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Systematic comparative analysis of Lyme disease emergence trajectories in Canada and Nordic countries

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Abstract

Background. Lyme disease (LD) is the most prevalent vector-borne infection in the Northern Hemisphere. Canada and the Nordic countries occupy analogous positions at the northern frontier of tick range expansion, yet no study has systematically compared their emergence trajectories. These regions present a natural experiment: identical climatic forcing operates upon fundamentally different vector-pathogen-host systems and surveillance architectures.

Material and methods. Data were drawn from companion analyses: a 16-year Canadian national surveillance time series and a 7-year Nordic multi-country analysis. Comparative metrics included compound annual growth rates (CAGR), normalized growth indices, COVID-19 impact comparisons, and ecological-surveillance framework mapping.

Results. Both regions demonstrate unambiguous upward trajectories consistent with climate-driven expansion. Canada's CAGR (27.1%) exceeded Norway's (6.8%) and Denmark's (19.1%). During 2018-2024, Canadian cases increased 252% versus 48.2% (Norway) and 184.8% (Denmark). Critical divergences include pathogen complexity, co-circulating tick-borne encephalitis (TBE) in the Nordic countries, different surveillance architectures, and emergence phases.

Conclusions. Convergent emergence across ecologically distinct systems confirms climate warming as the overarching driver, while divergent ecologies and surveillance systems produce fundamentally different disease profiles, underscoring the need for internationally harmonized surveillance standards.

Keywords: comparative epidemiology, tick-borne encephalitis, Lyme disease, Lyme borreliosis, climate change

Introduction

Tick-borne diseases have emerged as the defining vector-borne health challenge in temperate and northern regions of the Northern Hemisphere. Lyme disease (LD), caused by spirochaetes of the *Borrelia burgdorferi sensu lato* (s.l.) complex and transmitted by hard-bodied ticks of the genus *Ixodes*, is the most commonly reported vector-borne infection in both North America and Europe, with an estimated 476,000 annual cases in the United States [1,2] and 650,000-850,000 across Europe [3,4]. In European clinical and surveillance practice, the condition is more commonly designated Lyme borreliosis (LB), a term that reflects the broader spectrum of pathogenic *Borrelia* genospecies prevalent on that continent; Lyme neuroborreliosis (LNB), the neurological manifestation of the disease, is a particularly important clinical subset in the European context [5,6]. Both terminologies are employed throughout this comparative analysis to reflect their respective regional conventions. Unlike many infectious diseases that have receded with improvements in sanitation and healthcare infrastructure, tick-borne diseases are accelerating: incidence has risen across virtually every country with systematic surveillance over the past three decades [4,7-9]. This acceleration is most pronounced at northern latitudes, where warming is occurring at two to four times the global average, expanding the zone of climatic suitability for tick survival, reproduction, and host-seeking activity into regions that were historically inhospitable to these vectors [10-12].

Canada and the Nordic countries such as Denmark, Norway, Sweden, and Finland occupy symmetrical positions at the northern frontier of tick range expansion on their respective continents. Both regions are experiencing the progressive establishment of tick populations in territories where these vectors were rare or absent a generation ago, producing epidemiological trajectories characterized by accelerating case counts, expanding geographic risk zones, and growing public health concern [13-17]. Yet these superficially parallel emergence stories are underlain by fundamentally different biological realities. In Canada, a relatively streamlined vector-pathogen-host system prevails: *Ixodes scapularis transmits* predominantly *Borrelia burgdorferi sensu stricto* (s.s.), maintained in a cycle dominated by white-footed mice (*Peromyscus leucopus*) as the principal reservoir host and white-tailed deer (*Odocoileus virginianus*) as the primary reproductive host for adult ticks [18-20]. In the Nordic countries, the system is substantially more complex: *Ixodes ricinus* transmits multiple *Borrelia* genospecies, principally *B. afzelii*, *B. garinii*, and *B. burgdorferi* s.s., each with different reservoir host associations, tissue tropisms, and clinical manifestations, while simultaneously transmitting tick-borne encephalitis virus (TBEV), a flavivirus causing a potentially severe neurotropic infection with no equivalent in Canada [6,21-23].

This contrast between convergent climatic forcing operating upon divergent vector-pathogen-host ecologies constitutes a natural experiment of exceptional scientific and public health significance. Understanding which features of tick-borne disease emergence are universal (driven by climate) versus context-specific (driven by local ecology, surveillance design, or pathogen characteristics) is essential for developing transferable predictive frameworks and evidence-based policy responses applicable across the dozens of northern-latitude jurisdictions that will face analogous challenges in the coming decades [24,25].

Rationale for comparative analysis

Despite the evident parallels between Canadian and Nordic tick-borne disease emergence, no prior study has systematically compared the epidemiological trajectories of these two regions. Existing literature has examined them in isolation: Canadian LD trends have been documented through the Public Health Agency of Canada (PHAC) national surveillance analyses [13,14,26-28], while Nordic tick-borne disease patterns have been characterized through individual country studies and European-level surveillance compilations [7,8,15-17,29-31]. A landmark review by Marques et al. [23] compared LD between the United States and Europe at a broad level, identifying significant differences in *Borrelia* genospecies distribution and clinical manifestations but did not provide a temporally aligned epidemiological comparison between specific northern-latitude regions. Similarly, Blanchard et al. [32] compared national surveillance systems for LD across 34 European and North American countries, documenting persistent heterogeneity in case definitions and reporting mechanisms that complicate cross-jurisdictional comparison. Neither study nor any other in the published literature has directly compared time-series data between Canada and the Nordic countries to characterize convergent versus divergent emergence trajectories within an integrated analytical framework.

The absence of such a comparison represents a critical gap for several reasons. First, climate change projections indicate that both *I. scapularis* and *I. ricinus* will continue to expand northward, with range extensions of 46-48 km/year estimated for the former [33,34] and comparable rates documented for the latter [15,25]. Policy-relevant questions such as whether regions currently at the frontier of tick establishment can anticipate similar trajectory shapes, acceleration phases, or plateau points cannot be answered without comparative data. Second, the imminent arrival of the first Lyme vaccine in over two decades (VLA15, Pfizer/Valneva) targeting six OspA serotypes of *B. burgdorferi* s.l. creates unprecedented urgency for cross-regional baseline data against which a post-introduction vaccine impact can be evaluated [3]. Third, the ongoing debate about optimal surveillance strategies for tick-borne diseases, particularly the tension between comprehensive case capture and the feasibility of mandatory reporting across diverse healthcare systems, demands empirical evidence on how different surveillance architectures shape perceived disease trajectories [32,35].

Aim of the work

The specific objectives of this study are: (i) to compare temporal trajectories of reported LD/LB cases across the two regions, quantifying convergent upward trends and divergent growth dynamics using harmonized metrics including compound annual growth rates, normalized growth indices, and phase-specific analyses; (ii) to evaluate how fundamental differences in tick ecology (*I. scapularis* vs. *I. ricinus*), pathogen diversity (monospecific *B. burgdorferi* s.s. vs. multispecies *Borrelia* complex), and host community dynamics shape the epidemiological character of emergence in each region; (iii) to critically assess how differences in surveillance architecture, case definitions, and reporting practices between Canada and the Nordic countries influence the comparability and interpretation of observed trends; and (iv) to synthesize these comparative findings into a transferable analytical framework that can inform evidence-based public health policy for other northern-latitude jurisdictions facing climate-driven tick-borne disease expansion.

Material and methods

Study design and data sources

This comparative analysis synthesizes data from two companion epidemiological studies conducted as part of a systematic research program on tick-borne disease emergence at northern latitudes. The Canadian arm (Paper 1) comprises a 16-year descriptive time-series analysis of nationally reported LD cases from 2009 through 2024, using publicly available aggregate surveillance data from the PHAC national LD monitoring program [26]. The Nordic arm (Paper 2) comprises a seven-year analysis of LB and tick-borne encephalitis (TBE) case counts from 2018 to 2024, extracted from the European Centre for Disease Prevention and Control (ECDC) Surveillance Atlas of Infectious Diseases [36]. For LB, ECDC data were available for Denmark and Norway only; Sweden and Finland did not report LB cases to the ECDC during the study period. For TBE, data were available for all four Nordic countries. The full methodological details for each arm are provided in their respective manuscripts.

Comparative analytical framework

The comparative analysis employed the following harmonized metrics, applied across both datasets: compound annual growth rate (CAGR), calculated as CAGR = $(Cases_{2024}/Cases_{2018})^{(1/n)} - 1$; normalized growth index with all case series indexed to 2018=100; year-over-year (YoY) variability analysis; pre- versus post-COVID-19 comparison of mean annual case counts for 2018-2019 versus 2022-2024; phase-specific trajectory characterization mapping Canada's three-phase framework (Emergence 2009-2014, Acceleration 2015-2019, Entrenchment 2020-2024) against Nordic temporal patterns; and qualitative ecological-surveillance framework analysis comparing vector biology, pathogen diversity, reservoir host ecology, surveillance architecture, and case definitions between the two regions.

Limitations of the comparative approach

Several important caveats govern this comparison. First, the surveillance observation windows differ: 16 years for Canada versus 7 years for the Nordic countries. Second, the case definitions capture different disease manifestations (all LD stages in Canada; disseminated LB only in Norway; LNB only in Denmark). Third, absolute case counts are not directly comparable due to differences in population size, surveillance coverage, and case ascertainment. Fourth, under-ascertainment ratios likely differ between systems. The comparative analysis therefore emphasizes relative trends, growth dynamics, and qualitative trajectory shapes rather than absolute burden comparisons.

Results

Temporal trajectory comparison

Figure 1 presents the temporal trajectories of reported LD/LB cases in Canada and the Nordic countries in parallel. The Canadian time series (Panel A) demonstrates a dramatic 36-fold increase over 16 years, from 144 cases (2009) to a preliminary 5,239 (2024), with three distinct epidemiological phases clearly identifiable. The Nordic series (Panel B) show more modest absolute growth: Norwegian disseminated LB increased from 282 to 418 cases

(+48.2%) and Danish LNB from 66 to 188 cases (+184.8%, though with extreme volatility) over the seven-year period.

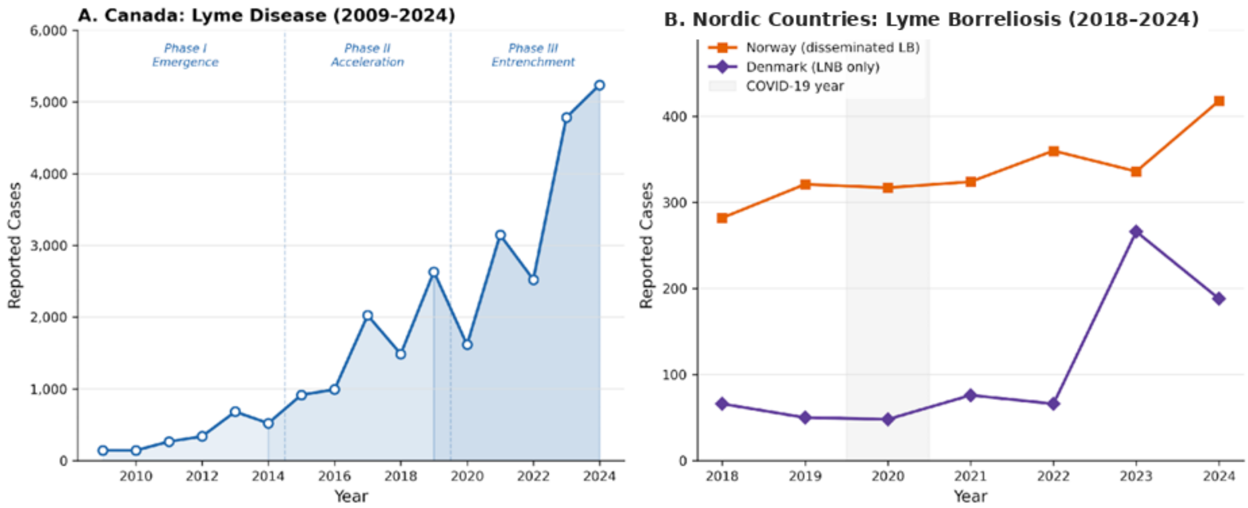

Figure 1. Parallel emergence trajectories of LD/LB in Canada (Panel A, 2009-2024) and the Nordic countries (Panel B, 2018-2024)

Notes: Panel A shows the three epidemiological phases identified in Canada (Emergence, Acceleration, Entrenchment). Panel B shows Norwegian disseminated LB (orange) and Danish LNB (purple) with COVID-19 year shaded. Note the difference in y-axis scales reflecting different surveillance scopes and population sizes.

Growth dynamics: CAGR and normalized indices

Table 1 presents comparative growth metrics. Canada's full-period CAGR of 27.1% substantially exceeded all the Nordic comparators. During the overlapping period (2018-2024), Canada's CAGR was 23.4%, compared with 6.8% for Norwegian LB and 19.1% for Danish LNB. However, the Danish LNB CAGR requires cautious interpretation given the extreme 2023 spike (+303.0% YoY) that may reflect surveillance artefacts.

Table 1. Comparative growth metrics for LD/LB and tick-borne encephalitis, Canada and the Nordic countries

Region/disease	Period	Total	Start	End	Fold Δ	CAGR	Peak
Canada – LD (full)	2009-2024	27,463	144	5,239	36.4×	27.1%	2024
Canada – LD (overlap)	2018-2024	21,834	1,487	5,239	3.5×	23.4%	2024
Norway – Dissem. LB	2018-2024	2,358	282	418	1.5×	6.8%	2024

Denmark – LNB	2018-2024	760	66	188	2.8×	19.1%	2023
Denmark – TBE	2018-2024	93	4	20	5.0×	30.8%	2023
Norway – TBE	2018-2024	445	26	76	2.9×	19.6%	2023
Sweden – TBE	2018-2024	2,959	359	384	1.1×	1.1%	2023
Finland – TBE	2018-2024	847	79	162	2.1×	12.7%	2023
Nordic countries – TBE	**2018-2024**	**4,344**	**468**	**642**	**1.4×**	**5.4%**	**2023**

Notes: CAGR = compound annual growth rate; LD = Lyme disease; LB = Lyme borreliosis; LNB = Lyme neuroborreliosis; TBE = tick-borne encephalitis; Dissem. = disseminated. The “overlap” period aligns Canada’s data with the Nordic observation window.

The US-normalized growth index (Figure 2, 2018=100) reveals different trajectory shapes. Canada’s index rose to 352 by 2024, demonstrating sustained acceleration. Norway’s index reached only 148, consistent with stable endemicity with gradual expansion. Denmark’s LNB index showed explosive but erratic growth (peaking at 403 in 2023 before declining to 285). The combined Nordic TBE index reached 137 by 2024, with a peak of 192 in 2023.

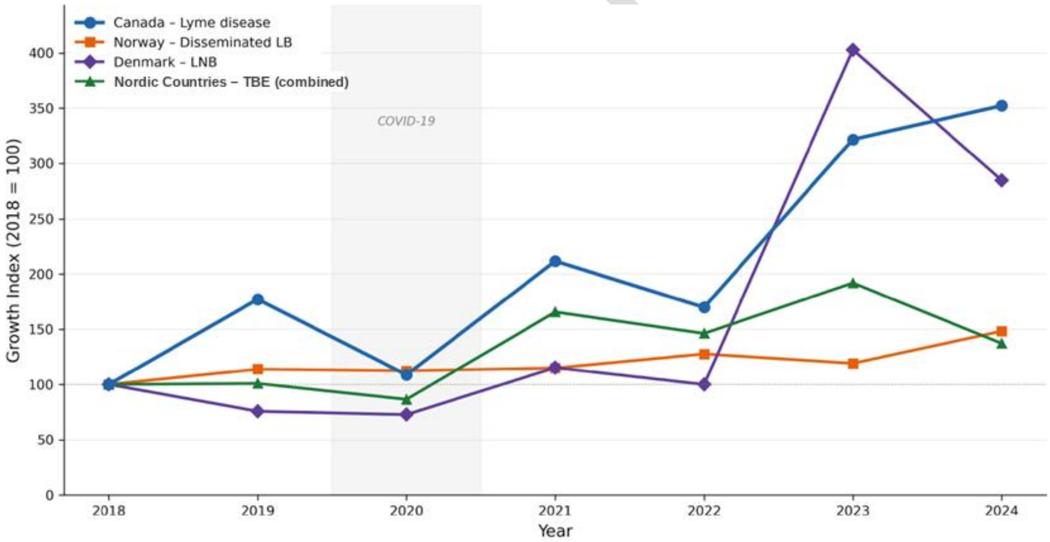

Figure 2. US-normalized growth index (2018=100) comparing relative growth trajectories of tick-borne diseases in Canada and the Nordic countries, 2018-2024

Notes: Canada’s LD trajectory (blue circles) shows the steepest sustained growth. Denmark’s LNB (purple diamonds) shows the highest volatility. Grey shading marks the COVID-19 pandemic year.

Year-over-year variability patterns

Both regions exhibited characteristic sawtooth patterns of year-over-year fluctuation superimposed on upward trends, but with different amplitudes and periodicities. In Canada, the sawtooth pattern was pronounced: years of major increase (+104.1% in 2017; +89.5% in 2023) alternated with significant declines (−26.6% in 2018; −38.6% in 2020). Critically, each Canadian trough was followed by a rebound exceeding the previous peak, confirming the underlying upward momentum. Norwegian LB displayed substantially lower amplitude variability (range: −6.7% to +24.4%), consistent with a more stable endemic system. Danish LNB showed extreme volatility, with the +303.0% YoY increase in 2023 representing the single largest annual percentage change observed in any series across either region (Figure 3).

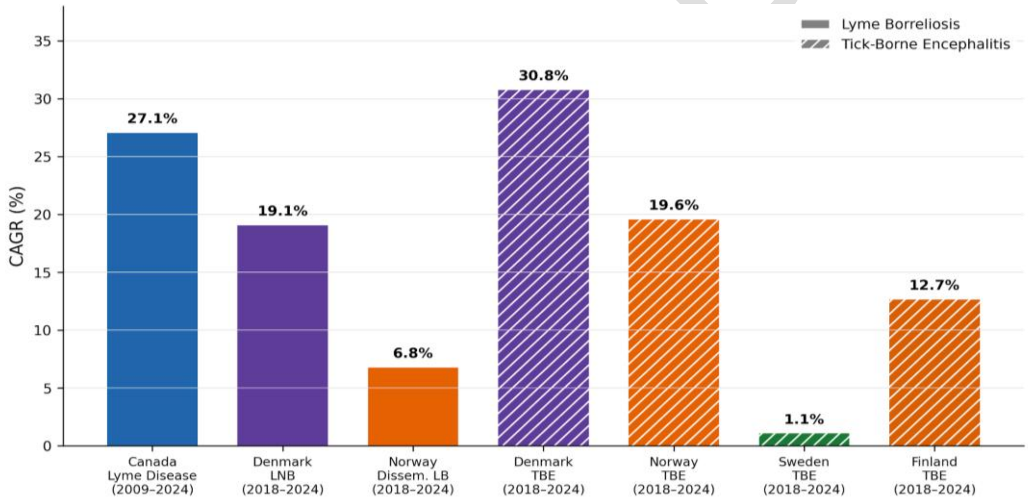

Figure 3. Compound annual growth rates (CAGR) across all the disease-country combinations

Notes: Solid bars represent LB; hatched bars represent tick-borne encephalitis. Canada's LD CAGR (27.1%) reflects active emergence from a low baseline. Denmark's TBE CAGR (30.8%) reflects newly established TBEV foci from an extremely low initial count.

COVID-19 pandemic impact

The COVID-19 pandemic produced strikingly different effects on tick-borne disease reporting across the two regions (Figure 4). Canada experienced a 38.6% decline in reported LD cases in 2020, the largest single-year drop in the 16-year surveillance period, consistent with documented pandemic effects on healthcare-seeking behavior and surveillance operations [37,38]. Norwegian LB was virtually unaffected (−1.2% in 2020), and Danish LNB showed only a modest decline (−4.0%). For TBE, the pattern was more complex: Sweden experienced a 24.8% decline and Denmark a 53.8% decline, while Finland anomalously recorded a 31.9% increase attributed to enhanced outdoor recreation during lockdowns [39].

Post-pandemic recovery metrics further illuminate the trajectories. Canada's mean annual LD cases increased 103% from the pre-COVID period (2018-2019: 2,061) to the post-COVID period (2022-2024: 4,183). The corresponding increase for the combined Nordic TBE was 57.7% (470 to 741). These figures confirm that the pandemic temporarily suppressed case ascertainment without interrupting the underlying drivers of emergence.

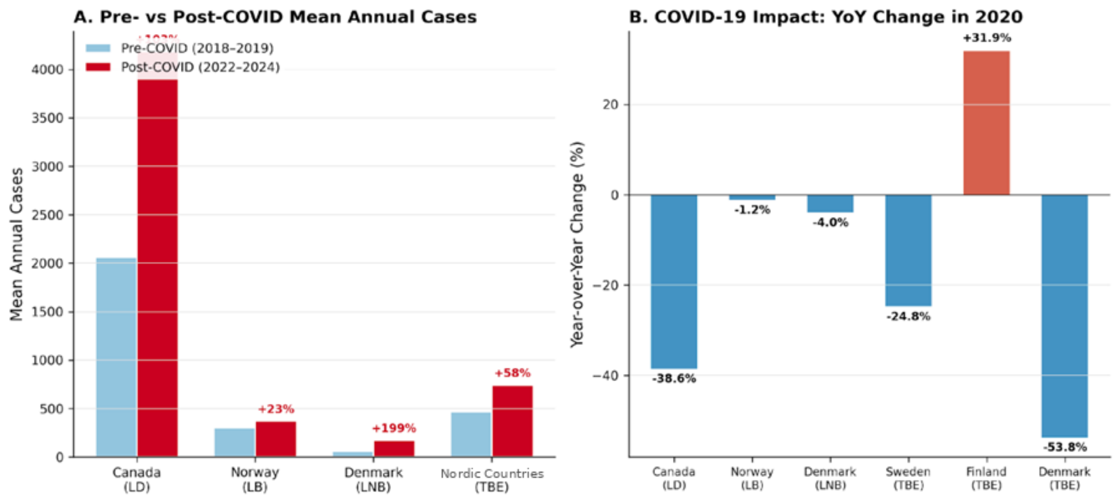

Figure 4. COVID-19 pandemic impact on tick-borne disease reporting

Notes: Panel A: Pre-COVID (2018-2019) versus post-COVID (2022-2024) mean annual cases showing substantial increases across all disease-region combinations. Panel B: Year-over-year percentage change in 2020, demonstrating Canada's severe reporting decline (−38.6%) contrasted with near-stability in Norwegian LB (−1.2%) and Finland's anomalous TBE increase (+31.9%).

Nordic countries-specific TBE dimension

A fundamental divergence between the two regions is the co-circulation of TBEV with *Borrelia* spp. in the Nordic countries, with no equivalent pathogen co-transmitted by *I. scapularis* in Canada. Figure 5 presents the TBE burden across the four Nordic countries. The combined Nordic TBE burden peaked at 898 cases in 2023, with Sweden contributing 68.1% of the regional total. Denmark's TBE CAGR of 30.8% exceeded every other metric in this analysis, reflecting the recent establishment of TBEV foci in a country where the disease was historically considered rare [40]. The concurrent escalation of both LB and TBE across Nordic countries provides powerful evidence that the underlying driver is vector population expansion, since both pathogens share *I. ricinus* as their common vector, rather than disease-specific artefacts.

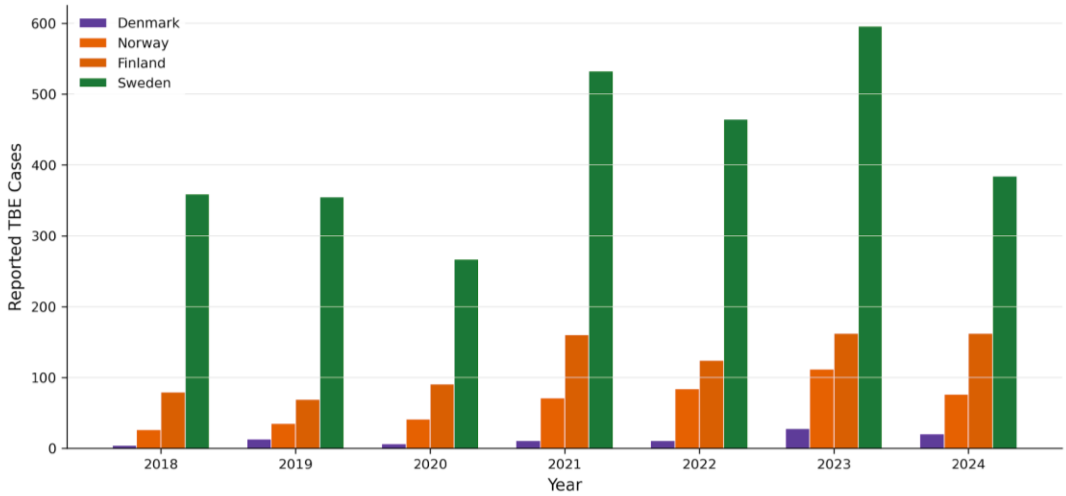

Figure 5. Tick-borne encephalitis cases by country across the Nordic countries, 2018-2024

Notes: Sweden dominates absolute case numbers. Denmark and Norway show the most rapid proportional growth. This TBE co-circulation has no epidemiological parallel in Canada.

Ecological and surveillance framework comparison

Table 2 systematically maps the key ecological, pathogenic, and surveillance differences between the two regions, providing the interpretive framework for understanding the divergences observed in the epidemiological data.

Table 2. Systematic comparison of vector ecology, pathogen biology, host community dynamics, and surveillance architecture between Canada and the Nordic countries

Dimension	Canada	Nordic countries
Primary vector	*Ixodes scapularis* (east/central); *I. pacificus* (BC)	*Ixodes ricinus* (all four countries)
Dominant *Borrelia* spp.	*B. burgdorferi* sensu stricto (>95% of infections)	*B. afzelii, B. garinii*, *B. burgdorferi* s.s.; ≥11 genospecies in complex
TBE co-transmission	Not applicable; no TBEV circulation	TBEV co-transmitted by *I. ricinus*; 4,344 cases (2018-2024)
Principal reservoir host	*Peromyscus leucopus* (white-footed mouse)	Multiple: *Apodemus* spp. (*B. afzelii*); passerine birds (*B. garinii*); lizards in southern range

Key reproductive host	*Odocoileus virginianus* (white-tailed deer)	*Capreolus capreolus* (roe deer); also cervids, livestock
Vector expansion rate	~46-48 km/year northward (I. scapularis)	Documented northward and altitudinal shift; −12°C thermal limit shifting north over 40 years
Critical thermal threshold	Cumulative annual degree-days >2,800	Winter minimum temperature >−12°C for overwintering survival
LD surveillance type	Mandatory; all stages; CNDSS + LDES	Variable: Norway = mandatory disseminated LB; Denmark = mandatory LNB only; Sweden/Finland = no ECDC LB data
Case definition scope	Confirmed + probable; all clinical stages including EM	Norway: disseminated only (excl. EM); Denmark: LNB only
Under-ascertainment estimate	3-12× reported cases	55-722× for LNB-only reporting countries
Surveillance period analyzed	2009-2024 (16 years)	2018-2024 (7 years)
Cumulative reported cases	27,463 (LD)	3,118 (LB; DK+NO only) + 4,344 (TBE; all four)

Notes: EM – erythema migrans; CNDSS – Canadian Notifiable Disease Surveillance System; LDES – Lyme Disease Enhanced Surveillance; LNB – Lyme neuroborreliosis; ECDC – European Centre for Disease Prevention and Control; TBEV – tick-borne encephalitis virus.

Synthesis: convergences and divergences

Table 3 distils the key convergent and divergent findings from the comparative analysis, providing a structured synthesis of the epidemiological patterns observed.

Table 3. Summary of convergent and divergent epidemiological patterns between Canada and Nordic countries

Convergences	Divergences
Unambiguous upward trajectory in reported LD/LB cases across both regions	Rate of emergence: Canada CAGR 27.1% vs. Norway 6.8% over comparable periods
Climate-driven tick vector range expansion as the overarching driver	Pathogen complexity: monospecific (Canada) vs. multispecies Borrelia complex (Nordic countries)
Sawtooth year-over-year variability superimposed on upward trends	Co-circulating TBE in Nordic countries with no Canadian equivalent
COVID-19 pandemic causing measurable disruption to case reporting (2020)	Magnitude of COVID-19 impact: −38.6% in Canada vs −1.2% in Norway
Post-COVID recovery to levels exceeding pre-pandemic baselines	Surveillance scope: all LD stages (Canada) vs. disseminated/LNB only (Nordic countries)

Record or near-record case counts in 2023-2024 in both regions	Phase of emergence: active acceleration (Canada) vs. established endemicity with extension (Nordic countries)
Documented northward range expansion of primary tick vectors	Reservoir ecology: mouse-dominated (Canada) vs. multi-host including birds (Nordic countries)
Under-ascertainment acknowledged as substantial in both regions	Under-ascertainment magnitude: 3-12× (Canada) vs 55-722× for LNB-only countries

Discussion

Convergence argument: climate as the universal driver

The most striking finding of this comparative analysis is the convergent upward trajectory of tick-borne disease across two ecologically distinct northern-latitude regions. Despite fundamental differences in vector species, pathogen portfolios, reservoir host communities, and surveillance infrastructure, both Canada and the Nordic countries are experiencing accelerating tick-borne disease burdens consistent with the well-documented effects of climate warming on tick ecology at northern range margins [10-12,16,24]. This convergence provides powerful empirical support for the proposition that climate change is the overarching driver of tick-borne disease emergence at high latitudes, operating independently of the specific biological configuration of local vector-pathogen-host systems.

The mechanistic pathways through which climate drives emergence are broadly parallel in both regions, despite differences in the specific thermal thresholds and ecological interactions involved. In Canada, the leading edge of *I. scapularis* range expansion has been estimated at approximately 46-48 km/year northward, driven by rising cumulative degree-days that enable accelerated tick life cycles and overwinter survival in a previously marginal habitat [33,34]. In the Nordic countries, a recent analysis of 40 years of European climate data (1979-2020) demonstrated that the thermal limit for *I. ricinus* shifted northward by approximately 400 km in the Boreal biogeographical region, with the critical winter survival threshold of −12°C shifting progressively northward [15,41]. The parallel timing and direction of these range expansions occurring simultaneously on two continents under the same global warming signal constitute perhaps the most compelling evidence available that tick-borne disease emergence at northern latitudes is a predictable consequence of anthropogenic climate change.

Divergence argument: ecology shapes the disease profile

While climate drives convergent emergence, the divergent ecologies of the Canadian and Nordic systems produce fundamentally different disease profiles from the same climatic forcing. Three critical divergences merit detailed discussion.

Pathogen complexity and clinical implications

North American LD system is dominated by a single pathogen species, *B. burgdorferi* s.s., which exhibits strong arthritogenic tropism, producing the high rates of Lyme arthritis (approximately 60% of untreated disseminated infections) characteristic of North American LD [23]. In contrast, the European system encompasses at least 11 *B. burgdorferi* s.l. genospecies, of which *B. afzelii* (dermatotropic, associated with acrodermatitis chronica atrophicans), *B. garinii* (neurotropic, the primary cause of LNB), and *B. burgdorferi* s.s. (arthritogenic) are the most clinically significant [6,21-23]. This pathogen diversity produces a broader clinical spectrum in Europe, with neuroborreliosis and skin manifestations more prevalent relative to arthritis. The practical consequence is that the "same disease" in Canada and the Nordic countries is not, in fact, the same disease – it is a convergent set of tick-borne infections driven by the same ecological process but producing different clinical profiles that require different diagnostic approaches, clinical algorithms, and surveillance case definitions.

TBE dimension

Perhaps the most consequential divergence is the co-circulation of TBEV with *Borrelia* spp. in the Nordic countries. TBE, a potentially fatal neurotropic flavivirus infection, has no epidemiological parallel in the Canadian system. The concurrent escalation of both LB and TBE across the Nordic countries documented in our finding, showing that 2023 represented peak TBE incidence across the region (898 combined cases), provides compelling evidence that the underlying driver is vector population expansion rather than disease-specific factors. Importantly, the availability of an effective TBE vaccine creates a policy dimension absent in Canada: the question of whether to expand TBE vaccination programs is under active deliberation in all four Nordic countries, with our data directly supporting the health-economic case for expanded coverage in Norway and Denmark, where TBE is accelerating most rapidly (CAGRs of +19.6% and +30.8%, respectively) [42-44].

Reservoir host ecology and the dilution effect debate

The reservoir host communities underpinning *Borrelia* transmission differ substantially between the two regions, with implications for the spatial heterogeneity of disease risk. In Canada, the dominant reservoir, *P. leucopus*, is an exceptionally competent host for *B. burgdorferi* s.s., producing high nymphal infection prevalences in areas where mouse populations are dense and host diversity is low [18-20]. This relationship has fueled the "dilution effect" hypothesis, whereby higher vertebrate host diversity is predicted to reduce disease risk by diverting tick feeding towards less competent reservoir species [45]. In Europe, the broader host range of *I. ricinus* and the multispecies *Borrelia* complex create a more complex ecological picture: *B. afzelii* is maintained primarily in rodent cycles (*Apodemus* spp., *Myodes* spp.), while *B. garinii* is maintained in avian reservoirs, and the dilution effect remains empirically contested in European systems due to this host-pathogen specificity [46,47]. The practical implication is that land-use interventions targeting host diversity may have different efficacy in the two regions.

Surveillance as a determinant of perceived burden

This comparative analysis provides compelling evidence that surveillance system design is not merely a methodological consideration but a fundamental determinant of how tick-borne disease emergence is perceived, quantified, and responded to. Canada's surveillance system captures all clinical stages of LD, including erythema migrans (EM), the most common initial manifestation. This broader scope inherently produces higher reported case counts relative to systems that capture only disseminated or late-stage disease. The Nordic countries' fragmented surveillance landscape with Norway reporting only disseminated LB (excluding EM), Denmark reporting only LNB, and Sweden and Finland contributing no LB data to the ECDC means that the reported Nordic LB burden represents a vastly greater underestimation of the true incidence than the Canadian figures. Under-ascertainment multipliers, estimated at 55-722× for LNB-only reporting countries [3,4] compared with 3-12× for Canada [48], translate this surveillance design difference into potentially orders-of-magnitude discrepancies in perceived versus actual disease burden.

The absence of ECDC-reported LB data for Sweden and Finland, countries with a combined population exceeding 16 million and estimated LB incidences among the highest in Europe (up to 464 per 100,000 in endemic Swedish regions) [16], exemplifies how surveillance gaps can render large disease burdens invisible in regional and international comparison frameworks. This gap is not merely a limitation of academic analyses; it directly undermines the evidence base for vaccine rollout planning, resource allocation, and cross-border public health coordination.

Phase of emergence: where each region stands

The three-phase framework developed in the Canadian analysis (Emergence, Acceleration, Entrenchment) provides a useful lens for understanding where each region sits on the emergence trajectory. Canada, over its 16-year observation window, has traversed all three phases, with Phase III (Entrenchment, 2020-2024) characterized by routinely high case burdens exceeding several thousand annually. The Norwegian LB trajectory, with its relatively stable CAGR of 6.8% and modest absolute growth, is more consistent with established endemicity analogous to a mature Phase III pattern, where vector populations are well-established and incidence increments reflect gradual geographic extension rather than exponential emergence. Denmark's explosive growth in LNB and TBE, conversely, suggests elements of an earlier-phase emergence, with rapid establishment of pathogen transmission in newly colonized areas producing volatile, high-growth trajectories analogous to Canada's Phase II [49].

This phase mapping has direct predictive implications. Regions currently at the frontier of tick establishment, such as the Nordic countries, northern Canada, the Baltic states, and Scotland. can anticipate traversing similar emergence phases, with an initial period of low sporadic cases, followed by acceleration as vector populations consolidate, and eventual entrenchment as the area transitions from emerging to endemic status. The Canadian trajectory provides a 16-year longitudinal template for this process that the shorter Nordic observation window cannot yet replicate.

Implications for global public health policy

The comparative findings carry several important implications that extend beyond the two study regions. Surveillance harmonization is essential: the current fragmentation of tick-borne disease surveillance across and between Canada, the Nordic countries, and the broader international community represents a fundamental barrier to evidence-based policy [36,50]. Vaccine evaluation demands baseline data: the imminent regulatory review of VLA15 makes the establishment of robust pre-vaccine incidence baselines an urgent priority in both regions [3]. Climate adaptation must incorporate tick-borne disease: the empirical evidence presented here demands that national climate change adaptation frameworks explicitly incorporate tick-borne disease surveillance, prevention, and healthcare capacity planning [28]. A One Health approach is essential: the interplay of climate, vector ecology, wildlife reservoir dynamics, land use, human behavior, and healthcare system capacity documented in this analysis underscores that tick-borne disease emergence cannot be addressed by any single sector in isolation [51,52].

Strengths and limitations

This study is, to our knowledge, the first systematic comparative analysis of LD emergence trajectories between Canada and the Nordic countries. Its principal strengths include the use of the most temporally comprehensive datasets available for both regions, the application of harmonized comparative metrics enabling meaningful cross-regional comparison, and the integration of epidemiological data with ecological, pathogenic, and surveillance system analysis within a single interpretive framework.

Several limitations warrant acknowledgement. The asymmetric observation windows (16 years for Canada versus 7 years for the Nordic countries) limit the temporal depth of comparison. The Nordic LB data cover only two of four countries, and the case definitions across all systems capture different disease manifestations, precluding comparison of absolute case counts. Under-ascertainment ratios differ substantially between systems, further complicating burden comparisons. The analysis is descriptive and does not employ inferential statistical modelling, ecological niche modelling, or formal causal analysis. Despite these limitations, the comparative framework developed here generates insights that could not be obtained from either regional dataset alone.

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Conclusions

This comparative analysis demonstrates that LD emergence at northern latitudes represents a convergent phenomenon driven by anthropogenic climate change, producing parallel upward trajectories across ecologically distinct vector-pathogen-host systems in Canada and the Nordic countries. At the same time, the divergent ecologies, such as monospecific versus multispecies *Borrelia* complexes, presence versus absence of co-circulating TBE, different reservoir host communities, and fundamentally different surveillance architectures, produce distinct disease profiles from the same climatic forcing, with profound implications for clinical management, surveillance design, and public health policy.

Canada's 16-year trajectory, characterized by a 36-fold increase and 27.1% CAGR, provides a longitudinal template for the emergence process that the shorter Nordic observation window is beginning to recapitulate. The three-phase framework (Emergence-Acceleration-Entrenchment) developed from the Canadian experience offers predictive value for any northern-latitude region at an earlier stage of tick colonization. The Nordic countries' concurrent escalation of both LB and TBE confirms that vector population expansion, rather than disease-specific factors, underlies the regional trend, and the differential pandemic impacts provide natural-experiment insights into the relative robustness of different surveillance systems.

Three urgent priorities emerge from this analysis. First, the international harmonization of tick-borne disease surveillance currently fragmented across incompatible case definitions, reporting scopes, and ascertainment levels is essential for evidence-based cross-jurisdictional comparison and coordinated response. Second, the establishment of robust pre-vaccine baseline data in all high-burden regions is a time-critical requirement ahead of the anticipated Lyme vaccine introduction. Third, the explicit incorporation of tick-borne disease into climate change adaptation frameworks, informed by the empirical emergence data documented here, is necessary to ensure that health system preparedness keeps pace with the accelerating ecological reality.

The experience of Canada and the Nordic countries documented here and in the companion analyses serves as both a warning and a roadmap for dozens of other northern-latitude regions that are on the same trajectory. What is happening in these sentinel regions today will be a global challenge in the coming decades. The time to prepare is now.

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References:

1. Mead P. Epidemiology of Lyme disease. Infect Dis Clin North Am. 2022; 36(3): 495-521. https://doi.org/10.1016/j.idc.2022.03.004
2. Kugeler KJ, Schwartz AM, Delorey MJ, Mead PS, Hinckley AF. Estimating the frequency of Lyme disease diagnoses, United States, 2010-2018. Emerg Infect Dis. 2021; 27(2): 616-619. https://doi.org/10.3201/eid2702.202731
3. Angulo FJ, Colby E, Lebech AM, Lindgren P-E, Moniuszko-Malinowska A, Strle F, et al. Incidence of symptomatic Lyme borreliosis in nine European countries. Int J Infect Dis. 2024; 149: 107242. https://doi.org/10.1016/j.ijid.2024.107242
4. Burn L, Phuong Tran TM, Pilz A, Vyse A, Fletcher MA, Angulo FJ, et al. Incidence of Lyme borreliosis in Europe from national surveillance systems (2005-2020). Vector Borne Zoonotic Dis. 2023; 23(4): 156-171. https://10.1089/vbz.2022.0071
5. Steere AC, Strle F, Wormser GP, Hu LT, Branda JA, Hovius JW, et al. Lyme borreliosis. Nat Rev Dis Primers. 2016; 2: 16090. https://doi.org/10.1038/nrdp.2016.90
6. Rizzoli A, Hauffe HC, Carpi G, Vourc'h GI, Neteler M, Rosà R. Lyme borreliosis in Europe. Euro Surveill. 2011; 16(27): 19906. https://doi.org/10.2807/ese.16.27.19906-en

7. Nagarajan A, Skufca J, Vyse A, Pilz A, Begier E, Riera-Montes M, et al. The landscape of Lyme borreliosis surveillance in Europe. Vector Borne Zoonotic Dis. 2023; 23(4): 142-155. https://doi.org/10.1089/vbz.2022.0067
8. Voyiatzaki C, Papailia SI, Venetikou MS, Pouris J, Tsoumani ME, Papageorgiou EG, et al. Climate changes exacerbate the spread of *Ixodes ricinus* and the occurrence of Lyme borreliosis and tick-borne encephalitis in Europe. How climate models are used as a risk assessment approach for tick-borne diseases. Int J Environ Res Public Health. 2022; 19(11): 6516. https://doi.org/10.3390/ijerph19116516
9. Gilbert L. The impacts of climate change on ticks and tick-borne disease risk. Annu Rev Entomol. 2021; 66: 373-388. https://doi.org/10.1146/annurev-ento-052720-094533
10. Jore S, Vanwambeke SO, Viljugrein H, Isaksen K, Kristoffersen AB, Woldehiwet Z, et al. Climate and environmental change drives *Ixodes ricinus* geographical expansion at the northern range margin. Parasit Vectors. 2014; 7: 11. https://doi.org/10.1186/1756-3305-7-11
11. Clow KM, Leighton PA, Ogden NH, Lindsay LR, Michel P, Pearl DL, et al. Northward range expansion of *Ixodes scapularis* evident over a short timescale in Ontario, Canada. PLoS One. 2017; 12(12): e0189393. https://doi.org/10.1371/journal.pone.0189393
12. Gasmi S, Koffi JK, Nelder MP, Russell C, Graham-Derham S, Lachance L, et al. Surveillance for Lyme disease in Canada, 2009-2019. Can Commun Dis Rep. 2022; 48(5): 219-227. https://doi.org/10.14745/ccdr.v48i05a05
13. Public Health Agency of Canada. Annual report: Lyme disease and other tick-borne diseases surveillance in Canada [Internet]. Ottawa: Public Health Agency of Canada; 2025 [access 2025 May 1]. Available from: https://health-infobase.canada.ca/zoonoses/ticks/annual-report.html
14. Lindgren E, Tälleklint L, Polfeldt T. Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick Ixodes ricinus. Environ Health Perspect. 2000; 108(2): 119-123. https://doi.org/10.1289/ehp.00108119
15. Da Re D, Gilson GF, Dalaiden Q, Goosse H, Bødker R, Jung Kjær L, et al. Northward expansion of the thermal limit for the tick *Ixodes ricinus* over the past 40 years. Parasit Vectors. 2025; 18: 449. https://doi.org/10.1186/s13071-025-07084-4
16. Bennet L, Halling A, Berglund J. Increased incidence of Lyme borreliosis in southern Sweden following mild winters and during warm, humid summers. Eur J Clin Microbiol Infect Dis. 2006; 25: 426-432. https://doi.org/10.1007/s10096-006-0167-2

17. Ogden NH, Lindsay LR, Morshed M, Sockett PN, Artsob H. The emergence of Lyme disease in Canada. CMAJ. 2009; 180(12): 1221-1224. https://doi.org/10.1503/cmaj.080148
18. Bouchard C, Leonard E, Koffi JK, Pelcat Y, Peregrine A, Chilton N, et al. The increasing risk of Lyme disease in Canada. Can Vet J. 2015; 56(7): 693-699.
19. Diuk-Wasser MA, VanAcker MC, Fernandez MP. Impact of land use changes and habitat fragmentation on the eco-epidemiology of tick-borne diseases. J Med Entomol. 2021; 58(4): 1546-1564. https://doi.org/10.1093/jme/tjaa209
20. Stanek G, Wormser GP, Gray J, Strle F. Lyme borreliosis. Lancet. 2012; 379(9814): 461-473. https://doi.org/10.1016/S0140-6736(11)60103-7
21. Lindquist L, Vapalahti O. Tick-borne encephalitis. Lancet. 2008; 371(9627): 1861-1871. https://doi.org/10.1016/S0140-6736(08)60800-4
22. Süss J. Tick-borne encephalitis 2010: epidemiology, risk areas, and virus strains in Europe and Asia – an overview. Ticks Tick Borne Dis. 2011; 2(1): 2-15. https://doi.org/10.1016/j.ttbdis.2010.10.007
23. Marques AR, Strle F, Wormser GP. Comparison of Lyme disease in the United States and Europe. Emerg Infect Dis. 2021; 27(8): 2017-2024. https://doi.org/10.3201/eid2708.204763
24. Baker RE, Mahmud AS, Miller IF, Rajeev M, Rasambainarivo F, Rice BL, et al. Infectious disease in an era of global change. Nat Rev Microbiol. 2022; 20(4): 193-205. https://doi.org/10.1038/s41579-021-00639-z
25. Medlock JM, Hansford KM, Bormane A, Derdakova M, Estrada-Peña A, George J-C, et al. Driving forces for changes in geographical distribution of *Ixodes ricinus* ticks in Europe. Parasit Vectors. 2013; 6: 1. https://doi.org/10.1186/1756-3305-6-1
26. Public Health Agency of Canada. Lyme disease: monitoring [Internet]. Ottawa: Public Health Agency of Canada; 2025 [access 2025 May 1]. Available from: https://www.canada.ca/en/public-health/services/diseases/lyme-disease/surveillance-lyme-disease.html
27. Gasmi S, Ogden NH, Lindsay LR, Burns S, Fleming S, Badcock J, et al. Surveillance for Lyme disease in Canada: 2009-2015. Can Commun Dis Rep. 2017; 43(10): 194-199. https://doi.org/10.14745/ccdr.v43i10a01

28. Ogden NH, Dumas A, Gachon P, Rafferty E. Estimating the incidence and economic cost of Lyme disease cases in Canada in the 21st century with projected climate change. Environ Health Perspect. 2024; 132(2): 27005. https://doi.org/10.1289/ehp13759
29. Dahl V, Wisell KT, Giske CG, Tegnell A, Wallensten A. Lyme neuroborreliosis epidemiology in Sweden 2010 to 2014: clinical microbiology laboratories are a better data source than the hospital discharge diagnosis register. Euro Surveill. 2019; 24(20): 1800453. https://doi.org/10.2807/1560-7917.ES.2019.24.20.1800453
30. Tetens MM, Haahr R, Dessau RB, Krogfelt KA, Bodilsen J, Andersen NS, et al. Changes in Lyme neuroborreliosis incidence in Denmark, 1996 to 2015. Ticks Tick Borne Dis. 2020; 11(6): 101549. https://doi.org/10.1016/j.ttbdis.2020.101549
31. Nygard K, Brantsaeter AB, Mehl R. Disseminated and chronic Lyme borreliosis in Norway, 1995-2004. Euro Surveill. 2005; 10(10): 235-238. https://doi.org/10.2807/esm.10.10.00568-en
32. Blanchard L, Jones-Diette J, Lorenc T, Sutcliffe K, Sowden A, Thomas J. Comparison of national surveillance systems for Lyme disease in humans in Europe and North America: a policy review. BMC Public Health. 2022; 22: 1307. https://doi.org/10.1186/s12889-022-13669-w
33. Westcott JR, Bowden JJ, Savage J, Doody KM. Rapid northward expansion of the blacklegged tick, *Ixodes scapularis*, in response to climate change. Glob Chang Biol. 2025; 31(11): e70591. https://doi.org/10.1111/gcb.70591
34. Leighton PA, Koffi JK, Pelcat Y, Lindsay LR, Ogden NH. Predicting the speed of tick invasion: an empirical model of range expansion for *Ixodes scapularis* in Canada. J Appl Ecol. 2012; 49(2): 457-464. https://doi.org/10.1111/j.1365-2664.2012.02112.x
35. Davidson A, Angulo FJ, Davis J, Halsby K, Brestrich G, Moïsi JC, et al. Comparison of the number of Lyme neuroborreliosis cases in European Centre for Disease Prevention and Control (ECDC) data and national public surveillance reports, 2018-2023. Ticks Tick Borne Dis. 2025; 16(6): 102542. https://doi.org/10.1016/j.ttbdis.2025.102542
36. European Centre for Disease Prevention and Control. Surveillance atlas of infectious diseases [Internet]. Stockholm: ECDC; 2025 [access 2025 Feb]. Available from: https://atlas.ecdc.europa.eu/public/index.aspx

37. McCormick DW, Kugeler KJ, Marx GE, Jayanthi P, Dietz S, Mead P, et al. Effects of COVID-19 pandemic on reported Lyme disease, United States, 2020. Emerg Infect Dis. 2021; 27(10): 2715-2717. https://doi.org/10.3201/eid2710.210903
38. Sun YQ, Zhu XY, Fan TC, Ma T, Ge HH, Shi RF, et al. Projecting Lyme disease risk in the United States: a machine learning approach integrating environmental, socioeconomic and vector factors. One Health. 2025; 21: 101111. https://doi.org/10.1016/j.onehlt.2025.101111
39. Jore S, Viljugrein H, Hjertqvist M, Dub T, Mäkelä H. Outdoor recreation, tick borne encephalitis incidence and seasonality in Finland, Norway and Sweden during the COVID-19 pandemic (2020/2021). Infect Ecol Epidemiol. 2023; 13(1): 2281055. https://doi.org/10.1080/20008686.2023.2281055
40. Skarpaas T, Golovljova I, Vene S, Ljøstad U, Sjursen H, Plyusnin A, et al. Tickborne encephalitis virus, Norway and Denmark. Emerg Infect Dis. 2006; 12(7): 1136-1138. https://doi.org/10.3201/eid1207.051567
41. Jaenson TGT, Jaenson DGE, Eisen L, Petersson E, Lindgren E. Changes in the geographical distribution and abundance of the tick *Ixodes ricinus* during the past 30 years in Sweden. Parasit Vectors. 2012; 5: 8. https://doi.org/10.1186/1756-3305-5-8
42. Palmborg A, Angulo FJ, Zhang P, Pilz A, Stark J, Moïsi JC, et al. Tick-borne encephalitis vaccine uptake, effectiveness, and impact in Sweden from 2018 to 2022. Sci Rep. 2025; 15: 2927. https://doi.org/10.1038/s41598-025-86968-y
43. Askling HH, Zavadska D. Tick-borne encephalitis (TBE) vaccine in the National Immunisation Programme – for whom, when and where?. Acta Paediatr. Forthcoming 2025. https://doi.org/10.1111/apa.70280
44. Beauté J, Spiteri G, Warns-Petit E, Zeller H. Tick-borne encephalitis in Europe, 2012 to 2016. Euro Surveill. 2018; 23(45): 1800201. https://doi.org/10.2807/1560-7917.ES.2018.23.45.1800201
45. Ostfeld RS, Keesing F. Biodiversity series: the function of biodiversity in the ecology of vector-borne zoonotic diseases. Can J Zool. 2000; 78(12): 2061-2078. https://doi.org/10.1139/z00-172
46. Hofmeester TR, Coipan EC, van Wieren SE, Prins HHT, Takken W, Sprong H. Few vertebrate species dominate the *Borrelia burgdorferi* s.l. life cycle. Environ Res Lett. 2016; 11(4): 043001. https://doi.org/10.1088/1748-9326/11/4/043001

47. Crandall KE, Millien V, Kerr JT. High-resolution environmental and host-related factors impacting questing *Ixodes scapularis* at their northern range edge. Ecol Evol. 2024; 14(2): e10855. https://doi.org/10.1002/ece3.10855
48. Ogden NH, Bouchard C, Badcock J, Drebot MA, Elias SP, Hatchette TF, et al. What is the real number of Lyme disease cases in Canada?. BMC Public Health. 2019; 19: 849. https://doi.org/10.1186/s12889-019-7219-x
49. Jung Kjær L, Bødker R, Król N, Skarphédinsson S, Jensen PM. Potential for integrated monitoring of tick-borne diseases: indices of tick activity, citizen science, and tick-borne Lyme neuroborreliosis in Denmark from 2017 to 2024. Ticks Tick Borne Dis. 2026; 17(1): 102602. https://doi.org/10.1016/j.ttbdis.2025.102602
50. European Commission. Commission Implementing Decision (EU) 2018/945 of 22 June 2018 on the communicable diseases and related special health issues to be covered by epidemiological surveillance. Off J Eur Union. 2018; L 170: 1-74.
51. Yang H, Gould CA, Jones R, St. Juliana A, Sarofim M, Rissing M, et al. By-degree health and economic impacts of Lyme disease, eastern and midwestern United States. Ecohealth. 2024; 21: 56-70. https://doi.org/10.1007/s10393-024-01676-9
52. Lantos PM, Rumbaugh J, Bockenstedt LK, Falck-Ytter YT, Aguero-Rosenfeld ME, Auwaerter PG, et al. Clinical Practice Guidelines by the Infectious Diseases Society of America (IDSA), American Academy of Neurology (AAN), and American College of Rheumatology (ACR): 2020 Guidelines for the Prevention, Diagnosis, and Treatment of Lyme Disease. Arthritis Care Res. 2021; 73(1): 1-9. https://doi.org/10.1002/acr.24495