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For the people by the people: Citizen science web interface for real-time monitoring of tick risk areas in Finland

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Abstract

1. Ticks and tick-borne diseases (TBDs) form a significant and growing threat to human health and well-being in Europe, with increasing numbers of tick-borne encephalitis (TBE) and Lyme borreliosis cases being reported during the past few decades. Increasing knowledge of tick risk areas and seasonal activity remains the primary method for preventing TBDs. Crowdsourcing provides the best alternative for rapidly obtaining data on tick occurrence on a national level.
2. In order to produce and share up-to-date data of tick risk areas in Finland, an online platform, Punkkilive (www.punkkilive.fi/en), was launched April 2021. On the website, users can submit and browse tick observations, report tick numbers and hosts, and upload pictures of ticks.
3. Here, we looked at trends in the crowdsourced data from 2021, assessed the effect of local tick species on seasonality of observations and examined sampling bias in the data.
4. The high number of tick observations ($n = 78{,}837$) highlights that there was demand for such a service. Approximately 97% of 5573 uploaded pictures represented ticks. Seasonal patterns of tick observations varied across Finland, highlighting variability in the risk associated with the two human-biting tick species *Ixodes ricinus* and *I. persulcatus*, the latter having a shorter, unimodal activity peak in late spring–early summer. Tick numbers were low and the proportion of new sightings high in northern Finland, as may be expected near the latitudinal distribution limits of both species. While the number of inhabitants generally explained the number of tick observations well, geographically weighted regression models also identified areas that deviated from this general pattern.
5. This study offers a prime example of how crowdsourcing can be applied to track vectors of zoonotic diseases, to the benefit of both researchers and the public. Areas with more or less observations than predicted based on number of inhabitants were revealed, wherein more specific analyses may reveal factors contributing to lower or higher risk levels that may be used in increasing awareness. We

hope that the success of Punkkilive serves to highlight the usefulness of citizen science in the prevention of vector-borne diseases.

KEYWORDS
citizen science, crowdsourcing, public health, sampling bias, tick risk areas, tick-borne diseases, ticks

1 | INTRODUCTION

Ticks and tick-borne diseases (TBDs) form a significant and growing threat to human health and well-being in Europe, with some hundreds of thousands of cases of TBDs reported annually (Marques et al., 2021). In Finland, cases of tick-borne encephalitis (TBE) and Lyme borreliosis have been increasing during the past few decades (Sajanti et al., 2017; Smura et al., 2019), with the years 2020 and 2021 forming two sequential peaks in cases of both diseases. In part, this is likely due to COVID-19 restrictions encouraging outdoor activities. In addition to TBDs, rising numbers of ticks have been observed in field surveys conducted across Finland (Klemola et al., 2019; Sormunen, Andersson, et al., 2020; Sormunen, Klemola, et al., 2016; Sormunen, Penttinen, et al., 2016), and anecdotal observations of rising tick densities have been increasingly communicated to the University of Turku Tick Project by concerned citizens (unpublished own data; www.puutiaiset.fi). These observations conform to previously made studies regarding the impacts of climate change on tick populations and TBDs in northern Europe, which have predicted that new climatic patterns will be beneficial for *Ixodes ricinus* (Linnaeus, 1758), the main vector for Lyme borreliosis and TBE in Europe, leading to range expansion and increases in densities (Jaenson et al., 2012; Jaenson & Lindgren, 2011; Laaksonen et al., 2017). The same is likely true regarding another tick species of medical interest, *Ixodes persulcatus* (Schulze, 1930), which appears to be continuing their range expansion in Finland (Kulha et al., 2022).

In the absence of vaccines against TBDs other than TBE, or effective ways for broadscale controlling of tick population sizes, increasing public awareness regarding tick risk areas, biotopes and activity seasons remains the primary method for preventing TBDs (Bayles et al., 2013; Keesing & Ostfeld, 2018; Mowbray et al., 2012; Niesobecki et al., 2019; Slunge & Boman, 2018; Zöldi et al., 2017). The identification and mapping of risk areas for tick encounters allow researchers and healthcare professionals to communicate health risks more effectively and concretely to citizens (Bayles et al., 2013; Niesobecki et al., 2019; Slunge & Boman, 2018; Zöldi et al., 2017). Furthermore, if made public, such data can be used independently by the citizens themselves to identify risk areas and help to promote caution. For example, knowledge of visiting a risk area may increase the likelihood of a citizen performing a tick search after outdoor activities, thus helping prevent Lyme borreliosis cases (Niesobecki et al., 2019; Slunge & Boman, 2018).

The most common method for surveying tick populations and identifying risk areas is cloth dragging (often followed by laboratory screening of tick-borne pathogens), which is widely used despite some intrinsic shortcomings of the method (Kjellander et al., 2021; Nyrhilä et al., 2020). While applicable to studies of tick occurrence and abundance, covering broad areas by cloth dragging is impossible. In order to form comprehensive and up-to-date maps of tick occurrence and, consequently, tick risk areas, vast networks of researchers or citizen science are required (Laaksonen et al., 2017; Lewis et al., 2018; Porter et al., 2021; Sgroi et al., 2022). Citizen science, sometimes referred to as crowdsourcing, is an efficient method for collecting data on invertebrate vectors, such as mosquitoes or ticks (Laaksonen et al., 2017; Pernat et al., 2021), over broad spatial scales, or to generally promote environmental protection by building scientific knowledge (McKinley et al., 2017).

Despite their unmatched power in generating data sets covering vast areas, opportunistically collected citizen science data also have drawbacks that challenge the usability of such observations (Welvaert & Caley, 2016). For example, the number of citizen science observations is intrinsically correlated with the number of observers. The number of observers—in turn—depends on factors such as population density, promotion success of a survey and site accessibility (Cretois et al., 2021; Mair & Ruete, 2016). Uneven spatiotemporal sampling effort may introduce sampling bias in the data and lead to spurious inferences if the bias is not accounted for (Sicacha-Parada et al., 2021).

In 2015, the University of Turku tick project launched a citizen science campaign in Finland, asking citizens to send ticks by letter to the University of Turku to be identified (Laaksonen et al., 2017). The aim of this study was to update information on the distribution of *I. ricinus* in Finland, for which previous nationwide data was from the late 1950s and thus outdated (Öhman, 1961). In addition, the campaign aimed at identifying areas where another tick species transmitting TBEV and *Borrelia burgdorferi* sensu lato spirochetes, *I. persulcatus*, could be found. *Ixodes persulcatus* was found to be much more common in Finland than previously thought, even appearing to dominate in certain parts of the country (Laaksonen et al., 2017). Consequently, Finland is one of the few countries in Europe with considerable populations of both these medically important tick species (Capligina et al., 2020; Katargina et al., 2015). While both species transmit the causative agents of TBE and Lyme borreliosis, some differences in their behaviour, phenology and habitat preferences have been observed (Kulha et al., 2022). For example, the activity period of *I. persulcatus* appears to be mostly limited to April–June in Finland, quickly diminishing thereafter (Laaksonen et al., 2017; Pakanen et al., 2020;

Sormunen, Andersson, et al., 2020). In contrast, activity of *I. ricinus* lasts until September–October, with peaks typically in May–June and August–September (Cayol et al., 2017; Laaksonen et al., 2017; Sormunen, Andersson, et al., 2020; Sormunen, Klemola, et al., 2016; Sormunen, Kulha, et al., 2020). For *I. ricinus*, these autumn peaks appear to often be higher than those in early summer (Sormunen, Andersson, et al., 2020; Sormunen, Klemola, et al., 2016).

However, with the rapid changes in tick abundance and distribution brought on by climate change and the ongoing range expansion of *I. persulcatus* in Finland, the data gathered in 2015 may already be at least partly outdated, increasing the demand for an updated nationwide database on tick occurrence. While the crowdsourcing campaign in 2015 was successful, repeating a similar survey was deemed unfeasible due to the extensive effort required to process the received samples. Therefore, development of less labor-intensive methods for tick risk area recognition was undertaken. As a result, in 2020, researchers from the University of Turku Tick Project and Pfizer Oy Finland started designing a web interface for citizens to report tick sightings and observe possible tick risk areas autonomously and continuously. The final product was a website titled Punkkilive (https://www.punkkilive.fi/en) (liberally translates to 'tick live'), where anyone can report their tick sightings and observe risk areas.

The Punkkilive website was launched in April 2021 and, during its first 9 months of operation (April–December 2021), received ~79,000 observations of ticks from all over Finland. In this paper, we present the website, look at trends visible in the data and examine the dependency between the number of observers and number of tick observations in the nationwide tick observation data from 2021.

2 | MATERIALS AND METHODS

The Punkkilive website (https://www.punkkilive.fi/en) was designed by members of the University of Turku Tick Project and Pfizer Oy Finland during 2020–2021. The aim of the website is to provide citizens with tools (text-based information and a live map) to observe and assess spatial and temporal tick risk across Finland independently. In its visual design, a neutral, non-alarming look was sought (avoiding signals that project threat such as red colours, warning signs etc.). The interactive tick map itself was based on the Google Maps interface. The website was optimized for smartphone use and the user interface was kept as simple as possible, to facilitate easiness in registering tick observations.

The website, including basic information on ticks and TBDs, is provided in three languages (Finnish, Swedish and English). On the 'Tick map' page (https://www.punkkilive.fi/en/tick-map), users can browse a map of Finland that shows all the observations made by themselves and others, with various possible time scales. On the 'Report a tick observation' page (https://www.punkkilive.fi/en/report-a-tick-observation), users can report a tick observation, either by searching for an address with a search bar or by manually scrolling the map and placing the observation icon—or a combination of both. Coordinates of the observation are stored automatically based on the location given.

When posting a tick observation, users are asked four questions. The questions are as follows:

1. date of observation;
2. number of ticks observed (three categories: 1, 2–5 and over 5);
3. host/where the tick was found (three categories: animal, human or nature; animal category has three sub-categories: dog, cat, other); and
4. have you previously observed ticks in the area?

Out of these, Questions 1 and 2 are mandatory, while answering Questions 3 and 4 is optional. In addition to the questions, users are given the option to upload photographs. No user data are collected or stored upon submitting an observation.

2.1 | Examination of trends in the tick observation data

For all analyses of the collected, nationwide tick observation data, we assigned observations to corresponding Finnish administrative regions (Figure 1a). Observations within each administrative region were used to calculate the following variables: percentage of observations in each tick number category, percentage of observations in each host category, and percentage of observations reporting no previous tick sightings.

As no data regarding tick species are available from Punkkilive, a previously collected crowdsourcing data set from 2015 was utilized to analyse how the tick species might affect the temporal patterns in observations (Laaksonen et al., 2017). From the 2015 data, we calculated the proportions of *I. ricinus* and *I. persulcatus* observations within each Finnish administrative region (Table S1). Administrative regions where >90% of observations were of a certain species were designated as areas dominated by the species, otherwise the region was classified as a sympatric area (forming 'tick presence classes'). We then applied a binary coding to each individual tick observation ($n = 78,837$), indicating whether it was reported during the active period of *I. persulcatus* in Finland in April, May or June (1) or not (0). Then, we used a generalized linear mixed model (GLMM) with binomial distribution and logit link function to estimate the probabilities of observations belonging to different tick presence classes (*I. ricinus*, *I. persulcatus*, sympatric) receiving the value 1. Administrative regions were used as a random effect in the model.

2.2 | Examination of sampling bias in the tick observation data

In order to examine the relationship between the number of observers and the number of tick observations in more detail, we focussed

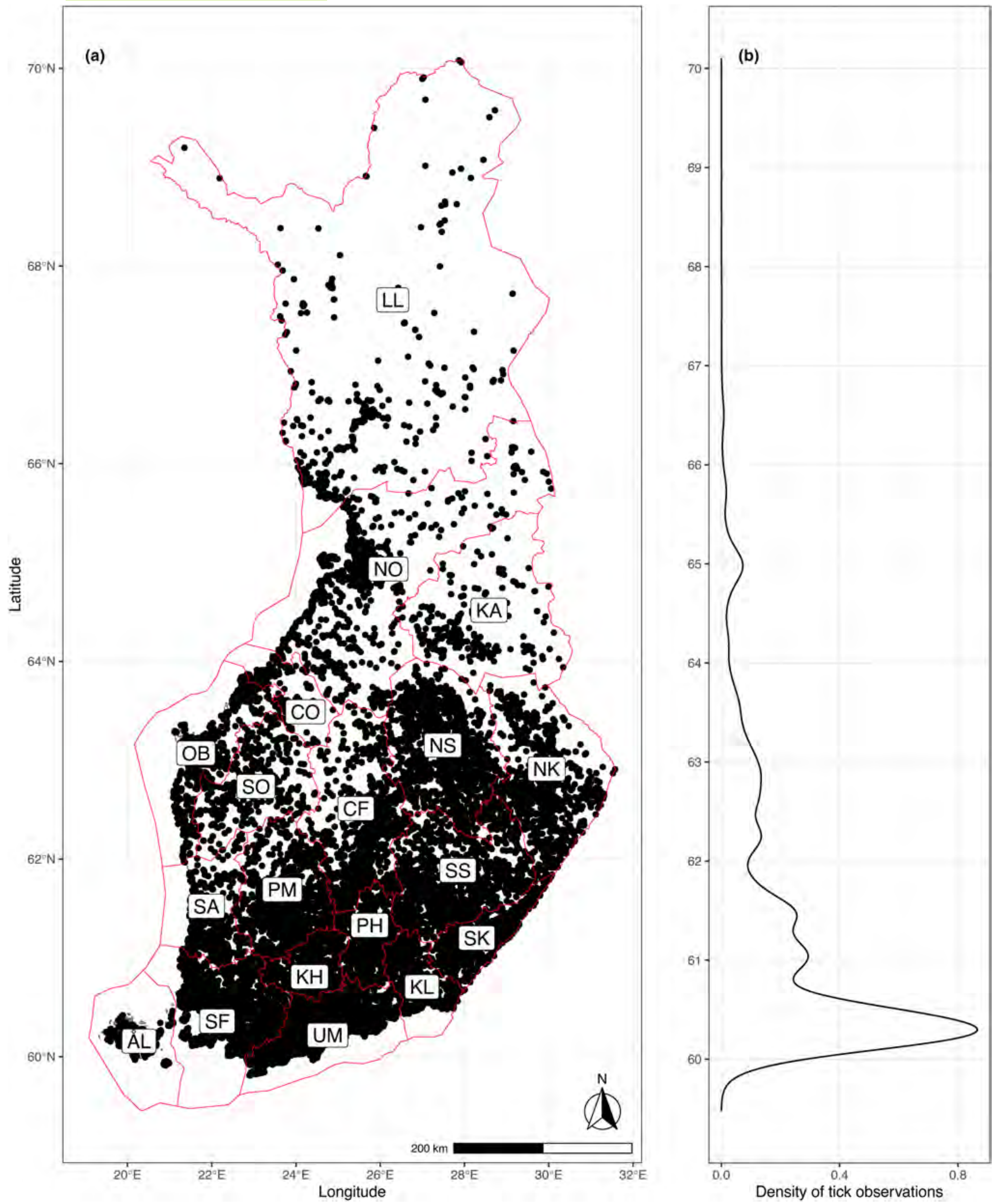

FIGURE 1 Point data of Punkkilive observations from 2021 (a) and spatial density of observations (b). Regions are: ÅL—Åland; SF—Southwest Finland; UM—Uusimaa; KL—Kymenlaakso; KH—Kanta-Häme; PH—Päijät-Häme; SK—South Karelia; SA—Satakunta; PM—Pirkanmaa; SS—South Savo; CF—Central Finland; NK—North Karelia; OB—Ostrobothnia; SO—South Ostrobothnia; NS—North Savo; CO—Central Ostrobothnia; NO—North Ostrobothnia; KA—Kainuu; LL—Lapland.

on three Finnish administrative regions with different dominant species and similar numbers of tick observations: North Ostrobothnia (NO; *n* tick observations = 3089), Pirkanmaa (PM; *n* = 3811) and Kymenlaakso (KL; *n* = 2895). Using the citizen science data from 2015 (Laaksonen et al., 2017), the administrative regions were labelled as *I. ricinus*-dominated (KL), *I. persulcatus*-dominated (NO), and a sympatric region (PM). We used geographically weighted regression (GWR) to explore whether the dependency between the number of observers and the number of tick observations differs within and between the chosen administrative regions with different dominant tick species. GWR is an exploratory technique that uses an isotropic spatial weigh kernel to indicate where locally weighted regression coefficients differ from their global values (Fotheringham et al., 2003). In model fitting we used a Gaussian kernel with a fixed bandwidth, selected separately for each administrative region by leave-one-out cross validation. We used a package spgwr (Bivand et al., 2017) in R to fit the models.

3 | RESULTS

A total of 78,837 tick observations from across Finland were registered in Punkkilive during the first 9 months of activity on the site (Figure 1a). The two southernmost mainland administrative regions, Varsinais-Suomi (SF) and Uusimaa (UM), accounted for approximately half of all observations (Figure 2a). These administrative regions also had the highest numbers of observations per square kilometre (Figure 2b). However, Åland Islands (ÅL) and several regions in eastern Finland showed higher counts of observations per citizen than UM (Figure 2c). Correlation between number of inhabitants and number of observations was high (Pearson's $r = 0.91$, $p < 0.0001$, $n = 19$ administrative regions).

In addition to the observations, 5573 pictures were uploaded to the site. Out of these, 5418 (97.2%) represented identifiable pictures of ticks. Fifty-three (1.0%) pictures were of the wrong animal species (Aphidoidea, Araneae, Acari, Heteroptera), whereas 102 (1.8%) were in an unsorted category (pictures of dogs, blurry pictures, pictures of *erythema migrans*). Varying quality of pictures and high rate of engorged ticks hindered analyses of life stage and species, but adults could be identified in 3021 pictures (55.8%), nymphs in 760 (14%) and larvae in 38 (0.7%). Ticks in visible stages of engorgement could be seen in 2306 pictures (42.6%). Separating the two tick species commonly found from humans and companion animals in Finland, *I. ricinus* and *I. persulcatus*, was not possible from the pictures.

Overall, tick observations were recorded from April to December (Figure 3). The majority of observations (93.4%) were recorded between May and September, with the highest numbers in May and June (50.6%). The seasonality of reports from different hosts (Figure 3a), of different tick numbers (Figure 3b), and of previous tick sightings (Figure 3c) mostly displayed similar trends in peaks. Dogs were generally the most commonly reported hosts throughout the year, but there was a peak in observations from humans around Midsummer in June, during which reports from humans were most common. There was a small but noticeable peak in observations in October–November, where observations were mostly from dogs, of single ticks, and from areas/users with previous tick sightings (Figure 3).

Temporal patterns of observations were different across administrative regions dominated by *I. persulcatus* or *I. ricinus* and sympatric regions (GLMM, $n = 78{,}837$, $F_{2,14.91} = 56.39$, $p = <0.0001$). In regions dominated by *I. persulcatus* ($n = 3$), the probability (estimated marginal mean with asymmetric 95% confidence interval) for any given observation being from April–June was as high as 0.80 (0.75–0.84), whereas in regions dominated by *I. ricinus* ($n = 10$), the

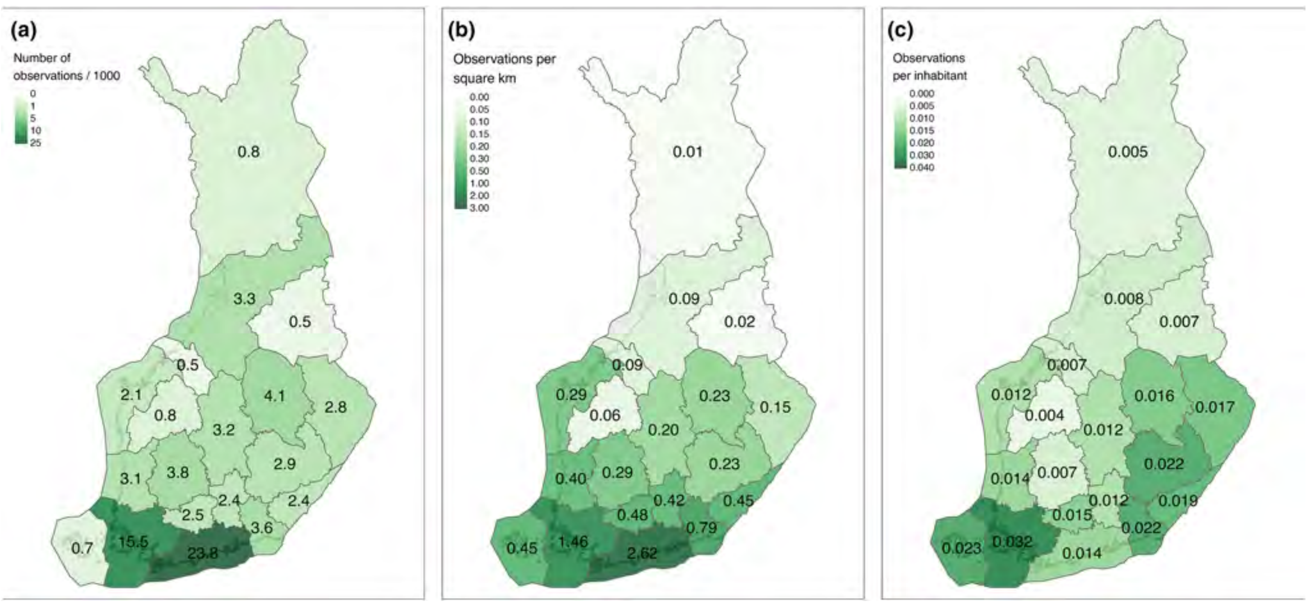

FIGURE 2 Numbers of observations (a), observations per square kilometre (b), and observations per inhabitant (c) in different administrative regions in Finland, based on the Punkkilive 2021 data.

same probability was only 0.45 (0.41–0.49). Sympatric regions ($n = 6$) had an intermediate probability of 0.66 (0.61–0.70) of observations being reported during April–June. There was also a high positive correlation between the proportion of observations made in the early season and the proportion of ticks in the region being *I. persulcatus* in the 2015 crowdsourcing campaign data (Pearson's $r = 0.95$, $p < 0.0001$, $n = 19$ administrative regions) (Laaksonen et al., 2017).

Out of the 78,837 tick observations, 47,091 (59.8%) were reported from animals, 29,834 (37.9%) from humans, 1610 (2.0%) from vegetation, and 253 (0.3%) answers were left blank. Regarding observations from animals, 36,905 (78% of observations from animals) were from dogs, 9983 (21.1%) from cats, 322 (0.7%) from other animals (domestic animals, wildlife), and 118 (0.2%) answers were left blank. Overall, 46.8% and 12.7% of all observations were from dogs and cats, respectively. The highest proportions of all observations being from humans were generally reported from the southern and eastern parts of Finland (Figure 4a). For cats, values were similar across Finland, apart from three regions in western Finland (Figure 4b). Finally, the proportions of observations from dogs were the highest in regions of northern and central Finland (Figure 4c).

Regarding the numbers of ticks observed, 48,510 (61.6%) observations reported 1 tick, 22,113 (28.1%) 2–5 ticks, and 8165 (10.3%) more than 5 ticks. In general, reports of 1 tick were most common across Finland, with some higher values in certain northern and central administrative regions (Figure 5b). The proportions of observations from categories '2–5 ticks' and 'over 5 ticks' were roughly

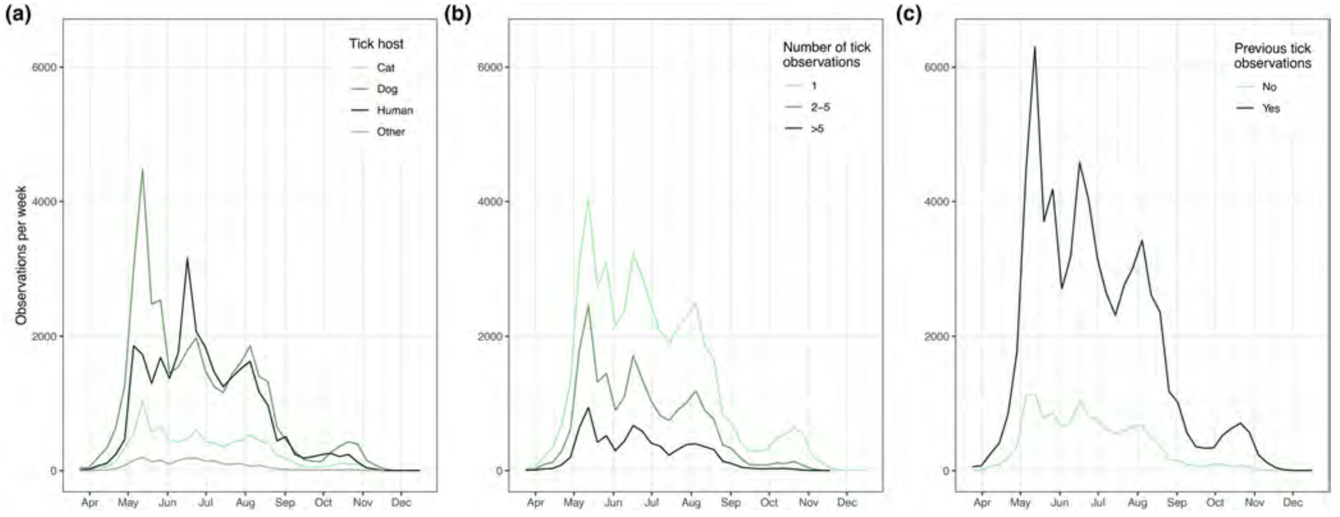

FIGURE 3 Seasonality of Punkkilive observations from 2021 reporting: different hosts (a), tick numbers (b), or whether users had previously observed ticks (c).

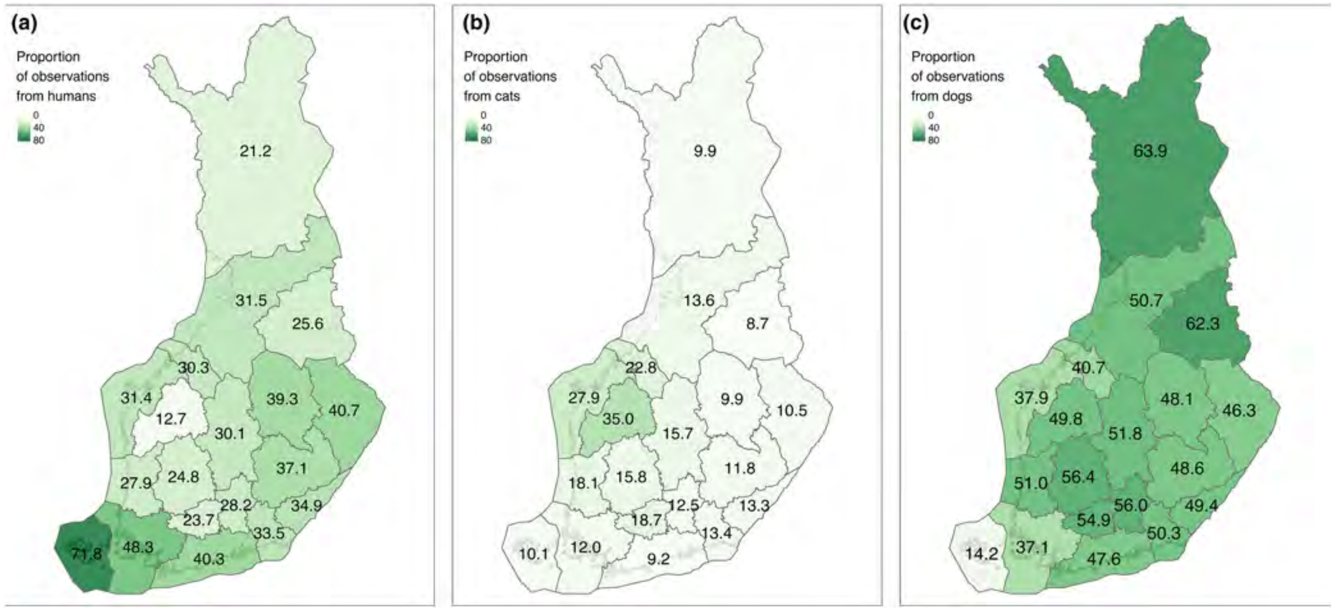

FIGURE 4 Proportions of Punkkilive observations reported from humans (a), cats (b), and dogs (c) per administrative region.

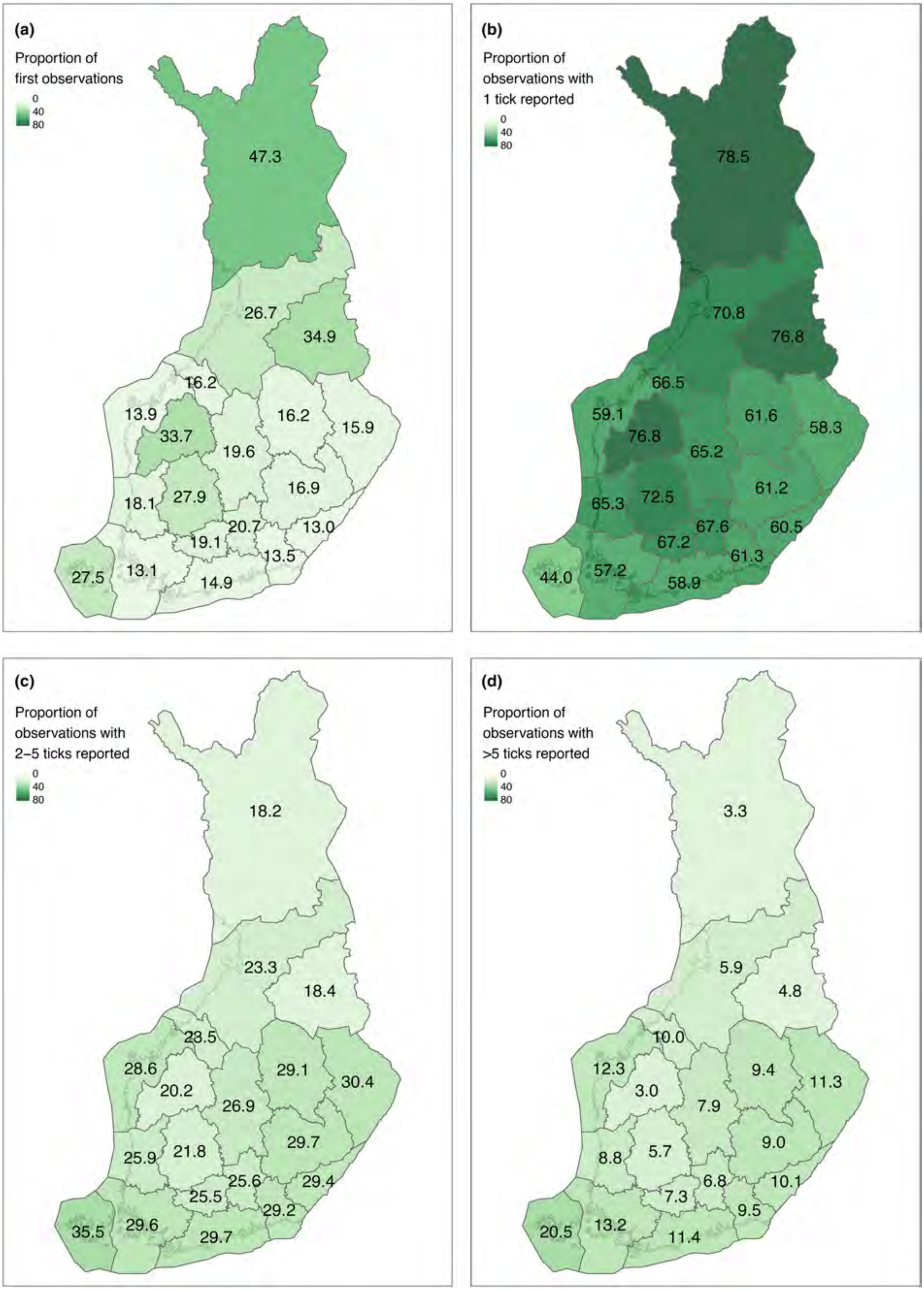

FIGURE 5 Proportions of Punkkilive observations reporting no previous tick sightings (a) and different tick number categories: 1 (b), 2–5 (c) or over 5 (d), per administrative region.

equally divided across Finland, apart from the northern parts, where proportions of such observations were low (Figure 5c,d). Generally, less ticks were reported from humans (72% reported 1 tick) than dogs or cats (55% and 53%, respectively).

Finally, 65,513 (83.2% of all) observations reported previous sightings of ticks in the area, whereas 12,173 (15.4%) reported no previous sightings, and 1102 (1.4%) gave blank answers. The proportion of observations reporting no previous tick sightings was highest in Lapland (LL) (Figure 5a). New sightings were most commonly reported from humans (23% of all observations from humans), followed by dogs (14% of all observations from dogs). Only 2% of observations from cats were new sightings.

In general, the number of inhabitants explained the number of tick observations well, the global (i.e., region-specific) coefficients of determination (R^2) ranging from 0.77 in PM to 0.83 in KL in the GWR analysis (Figure 6). However, the local R^2 values indicated spatial variation in the proportion of variance explained by the GWR models (Figure 6c1–c3). The studentized residuals showed that the model predictions were generally in good agreement with numbers of observations. However, certain areas, particularly in PM (Figure 6d2) and KL (Figure 6d3), showed a higher number of tick observations than predicted from the number of inhabitants alone. Individual areas in all three regions also had lower numbers of tick observations than predicted (Figure 6d1–d3).

4 | DISCUSSION

With approximately 79,000 tick sightings reported during the first 9 months of activity, the Punkkilive website can be considered a great success in the field of citizen science. The high usage rate of the site highlights that there was demand for such a service among the public. Likewise, the high rate of answers to non-mandatory questions when reporting tick sightings also demonstrates the high motivation of users.

Most of the observations were generally reported from the regions with the highest number of inhabitants, a feature known as

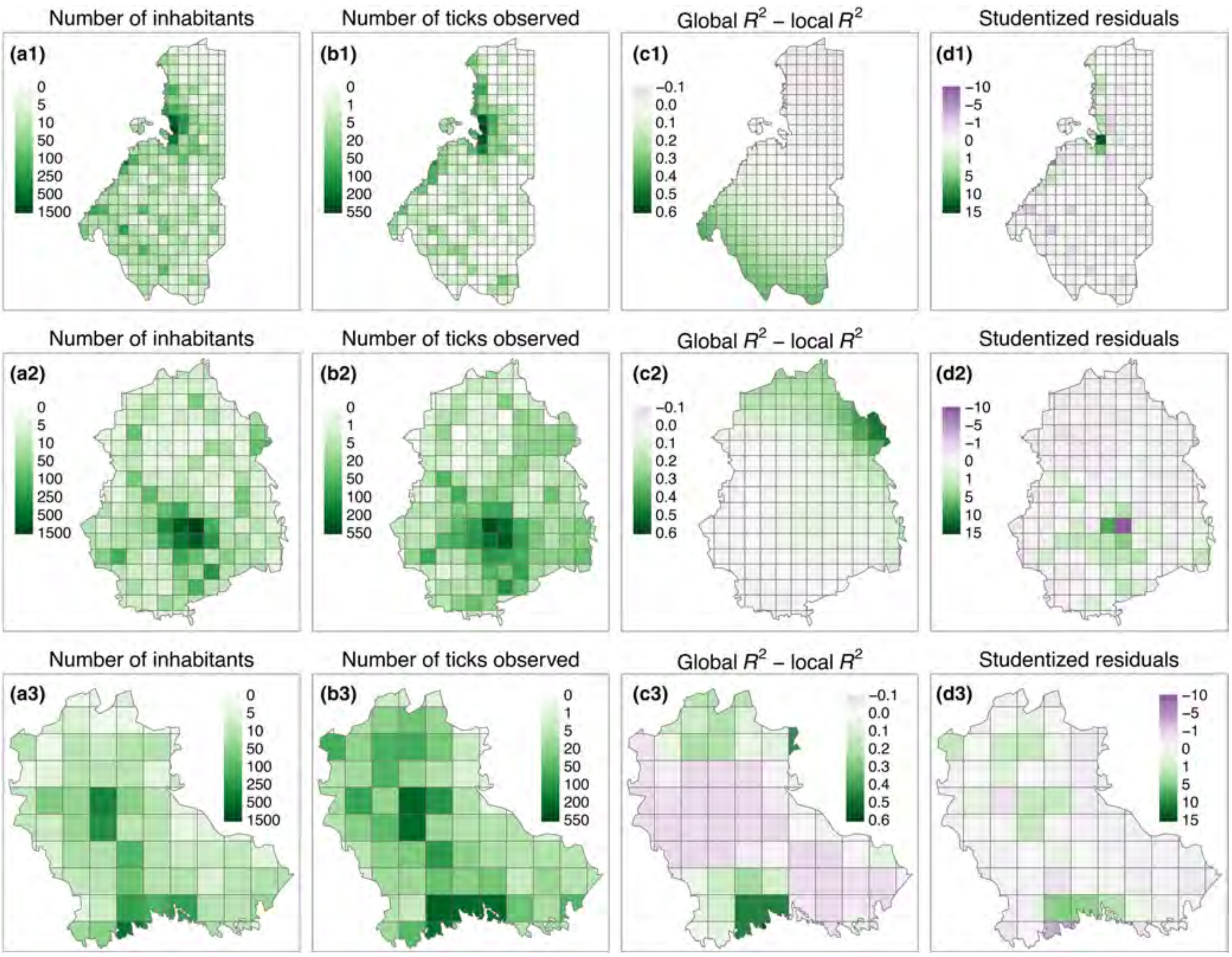

FIGURE 6 Relationship between the number of inhabitants (a1–a3) and number of ticks observed (b1–b3) in the three selected regions (NO: a1–d1; PM: a2–d2; KL: a3–d3), as indicated by the GWR models. The c-panels show the subtraction between global and local R^2 values, high values indicating low local R^2 in the GWR, and vice versa. The global R^2 values were 0.81 in NO, 0.77 in PM and 0.83 in KL. The d-panels show Studentized model residuals for comparability between the areas.

sampling bias in crowdsourced data (Welvaert & Caley, 2016). Due to the high correlation between population density and observations, assessing tick abundance based on such data is difficult—and indeed often not even attempted. The relationship between observers and observations is further complicated by several factors, such as spatial structures in the data that need to be preserved in spatially explicit analysis (Kulha et al., 2022), and different patterns of human movement, activity, and willingness to participate in online crowdsourcing (Brown & Kyttä, 2014).

This study investigated the presence and uniformity of sampling bias in three administrative regions with different dominant tick species and similar numbers of tick observations. Each region had sites with higher or lower numbers of observations than predicted by the number of inhabitants. This suggests that spatially varying factors other than population density contribute to the numbers of tick observations. However, these factors are difficult to distinguish. For example, the areas where the number of tick observations was higher than predicted by the number of inhabitants may indicate areas with high levels of human outdoor activity, but they may also have naturally high tick densities, increasing the number of human-tick encounters despite low number of inhabitants. Conversely, areas where the number of tick observations was lower than predicted by the number of inhabitants may have low tick densities due to poor environmental conditions, but they may also have limited human outdoor activity or low participation in online crowdsourcing due to, for example, the socio-demographic background of the residents or lack of website knowledge (Brown & Kyttä, 2014).

As an example of different factors potentially generating spatially heterogenous sampling bias, in the current study several administrative regions in eastern Finland showed higher numbers of observations per citizen than the capital region, Uusimaa (UM), which otherwise had the highest absolute, proportional and per km^2 numbers of observations. This is more likely due to the high number of summer cottages and lower population density in the eastern regions (and Åland Islands) than higher rate of tick contacts in the area. As national censuses do not include summer visitors, tick observations reported by them may cause overrepresentation in relation to population density. The lower the ratio of inhabitants to visitors, the more this effect is amplified. This may have tangible impact on the spatial distribution of observations on the national level, as 63 out of 309 Finnish municipalities reportedly have more summer cottages than permanent residences (data from Statistics Finland).

As assessed based on the photographs uploaded to the website, users generally correctly identified ticks. In addition to the vast majority of pictures where ticks could be identified, pictures of *erythema migrans* also signify contact with ticks and pictures of dogs likely represent the host from which the tick was removed (but no accompanying text could be given). Furthermore, some blurry images appeared to represent ticks, while others were more obscure. Consequently, only the pictures of wrong animal species can be considered certain misidentifications. In any case, it appears that ticks are generally well identified among the public.

The overwhelming majority of tick observations were made between May and September, which is also the main period of tick activity in Finland based on field studies (Cayol et al., 2017; Pakanen et al., 2020; Sormunen, Andersson, et al., 2020; Sormunen, Klemola, et al., 2016; Sormunen, Kulha, et al., 2020). Likewise, differences observed in the activity periods of *I. ricinus* and *I. persulcatus* in field studies appeared to manifest also in the crowdsourcing data (Cayol et al., 2017; Pakanen et al., 2020; Sormunen, Andersson, et al., 2020; Sormunen, Klemola, et al., 2016; Sormunen, Kulha, et al., 2020). In areas dominated by *I. persulcatus*, the vast majority of annual observations were made during April–June, whereas less than half of all observations in *I. ricinus* dominated areas were made during these months. These results highlight the differences in the temporal risk of TBDs related to each species. In areas dominated by *I. persulcatus*, the main risk period is in late spring and early summer, whereas in *I. ricinus* areas, TBD risk remains high until September. Also in sympatric areas, the activity of *I. persulcatus* mainly in late spring/early summer may increase the risk of TBDs during this time, relative to the rest of the tick activity season. The shorter main risk period for *I. persulcatus* may significantly impact the numbers of acquired TBE and borreliosis cases, particularly as many Finnish citizens participate in hunting and berry and mushroom picking, which are high risk activities most commonly taking place in July–October. In areas where *I. persulcatus* is the main species present, these autumn activities may be presumed to be significantly safer.

Interestingly, there was a small peak in observations visible in October–November. During this peak, most observations were from dogs, of single ticks, and from users (or areas) that had also previously observed ticks. In areas with lower tick densities or times of lower tick activity (such as winter in northern Europe), it may be expected that dogs contact ticks more commonly than humans or cats, due to their nature of roaming around in the vegetation despite the weather. Likewise, tick activity during winter months is most probable in the southernmost parts of Finland, where temperatures and tick numbers are also generally the highest (Laaksonen et al., 2017; Sormunen, Andersson, et al., 2020). Most participants reporting tick observations to Punkkilive from southern Finland reported also previous observations of ticks. As such, this October peak may indicate that limited tick questing activity is possible in suitable weather conditions even during winter months in the warmer areas of Finland. Due to the low numbers of ticks expected to be active, observations are likely to be of only single ticks, and dogs are more likely to contact them than humans.

Dogs and humans were the most common hosts of observed ticks. This somewhat contrasts findings from the previous crowdsourcing study conducted in Finland, where a significantly larger proportion of samples were from cats than from humans (27.6% vs. 15.6%) (Laaksonen et al., 2017). The overall proportion of all samples being from cats was also higher in 2015 than in the Punkkilive data (27.6% vs. 12.7%) (Laaksonen et al., 2017). However, this may partly be explained by the methods of data collection: The previous crowdsourcing study was based on ticks sent to researchers at the University of Turku by letter, whereas observations could be reported electronically to Punkkilive. Consequently, as pet owners groomed their pets and removed ticks at home, they were generally in a better position to store and send the ticks in the previous study. Likewise, reporting sightings to Punkkilive is faster and easier, and the results visible nearly immediately, which may have increased the likelihood of reports from individuals typically less inclined to participate. These factors likely increased the proportion of tick observations reported from humans.

Regarding the spatial distribution of observations in each host group, different trends were observed. The highest proportions of observations from humans were recorded in the southernmost parts of Finland. These areas are typically considered to have the highest densities of ticks in Finland, so contacts with humans may indeed be more common therein (Laaksonen et al., 2017; Sajanti et al., 2017; Sormunen, Andersson, et al., 2020). However, also in some eastern regions, not renown for high tick densities (Bugmyrin et al., 2012), a high proportion of observations from humans was observed. This observation could be related to a reduced number of dogs and cats being kept and/or allowed to roam free in the area due to higher densities of large wild carnivores such as wolves (*Canis lupus*) and brown bears (*Ursos arctos*) (Kojola et al., 2014; Kojola & Heikkinen, 2012), as well as high proportions of sparsely populated areas, allowing these animals to get closer to settlements (Ala-Karvia & Terama, 2018). This may reduce the frequency and range of roaming for dogs and cats and thus equalize host proportions.

For cats, the highest proportions were observed in three regions in western Finland. Heavy agriculture therein could promote the keeping of occasionally or mostly free-roaming cats as rodent pest control, and reduced car traffic compared with agricultural areas in southern Finland with higher population densities may further promote the free roaming of cats (Ala-Karvia & Terama, 2018). For dogs, proportions were more uniform, with typically 40%–60% of all observations being from dogs. However, the highest values were reported from the northern parts of Finland. The latitudinal distribution limits for both *I. ricinus* and *I. persulcatus* are located in northern Finland (extending in a northwesterly line from roughly 64° N at the eastern border to 66° N at the western border), so tick densities therein may be expected to be low in general (Laaksonen et al., 2017). In areas of low tick densities, their peerless ability to collect ticks from the nature may lead to most observations being made from dogs. However, many of the northernmost tick observations (roughly above the Arctic Circle at 66°33′ N) in the previous crowdsourcing study (Laaksonen et al., 2017) could be linked to dog owners previously visiting—or visitors bringing dogs from—more southerly areas. As such, it was deemed that the observations likely do not signify viable local tick populations. The Finnish Lapland is a very popular holiday destination among Finnish citizens—especially so in 2020–2021, when travel outside the borders was restricted due to COVID-19. Therefore, more dogs may also have visited northern Finland during the past few years. Consequently, these northernmost observations of ticks, both from dogs and generally, have to be regarded with caution.

In general, observations from the northernmost parts of Finland (above 64° N) displayed what could be expected near the northernmost limits of distribution for both tick species during the ongoing expansion of distribution range due to global warming. The proportion of observations being of only one tick was high, suggesting low densities of ticks in nature. Likewise, the proportion of observations reporting no previous tick sightings was high, suggesting that people therein are encountering ticks in new areas more commonly than elsewhere. While many observations from the northernmost parts of the country may represent imported ticks rather than local populations, it appears possible that a viable population is emerging in the Rovaniemi region (66.50 N, 25.72 E) at the Arctic Circle. While numbers of observations were low in the previous crowdsourcing campaign in 2015 (Laaksonen et al., 2017), over 160 observations were reported from the area in 2021. Increased warmth due to the urban heat island (UHI) effect (Kim, 1992), as well as the increased humidity and temperature regulation provided by two large rivers (Ounasjoki and Kemijoki) running past and through the city, may promote the survival of local tick populations at these northern distribution limits of both species. However, the increased local tourism in 2020–21 may also have contributed to more dogs and humans visiting from the south, possibly bringing ticks with them and then reporting them as local observations. Consequently, field surveys are required to confirm whether the crowdsourced data has revealed the northernmost established tick populations in Finland in the area. In any case, this observation highlights the usefulness of crowdsourcing in tracking changes in tick distribution. We hope that our successful example inspires others to promote citizen science to monitor disease vectors.

AUTHOR CONTRIBUTIONS

Jani J. Sormunen, Eero J. Vesterinen, Tero Klemola and Ilari Sääksjärvi conceived, designed and developed the Punkkilive website and participated in promoting the service to the public; Jani J. Sormunen, Niko Kulha and Tero Klemola analysed the data; Jani J. Sormunen led the writing of the manuscript; all authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The Punkkilive website was designed as a collaboration between researchers from the University of Turku Tick Project and Pfizer Oy Finland. The website is maintained through Pfizer Oy Finland. Pfizer Oy Finland has not had any input on the use of the gathered data, nor the design and content, analysis of data or the interpretation of results in the current manuscript.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.12294.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.k6djh9wd9 (Sormunen et al., 2023).

STATEMENT ON INCLUSION

Our study was based on a data set gathered via unrestricted crowdsourcing. As such, everyone with internet access was able to participate in the gathering of the data, leading to the inclusion of all stakeholders. In addition to researchers from the University of Turku Tick Project, a researcher from the Natural Resource Institute of Finland (Luke) was invited to contribute and included in manuscript preparation.

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SUPPORTING INFORMATION

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

Table S1: Numbers of samples and percentage of each tick species in different Finnish administrative regions.

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