictive ability of the regression model, according to the method proposed by Hanley and McNeil [36]. The ROC curve was generated by plotting the true positive rate against the false positive rate across a range of probability thresholds, comparing the model's predicted probabilities of tick bites with the actual reported outcomes. The area under the curve (AUC) was used to quantify the classification performance. AUC values above 0.7

are generally considered to indicate acceptable predictive capability [37]. The AUC of this model was 0.71. To further explore determinants of protective measures against tick bites, we constructed six additional binary logistic regression models. Each model used one specific protective measure (yes/no) as the dependent variable, and the same fitting and evaluation methods as described above.

All statistical analyses were performed in IBM SPSS Statistics version 27.0. Landscape factors were calculated with FRAGSTATS version 4.2.1. Geographic data processing and thematic map creation were conducted in ArcGIS version 10.7.

RESULTS

Overview of survey participants

Responses were received from 1317 (43.9%), 1028 (34.2%), and 655 (21.8%) individuals from Heilongjiang, Liaoning, and Jilin provinces, respectively, in northeastern China. The 3000 participants comprised 1628 men (54.2%) and 1372 women (45.7%) (Table 1). All participants were older than 18 years, and approximately 46% were 31–40 years of age. Nearly half the respondents held an undergraduate, postgraduate, or higher degree. The cohort represented a broad spectrum of professional sectors, including healthcare, education, government administration, business management, agriculture, academia, and freelance occupations. Notably, 58.1% of the respondents were pet owners, and almost 70% reported a keen interest in outdoor activities and often visited rural areas for recreational purposes.

Self-reported tick bites

In the prior 24 months, 630 respondents (21.0%) reported tick bites affecting themselves, their family members, or their pets. Most tick bites occurred during the peak tick season, primarily between May and October, and 32.6% occurred in August. Parks were the most common sites where tick bites occurred (35.5%), and were followed by grasslands (29.4%), and forests (21.1%). The distribution of bite sites in Heilongjiang and Jilin provinces mirrored the overall trend. However, in Liaoning Province, 40.0% of tick bites occurred in grasslands, possibly because of the extensive grassland coverage and grassland tourism resources. In humans, tick bites most frequently occurred on the legs, hands, and arms, whereas in pets, the face, paws, abdomens, and ears were most commonly affected. Among participants reporting tick bites, 50.9% experienced a single incident, whereas approximately 7% reported multiple bites (five or more).

The mean number of tick bites per respondent over the previous 24 months was 1.99 in Heilongjiang, 1.66 in Liaoning, and 1.93 in Jilin. Despite these relatively similar averages, the three provinces displayed considerable variation in self-reported tick bite prevalence. The factors contributing to these differences are examined in the Discussion section, particularly in relation to landscape.

The self-reported tick bite rates among respondents were 20.7% in Heilongjiang, and were lower in Liaoning and Jilin (7.8% and 9.3%, respectively). Notably, 10.3% of respondents reported having been diagnosed with TBE after a tick bite in the prior 5 years, whereas the self-reported rates of LD and SFTS post-bite were approximately half that of TBE, at 4.9% and 5.2%, respectively. However, because the present study was based solely on self-reported data without clinical confirmation or detailed exposure assessment, no direct causal inference can be drawn between reported tick bites and subsequent disease occurrence. Self-reported tick bite rates at the county level in three provinces are shown in Fig 1.

Socio-demographic factors associated with tick bites

Binary logistic regression analysis identified several socio-demographic factors significantly associated with tick bites, including age, gender, occupation, and life-style (Table 2). The analysis revealed variations in the risk of tick bites across age groups. Notably, individuals 51–60 years of age exhibited a likelihood of tick bites 0.40 times that observed among individuals 18–30 years of age (OR = 0.40, 95% CI: 0.22–0.74). Moreover, men were more likely to experience tick bites than women (OR = 1.29, 95% CI: 1.07–1.56).

In terms of occupation, students (OR = 0.44, 95% CI: 0.28–0.67) had a lower likelihood of tick bites than non-students. Unexpectedly, farmers, despite their presumed elevated exposure risk because of prolonged outdoor activities, were 0.58 times less likely to be bitten by ticks than non-farmers (OR = 0.58, 95% CI: 0.36–0.96). Interestingly, healthcare workers appeared to have an elevated risk of tick bites (OR = 1.72, 95% CI: 1.13–2.63). Additionally, individuals keeping pets faced a risk 3.76 times that of individuals without pets (OR = 3.76, 95% CI: 2.99–4.72). Elevated risks were also observed among individuals participating in outdoor sports (OR = 1.28, 95% CI: 1.00–1.64) and those frequently engaging in leisure activities in rural areas (OR = 1.32, 95% CI: 1.03–1.69).

Adoption of protective measures

Among the 3000 respondents, 80.3% ($n = 2410$) reported taking five or more of the listed measures (occasionally, often, or always), and 20.9% ($n = 627$) reported adhering to all seven. However, 0.8% ($n = 24$) of respondents, 75.0% ($n = 18$) of whom were from Liaoning, reported not using any protective measures. Wearing long sleeves and pants (65.3%) and showering after activities in forest or grassy areas (61.1%) were the two most commonly practiced measures. Checking the body and removing ticks was less frequently practiced (46.7%). Detailed frequencies of use of protective measures are shown in Tables 3 and 4.

The results of the other six regression models (Table 5) indicated a strong correlation between experiencing tick bites and using certain protective measures. Respondents with a history of tick bites were more likely than those

TABLE 2 | Factors associated with tick bites in northeastern China: binary logistic regression (N = 3000).

Variable	B	SE	OR	95% CI
Men**	0.26	0.10	1.29	1.07 1.56
Healthcare worker*	0.54	0.22	1.72	1.13 2.63
Student***	-0.83	0.22	0.43	0.28 0.67
Farmer*	-0.56	0.25	0.58	0.36 0.96
Keep pets***	1.32	0.12	3.76	2.99 4.72
Enjoy outdoor sports*	0.25	0.13	1.28	1.00 1.64
Engaged in leisure activities in rural areas*	0.28	0.14	1.32	1.03 1.69
Age 31–40 yr*	-0.25	0.12	0.78	0.62 0.98
Age 41–50 yr*	-0.38	0.15	0.69	0.52 0.91
Age 51–60 yr**	-0.92	0.32	0.40	0.22 0.74
Age 61–70 yr ^{ns}	-1.80	1.04	0.17	0.02 1.27
Age 71+ yr ^{ns}	-0.53	0.78	0.59	0.13 2.74
Shannon diversity index (SHDI)***	-0.59	0.15	0.56	0.41 0.75
Forest patch density (PD) ^{ns}	-0.08	0.05	0.92	0.84 1.01

Note: (1) * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; ns, insignificant. (2) CI = confidence interval; OR = odds ratio; SE = standard error, B = regression coefficient. (3) The model was developed with a stepwise variable selection method, in which the independent variables were iteratively included or excluded on the basis of statistical criteria. Only the variables retained in the final model are presented in Table 2.

without such experience to engage in three key protective measures: checking the body and promptly removing ticks after outdoor activities (OR = 1.20, 95% CI: 1.00–1.44), using insect repellents (OR = 1.31, 95% CI: 1.09–1.58), and showering after visiting forested or grassy environments (OR = 1.42, 95% CI: 1.17–1.72). Men (OR = 0.78, 95% CI: 0.67–0.90) were less likely than women to avoid staying close to trees and shrubs. However, no statistically significant gender-specific differences were observed for the remaining five protective measures. Respondents engaging in outdoor sports and frequent leisure activities in rural areas demonstrated greater awareness and were more likely to practice all six protective measures than the other respondents.

Landscape factors associated with tick bites

The mean SHDI for Liaoning, Jilin, and Heilongjiang provinces was 1.41, 1.30, and 1.19 (Fig 2). A higher SHDI indicates more balanced representation of multiple land use types. In terms of land use composition, cropland was the main land cover in Liaoning, accounting for 38.4% of the total area, whereas forests were the major land cover in Jilin and Heilongjiang, and comprised 39.9% and 45.6% of their area, respectively.

Tick bite rates showed a strong negative correlation with the SHDI (OR = 0.56, 95% CI: 0.41–0.75, $p < 0.001$).

After stratification by SHDI category, the mean tick bite rates showed a clear inverse gradient: 23% in low-SHDI areas (0–0.5), 16.1% in moderate-SHDI areas (0.5–1.0), and 10.2% in high-SHDI areas (1.0–1.5) (all intervals were defined as left-inclusive and right-exclusive). This overall pattern was also reflected at the provincial level. For instance, Heilongjiang, which had the lowest SHDI (1.19), had a tick bite rate of 20.7%, a value notably higher than those observed in Jilin and Liaoning (9.5% and 7.8%, respectively). We outlined possible ecological mechanisms in the Discussion section to further explain this counter-intuitive inverse relationship.

The average PD values in Heilongjiang, Liaoning, and Jilin were 0.44, 1.64, and 0.97, respectively, thus indicating that Liaoning experienced the most severe forest fragmentation. However, forest PD varied significantly across districts and counties within each province. In particular, northern Heilongjiang, southern Jilin, and eastern Liaoning exhibited more pronounced fragmentation than other regions in the same provinces. Although forest PD was not a statistically significant factor associated with tick bites in the binary logistic regression model (OR = 0.92, 95% CI: 0.84–1.01), a spatial association was observed between higher forest PD and self-reported LD diagnosis in certain provinces. In Liaoning, for instance, the average value of forest PD in counties reporting LD diagnosis (2.14) was 1.30 times that in counties without reported diagnosis (1.64), and a similar pattern was observed in Jilin (1.31 times). Notably, these patterns, derived from aggregated self-reported diagnosis data, reflect exploratory spatial trends rather than statistically tested or causal relationships. This divergence suggests a complex ecological linkage between forest PD and tick bites, which might potentially be mediated by factors such as host abundance, microclimatic conditions, and human-environment interactions. Further empirical research is warranted to disentangle these interacting mechanisms and to validate the patterns observed in this study.

DISCUSSION

Regional variations in tick exposure and underlying factors

Geographically, Heilongjiang, Jilin, and Liaoning provinces form a distinct unit characterized by frequent changes in administrative distribution and a shared cultural identity. Consequently, they are often analyzed as a cohesive entity. However, the present study revealed substantial variance in self-reported tick bites across the three provinces. Respondents from Heilongjiang reported markedly more tick bites (20.7%) than those from Jilin (9.5%) and Liaoning (7.8%). Notably, Heilongjiang does not have the highest number or widest distribution of tick species among the three northeastern provinces [3], thus challenging the assumption that tick bite rates directly correlate with tick abundance or diversity. This discrepancy

TABLE 3 | Number of people who never or occasionally used the seven protective measures in Heilongjiang, Jilin, and Liaoning Provinces.

Protective measures	Bitten	Heilongjiang Province		Jilin Province		Liaoning Province	
		Never	Occasionally	Never	Occasionally	Never	Occasionally
		n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Checking body for ticks and promptly removing them after outdoor activities	1	32 (8.5)	171 (45.3)	6 (5.9)	35 (34.3)	12 (7.9)	52 (34.4)
	0	169 (18.0)	355 (37.7)	51 (9.2)	165 (29.8)	180 (17.5)	370 (37.8)
Wearing long sleeves and pants	1	34 (9.0)	108 (28.6)	9 (8.8)	22 (21.5)	2 (1.3)	45 (29.8)
	0	64 (6.8)	295 (31.3)	35 (6.3)	150 (27.1)	57 (5.5)	265 (27.1)
Tucking pants into socks	1	69 (18.3)	117 (31.0)	22 (21.6)	28 (27.4)	19 (12.6)	47 (31.1)
	0	179 (19.0)	257 (27.3)	114 (20.6)	142 (25.6)	205 (19.9)	273 (27.9)
Applying insect repellents	1	26 (6.9)	119 (31.5)	15 (14.7)	26 (25.4)	15 (9.9)	47 (31.1)
	0	139 (14.8)	306 (32.5)	64 (11.6)	160 (28.9)	211 (20.5)	311 (31.8)
Staying away from tall trees and shrubs	1	32 (8.5)	118 (31.2)	5 (4.9)	36 (35.2)	11 (7.3)	55 (36.4)
	0	85 (9.0)	309 (32.8)	43 (7.8)	166 (30.0)	149 (14.5)	347 (35.5)
Checking pets for ticks	1	133 (35.3)	80 (21.2)	54 (52.9)	14 (13.7)	98 (64.9)	9 (5.9)
	0	638 (67.9)	111 (11.8)	345 (62.4)	59 (10.6)	762 (74.1)	35 (3.5)
Showering after activities in forest or grassy areas	1	48 (12.7)	84 (22.2)	12 (11.8)	15 (14.7)	17 (11.3)	31 (20.5)
	0	157 (16.7)	258 (27.4)	93 (16.8)	106 (19.1)	185 (18.0)	159 (16.2)

Note: (1) Codes 1 and 0 represent people who were bitten or not bitten, respectively.

TABLE 4 | Number of people who often or always used the seven protective measures in Heilongjiang, Jilin, and Liaoning Provinces.

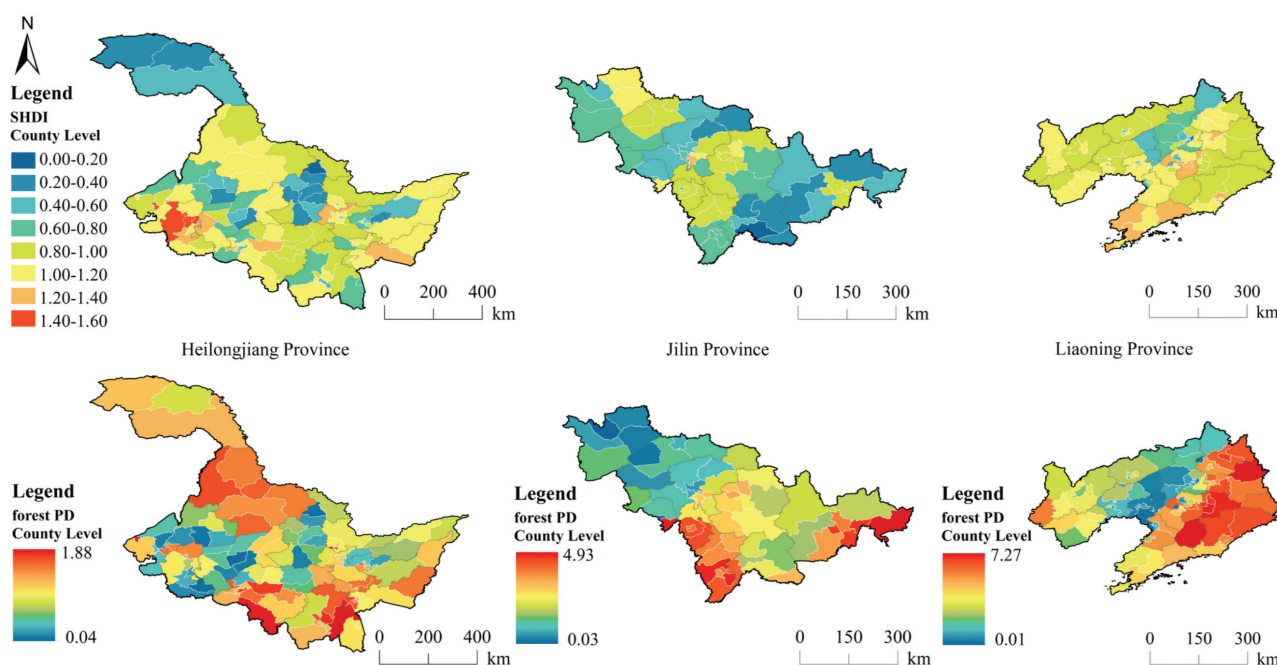
Protective measures	Bitten	Heilongjiang Province		Jilin Province		Liaoning Province	
		Often	Always	Often	Always	Often	Always
		n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Checking body for ticks and promptly removing them after outdoor activities	1	135 (35.8)	39 (10.3)	44 (43.1)	17 (16.7)	66 (43.7)	21 (13.9)
	0	307 (32.6)	109 (11.6)	244 (44.1)	93 (16.8)	215 (22.0)	112 (10.9)
Wearing long sleeves and pants	1	156 (41.3)	79 (21.0)	42 (41.1)	29 (28.4)	66 (43.7)	38 (25.2)
	0	381 (40.5)	200 (21.3)	213 (38.5)	155 (28.0)	468 (47.9)	238 (23.2)
Tucking pants into socks	1	123 (32.6)	68 (18.0)	37 (36.2)	15 (14.7)	54 (35.7)	31 (20.5)
	0	303 (32.2)	201 (21.4)	192 (34.7)	105 (19.0)	254 (25.9)	145 (14.1)
Applying insect repellents	1	172 (45.6)	60 (15.9)	43 (42.1)	18 (17.6)	60 (39.7)	29 (19.2)
	0	331 (35.2)	164 (17.4)	196 (35.4)	133 (24.1)	245 (25.0)	110 (10.7)
Staying away from tall trees and shrubs	1	145 (38.4)	82 (21.8)	42 (41.1)	19 (18.6)	53 (35.0)	32 (21.2)
	0	373 (39.6)	173 (18.4)	249 (45.0)	95 (17.2)	244 (24.9)	137 (13.3)
Checking pets for ticks	1	108 (28.6)	56 (14.9)	23 (22.5)	11 (10.8)	20 (13.2)	24 (15.9)
	0	130 (13.8)	61 (6.5)	84 (15.1)	65 (11.8)	46 (4.7)	34 (3.3)
Showering after activities in forest or grassy areas	1	136 (36.0)	109 (28.9)	43 (42.1)	32 (31.4)	62 (41.0)	41 (27.2)
	0	307 (32.6)	218 (23.2)	192 (34.7)	162 (29.3)	322 (32.9)	211 (20.5)

Note: (1) Codes 1 and 0 represent people who were bitten or not bitten, respectively.

TABLE 5 | Factors significantly associated with the adoption of six protective measures against tick bites.

		Having been bitten by ticks (vs. not having been bitten by ticks)	Enjoying outdoor sports (vs. not enjoying outdoor sports)	Engaging in outdoor sports and frequent leisure activities in rural areas (vs not engaging in activities described above)	Men (vs women)
Model 1	Checking body for ticks and promptly removing them after outdoor activities	OR = 1.20 (95% CI: 1.00–1.44)	OR = 1.50 (95% CI: 1.25–1.80)	OR = 1.29 (95% CI: 1.07–1.53)	
Model 2	Wearing long sleeves and pants		OR = 1.20 (95% CI: 1.00–1.45)	OR = 1.30 (95% CI: 1.09–1.56)	
Model 3	Tucking pants into socks		OR = 1.39 (95% CI: 1.16–1.66)	OR = 1.43 (95% CI: 1.20–1.70)	
Model 4	Applying insect repellents	OR = 1.31 (95% CI: 1.09–1.58)	OR = 1.20 (95% CI: 1.00–1.44)	OR = 1.38 (95% CI: 1.15–1.65)	
Model 5	Staying away from tall trees and shrubs		OR = 1.24 (95% CI: 1.58–1.46)		OR = 0.78 (95% CI: 0.67–0.90)
Model 6	Showering after activities in forest or grassy areas	OR = 1.42 (95% CI: 1.17–1.72)		OR = 1.33 (95% CI: 1.14–1.56)	

Note: (1) OR = odds ratio, CI = confidence interval. (2) The models were developed with a stepwise variable selection method, in which the independent variables were iteratively included or excluded on the basis of statistical criteria. Only the significant variables ($p < 0.05$) are presented in Table 5.

**FIGURE 2** | Comparison of Shannon diversity index (SHDI) and forest patch density (PD) among Heilongjiang, Jilin, and Liaoning provinces. Note: All intervals are defined as left-inclusive and right-exclusive (e.g., 0.00–0.20 denotes values ≥ 0.00 and < 0.20).

confirmed that tick bite rates are influenced by multiple factors, including differences in human behaviors, local ecological conditions, and the potential underreporting of tick populations in this region.

Additionally, Heilongjiang has the most extensive forest coverage and the largest area of forestry operations. Previous research has identified the Xing'an Mountains in Heilongjiang province as an endemic region for TBE [38], where the virus circulates within the environment.

Suitable habitats might contribute to a greater presence of ticks, thus placing individuals who live, work, or engage in recreational activities in wooded environments at elevated risk of exposure. Climatic and landscape heterogeneity among the three provinces further shapes the spatial distribution of tick bites. In Heilongjiang and Jilin provinces, most bites were reported in parks, followed by grasslands and forests, whereas in Liaoning province, tick bites occurred most frequently in grasslands. Although

these findings differ from the results of a recent national survey in France [39], the underlying causes are analogous: Liaoning has extensive grasslands, well-developed grassland tourism resources, and distinct land use and landscape composition, in contrast to the other two provinces. These findings highlight the need for public health interventions to integrate climatic and landscape variability into tick-borne disease prevention strategies.

Effectiveness, gender differences, and regional variations in the use of protective measures

Studies on the use of protective measures against tick-borne diseases are common in endemic areas but have often yielded inconsistent results. In a study in Lublin Province, Poland (2020–2022), 92.2% of individuals checked their bodies after outdoor activities; 80.9% wore protective clothing; and 76.0% used repellents in tick habitats, which was the least favored method [40]. In contrast, in a survey among Hispanic populations in the U.S., the predominant protective measure to avoid tick bites was applying insect repellents (28.5%), followed by body checks (11.6%) and showering after time outdoors (11.2%) [41].

In our study, the most frequently reported measures were wearing long sleeves and pants (41.8%) and showering after activities in forests or grasslands (40.0%). Avoiding tall vegetation (39.3%) and using repellents (37.2%) ranked slightly lower. Approximately one-third of respondents tucked their pants into their socks (34.8%) and checked for and removed ticks after outdoor activities (32.9%). Among pet owners, 37.9% frequently checked their pets for ticks. Meanwhile, preferences for the seven protective measures varied slightly across the three provinces, in agreement with observations from the Northeastern United States [42]. Although 80.3% of respondents reported using multiple (five or more) protective measures, the proportion applying these measures consistently (indicating “frequently” or “always”) remained low.

A marked difference in the use of repellents was observed across studies. This discrepancy might have reflected differing public health strategies and levels of public confidence in repellents [43] across countries. Despite ongoing debates regarding their efficacy, safety, and cost-effectiveness, insect repellents remain widely recommended by authorities [44]. Our findings highlight a general reluctance to use repellents as a primary protective measure, thus underscoring the need for robust product evaluations in China to strengthen public trust and uptake.

We also observed that individuals with a history of tick bites were significantly more likely to use specific protective measures, particularly checking their bodies for ticks, applying insect repellents, and showering after outdoor exposure. This pattern might reflect behavioral adjustments after exposure, either through increased perceived risk or experiential learning. Protective measures might have been initiated or intensified after an initial tick bite. Moreover, insufficiency of previous measures

might have prompted more active post-exposure practices. Previous research has indicated that combining body checks and showering offers enhanced protection against tick bites, particularly during prolonged exposure [45], whereas measures such as tucking pants into socks or wearing light-colored clothing have yielded mixed evidence regarding efficacy [46]. Nevertheless, consistent use of protective measures cannot ensure complete prevention, because their effectiveness may be influenced by a range of ecological and biological factors, including repellent resistance, tick host-seeking behavior, environmental exposure intensity, and proper implementation of the measures. Future research is warranted to evaluate the effectiveness and limitations of commonly used protective methods across diverse ecological contexts.

Gender-specific differences are often noted in the discussion of factors associated with tick exposure prevention. In a study by Gupta et al., women in Delaware were more aware and proactive in taking protective measures than men [47]. Aenishaenslin et al. have presented mixed findings, with one study indicating higher preventive action rates among women than men (82% vs. 69%) [48] and another showing lower preventive behavior scores [49]. In our study, gender differences were observed only in the avoidance of tall trees and shrubs, and we observed no significant correlation between gender and other protective measures. These findings suggested that the efficacy of gender-targeted prevention campaigns for decreasing tick exposure risk remains inconclusive.

Effects of human behavior and environmental factors on tick exposure

Regression analysis revealed that profession was significantly associated with the population’s risk of tick bites. Specifically, students exhibited a relatively low incidence of tick bites, whereas farmers, previously considered a high-risk group, were 0.58 times less likely to experience tick bites than non-farmers [39]. These findings differ from those of previous studies in which farmers reported higher tick bites than administrative employees [50]. Two factors might explain this discrepancy. First, our study was based on self-reported data, which might not have fully captured the actual prevalence of tick bites among farmers. A low reporting rate does not necessarily indicate a low actual risk but instead might reflect farmers’ limited awareness or difficulties in identifying tick bites and early symptoms of tick-borne diseases. This interpretation is supported by the pattern observed among healthcare workers, who were more likely to report tick bites than non-healthcare workers, possibly because of their heightened health literacy and greater ability to recognize tick exposure. Second, cross-country differences in cultural and healthcare contexts might have influenced respondents’ behavior. Although self-reported data are commonly used in epidemiological studies, some studies have supplemented them with objective diagnostic approaches, such as serological testing for IgG antibodies to tick-borne

pathogens. These methods offer a more direct measure of prior exposure that is independent of respondents' awareness or recall. In contrast, our self-reported data, particularly among farmers, were likely to have reflected a substantial awareness gap and to have contributed to underreporting of tick bites. Therefore, targeted educational interventions are critical among agricultural populations in Northeastern China.

Lifestyle factors were also significantly associated with tick bite risk, particularly among pet owners and individuals engaging in outdoor activities. Owning a dog, for instance, has been associated with a likelihood of tick bites 2.7 times that among non-pet owners [51]. These risks might vary depending on pet species, pet housing conditions, access to tick-prone areas such as grasslands or forests, tick control practices, and pet hygiene behaviors. Similarly, participating in outdoor activities correlates with elevated tick bite frequencies [52,53]. Variations in the type, frequency, and location of outdoor activities might also influence exposure, thus highlighting the need for refined risk assessment and targeted policy measures for high-risk populations.

In analyzing the associations between landscape metrics on tick bites and the SHDI and PD, we observed a negative correlation between SHDI and tick bites, but no significant association between forest PD and tick bite risk. Although this finding might appear counterintuitive, it can be better understood by considering two perspectives: the effects of landscape heterogeneity on tick population density and host community structure. First, regarding tick population density, heterogeneous landscapes (higher SHDI) generally comprise a mosaic of land use, including diverse habitats, thus potentially increasing the overall environmental complexity. Whereas some studies have suggested that complex landscapes support higher tick densities [54,55], others have indicated that non-forested or intensively managed land use (e.g., croplands or pastures) can be unsuitable for ticks and limit their population [56]. Second, more importantly, landscape heterogeneity might affect the composition and abundance of tick hosts, thereby influencing pathogen transmission risk. In low-SHDI landscapes, characterized by homogeneous land cover dominated by a single type (e.g., extensive farmland, continuous forest, or urban development), tick communities are often dominated by several generalist, competent reservoir hosts, such as *Peromyscus leucopus*. These rodents thrive in relatively simple landscapes with few predators and competitors, and they are efficient reservoirs of tick-borne pathogens. In contrast, high-SHDI areas tend to support greater host biodiversity, including less competent or non-competent species, which might dilute the pathogen transmission cycle, in a phenomenon known as the dilution effect.

We additionally explored the role of forest fragmentation by using PD as a proxy. Although our regression analysis did not identify a significant association between forest PD and tick bites, counties with rather than without

confirmed LD cases in Liaoning and Jilin provinces had slightly higher forest PD values, thus suggesting a potential ecological link. Fragmented forests might increase tick-borne disease risk through two mechanisms: (i) direct effects on tick density, as shown by Allan et al. [57], who have found an association between smaller forest patches and higher densities of infected tick nymphs, and (ii) indirect effects on host dynamics, because forest edges and patch isolation promote favorable conditions for rodent hosts by increasing ecotone habitats and decreasing predation pressure [58,59]. Importantly, SHDI is a macro-scale index, and its observed relationship with tick bite risk might be confounded by unmeasured micro-environmental and behavioral factors, such as human activity patterns, local vegetation structure, or microclimate conditions. Additionally, factors such as spatial scale [54], forest stand structure [52], patch connectivity [60], elevation, and regional climate further contribute to these complex dynamics. These complex mechanisms of influence are beyond the scope of this study and warrant more refined investigation in future research.

Public health implications and policy recommendations

To address the public health challenges posed by tick exposure and tick-borne diseases, several strategies are recommended: (i) Awareness of ticks and related diseases must be increased, particularly among high-risk groups such as farmers, foresters, pet owners, and outdoor enthusiasts. Tailored educational campaigns are needed to disseminate information on risks, protective measures, and appropriate responses after tick bites. Special emphasis should be placed on regions such as Heilongjiang, where tick bite rates are notably high. (ii) Improved understanding and monitoring of tick populations and the diseases they carry will be essential. Achieving these goals will require comprehensive field investigations to evaluate the influence of environmental factors such as landscape diversity and forest fragmentation on tick prevalence and disease transmission. (iii) Landscape management strategies should be used to decrease suitable tick habitats and thereby limit human exposure. Recommended practices include minimizing forest fragmentation, preserving biodiversity, and integrating these ecological considerations into land use planning to mitigate conditions that facilitate tick proliferation. (iv) Public health guidelines should emphasize consistently using repellents, wearing appropriate clothing, and performing thorough body checks after exposure to tick-prone environments. Increased public use of these protective measures will be critical to decrease tick bites and prevent associated diseases.

Limitations and future research directions

Our study has several limitations. First, the data were collected through online questionnaires, and respondents' self-reports might have been subject to information and common method biases, which are frequently encountered

in similar studies [41,61]. These biases might potentially have led to inaccurate estimation of the true tick bite incidence, because not all tick bites might have been observed or reported by participants, and other arthropods, particularly in immature stages, can be mistakenly identified as ticks. This limitation was further compounded by the absence of clinical confirmation, which decreased the reliability of self-reported tick bites and tick-borne disease incidence, and hindered determination of any definite associations between tick bites and disease outcomes. Second, although our spatially stratified sampling strategy ensured broad geographic coverage, certain key groups, such as older adults, individuals younger than 18 years, rural residents, and people living in remote regions with limited internet access, might have been underrepresented because of the inherent constraints of the online survey methods. Although the overall sample size was sufficient to detect significant associations at the population level, the interpretation of associations for some smaller subgroups should be approached with caution due to widened confidence intervals and reduced statistical precision. Third, this study might have been subject to residual clustering effects, because individuals within the same county might have shared common risk factors for tick exposure, and the sample sizes across provinces were not proportional to their population sizes. Together, these aspects might have influenced the comparability of provincial results and introduced minor structural bias into the overall analysis. Finally, tick bites and human exposure data are influenced by a complex interplay among ecological suitability, host abundance, human activity patterns, as well as potential differences in surveillance or reporting systems. This study relied solely on satellite imagery to conduct a large-scale analysis, without fieldwork to capture finer-scale climatic and landscape features more directly relevant to the respondents' exposure environments. Moreover, potential spatial auto-correlation between SHDI/PD and tick bite incidence was not explicitly addressed. The lack of further investigation of such spatial dependencies might have inflated the statistical significance of the observed associations.

Future studies should use mixed-method approaches, combining online and offline surveys (e.g., paper-based questionnaires, telephone and in-person interviews, or focus groups), and involving local health workers or community organizations to conduct field surveys in underrepresented areas. To improve the accuracy of self-reported tick bite data, we recommend including high-resolution images of ticks at different life stages, alongside visually similar arthropods for direct comparison. Additionally, more standardized and detailed questions regarding bite characteristics, such as appearance of the attached organism and duration of attachment, might strengthen the reliability of survey data. Objective diagnostic data, such as medical records, serological surveys, or laboratory-based testing, should be incorporated to

increase diagnostic accuracy and the validity of epidemiological associations.

Future studies should also combine field ecological surveys with satellite remote sensing imagery and use higher-resolution technologies to enhance the accuracy of landscape data. In addition, future research should consider using more advanced spatial statistical models, such as spatial lag/error models, to better account for geographic clustering, strengthen causal inference, and clarify the ecological drivers of tick exposure. Longitudinal studies are recommended to track changes in tick exposure and evaluate the effectiveness of protective measures across diverse ecological backgrounds and demographic groups.

CONCLUSION

This study provided an overview of individual tick exposure and protective measures in Northeastern China, on the basis of a comprehensive online questionnaire survey. It examined the correlations of various socio-demographic and landscape factors with tick bites, and explored potential underlying mechanisms. The findings might contribute to public health policies, and enhance knowledge, education, and awareness. Our analysis indicated that tick bite risk is associated with factors such as geographic region, occupation, lifestyle, and landscape characteristics. We also identified a potential lack of relevant knowledge and frequent inaccurate self-diagnosis among farmers. We recommend strengthening awareness and education efforts among high-risk groups, improving data collection processes for tick bites and tick-borne diseases, and further investigating how ecological changes influence tick populations.

DATA AVAILABILITY STATEMENT

Supplementary data and materials supporting the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study involved an anonymous online survey and contains no data enabling identification of individuals. All participants provided informed consent before participating in the study and could choose to terminate their participation in the study at any time.

AUTHOR CONTRIBUTIONS

Sirui Li and Yunting Lyu were responsible for conceptualization, methodology, investigation, formal analysis, data curation, validation, writing – original draft, and visualization. Ruying Fang, Xin Yang, and Tingting Wang contributed to methodology and writing – review and editing. Sen Li supervised the study and was responsible for funding acquisition and writing – review and editing. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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