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Original article

Ixodid tick species found in northern Sweden – Data from a frontier area

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ABSTRACT

Environmental and climatic changes in northern Europe have shaped a geographical area in which new tick species may become established and introduce new tick-borne pathogens. In recent decades, ticks have expanded their latitudinal and altitudinal range limits in northern Sweden. In this study, ticks were collected in 2018 and 2019 in northern Sweden from different hosts, mainly from dogs, cats and humans. The ticks in 2018 ($n = 2141$, collected from 65 municipalities in 11 provinces) were identified as *Ixodes ricinus* ($n = 2108$, 98.5%), *Ixodes persulcatus* ($n = 18$, 0.8%), *Ixodes trianguliceps* ($n = 14$, 0.7%) and *Hyalomma marginatum* ($n = 1$, 0.05%). The ticks collected in 2019 ($n = 519$, across a smaller area than in 2018, i.e. Sweden's four northernmost provinces) were identified as *I. ricinus* ($n = 242$, 46.6%) and *I. persulcatus* ($n = 277$, 53.4%). Among those collected in 2019, the majority of *I. ricinus* ($n = 111$, 45.9%) were submitted from the province of Västerbotten, while most *I. persulcatus* ($n = 259$, 93.5%) were collected in the province of Norrbotten. This study provides updated figures on the geographical distribution of two *Ixodes* species in northern Sweden. The results confirmed *I. ricinus* to be the dominant species and that *I. persulcatus* has enlarged its distributional area compared with previous reports. Updated knowledge of tick distribution is fundamental for the creation of risk maps and will allow relevant advice to be provided to the general public, suggesting measures to prevent tick bites and consequently tick-borne diseases.

1. Introduction

Ticks (Acari: Ixodida) are blood-feeding arthropods that play a vital role in public and veterinary health as vectors of a wide range of viral, bacterial and protozoan pathogens (tick-borne pathogens, (TBPs)) (de la Fuente et al., 2017). Environmental and climatic changes may boost tick activity and expand their occurrence, leading to an increase in both the circulation of TBPs and the incidence of tick-borne diseases (TBDs) (Gray et al., 2009). Moreover, environmental and climatic changes in northern regions have shaped a geographical area in which new tick species may become established and introduce new TBPs (Paulauskas et al., 2015; Springer et al., 2020). Hence TBD monitoring should include surveys on the geographic distribution of tick fauna (Braks et al., 2011).

According to Guglielmone et al. (2023), around 760 ixodid tick species (hard ticks, Acari: Ixodida: Ixodidae) and more than 220 argasid tick species (soft ticks, Acari: Argasidae) (Mans et al., 2019) are currently identified and classified worldwide. In Scandinavia, as in large parts of Europe except its southernmost area, the most common tick species belong to the group of hard ticks. Sweden's tick fauna has been studied since the 1920s (Schulze, 1930; Brinck et al., 1967; Nilsson, 1988). Jaenson et al. (1994) recorded 14 tick species in Sweden and studied their geographic distribution and host relationships. Of these, most tick species were confirmed as being permanently present in Sweden and were classified according to their host species: 1) tick species feeding on birds are *Ixodes arboricola, Ixodes caledonicus, Ixodes lividus, Ixodes unicavatus* and *Ixodes uriae*, 2) tick species feeding on mammals are *Carios vespertilionis, Ixodes canisuga, Ixodes hexagonus* and *Ixodes trianguliceps* and 3) tick species feeding on both birds and mammals are *Haemaphysalis punctata* and *Ixodes ricinus*. Recently *Ixodes persulcatus*, probably introduced by birds, has become established in northern Sweden, and its geographical distribution and population

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density are gradually increasing (Jaenson et al., 2016). In Finland, the north-western limit of the geographical range of *I. persulcatus*, this species was first reported in scattered foci along the country's western coast, including in the archipelago of Kokkola and Närpiö municipality (Alekseev et al., 2007; Jääskeläinen et al., 2010, 2006). More recently, three distinct geographical clusters of *I. persulcatus* have been reported on the coast of the Gulf of Bothnia, in eastern Finland and in the middle of southern Finland (Laaksonen et al., 2017).

Other tick species have been introduced (but are not yet established in Sweden) either by imported dogs, e.g. *Dermacentor reticulatus* and *Rhipicephalus sanguineus* sensu lato, or by migratory birds, e.g. *Hyalomma marginatum* and *Hyalomma rufipes* (Grandi et al., 2020).

Ixodes ricinus is a widespread tick species in Europe and the most common in Sweden. Until the early 1980s, the geographical range of *I. ricinus* was mainly centered on southern and central Sweden, with its northern range limit at Limes Norrlandicus, the biological border of Norrland, which is often used to indicate the northern boundary of the geographical distribution of vegetation and animals in Sweden (Jaenson et al., 2012b; Tälleklint and Jaenson, 1998). In 1994, a new northern boundary for *I. ricinus* was reported that runs through central Sweden and along the coastal region of northern Sweden (Jaenson et al., 1994). Recently, *I. ricinus* has also been reported to have gradually spread its range of territory northwards, and ticks can now be found along the Baltic Sea coastline, i.e. up to 66 °N (Gray et al., 2009; Jaenson et al., 2016).

Between the 1980s and the early 21st century, the population of the main tick host of *I. ricinus* (roe deer, *Capreolus capreolus*) greatly increased in Sweden (Jaenson et al., 2012a). Global environmental changes, among other factors, have contributed to the tick's expanded distribution in Fennoscandia and to shifts in the tick's latitudinal and altitudinal distribution (Hvidsten et al., 2020; Jaenson and Lindgren, 2011; Jore et al., 2014, 2011; Lindgren et al., 2000; Kahl and Gray, 2023). It has been shown that the northward shift in its latitudinal distribution is related to a decrease in the number of degree days with temperatures below -12 °C, which is vital for tick survival, activity and development, as well as to mild winters and extended spring and autumn seasons (Gray et al., 2009; Lindgren et al., 2000). In addition, a recent study by Hvidsten et al. (2020) has shown a marked increase in permanent tick populations in northern Norway, with the northernmost location at latitude 66°N. Changes towards a warmer and wetter climate with milder winters and less snow cover are likely to improve tick survival, and affect their distribution and abundance (Jore et al., 2014). In contrast, Dautel et al. (2016) have shown an evident decline in *I. ricinus* host-seeking activity during the tick season after an extreme cold spell in areas with an absence of snow cover in Germany in 2012. This study also confirms that the presence of snow cover appears to be an effective buffer, protecting *I. ricinus* ticks from low temperatures (Dautel et al., 2016). Furthermore, the scenario models of Jaenson and Lindgren (2011) show that climate change this century will probably increase the geographic range of *I. ricinus*, as vegetation communities and mammals associated with high tick densities increase their geographic ranges due to a prolonged vegetation period, i.e. the distribution of *I. ricinus* in Sweden coincides with regions where the vegetation growing season exceeds 170 days. This has also been confirmed by analysis of climate data in the study by Hvidsten et al. (2020) in Norway, which shows that established tick populations occur where the growing season is 170–180 days or more. In addition, Gray et al. (2009) suggest that possible climate effects will have a greater impact closer to the ticks' geographical distribution limits. All these factors combined have led to the spread of *I. ricinus* in northern Fennoscandia, which increases the risk of the human population in Nordic countries coming into contact with pathogens transmitted by this tick species (Kahl and Gray, 2023).

The complex ecology and focal distribution of *I. ricinus* and *I. persulcatus* make it difficult to map their distribution. Tälleklint and Jaenson (1998) and Jaenson et al. (2012b) performed two questionnaire surveys targeting members of the public in central and northern Sweden in order to obtain information about whether ticks were present in the area around respondents' homes in the early 1990s and in 2009. The results from these studies indicate that *I. ricinus* has spread to new localities north of its previous range, as well as becoming more abundant during this period. The aim of the present study, consisting of two citizen science studies, was to provide updated information with greater accuracy on the distribution of tick species in northern Sweden.

2. Materials and methods

2.1. Tick collection

The first citizen science collection was performed between June and October in 2018, and covered municipalities in the provinces located north of the river Dalälven, one of the geographical borders traditionally dividing the northern region of Sweden (Norrland) from its central and southern regions (Fig. 1A).

The second citizen science collection was performed between June and October 2019, and focused on municipalities in Sweden's northernmost provinces (i.e. Lappland, Norrbotten, Västerbotten and Jämtland; Fig. 2A). This area is considered the most interesting for monitoring the northern expansion of *I. ricinus* and the population growth of *I. persulcatus*.

The National Veterinary Institute (SVA, Uppsala, Sweden) issued press releases in early June 2018 and 2019 to notify the public about the citizen study. Information about the tick collection was disseminated with the help of local and national newspapers, radio, television and social media. SVA also had dedicated webpages on its public website (https://www.sva.se) to communicate information about the study, which were updated once in August in both years. All citizens within the study area had the opportunity to become a "tick collector" and could send in ticks on one or several occasions during the tick season (from June to October in both years). Members of the public who had found ticks either on themselves or on domestic animals, and in a few cases on wild animals, participated in the study. The tick samples were sent by post to SVA.

At SVA, all the ticks were registered with information about the municipalities from where they had been submitted and the associated host species from which they were collected. Individual ticks were stored at -80 °C pending morphological identification. Samples with incomplete information (municipality of origin, host species) or severely damaged specimens were not processed further.

2.2. Morphological identification

Prior to morphological identification, each tick was washed for 1 min in 70% ethanol solution followed by MilliQ water in preparation for further molecular analyzes, and then dried separately on a clean sheet of paper. A stereomicroscope (Leica MZ16, Leica Microsystems, Stockholm, Sweden) with up to x200 magnification was used for species identification together with morphological taxonomic keys and illustrations (Estrada-Peña et al., 2017; Filippova, 1977). The developmental stage was also recorded.

2.3. Molecular identification of I. ricinus and I. persulcatus

Each individual tick was placed in a 2 ml screw-cap micro tube with 450 μl lysis buffer solution, which comprised 441 μl Buffer RLT (Qiagen, Hilden, Germany) and 9 μl 2 M Dithiothreitol (DTT) (Sigma-Aldrich, St Louis, MO, USA), plus a 5 mm stainless steel bead (Qiagen, Hilden, Germany). The ticks were then homogenised in a TissueLyser (Qiagen, Hilden, Germany) for two cycles of one min each at a frequency of 30 Hz. The tubes were centrifuged for 3 min at 20,000 x g and 90 μl of the supernatants were incubated with 10 μl of Proteinase K (P4850; Sigma-Aldrich, St Louis, MO, USA) for at least 10 min in a 96-well plate. The extraction of total nucleic acid (NA) was performed in the Magnatrix

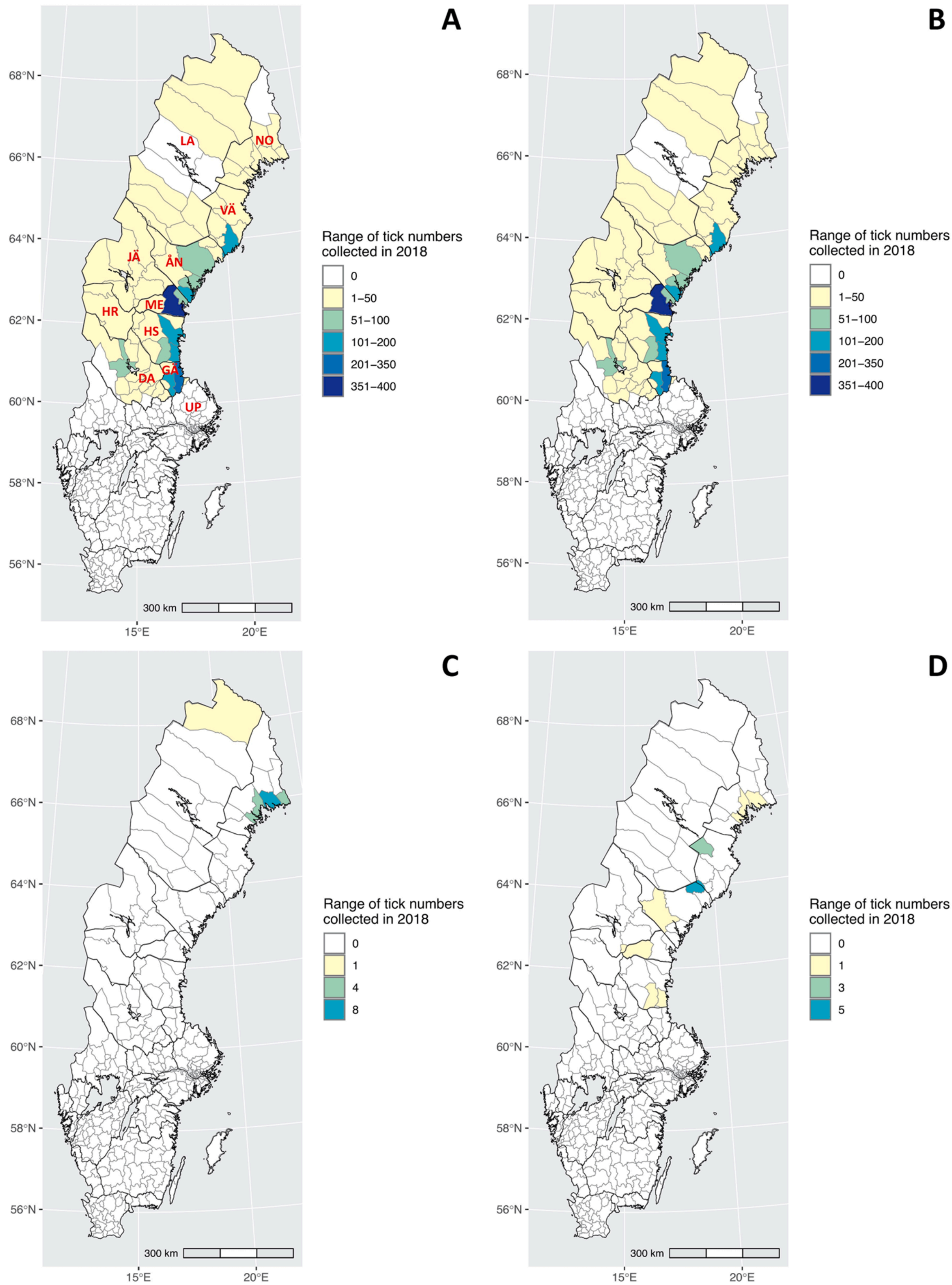

Fig. 1. Geographical distribution of all tick species – (A), *Ixodes ricinus* (B), *Ixodes persulcatus* (C), *Ixodes trianguliceps* (D) – collected from 11 northern provinces in Sweden in 2018. The unit of sampling area is municipality, with borders represented by a grey line. Provincial borders are shown by a black line.
Abbreviations of province name: LA, Lappland; NO, Norrbotten; VÄ, Västerbotten; JÄ, Jämtland; ÅN, Ångermanland; HR, Härjedalen; ME, Medelpad; HS, Hälsingland; DA, Dalarna; GÄ, Gästrikland; UP, Uppland

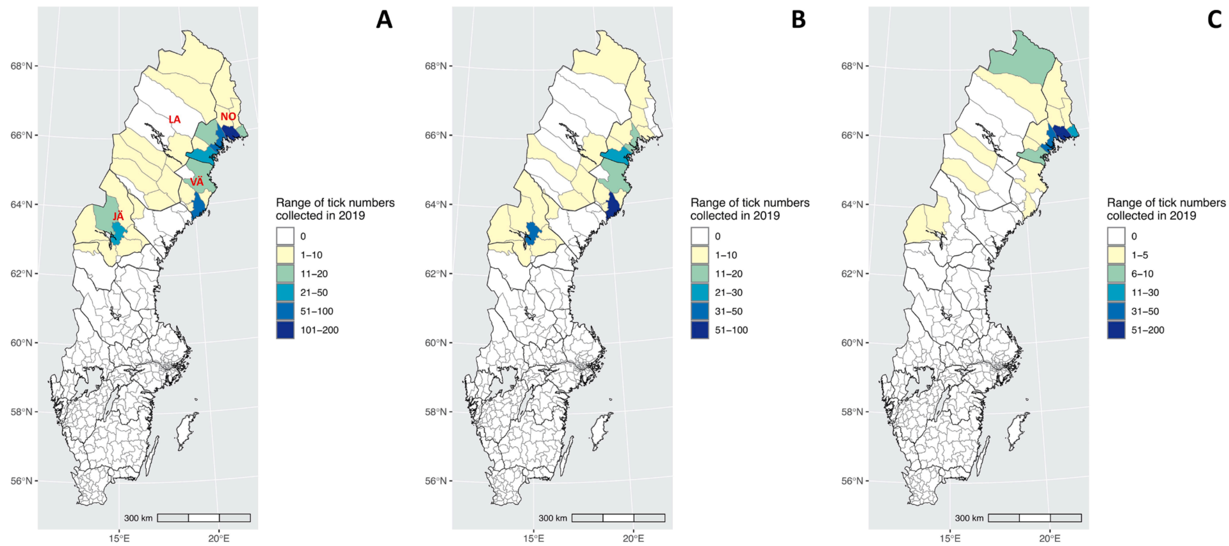

Fig. 2. Geographical distribution of all tick species – (A), *Ixodes ricinus* (B) and *Ixodes persulcatus* (C) – collected from Sweden's four northernmost provinces in 2019. The unit of sampling area is municipality, with borders represented by a grey line. Provincial borders are shown by a black line.
Abbreviations of province name: LA, Lappland; NO, Norrbotten; VÄ, Västerbotten; JÄ, Jämtland

8000+ extraction robot (Magnetic Biosolutions, Stockholm, Sweden) with one of two commercial extraction kits – either the Bullet Stool Kit 1.32.104 (DiaSorin, Saluggia, Italy) or the Vet NA kit 1.001 (Bioservices, Stockholm, Sweden) – with an elution volume of 60 µl. DNA pre-amplification and high-throughput microfluidic real-time amplification were carried out as previously described (Michelet et al., 2014). Three PCR reactions were employed. One reaction with primers and a probe targeting a conserved region of the tick 16S rRNA gene (Gondard et al., 2020) served as an extraction control and to confirm the presence of tick DNA. Two primer/probe sets were applied for species-specific reactions for *I. persulcatus* and *I. ricinus* respectively in order to confirm their morphological identification (Gondard et al., 2020). Data were acquired on the BioMark™ real-time PCR system and analyzed using Fluidigm real-time PCR analysis software (Fluidigm, San Francisco, USA) to obtain crossing point (CP) values.

2.4. Ethics statement

An ethics statement is not applicable as this study was not classified as a human or animal experiment. Ticks were sent in voluntarily by people living in the study area. Their personal data were only used to locate the geographical area and host information, and will not be made public. SVA processed the data in accordance with Data Protection Regulation (EU) 2016/679. The senders were informed that SVA reserves the right to use the submitted ticks and the accompanying metadata for research purposes as part of SVA's activities. The research is published without reference to individual survey responses, unless required by Swedish law.

3. Results

3.1. Tick submission and species identification

In 2018, a total of 3131 ticks were submitted from 11 northern provinces in Sweden: Lappland, Norrbotten, Västerbotten, Jämtland, Ångermanland, Härjedalen, Medelpad, Hälsingland, Dalarna, Gästrikland and Uppland (Fig. 1A, Table 1). Due to incomplete information regarding some of the collected material, a subset of 2141 ticks were analyzed for their species, life stage and sex by morphological or molecular identification. Molecular identification of *I. ricinus* and *I. persulcatus* was performed on 236 ticks from the following provinces: Lappland, Norrbotten, Västerbotten (except Umeå municipality), Jämtland, Ångermanland (only Nordmaling municipality), Härjedalen (only Härjedalen municipality) and Dalarna (only Älvdalen municipality). The majority of ticks were identified as *I. ricinus* ($n = 2108$, 98.5%). The remaining specimens were identified as *I. persulcatus* ($n = 18$, 0.8%) or *I. trianguliceps* ($n = 14$, 0.7%). One tick was identified as a female *H. marginatum* (Table 1).

In 2019, 558 ticks were collected and registered from municipalities in Sweden's four northernmost provinces, i.e. Lappland, Norrbotten,

Table 1
Geographical distribution of ticks collected through the citizen-science programme in 11 northern provinces in Sweden in 2018.

Province	Tick no. (%)	*Ixodes ricinus*			*Ixodes persulcatus*			*Ixodes trianguliceps*			*Hyalomma marginatum*
		Nymph	Female	Male	Nymph	Female	Male	Nymph	Female	Male	Female
Lappland	25 (1.2)	1	21	1		2					
Norrbotten	65 (3.0)		46	1		12	4		2		
Västerbotten	189 (8.8)	4	167	10				1	7		
Jämtland	51 (2.4)	1	49	1							
Ångermanland	283 (13.2)	6	249	27					1		
Härjedalen	11 (0.5)		11								
Medelpad	451 (21.1)	8	368	74					1		
Hälsingland	407 (19.0)	18	331	55					2		1
Dalarna	188 (8.8)	7	159	22							
Gästrikland	461 (21.5)	25	345	91							
Uppland	10 (0.5)		9	1							
Total no.	2141	70	1755	283	0	14	4	1	13	0	1

Västerbotten and Jämtland (Fig. 2A). Complete information was available for 519 samples, which were further identified through PCR as either *I. ricinus* (*n* = 242, 46.6%) or *I. persulcatus* (*n* = 277, 53.4%). The sex of five adult ticks (three *I. ricinus* and two *I. persulcatus*) could not be determined due to severe damage to their body, with key body parts missing in some cases. Among 242 *I. ricinus*, two ticks (0.8%) were nymphs and the vast majority (99.2%) were adults. Among 277 *I. persulcatus*, only one nymph (0.4%) was collected and the remainder (99.6%) were adults (Table 2).

As expected in ticks collected from hosts rather than flagged from the environment, the majority of the collected ticks (excluding males) showed some degree of engorgement.

3.2. Geographical distribution of ticks

In 2018, *I. ricinus* was collected from all 65 municipalities in 11 provinces, with 60% (*n* = 1280) of these collected from seven municipalities in five provinces: Umeå (*n* = 119) in Västerbotten, Härnösand (*n* = 128) in Ångermanland, Sundsvall (*n* = 380) in Medelpad, Hudiksvall (*n* = 126) in Hälsingland, Söderhamn (*n* = 133) in Hälsingland, Gävle (*n* = 260) in Gästrikland and Sandviken (*n* = 134) in Gästrikland (Table 1, Fig. 1B).

In 2019, tick samples (*n* = 519) were submitted from 30 municipalities in Sweden's four northernmost provinces (Table 2, Fig. 2A). Of all the *I. ricinus* samples collected (*n* = 242), around half were sent from two municipalities: Umeå (*n* = 84) in Västerbotten and Östersund (*n* = 35) in Jämtland. Of the *I. persulcatus* samples submitted (*n* = 277), more than half (*n* = 180) were collected from Kalix in Norrbotten alone (Fig. 2B, C).

3.3. Host association of ticks

In 2018, ticks were collected from 11 host animal species including humans. The majority of ticks (*n* = 2018, 94.3%) were collected from cats or dogs, followed by humans (Table 3).

In 2019, the majority of ticks (*n* = 378, 72.8%) were collected from dogs (Table 4).

4. Discussion

Data on the presence of ticks in northern Sweden are limited. The last available description of Swedish tick fauna dates back to the mid-1990s (Jaenson et al., 1994). More recently, the tick fauna in northern Sweden has been examined in citizen science studies with the help of questionnaires by Tälleklint and Jaenson (1998) and Jaenson et al. (2012b). Altogether, these studies suggest that the permanent population of *I. ricinus* has expanded its range in northern Sweden (above latitude 60 °N) in the last three decades. However, *I. ricinus* is still considered to be absent in the northern mountain region (above the tree line). The tick species composition found here confirmed the dominant role of *I. ricinus*, the common tick, which in this study was found in all northern provinces, including Härjedalen where *I. ricinus* has not previously been reported. These findings are in line with Hvidsten et al. (2020), who recently provided evidence of permanent *I. ricinus* populations (completion of a full life cycle) in northern Norway (up to latitude 66 °N).

Most of the ticks collected were females, followed by males and nymphs. This is most likely because nymphs are smaller and thus detected less often, especially on pets. According to these results, *I. ricinus* was not only present close to the coastline, but also in the inland area of northern Sweden (Figs. 1B, 2B). This could be a consequence of climate change and may also reflect the collection method, i.e. these specimens were not collected from the environment and therefore their exact site of questing is not available.

The taiga tick, *I. persulcatus*, has already been recorded in Sweden (Jaenson et al., 2016, 1994), but in the present study this tick species was found across a broader geographical area. The only finding of *I. persulcatus* reported in the previous description of Swedish tick fauna (Jaenson et al., 1994) was a nymph collected on Stora Fjäderägg island in the province of Västerbotten. Tick flagging performed more recently with the aim of ascertaining whether the Taiga tick has become established in Sweden revealed the presence of questing *I. persulcatus* ticks on some islands in the Kalix archipelago (province of Norrbotten Jaenson et al. 2016). Interestingly, the present study found *I. persulcatus* adults in the provinces of Lappland and Norrbotten in 2018 (Fig. 1C), and in all four provinces (Lappland, Norrbotten, Västerbotten and Jämtland) examined in 2019 (Fig. 2C), when a nymph was also found. These findings indicate that permanent populations of *I. persulcatus* may be primarily distributed along Sweden's northernmost coastline, but can also be found further west in northern Sweden. Traditionally the distributional area of *I. ricinus* has been seen as a barrier to the expansion of *I. persulcatus* towards western Europe since the hybrids of these two species are infertile (Bugmyrin et al., 2016, 2015; Kovalev et al., 2016). More studies are needed to continue to monitor and confirm the trend observed in the present study, i.e. whether the taiga tick is becoming more abundant in the western limits of its distributional area. Further investigations of how this expansion of *I. persulcatus* will influence the distribution and fitness of *I. ricinus* are also needed.

Ixodes trianguliceps, previously found on eleven species of rodents and shrews in Sweden (Jaenson et al., 1994), was reported to be found on a short-tailed field vole (*Microtus agrestis*), a yellow-necked mouse (*Apodemus flavicollis*) and dogs and cats in the 2018 tick collection (Table 3). There was no expectation that numerous *I. trianguliceps* specimens would be sent in, since the major contributors to the collection were owners of pets or production animals and no ticks from rodents were collected in 2019.

In the present study, the northernmost collection of a female *H. marginatum* ever recorded was reported; this, together with repeated findings of *Hyalomma* spp. adult ticks in central and southern Sweden at the same time as this collection, might be another consequence of climate change (Grandi et al., 2020). Although the finding of an adult *Hyalomma* sp. was an exceptional event (Grandi et al., 2020), a similar phenomenon was reported in Germany in 2018 (Chitimia-Dobler et al., 2019). In addition, the first case of adult *Hyalomma* sp. from a horse in the UK was reported in 2018 (Hansford et al., 2019) and a *H. marginatum* male was found on a horse in Norway more recently (Stuen, 2021). These findings require ongoing monitoring and a risk assessment for the potential introduction, spread and establishment of tick-borne pathogens carried by *Hyalomma* sp. in Sweden and neighbouring countries.

In comparison with the tick species previously reported in the same

Table 2
Geographical distribution of ticks collected through the citizen-science programme in 4 northern provinces in Sweden in 2019.

Province	Tick no. (%)	*Ixodes ricinus*				*Ixodes persulcatus*			
		Nymph	Female	Male	Unknown sex	Nymph	Female	Male	Unknown sex
Lappland	20 (3.9)		9		1		10		
Norrbotten	315 (60.7)		52	4		1	172	84	2
Västerbotten	117 (22.5)	2	101	6	2		5	1	
Jämtland	67 (12.9)		59	6			2		
Total no.	519	2	221	16	3	1	189	85	2

Table 3
Associated host animals of collected ticks through the citizen-science programme in northern Sweden in 2018.

Host	Tick no. (%)	*Ixodes ricinus*			*Ixodes persulcatus*			*Ixodes trianguliceps*			*Hyalomma marginatum*
		Nymph	Female	Male	Nymph	Female	Male	Nymph	Female	Male	Female
Cat	936 (43.7)	7	813	111		3			2		
Dog	925 (43.2)	4	772	132		10	5		2		
Human	157 (7.3)	56	73	28							
Cattle	40 (1.9)		35	5							
Horse	8 (0.4)		7								1
Short-tailed field vole	6 (0.3)								6		
Yellow-necked mouse	4 (0.2)							1	3		
Rabbit	2 (0.1)	1	1								
Deer	1 (0.0)		1								
Moose	1 (0.0)		1								
Unidentified host	61 (2.8)	2	52	7							
Total no.	2141	70	1755	283	0	13	5	1	13	0	1

Table 4
Associated host animals of collected ticks through the citizen-science programme in northern Sweden in 2019.

Host	Tick no. (%)	*Ixodes ricinus*				*Ixodes persulcatus*			
		Nymph	Female	Male	Unknown sex	Nymph	Female	Male	Unknown sex
Dog	378 (72.8)		141	12	3	1	146	74	1
Cat	66 (12.7)		56	1			9		
Human	26 (5.0)	1	4	1			16	3	1
Rabbit	1 (0.2)			1					
Unidentified host	48 (9.2)	1	20	1			18	8	
Total no.	519	2	221	16	3	1	189	85	2

region (Jaenson et al., 1994), neither *I. lividus* (reported in 1994 from the provinces of Lappland, Norrbotten, Västerbotten and Dalarna) nor *I. uriae* (collected in Ångermanland in 1994) were collected. Both tick species are associated with marine birds, a type of host not represented in these collections. No specimens of *Rhipicephalus sanguineus* sensu lato (this species was described in the provinces of Medelpad and Uppland in 1994) were submitted from the study area, despite cases of indoor infestation of this tick species being reported elsewhere in Sweden by households where it has been introduced by travelling pets (Simoni and Grandi, 2018). Only a small part of the Uppland province was included in the present study (municipalities located north of the river Dalälven) and therefore it is unsurprising that the same variability in tick species as described previously (i.e. *I. arboricola, I. canisuga, I. hexagonus*; Jaenson et al. 1994) was not recorded here.

Regarding the geographical origin of the collected ticks, this study demonstrates how information on ticks can be retrieved from a wide geographical area thanks to the involvement of the general public. This might have been difficult to achieve if the collection had to be based on environmental sampling (i.e. flagging). The collection material within citizen science studies can be subject to several biases, i.e. (i) it may be more like for clusters of ticks to be collected in large urban centers characterised by higher population density, as demonstrated by the larger numbers of ticks collected in Sundsvall and Gävle for example, (ii) some very engaged people might send in several ticks from the same collection site, and (iii) as mentioned above, the collection of ticks from their hosts cannot reflect the exact geographical distribution of the findings.

It is difficult to compare the distribution and abundance recorded in this study since there have been no other studies of this kind performed in a similar way in Sweden. However, from other studies using similar approaches elsewhere, it can be hypothesised that tick populations are expanding their geographical distribution, as is the case in the UK and Finland (Gandy et al., 2023; Hansford et al., 2022; Laaksonen et al., 2017). Regarding the four northernmost provinces, in 2019 57% more ticks were received compared with 2018 (519 vs 330 for all the four provinces, and 315 vs 65 in Norrbotten province alone). This might be explained by people's increased awareness and engagement after the first collection season, and could represent one of the biases related to citizen science studies. Nevertheless, the increase in the number of *I. persulcatus* found (fifteen times more: 277 vs 18 for all the four provinces, and 259 vs 16 in Norrbotten province alone) cannot be explained simply by the increased number of samples collected. Instead, this result most likely reflects a real increase in the occurrence of this tick species, especially in the province of Norrbotten. A proper estimation of permanent tick establishment and tick abundance is necessary to define relative risks in a certain geographical region. It should be noted that the nature of the data collected in this study only recorded the occurrence of individual ticks in certain areas, rather than determining the existence of permanent populations. While there is a consensus on the criteria for establishing the existence of permanent populations of Lyme disease vectors in the US (Anonymous, 1991), such criteria have not yet been established for European tick species.

The kind of hosts from which the most ticks were received (dogs and cats) have previously been demonstrated to be an excellent source of information on ticks within the context of passive surveillance (Abdullah et al., 2016; Davies et al., 2017) and will probably continue to be used in future studies. The fact that no *I. hexagonus* or *I. canisuga* were found deserves further investigation in order to understand whether these nidicolous species parasitising cats and dogs are really absent from the considered area or whether the collection method can somehow be improved. Furthermore, it was confirmed that *I. ricinus* nymphs were detected on humans more often than on pets, presumably because dogs are not good hosts for this life stage. This study's figures are also consistent with the findings of another study of ticks collected from dogs, where the majority of ticks were adults (Abdullah et al., 2016).

It is hoped that the data generated by this study can be used for modelling purposes as well as in the design of risk maps. In particular, the integration of passive methods (as in the present study) with active surveillance could lead to the creation of detailed risk maps that will ultimately increase public awareness of the risks associated with outdoor activities such as trekking and camping, a fundamental part of Scandinavian lifestyle.

5. Conclusions

The northward expansion of ticks and tick-borne pathogens in

Sweden presents a considerable public health concern. However, human population densities in northern Sweden are low compared with the country's southern regions, and a northward expansion of the tick range will therefore affect a small proportion of the human population. These results suggest that it may be desirable to target surveillance and preventive measures in areas where there is high human population density and where ticks are well established, i.e. Sweden's densely populated eastern coast along the Bothnian Bay. In order to compensate for some of the biases of the present method of collection, tick flagging in some of the localities identified by this study (for example, at the northern limit identified both on the coast and in the inland region) should be planned and performed to obtain more precise information about tick ecology, distribution and abundance. Finally, the publication of complementary information on TBPs carried by ticks in the studied geographical area will allow the creation of risk maps that offer details on the emergence and spread of TBPs in a particular region.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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