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Temporal trends in Lyme borreliosis and tick-borne encephalitis in Nordic countries, 2018-2024: a descriptive epidemiological analysis of European surveillance data

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Abstract

Background. Tick-borne diseases are the fastest-growing vector-borne infections in northern Europe, yet no comprehensive multi-country analysis of Lyme borreliosis (LB) and tick-borne encephalitis (TBE) trends across the Nordic countries using standardized post-2018 European surveillance data has been published.

Material and methods. Annual case counts were extracted from the European Center for Disease Prevention and Control (ECDC) Surveillance Atlas for LB (Denmark, Norway) and TBE (all four countries). Descriptive time-series analysis included year-over-year changes, compound annual growth rates (CAGR), crude incidence rates, and pre- versus post-COVID-19 comparisons.

Results. Over seven years, 3,118 LB and 4,344 TBE cases were reported. Denmark showed the most rapid growth for both LB (CAGR +19.1%) and TBE (CAGR +30.8%). Combined Nordic TBE burden increased 37.2% (2018-2024), with post-COVID-19 annual cases exceeding pre-pandemic levels by 57.7%. Peak regional TBE case count occurred in 2023 (898 cases).

Conclusions. Both diseases show escalating trends with substantial inter-country variation. These findings establish pre-vaccine baselines for LB, strengthen the case for expanding TBE vaccination, and highlight critical surveillance gaps – particularly the absence of ECDC-reported LB data for Sweden and Finland.

Keywords: tick-borne encephalitis, Lyme borreliosis, Nordic countries, epidemiology, surveillance

Introduction

Tick-borne diseases have emerged as the pre-eminent vector-borne health threat in temperate regions of the Northern Hemisphere, with an estimated 476,000 Lyme borreliosis (LB) cases annually in the United States and 650,000-850,000 across Europe [1-3]. Among tick-borne infections, LB caused by spirochaetes of the *Borrelia burgdorferi* sensu lato complex and tick-borne encephalitis (TBE) caused by tick-borne encephalitis virus (TBEV), a flavivirus of the family *Flaviviridae*, constitute the two most epidemiologically significant human diseases transmitted by *Ixodes ricinus* ticks in Europe [4-6]. Unlike many infectious diseases that have declined with improvements in sanitation and health care, tick-borne diseases are accelerating: their incidence has risen across virtually every European country with systematic surveillance over the past three decades [7-12]. Understanding the pace, pattern, and drivers of this acceleration is essential for evidence-based public health responses, yet comprehensive, multi-country, multi-disease analyses using standardized surveillance data remain scarce.

Nordic countries such as Denmark, Norway, Sweden, and Finland are among the most important sentinel regions globally for monitoring climate-driven tick-borne disease emergence. Situated at the northern margin of the *I. ricinus* distribution range, these nations are experiencing disproportionately rapid warming: Arctic and sub-Arctic regions are heating at two to four times the global average rate [8,13]. This accelerated warming translates directly into vector ecology. Rising winter minimum temperatures have driven a documented northward expansion of tick populations across the Nordic region over the past four decades [14-16].

Recent analysis of 40 years of European climate data demonstrated that the thermal limit for *I. ricinus* expanded northward by approximately 400 km in the Boreal biogeographical region between 1979 and 2020 [17]. Concurrently, the expansion of roe deer populations has facilitated tick dispersal to new latitudes [18,19]. What happens in the Nordic countries today is therefore a preview of what will likely occur in other northern-latitude regions such as Canada, northern Russia, Scotland, the Baltic states, and northern Japan in the coming decades. Documenting the Nordic trajectory is not a matter of regional interest alone; it generates transferable knowledge for global public health preparedness.

This analysis arrives at a uniquely consequential moment for tick-borne disease policy. Two developments create extraordinary urgency. First, the first LB vaccine in over two decades (VLA15, Pfizer/Valneva) is in Phase III clinical trials with regulatory review anticipated in the near term [20]. Second, TBE vaccination program expansion is under active deliberation across the Nordic countries [21-23]. Both vaccine decisions require robust, current epidemiological baselines against which the post-introduction impact can eventually be measured. Without such baselines, the effectiveness of future interventions will be impossible to evaluate rigorously.

Despite the shared ecological context, the four Nordic countries employ markedly different surveillance architectures for tick-borne diseases (see Methods for details), creating a fragmented evidence landscape that this study seeks to remedy [21,22,24-32].

In June 2018, the European Commission formally added LNB (Lyme neuroborreliosis) to the list of diseases under the EU/EEA epidemiological surveillance, establishing a uniform case definition and initiating standardized reporting through the European Center for Disease Prevention and Control (ECDC) [33]. This was a watershed event: for the first time, a mechanism existed for generating comparable LB data across European countries. Seven years later, however, the promise of that decision remains incompletely fulfilled. Two of the four

Nordic countries, representing a combined population exceeding 16 million, have not reported LB data to the ECDC Surveillance Atlas. This gap is not merely an administrative inconvenience; it means that the largest Nordic country by population (Sweden, 10.5 million) and one of the most LB-endemic nations in Europe (Finland, with national incidence exceeding 100 per 100,000) [30,34] are invisible in the European surveillance picture. Even in countries that do report to the ECDC, such as Norway, mandatory surveillance captures only laboratory-confirmed disseminated cases, leaving the majority of symptomatic infections undetected [35]. Quantifying what is available and explicitly documenting what is missing is itself a contribution to the evidence base, as it creates a citable, peer-reviewed record of the surveillance gap that policymakers and the ECDC working groups can reference when advocating for reform.

To date, no study has simultaneously analyzed temporal trends in both LB and TBE across all four Nordic countries using the standardized ECDC Surveillance Atlas data from the post-2018 harmonized reporting era. Previous work has either examined individual countries in isolation [21,26-29,36], compiled European-wide surveillance overviews where the Nordic countries appear as one data point among dozens [11,12], or focused on a single disease without integrating the two major tick-borne infections that share the same vector, hosts, and ecological drivers [32,37].

This fragmentation means that a fundamental epidemiological question remains unanswered: are both LB and TBE escalating in concert across the Nordic countries, confirming that the underlying driver is vector population expansion rather than disease-specific artefacts? And if so, at what rate, in which countries most rapidly, and with what implications for policy?

Aim of the work

The objectives of this study are threefold. First, to characterize temporal trends in reported LB and TBE cases across the Nordic countries from 2018 to 2024, providing the first integrated multi-country, multi-disease time-series analysis from the post-2018 ECDC reporting era. Second, to quantify growth metrics including compound annual growth rates, year-over-year changes, and pre- versus post-COVID-19 burden comparisons, thereby establishing pre-vaccine baselines of direct relevance to imminent policy decisions. Third, to document the current state of tick-borne disease surveillance across the Nordic countries, including its gaps, as evidence supporting calls for harmonized European surveillance, expanded TBE vaccination, and the integration of tick-borne disease monitoring into national climate change adaptation frameworks.

Material and methods

Data sources

Annual reported case counts for LB and TBE were extracted from the ECDC Surveillance Atlas of Infectious Diseases for the period 2018-2024 [38]. Data were extracted on February 15, 2025. The ECDC Atlas aggregates data submitted by the EU/EEA member states under standardized case definitions established by European Commission Implementing Decision 2018/945 [33]. For LB, 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 (Denmark, Norway, Sweden, and Finland).

Population denominators for the calculation of crude incidence rates were obtained from Eurostat for the respective mid-year populations. The following approximate mid-period populations were used: Denmark 5,850,000; Norway 5,450,000; Sweden 10,500,000; Finland 5,550,000 [39]. Population variation across the seven-year study period was less than 5% for all four countries (Denmark 3.2%, Norway 4.9%, Sweden 3.9%, Finland 1.9%). Verification using year-specific Eurostat mid-year population denominators [39] confirmed that the maximum relative difference in calculated crude incidence rates compared with the mid-period approximation was 3.1%, indicating that the use of approximate mid-period populations does not materially alter the reported trends. Surveillance systems: for LB, Norway conducts mandatory reporting of laboratory-confirmed disseminated cases (excluding erythema migrans) through MSIS [24,25], while Denmark mandatorily reports only LNB through the Statens Serum Institut [26,27]. Sweden lacks national mandatory LB surveillance [28,29], and Finland has not consistently reported LB to the ECDC platform [30]. For TBE, all four countries maintain mandatory notification under standardized case definitions [31,32].

Case definitions

The ECDC case definitions for LNB require clinical presentation compatible with neuroborreliosis plus laboratory confirmation through detection of intrathecal anti-*Borrelia* antibodies (confirmed case) or compatible clinical symptoms with supportive serology (probable case) [33]. It is essential to note that Denmark reports only LNB to the ECDC, while Norway reports all forms of laboratory-confirmed disseminated LB (including neuroborreliosis, Lyme arthritis, acrodermatitis chronica atrophicans, and Lyme carditis) but excludes erythema migrans [24-27]. This difference in case definitions means that the two countries' LB data are not directly comparable in absolute terms but are internally consistent and suitable for trend analysis within each country.

For TBE, the EU case definition requires clinical presentation of central nervous system inflammation plus laboratory confirmation through detection of TBE-specific IgM antibodies in serum or cerebrospinal fluid, seroconversion, or virus detection [31]. This definition has been applied relatively consistently across all four Nordic countries.

Statistical analysis

Descriptive time-series analysis was performed. Year-over-year (YoY) percentage changes were calculated as: $\text{YoY\%} = [(\text{Cases}_t - \text{Cases}_{t-1}) / \text{Cases}_{t-1}] \times 100$. The compound annual growth rate (CAGR) was calculated over the six annual intervals (2018-2024) using the formula: $\text{CAGR} = (\text{Cases}_{2024}/\text{Cases}_{2018})^{(1/6)} - 1$. Crude incidence rates were expressed per 100,000 population. Although the ECDC provides age-standardized rates (ASR) alongside crude notification rates in its annual epidemiological reports, this study uses reported confirmed case counts and crude incidence rates rather than ASR for the following reasons.

First, the primary analysis focuses on within-country temporal trends over a seven-year period, during which the age structure of Nordic populations remained essentially stable (Eurostat data confirm <2% shift in median age across all four countries, 2018-2024), minimizing the confounding that age standardization is designed to correct [32,40]. Second, for the limited cross-country comparisons presented, differences in case definitions between Denmark (LNB only) and Norway (all disseminated LB) already preclude meaningful inter-country rate comparison, rendering the additional adjustment provided by ASR moot for that purpose. Third, age standardization applied to very small case numbers (e.g. Denmark TBE: 4-28 annual cases) would require age-specific rates based on single-digit or zero cases per stratum, producing statistically unstable estimates regardless of the standardization method applied [41]. Fourth, the ECDC's own annual epidemiological reports present and discuss temporal trends using crude notification rates as the primary metric [31,32], and major

European LB surveillance analyses follow the same practice [11,12]. Reported confirmed cases represent the direct, transparent output of national surveillance systems and constitute the metric upon which public health authorities base operational decisions, making them the most appropriate choice for establishing pre-vaccine surveillance baselines. Pre-COVID-19 (2018-2019) and post-COVID-19 (2022-2024) mean annual case counts were compared to assess pandemic impact and subsequent recovery.

The year 2020 was designated as the primary pandemic-affected year based on the introduction of national lockdown measures across Denmark (March 2020), Norway (March 2020), and Finland (March 2020), with Sweden implementing partial restrictions during the same period [42]. The year 2021 was treated as a transitional period during which restrictions were progressively lifted and is therefore excluded from both the pre- and post-pandemic comparison groups. All calculations were performed in Python 3.12 using NumPy and Matplotlib libraries [43]. As this is a descriptive epidemiological analysis based on complete national surveillance counts rather than sampled data, formal inferential statistics (confidence intervals, *p*-values) are not applied to the pre- versus post-COVID-19 comparisons, which are presented as descriptive observations consistent with standard practice in surveillance-based trend analyses [31,32].

Results

LB: Denmark and Norway, 2018-2024

Over the seven-year study period, a total of 3,118 LB cases were reported to the ECDC from Denmark and Norway combined (Table 1, Figure 1). Norway contributed the majority (2,358 cases; 75.6%), reflecting its broader case definition that captures all disseminated LB manifestations, while Denmark reported 760 LNB cases (24.4%).

Norway showed a steady upward trend (CAGR +6.8%; range 282-418 cases/year; crude incidence 5.2-7.7 per 100,000), with relative stability from 2018 to 2022, followed by a record 418 cases in 2024 (Table 1).

Denmark exhibited a more volatile pattern (CAGR +19.1%; range 48-266 cases/year; crude incidence 0.8-4.5 per 100,000), with a dramatic four-fold increase in 2023 that was sustained into 2024 (Table 1).

Table 1. Annual reported LB cases, year-over-year changes, and crude incidence rates: Denmark and Norway, 2018-2024

Year	DK Cases	DK YoY%	DK Inc/100k	NO Cases	NO YoY%	NO Inc/100k	Combined	Combined Inc*
2018	66	–	1.13	282	–	5.17	348	3.08
2019	50	−24.2	0.85	321	+13.8	5.89	371	3.28
2020	48	−4.0	0.82	317	−1.2	5.82	365	3.23
2021	76	+58.3	1.30	324	+2.2	5.94	400	3.54
2022	66	−13.2	1.13	360	+11.1	6.61	426	3.77
2023	266	+303.0	4.55	336	−6.7	6.16	602	5.33
2024	188	−29.3	3.21	418	+24.4	7.67	606	5.36
Total	**760**	-	-	**2,358**	-	-	**3,118**	-

Notes: *Combined crude incidence calculated using the summed population of Denmark and Norway (~11.3 million). DK = Denmark; NO = Norway; YoY = year-over-year; Inc = incidence.

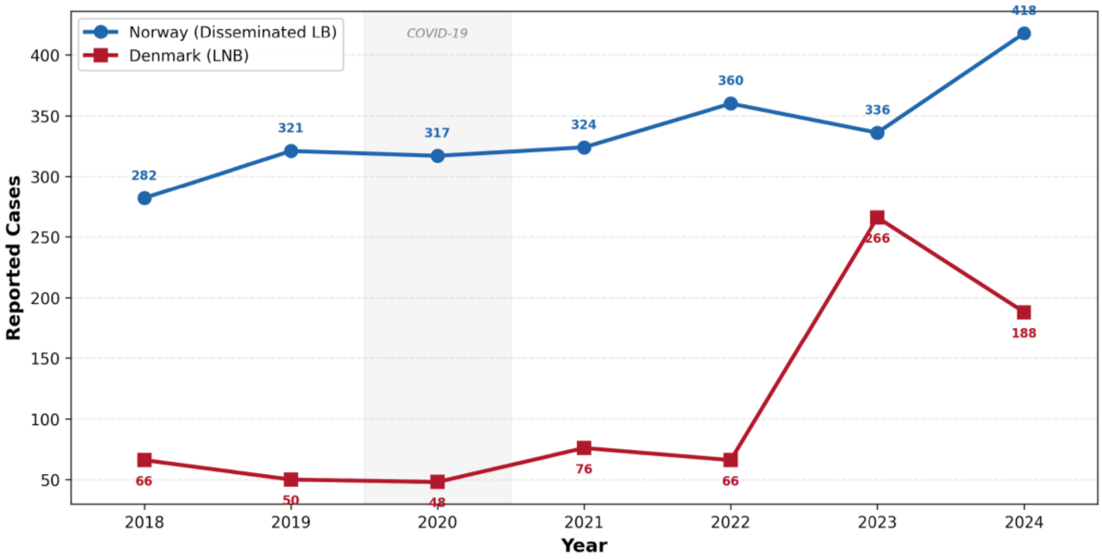


Figure 1. Temporal trends in reported LB cases: Denmark (Lyme neuroborreliosis) and Norway (disseminated LB), 2018-2024

Notes: Grey shading indicates the COVID-19 pandemic year (2020; see Methods for pandemic period rationale; 2020, the year of initial national lockdown implementation; 2021 is discussed as a transitional year in the text).

Tick-borne encephalitis: all four countries, 2018-2024

A total of 4,344 TBE cases were reported across the four Nordic countries during 2018-2024 (Table 2). Sweden accounted for the overwhelming majority (2,959 cases; 68.1%), followed by Finland (847; 19.5%), Norway (445; 10.2%), and Denmark (93; 2.1%).

Sweden dominated the regional TBE burden with the highest absolute numbers (mean 422.7 cases/year; CAGR +1.1%) but substantial inter-annual volatility (range 267-596). A marked COVID-19-related dip in 2020 was followed by a rebound exceeding pre-pandemic levels, peaking at 596 cases in 2023 (Table 2, Figures 2-3).

Table 2. Annual reported TBE cases and crude incidence rates per 100,000 population: Denmark, Norway, Sweden, and Finland, 2018-2024

Year	DK	DK Inc	NO	NO Inc	SE	SE Inc	FI	FI Inc	Total
2018	4	0.07	26	0.48	359	3.42	79	1.42	468
2019	13	0.22	35	0.64	355	3.38	69	1.24	472
2020	6	0.10	41	0.75	267	2.54	91	1.64	405
2021	11	0.19	71	1.30	533	5.08	160	2.88	775
2022	11	0.19	84	1.54	465	4.43	124	2.23	684
2023	28	0.48	112	2.05	596	5.68	162	2.92	898
2024	20	0.34	76	1.39	384	3.66	162	2.92	642
Total	**93**	-	**445**	-	**2,959**	-	**847**	-	**4,344**

Notes: DK = Denmark; NO = Norway; SE = Sweden; FI = Finland; Inc = crude incidence per 100,000 population.

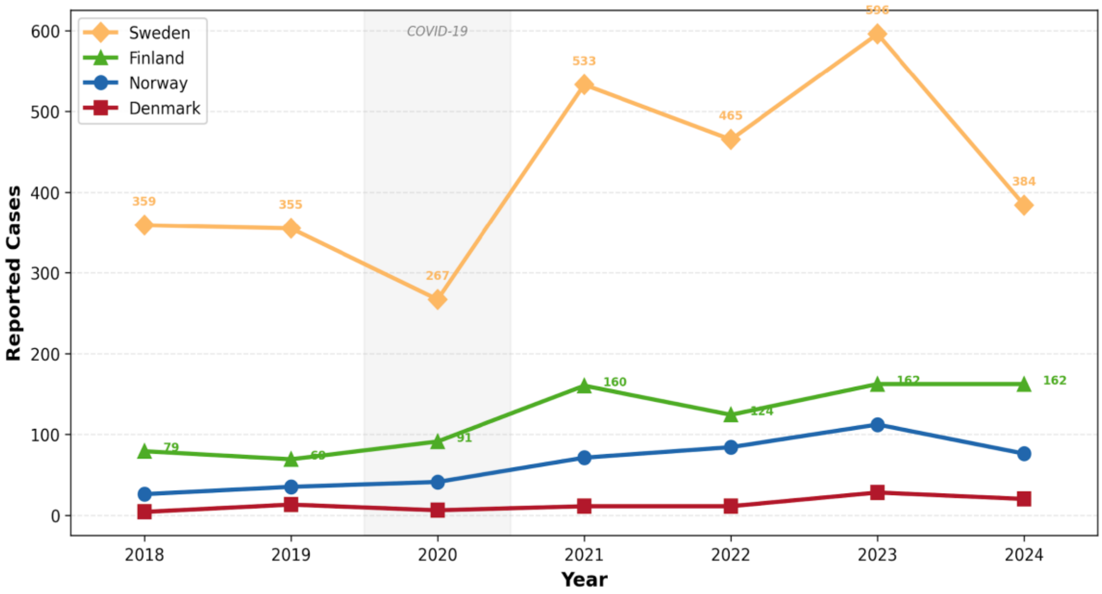


Figure 2. Temporal trends in reported TBE cases across four Nordic countries, 2018-2024

Notes: Grey shading indicates the COVID-19 pandemic year.

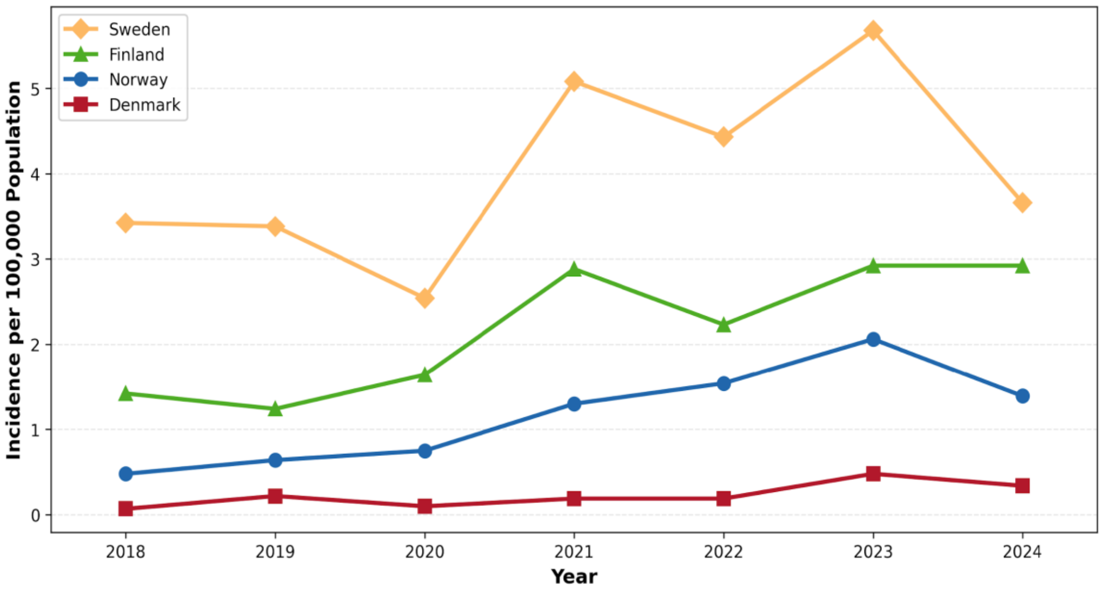


Figure 3. TBE incidence per 100,000 population across four Nordic countries, 2018-2024

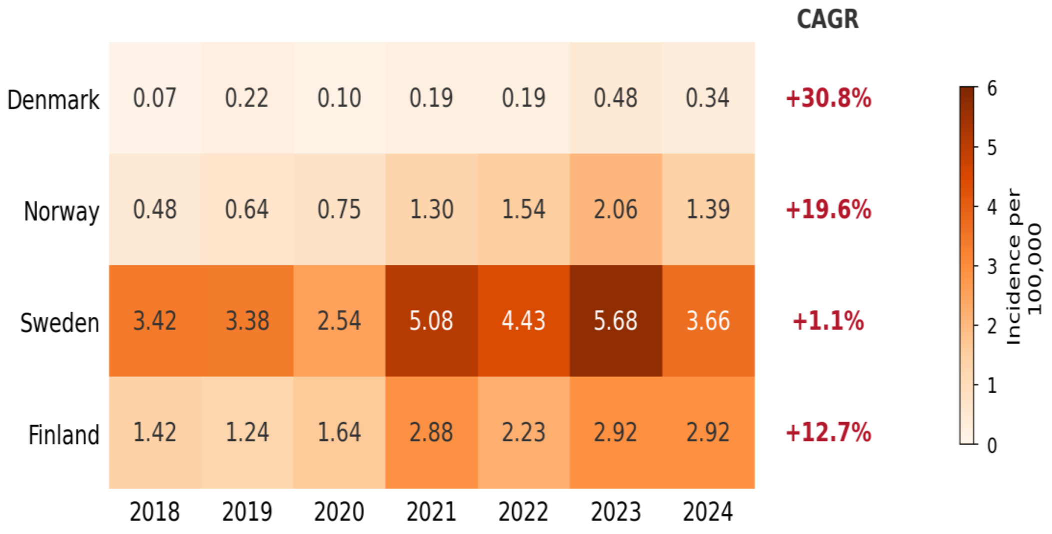
Finland demonstrated sustained growth (CAGR +12.7%; crude incidence rising from 1.42 to 2.92 per 100,000), with cases plateauing at 162 in 2023-2024. Notably, Finland experienced the largest TBE increase in 2020 (+31.9% YoY), while Norway also recorded a modest rise (+17.1%). These were the only two Nordic countries where TBE cases increased during the first pandemic year. Finland's increase was followed by a further surge to 160 in

2021 (+75.8%). The anomalous Finnish increase has been attributed to heightened outdoor recreational activity during pandemic lockdowns [37].

Norway exhibited the second-fastest growth trajectory (CAGR +19.6%), rising from 26 cases in 2018 to 76 in 2024, with a peak of 112 in 2023. The crude incidence increased from 0.48 to 1.39 per 100,000. The trend was characterized by steady acceleration, with every year from 2019 to 2023 showing increases, before a 32.1% decline in 2024.

Denmark, while reporting the lowest absolute numbers, exhibited the most rapid proportional growth (CAGR +30.8%), increasing from 4 cases in 2018 to 20 in 2024, with a peak of 28 in 2023. The crude incidence rose from 0.07 to 0.34 per 100,000. This trajectory is consistent with the recent emergence and establishment of TBEV foci in Denmark, a country where TBE was historically considered rare [44].

The intensity of TBE incidence across countries and years is further visualized in Figure 4, where the color gradient encodes incidence magnitude, highlighting the acceleration in Denmark and Norway.



	2018	2019	2020	2021	2022	2023	2024	CAGR
Denmark	0.07	0.22	0.10	0.19	0.19	0.48	0.34	+30.8%
Norway	0.48	0.64	0.75	1.30	1.54	2.06	1.39	+19.6%
Sweden	3.42	3.38	2.54	5.08	4.43	5.68	3.66	+1.1%
Finland	1.42	1.24	1.64	2.88	2.23	2.92	2.92	+12.7%

Figure 4. TBE incidence per 100,000 population across four Nordic countries, 2018-2024

Notes: Color intensity encodes incidence magnitude. CAGR = compound annual growth rate.

The integrated growth metrics for both LB and TBE across all four Nordic countries are summarized in Table 3, which consolidates the trajectories described above into a single comparative overview.

Table 3. Summary growth metrics for LB and TBE across Nordic countries, 2018-2024

Country / Disease	Total cases	Mean/year	Min	Max	Overall Δ%	CAGR %	Peak year
Denmark – LB	760	108.6	48	266	+184.8	+19.1	2023
Norway – LB	2,358	336.9	282	418	+48.2	+6.8	2024
Denmark – TBE	93	13.3	4	28	+400.0	+30.8	2023
Norway – TBE	445	63.6	26	112	+192.3	+19.6	2023
Sweden – TBE	2,959	422.7	267	596	+7.0	+1.1	2023
Finland – TBE	847	121.0	69	162	+105.1	+12.7	2023/24
All 4 – TBE	**4,344**	**620.6**	**405**	**898**	**+37.2**	**–**	**2023**

Notes: LB = Lyme borreliosis; TBE = tick-borne encephalitis; CAGR = compound annual growth rate; Δ% = overall percentage change 2018 to 2024.

Figure 5 provides a comparative visualization of compound annual growth rates, illustrating that Denmark exhibited the most rapid proportional acceleration for both LB and TBE, while also highlighting the absence of the ECDC-reported LB data for Sweden and Finland.

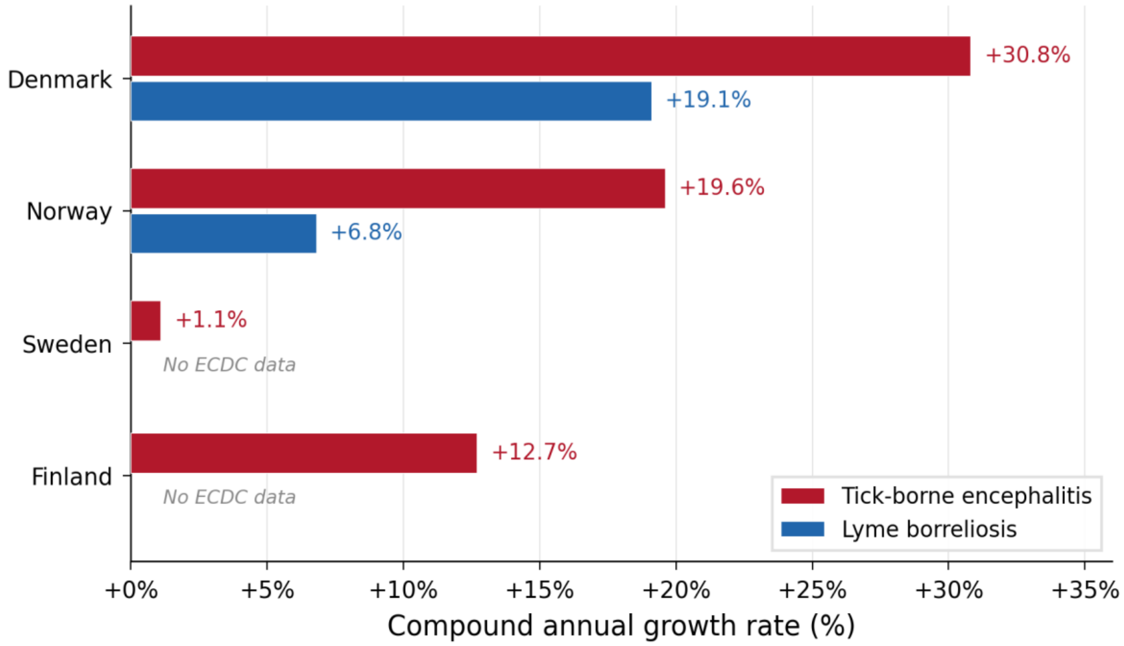


Figure 5. Compound annual growth rates (CAGR, %) for LB and TBE across Nordic countries, 2018-2024

Notes: LB data were not available from the ECDC for Sweden and Finland.

The stacked area representation (Figure 6) illustrates the cumulative Nordic TBE burden over time, demonstrating Sweden's dominant contribution while revealing the growing proportional shares of Norway, Finland, and Denmark.

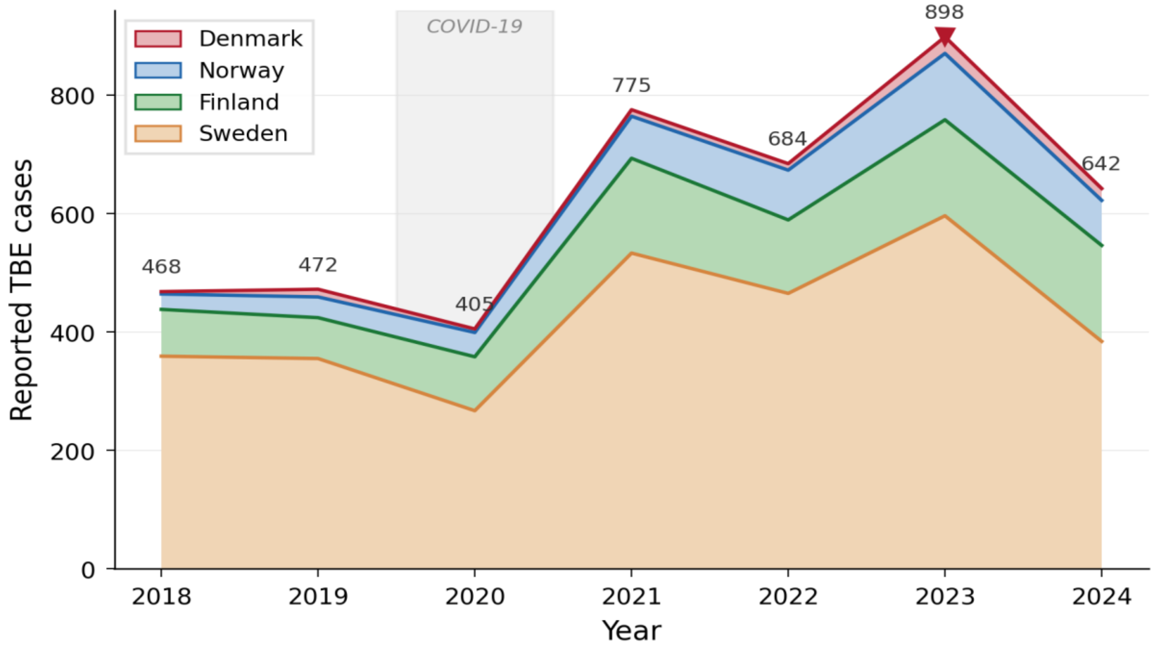


Figure 6. Stacked area chart of total TBE cases across four Nordic countries, 2018-2024

Notes: Grey shading indicates 2020 (primary pandemic year). A peak regional burden of 898 cases occurred in 2023.

COVID-19 pandemic impact

The COVID-19 pandemic exerted differential effects on reported tick-borne disease cases across the region (Table 2, Figures 1-2). The pre-COVID-19 mean annual combined TBE cases (2018-2019) was 470, compared to a post-COVID-19 mean (2022-2024) of 741, representing a 57.7% increase. The year 2020 saw reduced TBE cases in Sweden (−24.8%) and Denmark (−53.8%), consistent with reduced outdoor exposure, altered healthcare-seeking behavior, and diagnostic capacity constraints. Conversely, Finland experienced increased TBE in 2020 (+31.9%) and 2021 (+75.8%), an anomaly attributed to pandemic-related increases in outdoor recreational activities in Finnish forest and archipelago environments [37]. Norway also recorded a modest increase in 2020 (+17.1%), suggesting that pandemic-related behavioral changes did not uniformly suppress tick-borne disease reporting across the region.

For LB, Denmark's cases declined to 48 in 2020 (−4.0% from 50 in 2019, following an earlier decline from 66 in 2018), while Norway showed remarkable stability (317 cases in 2020 versus 321 in 2019; −1.2%), suggesting that disseminated LB diagnosis was less susceptible to pandemic-related disruptions than TBE. The magnitude of the post-pandemic increase varied substantially across countries (Figure 7).

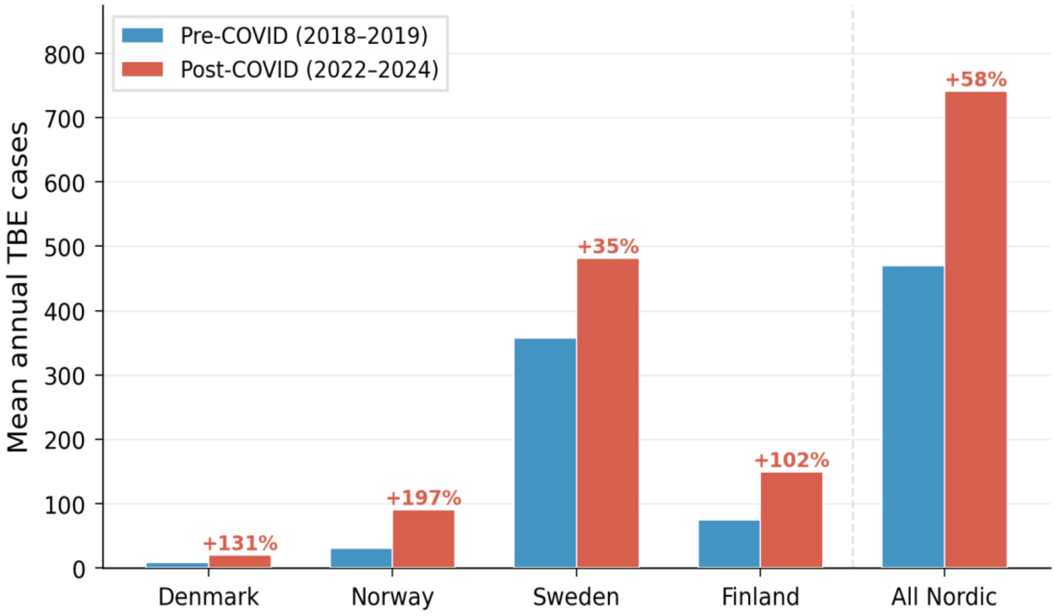


Figure 7. Pre-COVID-19 (2018-2019) versus post-COVID-19 (2022-2024) mean annual TBE cases across four Nordic countries

Notes: Percentage increase shown above post-COVID-19 bars.

Discussion

This study presents the first integrated analysis of temporal trends in both LB and TBE across the Nordic countries using the standardized ECDC surveillance data spanning 2018-2024. The findings reveal escalating tick-borne disease burden across the region, with substantial inter-country variation that reflects the complex interplay of ecological, climatic, surveillance, and policy factors.

Divergent LB trajectories

The contrasting LB trends between Denmark and Norway merit careful interpretation. Norway's relatively stable trajectory (CAGR +6.8%) is consistent with an established endemic pattern, where *I. ricinus* populations along the southern and western coastlines have been well-documented for decades [24,25]. The steady upward trend likely reflects genuine expansion of both vector range and human exposure rather than surveillance artefacts, given that Norway's MSIS system operated with consistent case definitions throughout the study period.

Denmark's dramatic surge in 2023 (266 cases; +303.0% YoY) is more complex to interpret. While some genuine increase is plausible given documented expansion of *I. ricinus* populations and increasing *B. burgdorferi* prevalence in Danish ticks [45,46], a four-fold increase in a single year warrants careful scrutiny of surveillance-related factors, including possible changes in diagnostic testing algorithms, enhanced clinical awareness, or reporting practices. Notably, a recent analysis of LNB surveillance in Denmark from 2017 to 2024 using integrated tick monitoring approaches found that tick activity models strongly predicted disease incidence with temporal lags [47], providing ecological rather than artefactual support for the surge. However, definitively distinguishing genuine epidemiological acceleration from surveillance artefact requires prospective validation, ideally through population-based seroprevalence studies in Denmark comparable to those conducted in Norway [35], and this represents a priority research gap.

Nordic TBE expansion

The TBE findings are particularly striking. The combined Nordic TBE burden peaked at 898 cases in 2023 – a level unprecedented in the region's epidemiological history. Sweden's dominance of the regional TBE burden (68.1%) reflects its larger population but also its extensive endemic foci, particularly around Stockholm, Lake Mälaren, and southern coastal areas [21,36]. The relatively modest CAGR (+1.1%) for Sweden masks considerable inter-annual variability (range: 267-596), a hallmark of TBE epidemiology, which has been attributed to the complex interaction between tick abundance, rodent host population cycles, and climatic factors [32,48].

Finland's sustained growth (CAGR +12.7%) and the plateauing at 162 cases in both 2023 and 2024 suggest a new endemic equilibrium. Finland is one of only three European countries (alongside Latvia and Slovenia) to have incorporated TBE vaccination into its national immunization program, targeting endemic areas including the Åland Islands and selected coastal municipalities [22,23]. Despite this program, incidence continues to rise in previously non-endemic areas, suggesting ongoing geographic expansion of TBEV foci.

Denmark's TBE trajectory (CAGR +30.8%) is perhaps the most epidemiologically significant finding in this analysis. TBE was historically considered rare in Denmark, with the first confirmed cases reported from Bornholm Island in the 1990s [44]. The steady escalation from 4 cases in 2018 to 28 in 2023 signals the establishment of new TBEV foci on the Danish mainland and islands, consistent with documented northward expansion of TBEV-infected ticks. Similarly, Norway's trajectory (CAGR +19.6%) parallels the pattern of tick-borne disease emergence in previously low-endemicity regions observed in both European and North American contexts [44,49].

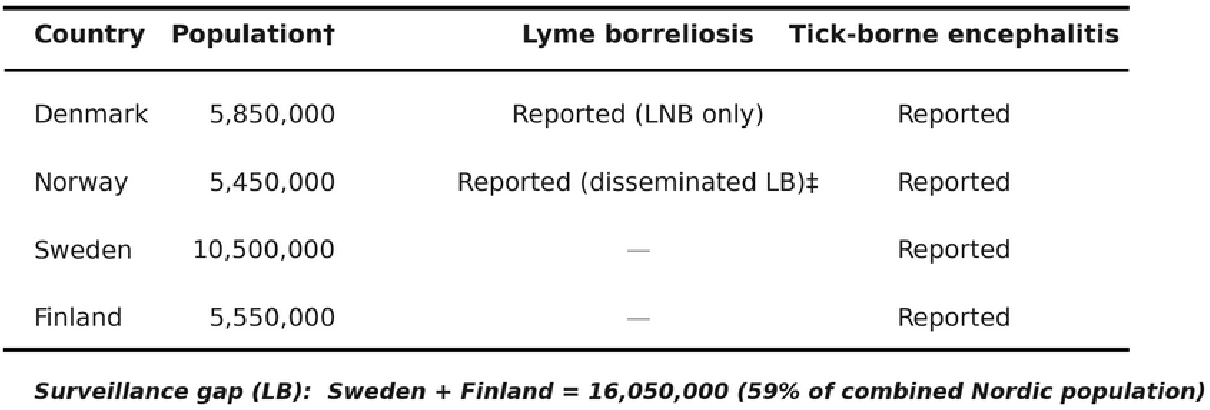
Climate change as the overarching driver

The concurrent escalation of both LB and TBE across the Nordic countries is most parsimoniously explained by the northward expansion and increasing density of *I. ricinus* populations driven by climate change. The thermal limit for *I. ricinus* has shifted northward over the past 40 years, with winter minimum temperatures, particularly the number of days below −12°C, a critical survival threshold showing the strongest correlation with tick distribution at high latitudes [14,16,17]. Extended growing seasons and warmer autumn temperatures prolong the tick questing period, while milder winters reduce tick mortality and enable establishment at previously inhospitable latitudes [13,15].

Host population dynamics further amplify these climate effects. The expansion of roe deer (*Capreolus capreolus*) populations, key reproductive hosts for adult *I. ricinus*, into the northern Nordic countries has been facilitated by the same climatic warming that benefits ticks [18,19]. This co-expansion of vectors and hosts creates a positive feedback loop that accelerates tick-borne disease emergence. Additionally, changes in avian migration patterns may influence the geographic spread of *Borrelia garinii*, the primary causative agent of LNB in Europe, which is maintained in bird reservoirs [50].

Surveillance gap: Sweden and Finland

The absence of ECDC-reported LB data for Sweden and Finland (Figure 8) represents a critical limitation not only of this study but of European LB surveillance more broadly. Sweden lacks any national mandatory notification system for LB [28,29], meaning that the true burden of LB in the country with the largest Nordic population and extensive *I. ricinus* habitat remains poorly characterized at the national level. Regional studies have estimated incidences as high as 464 per 100,000 in highly endemic areas of southeastern Sweden [9], suggesting a substantial disease burden that is invisible in European-level surveillance.



Country	Population†	Lyme borreliosis	Tick-borne encephalitis
Denmark	5,850,000	Reported (LNB only)	Reported
Norway	5,450,000	Reported (disseminated LB)‡	Reported
Sweden	10,500,000	—	Reported
Finland	5,550,000	—	Reported

Surveillance gap (LB): Sweden + Finland = 16,050,000 (59% of combined Nordic population)

Figure 8. Surveillance coverage matrix: LB and TBE reporting to the ECDC across Nordic countries Notes: Over 16 million people in Sweden and Finland are not represented in European LB surveillance. Denmark reports LNB only; Norway reports all disseminated LB (excluding erythema migrans). LNB = Lyme neuroborreliosis, LB = Lyme borreliosis, TBE = Tick-borne encephalitis, † = Approximate mid-period population, ‡ = Excluding erythema migrans; reported through MSIS, — = No data submitted during the study period (2018-2024). Population data: Eurostat dataset tps00001 [39]; disease data: ECDC Surveillance Atlas of Infectious Diseases [38].

Finland operates a comprehensive national infectious disease register that captures all LB forms, with reported incidences exceeding 100 per 100,000 in some years [30]. However, Finland's data were not available in the ECDC Surveillance Atlas for the study period, likely reflecting differences in reporting workflows rather than an absence of surveillance. Recent efforts to estimate total LB incidence in countries that only report LNB, using ratios of erythema migrans to LNB derived from countries with broader surveillance, have an estimated total LB incidence of approximately 151.5 per 100,000 in Denmark and 285 per 100,000 in Sweden [34], A seroprevalence-based analysis of Norway's five most endemic southern coastal counties estimated 315-630 symptomatic LB cases per 100,000 adults in 2022, representing 24-48 symptomatic cases for every surveillance-reported disseminated case, confirming that Norwegian mandatory surveillance captures only 2-4% of the true symptomatic burden [35]. These estimates underscore the vast gap between reported LNB cases and the true burden of LB infection.

The multidimensional relationship between growth trajectory, peak burden, and total case volume is summarized in Figure 9, which reveals that Denmark occupies a uniquely concerning position with the highest growth rates for both diseases despite a currently low absolute burden.

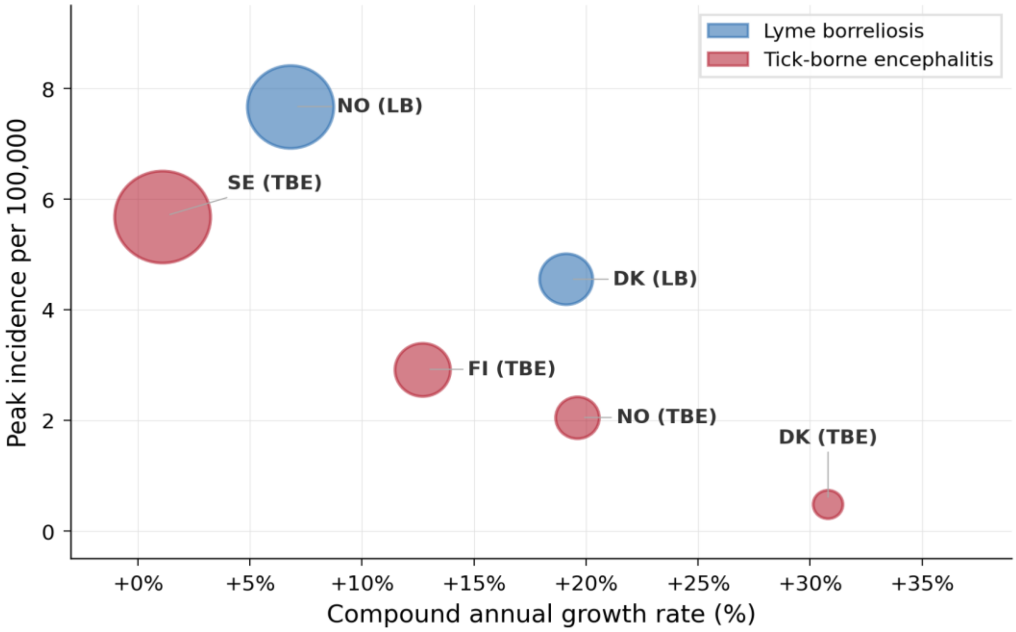


Figure 9. Relationship between compound annual growth rate and peak incidence for LB and TBE across Nordic countries, 2018-2024

Notes: Bubble size proportional to total reported cases. DK = Denmark; NO = Norway; SE = Sweden; FI = Finland.

Implications for public health policy

These findings carry several important policy implications. First, the consistent upward trajectory of TBE across all four countries strengthens the case for expanded vaccination programs. Sweden currently recommends TBE vaccination for residents of and visitors to endemic areas but does not include it in the national immunization program; recent studies have a documented vaccine effectiveness of 84-92% and estimated that vaccination averted approximately 42% of potential TBE cases in studied Swedish populations [21]. Extension of vaccination recommendations, particularly to newly endemic areas in Norway and Denmark, warrants serious consideration.

Second, the harmonization of LB surveillance across the Nordic countries and Europe more broadly remains an urgent priority. The current situation, where two of four Nordic countries contribute no LB data to the ECDC, fundamentally undermines the capacity for regional risk assessment, resource allocation, and evaluation of prevention strategies. The 2018 establishment of standardized LNB reporting was a welcome step; however, full implementation across all member states is essential [33]. Specifically, it is recommended that Sweden implement mandatory laboratory notification of disseminated LB cases through its existing SmiNet electronic reporting platform, following the Norwegian MSIS model, and that Finland prioritizes formalizing the transmission of its national infectious disease register data to ECDC's TESSy platform – a technical and administrative step that would not require new surveillance infrastructure given Finland's existing comprehensive register, but would necessitate a bilateral data-sharing agreement between the Finnish Institute for Health and Welfare (THL) and the ECDC, along with alignment of case definition coding to the EU 2018/945 format [33].

Third, with LB vaccines approaching regulatory review [20], the need for robust baseline surveillance data against which vaccine impact can be assessed is immediate. This analysis provides precisely those baselines for two Nordic countries during the critical pre-vaccine era. The concurrent escalation of both diseases confirms that the underlying driver is vector expansion rather than disease-specific factors, and the differential COVID-19 impacts illuminate distinct epidemiological pathways. The Nordic experience serves as a sentinel case study for other northern-latitude regions facing analogous climate-driven tick-borne disease emergence.

Limitations

Several limitations should be noted. The seven-year study period is relatively short for robust trend analysis. LB data were available for only two of four countries, limiting generalizability. Differences in case definitions between Denmark (LNB only) and Norway (all disseminated LB) preclude direct inter-country comparison of absolute counts, though within-country trends remain valid. Surveillance data are subject to substantial underascertainment, with underdetection multipliers estimated at 54.6-722.2 for countries reporting only LNB [11]. The 2024 data should be considered preliminary due to potential late notifications. Finally, crude incidence rates do not account for age or geographic distribution; however, for within-country trends over a period of minimal demographic change, crude rates are consistent with the ECDC methodology and standard surveillance practice [31,32].

Conclusions

This study provides the first integrated analysis of temporal trends in both LB and TBE across the Nordic countries using the standardized ECDC surveillance data from 2018 to 2024. Both diseases show unambiguous escalating trends consistent with the ongoing climate-driven expansion of *I. ricinus* at northern latitudes. The combined Nordic TBE burden reached an unprecedented 898 cases in 2023, with a 57.7% increase between pre-COVID-19 (2018-2019) and post-COVID-19 (2022-2024) periods. Denmark and Norway demonstrate the most rapid proportional growth in both LB and TBE (CAGRs of +19.1–+30.8%), signaling active emergence and geographic expansion of tick-borne pathogens into areas previously considered low-endemicity.

These findings carry immediate and actionable implications. For vaccination policy, the data provide the pre-vaccine incidence baselines essential for evaluating future LB vaccine impact, and they strengthen the health-economic case for expanding TBE vaccination programs in Norway and Denmark, where incidence is accelerating most rapidly. For surveillance reform, the documented absence of ECDC-reported LB data from Sweden and Finland, representing over 16 million people and among Europe's highest estimated LB burdens, constitutes a peer-reviewed record of a critical gap that demands rectification. Seven years after the European Commission established harmonized LNB reporting, the incomplete implementation of this framework across the Nordic countries undermines the very capacity for the regional risk assessment and resource allocation it was designed to enable.

For climate change adaptation, this analysis transforms abstract projections of vector range expansion into quantified, empirical evidence of disease burden increase evidence that can be incorporated directly into national adaptation plans, health system preparedness models, and climate-health impact assessments. For the broader scientific community, the Nordic experience documented here serves as a sentinel case study for other northern-latitude regions, such as Canada, the Baltic states, Scotland, and northern Russia, on the same trajectory of climate-driven tick-borne disease emergence. Tick-borne diseases are no longer an emerging threat in the Nordic countries – they are an established and accelerating reality. The window for proactive intervention through expanded vaccination, harmonized surveillance, and climate-informed public health planning is narrowing, and the evidence presented here provides both the baseline data and the urgency to act.

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The conducted research is not related to either human or animals use. This study used exclusively aggregated, publicly available surveillance data with no individual-level information. No ethics committee approval was required.

Artificial intelligence was not used to prepare the manuscript. All the scientific content, data analysis, interpretation, and conclusions are solely the work of the author.

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SUPPLEMENTARY MATERIAL

Verification of crude incidence rates: year-specific versus mid-period population denominators

Temporal trends in Lyme borreliosis and tick-borne encephalitis in Nordic countries, 2018-2024

1. Purpose

This supplementary material presents a systematic comparison of crude incidence rates calculated using two approaches: (1) year-specific mid-year population denominators derived from Eurostat "Population on 1 January" data, and (2) approximate mid-period population denominators used in the main analysis. The purpose is to verify that the use of mid-period approximations does not materially alter the reported trends.

2. Data sources

Population data were obtained from Eurostat "Population on 1 January by age and sex" (dataset tps00001, downloaded as estat_tps00001_tsv.gz), accessed January 2026. Mid-year population estimates were calculated as the arithmetic mean of the 1 January population of year t and 1 January population of year t+1. Case counts for Lyme borreliosis (LB) and tick-borne encephalitis (TBE) were extracted from the ECDC Surveillance Atlas of Infectious Diseases on 15 February 2025.

3. Population variation

Table S1 presents the year-specific mid-year population estimates for each country. Table S2 summarizes the population variation over the study period.

Table S1a. Raw Eurostat data: Population on 1 January (dataset tps00001, file estat_tps00001_tsv.gz)

Country	2018	2019	2020	2021	2022	2023	2024	2025
Denmark	5,781,190	5,806,081	5,822,763	5,840,045	5,873,420	5,932,654	5,961,249	5,992,734
Norway	5,295,619	5,328,212	5,367,580	5,391,369	5,425,270	5,488,984	5,550,217	5,594,340
Sweden	10,120,242	10,230,185	10,327,589	10,379,295	10,452,326	10,521,556	10,551,707	10,587,710
Finland	5,513,130	5,517,919	5,525,292	5,533,793	5,548,241	5,563,970	5,603,851	5,635,971

Notes: source – Eurostat, estat_tps00001_tsv.gz, downloaded by the author. Values read directly from the data file without any modification.

Table S1b. Year-specific mid-year population estimates, 2018-2024

Country	2018	2019	2020	2021	2022	2023	2024
Denmark	5,793,636	5,814,422	5,831,404	5,856,733	5,903,037	5,946,952	5,976,992
Norway	5,311,916	5,347,896	5,379,475	5,408,320	5,457,127	5,519,601	5,572,279
Sweden	10,175,214	10,278,887	10,353,442	10,415,811	10,486,941	10,536,632	10,569,709
Finland	5,515,525	5,521,606	5,529,543	5,541,017	5,556,106	5,583,911	5,619,911

Notes: Mid-year estimate = (Population on 1 January of year t + Population on 1 January of year t+1) / 2.

Table S2. Population variation across the study period and comparison with mid-period approximations

Country	Min. mid-year pop.	Max. mid-year pop.	Approx. mid-period	Range (%)
Denmark	5,793,636	5,976,992	5,850,000	3.2
Norway	5,311,916	5,572,279	5,450,000	4.9
Sweden	10,175,214	10,569,709	10,500,000	3.9
Finland	5,515,525	5,619,911	5,550,000	1.9

Notes: All four countries showed population variation of less than 5% over the seven-year study period, with Finland showing the least variation (1.9%) and Norway the most (4.9%).

4. Incidence rate comparisons

Tables S3-S8 present the year-by-year comparison of crude incidence rates calculated using year-specific mid-year denominators versus mid-period approximate denominators. Absolute difference = |Rate(year-specific) – Rate(mid-period)|. Relative difference = Absolute difference / Rate(year-specific) × 100.

Table S3. Lyme Borreliosis – Denmark (LNB): year-specific versus mid-period crude incidence rates per 100,000 population

Year	Cases	Mid-year pop.	Rate (year-specific)	Rate (mid-period)	Abs. diff.	Rel. diff. (%)
2018	66	5,793,636	1.14	1.13	0.011	1.0
2019	50	5,814,422	0.86	0.85	0.005	0.6
2020	48	5,831,404	0.82	0.82	0.003	0.3
2021	76	5,856,733	1.30	1.30	0.001	0.1
2022	66	5,903,037	1.12	1.13	0.010	0.9
2023	266	5,946,952	4.47	4.55	0.074	1.7
2024	188	5,976,992	3.15	3.21	0.068	2.2
Maximum	-	-	-	-	**0.074**	**2.2**

Table S4. Lyme Borreliosis – Norway: year-specific versus mid-period crude incidence rates per 100,000 population

Year	Cases	Mid-year pop.	Rate (year-specific)	Rate (mid-period)	Abs. diff.	Rel. diff. (%)
2018	282	5,311,916	5.31	5.17	0.135	2.5
2019	321	5,347,896	6.00	5.89	0.112	1.9
2020	317	5,379,475	5.89	5.82	0.076	1.3
2021	324	5,408,320	5.99	5.94	0.046	0.8
2022	360	5,457,127	6.60	6.61	0.009	0.1
2023	336	5,519,601	6.09	6.17	0.078	1.3
2024	418	5,572,279	7.50	7.67	0.168	2.2
Maximum	-	-	-	-	**0.168**	**2.5**

Table S5. TBE – Denmark: year-specific versus mid-period crude incidence rates per 100,000 population

Year	Cases	Mid-year pop.	Rate (year-specific)	Rate (mid-period)	Abs. diff.	Rel. diff. (%)
2018	4	5,793,636	0.07	0.07	0.001	1.0
2019	13	5,814,422	0.22	0.22	0.001	0.6
2020	6	5,831,404	0.10	0.10	0.000	0.3
2021	11	5,856,733	0.19	0.19	0.000	0.1
2022	11	5,903,037	0.19	0.19	0.002	0.9
2023	28	5,946,952	0.47	0.48	0.008	1.7
2024	20	5,976,992	0.33	0.34	0.007	2.2
Maximum	-	-	-	-	**0.008**	**2.2**

Table S6. TBE – Norway: year-specific versus mid-period crude incidence rates per 100,000 population

Year	Cases	Mid-year pop.	Rate (year-specific)	Rate (mid-period)	Abs. diff.	Rel. diff. (%)
2018	26	5,311,916	0.49	0.48	0.012	2.5
2019	35	5,347,896	0.65	0.64	0.012	1.9
2020	41	5,379,475	0.76	0.75	0.010	1.3
2021	71	5,408,320	1.31	1.30	0.010	0.8
2022	84	5,457,127	1.54	1.54	0.002	0.1
2023	112	5,519,601	2.03	2.06	0.026	1.3
2024	76	5,572,279	1.36	1.39	0.031	2.2
Maximum	-	-	-	-	**0.031**	**2.5**

Table S7. TBE – Sweden: year-specific versus mid-period crude incidence rates per 100,000 population

Year	Cases	Mid-year pop.	Rate (year-specific)	Rate (mid-period)	Abs. diff.	Rel. diff. (%)
2018	359	10,175,214	3.53	3.42	0.109	3.1
2019	355	10,278,887	3.45	3.38	0.073	2.1
2020	267	10,353,442	2.58	2.54	0.036	1.4
2021	533	10,415,811	5.12	5.08	0.041	0.8
2022	465	10,486,941	4.43	4.43	0.006	0.1
2023	596	10,536,632	5.66	5.68	0.020	0.3
2024	384	10,569,709	3.63	3.66	0.024	0.7
Maximum	-	-	-	-	**0.109**	**3.1**

Table S8. TBE – Finland: year-specific versus mid-period crude incidence rates per 100,000 population

Year	Cases	Mid-year pop.	Rate (year-specific)	Rate (mid-period)	Abs. diff.	Rel. diff. (%)
2018	79	5,515,525	1.43	1.42	0.009	0.6
2019	69	5,521,606	1.25	1.24	0.006	0.5
2020	91	5,529,543	1.65	1.64	0.006	0.4
2021	160	5,541,017	2.89	2.88	0.005	0.2
2022	124	5,556,106	2.23	2.23	0.002	0.1
2023	162	5,583,911	2.90	2.92	0.018	0.6
2024	162	5,619,911	2.88	2.92	0.036	1.3
Maximum	-	-	-	-	**0.036**	**1.3**

5. Summary

Table S9. Summary of maximum absolute and relative differences between year-specific and mid-period incidence rates

Disease – country	Max. abs. diff. (/100,000)	Max. rel. fiff. (%)
LB – Denmark	0.074	2.2
LB – Norway	0.168	2.5
TBE – Denmark	0.008	2.2
TBE – Norway	0.031	2.5
TBE – Sweden	0.109	3.1
TBE – Finland	0.036	1.3
OVERALL MAXIMUM	**0.168**	**3.1**

The maximum absolute difference across all country–disease combinations was 0.168 per 100,000 (LB, Norway, 2024), and the maximum relative difference was 3.1% (TBE, Sweden, 2018). These differences are negligible and do not alter any observed trend direction, magnitude, or interpretation.

6. Conclusion

The use of approximate mid-period population denominators in the main analysis is validated. Year-specific Eurostat denominators produce incidence rates that differ by a maximum of 3.1% from those reported in the manuscript. This level of variation is well within the inherent uncertainty of passive surveillance data and does not affect the study's findings or conclusions.

Reference:

1. Eurostat. Population on 1 January by age and sex [tps00001] [Internet]. Luxembourg: European Commission; 2026 [access Jan 2026]. Available from: https://ec.europa.eu/eurostat/databrowser/view/tps00001