Accessibility analysis in evaluating exposure risk to an ecosystem disservice

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Highlights

- Spatial accessibility gives new insights into assessing exposure to disservices
- We analyze potential tick contacts and activity of people in high-risk areas
- This kind of information is crucial for control and minimizing tick-borne diseases

Abstract

Ecosystem services are fundamental to the well-being and health of people. Despite the growing awareness of the positive impacts of ecosystem services on human health, researchers have often ignored many ecosystem functions that are disadvantageous to humans. These negative facets of ecosystems are called ecosystem disservices. The central focus of this study was to test the applicability of Geographic Information Systems-based spatial accessibility analysis in mapping the potential risk of ecosystem disservice at a national scale. We used tick exposure as an example of a disservice. Worldwide, ticks (genus *Ixodes*) are the primary vectors of several dangerous diseases which pose threats to people. As the probability of encountering infectious ticks has increased during the last decades, new spatial information on high-risk tick exposure areas are needed. To evaluate exposure risk, we developed a tick probability map based on tick observations and environmental variables in Finland. **First**, we analyzed what kind of threat ticks pose to populations in residential areas and around free-time residences. **Second**, we studied if the movement of people (here school children) in the everyday environment increased tick exposure risk. We calculated the shortest school route for all children by using spatial accessibility analysis. Our results showed that taking the movement of people into consideration through the accessibility analysis, we can get a more realistic picture of tick exposure risk. Further, we gained a better overview of the number of children at higher exposure risk. This kind of information is crucial for pre-assessment and identification of public health strategies for control and minimizing tick-borne diseases. In general, the accessibility approach provided a good overview of areas where the greatest tick exposure was present and produced valuable information to support decision-making. The method enabled new insights into the assessment of exposure to ecosystem disservices.

Key words: Ecosystem service; Finland; Geographic Information Systems; health risk assessment; *Ixodes*; Least-cost path; Species distribution modelling

1. Introduction

Ecosystem services (ES) are essential to the well-being and health of people all over the world. People are fundamentally dependent on ES such as food, water, clean air and disease control (Costanza et al., 1997; Haines-Young and Potschin, 2010; MA, 2005). Changes in these services could cause major health impacts, such as injuries, behavioral disorders and diseases (MA, 2003; Oosterbroek et al., 2016). Assessing the consequences of ecosystem change for human well-being and health has been set as one of the main targets of the Millennium Ecosystem Assessment (MEA, 2005). However, despite the growing awareness of the positive impacts of ES on human health, ES research often ignores many ecosystem functions which do not provide benefits to humans (Shackleton et al., 2016; Shapiro and Báldi, 2014). These ecosystem drawbacks causing unpleasant and harmful effects on human well-being are called ecosystem disservices (EDS) (e.g. Lyytimäki and Sipilä, 2009; Vaz et al., 2017).

The use of the EDS concept has been growing in scientific literature (Blanco et al., 2019; Ceașu et al., 2019; Daily, 1997; Dunn, 2010; Escobedo et al., 2011; Lyytimäki and Sipilä, 2009; Potgieter et al., 2017; Shackleton et al., 2016). The idea that ecosystems have negative impacts on human health is not a new one, and studies on this issue are conducted across several scientific disciplines. However, framing the negative ecological effects as part of ES seems to be rarely discussed (Blanco et al., 2019; Shackleton et al., 2016; Von Döhren and Haase, 2015). Furthermore, incorporating the concept of EDS into ES research has faced criticism. In the field of nature conservation, the core of the criticism is based on the concern that the concept compromises conservation efforts by emphasizing the harms of natural ecosystems giving arguments for intensive management and utilization of natural resources (Shapiro and Báldi, 2014; Villa et al., 2014). The fact that the complex nature of ecosystems may produce both positive and negative impacts on human health at the same time has caused a lack of clarity on how to integrate ES and EDS in human well-being studies (see Saunders and Luck, 2016). To solve this problem, taking the full range of both positive and negative ecosystem functions into account for solving controversies related to environmental management, particularly in planning, is suggested (Blanco et al., 2019; Lyytimäki, 2015; Shackleton et al., 2016; Vaz et al., 2017).

Geographic Information Systems-based (GIS) spatial accessibility analysis can provide a promising approach to evaluate the exposure risk of harmful EDS. The concept of spatial accessibility

determines how easily a location can be reached from another location (Rodríguez et al., 2006) or the opportunity to reach geographically distributed activities, which may be reached via transport systems (Páez et al., 2012). The movement of people has always been a fundamental part of societies and people have become increasingly dependent on transport systems to support a wide variety of activities ranging from tourism and energy needs to final goods – so-called ES (Rodrigue et al., 2017). In the ES concept, human welfare is indisputably dependent on the availability of ecosystem services, and spatial accessibility measures the extent to which a land-use transport system enables people or ES goods to reach destinations by means of a particular transport mode(s) (Ala-Hulkko et al., 2019, 2016; Geurs and Ritsema van Eck, 2001). The risk of exposure to ecosystem attributes perceived as unwanted or unpleasant could be mapped in detail at broader scales by using the accessibility approach. Mapping the movement pattern of people between different locations gives new insight into assessing EDS exposure.

EDS can be produced by any ecosystem attributes that are perceived as unwanted, unpleasant or economically harmful (Escobedo et al., 2011; Lyytimäki, 2014; Lyytimäki and Sipilä, 2009). Ecosystems can cause harms, for example, through presence of unpleasant animals, pests, allergenic and poisonous organisms. Worldwide, ticks (genus *Ixodes*) are the primary vectors of several dangerous diseases which pose danger to people (Feuth, 2017; Laaksonen et al., 2017; Rizzoli et al., 2014). Ticks may transmit the pathogenic bacterium (*Borrelia burgdorferi*) responsible for causing Lyme borreliosis (LB) or tick-borne encephalitis virus (TBEV) which both cause some of the most serious public health problems in Europe (World Health Organization, 2004). The annual number of LB cases has been estimated to exceed 85,000 in Europe and high incidences have been reported especially in Central Europe and Baltic states (Sajanti et al., 2017; World Health Organization, 2004). The annual economic burden of LB from societal perspective has estimated to be hundreds of thousands of Euros at national level (Mac et al., 2019). For example, in Germany, the direct and indirect economic impact of LB has reported to be more than 123M Euros during the years 2008–2011 (Lohr et al., 2015).

In Finland, the abundance of two important tick species (*Ixodes ricinus* and *I. persulcatus*) have increased and their geographical distribution has expanded significantly during the past few decades (Feuth, 2017; Laaksonen et al., 2017). The number of microbiologically confirmed LB cases has increased fivefold, from 345 (7/100 000 population) in 1995 to 1,679 (31/100 000) in 2004. A total number of annual LB cases are estimated to be even 6,440 cases (118/100,000 population) in 2014

when clinically diagnosed cases are also included in the assessment (Sajanti et al., 2017). Sormunen (2018) has reported increasing tick densities and tick-borne pathogens from all coastal areas in southwestern Finland, but also within and around in urban and suburban areas such as urban city parks, yards and vegetation-flanked walkways. Moreover, Junttila et al. (1999) conclude that Lyme borreliosis can be contracted even in urban environments not populated with suitable tick host animals like deer or elk. Urban ticks may potentially form a larger threat to human welfare than previously thought (Cayol et al., 2018; Lohr et al., 2015; Sormunen, 2018). This increases the risk of encountering infectious ticks in the everyday environment, especially when people are moving from one place to another across different environmental characteristics.

The aim of this study was to assess the applicability of spatial accessibility analysis to map the risk of EDS exposure at a national scale. We used spatial distribution of ticks (*Ixodes ricinus* and *I. persulcatus*) as an example of EDS and evaluate its possibility to cause negative impacts on human health in Finland. Specifically, we: **(1)** model the probability of tick presence in Finland based on tick observations and environmental variables. This modelled probability map provides a background information for the next step of the study where we **(2)** estimate the tick threat to people in residential areas and around free-time residences and **(3)** analyze how the movement of people in the everyday environment increased the risk of tick exposure and subsequent EDS by using spatial accessibility analysis. To our knowledge, this is one of the first studies where tick abundance and distribution are spatially connected with the movement of people in the everyday environment. The study has high potential to offer important insights into EDS research by developing a GIS-based EDS measures in a spatially explicit manner. EDS research has thus far been dominated by qualitative approaches (Von Döhren and Haase, 2015), highlighting the need for quantitative assessments to study EDS (Blanco et al., 2019).

2. Material and methods

2.1. Study area and free-time activity of Finnish people

The study area is located in Finland in northern Europe (19°–32°E, 60°–70°N, Fig. 1) covering most of the country. Only the northern part of Finland is excluded from the study on the basis of northernmost tick observations around the Arctic Circle (Fig. 2). Finland belongs to the boreal vegetation zone characterized by landscapes dominated by coniferous forests with sparse settlements and agricultural areas usually close to freshwaters. Majority of the country has an

96 elevation less than 200-m, with highest peaks found in the far north. The annual average temperature
97 ranges from +6.5 °C in southern Finland to −1.9 °C in northern Finland (Pirinen et al., 2012). Largest
98 population centers are in the southern parts of the country around major cities and near stream
99 networks.

100
101 *Figure 1. Distribution of the population and number of free-time residences in the study area.*

Figure 2. Crowdsourcing-based nation-wide tick observations from year 2014 (ArcGIS, 2014) (A) and probability of tick presence at 1 x 1 km resolution across the study area (B).

Our work is based on two different outdoor environments in Finland: First, 95% of all Finns enthusiastically recreate in outdoor environments near their home or free-time residence (Sievänen and Neuvonen, 2011); we considered residential areas and free-time residences as such places, where people are vulnerable to tick encounters. More than 50% of Finns name walking or cycling as one of their hobbies and nearly 90% of recreational use of nearby nature is directed to forest environments. In addition to forest, people have named especially water areas as an attractive environments (Sievänen and Neuvonen, 2011). Both environments are significant areas for tick encounters (Cayol et al., 2018; Sormunen, 2018). In Finland, outdoor recreation is based on the principle of 'everyman's right', which means that all forests, shores and water areas, including those that are privately owned, are open to public access of everyone. The thousands of lakes and forest cover of three fourths of the land area (Natural Resources Institute Finland, 2019; Official Statistics of Finland, 2019) provides a high level of recreation potential fairly homogenously throughout the country, even in the densely populated regions. In year 2017, there was more than a half million free-

time residences for a total population of 5.5 million (Fig. 1) and nearly a million Finns belong to a household that owns a free-time residence (Official Statistics of Finland, 2015a). A free-time residence refers to a residential building that is used as a holiday dwelling or to a recreational building. Spending a time in free-time residences have reported to increase outdoor recreation activities (Sievänen and Neuvonen, 2011). Furthermore, the use of free-time residences takes place especially during spring and summertime (Sievänen and Neuvonen, 2011) when ticks have their seasonal activity peaks (Laaksonen et al., 2017).

Second, Finland is an exceptional country where children typically walk or bicycle to school when the distance between home and school is less than five kilometers. When the distance is longer, municipal authorities are obligated by law to offer public transportation to school. To guarantee that the study data would include areas where children would actually have the potential to be in contact with environments suitable for ticks, we considered only distances less than five kilometers. Sajanti et al. (2017) have observed that the tick incidence rate is relatively high for children. For that reason, this study especially concentrates on children's (age between 7 and 14 years) everyday activity environment between home and school.

2.2. Mapping tick distribution as an ecosystem disservice

Known distribution of ticks in Finland is focused on central and southern Finland close to freshwater and coastal areas (Laaksonen et al., 2017). Several environmental characteristics influence on the distribution and abundance of ticks. Temperature, in addition to photoperiod, drives development rates of ticks especially in cold climates (Feuth, 2017). Precipitation has also been evidenced to strongly contribute to tick distributions (Del Fabbro et al., 2015). For example, relative humidity in vegetation should not decrease below 80% to avoid increased mortality rate in ticks (Feuth, 2017). Long winters, especially without thick snow cover, can reduce the survival of ticks, which overwinter on the ground (Estrada-Peña and De La Fuente, 2014). Topographic characteristics may also influence where ticks are present and abundant (Gilbert, 2010). Besides, presence of forests (e.g., broadleaved and mixed deciduous) and agricultural areas, and distance to coastline affect the tick distributions (Del Fabbro et al., 2015; Jaenson et al., 2009). In addition to these environmental characteristics, existence of suitable host animals contributes to the tick distribution but above mentioned environmental characteristics function also as a proxy for the presence of the host animals (e.g., shrews, rodents, hares, deer and birds) in boreal region (Jaenson et al., 2009).

151

152 We modelled tick distribution using Maxent (maximum entropy model), which is developed for
153 species distribution modelling based on presence-only data (Phillips et al., 2006). The basic idea of
154 Maxent is to assess a target probability distribution by looking for the probability distribution of
155 maximum entropy (see Phillips et al., 2006). Maxent has been shown to reliably model species
156 distributions with limited sample sizes (Pearson et al., 2007; Wisz et al., 2008). In Maxent, grid cells
157 of the study area make up the space on which the Maxent probability distribution is defined. The grid
158 cells consisting of information on species occurrence constitute the sample points and environmental
159 information constitute the features. Maxent takes a random sample of the grid cells from the study
160 area (known as background data) and uses them in place of absence data (Phillips et al., 2006; Phillips
161 and Dudík, 2008). As an output, Maxent gives probability values on a continuous scale ranging
162 between 0 and 1, where 1 indicates a high probability of species presence.

163

164 Maxent analysis was run ten times and an average of the results was used. Maxent models were
165 based on 777 individual tick observations and ecologically relevant environmental variables (Del
166 Fabbro et al., 2015; Feuth, 2017; Gilbert, 2010; Jaenson et al., 2009), which consisted of climate
167 characteristics (mean for 1980–2010 at 1-km² resolution), topographic factors (25-m resolution),
168 CORINE land cover data (year 2012 at 25-m resolution) and productivity variables (250-m resolution)
169 (Table S1). Tick observations were obtained from an open-access database (ArcGIS, 2014). The
170 dataset was based on crowdsourcing-based, nation-wide tick collection for 2014 carried out by the
171 University of Turku (Laaksonen et al., 2017). Of the 814 tick observations in the dataset, 37 were
172 deleted because they were located in water (i.e. final n=777). The used 777 observations were
173 converted to grid cells of 1-km² for distribution modelling.

174

175 Of all the 15 available environmental variables (see Table S1 for details of all environmental variables),
176 annual mean temperature (average relative contribution in the Maxent models: 68.8%), latitude
177 (18.4%), cover of deciduous forest (5.8%), topographic wetness index (5.2%) and shoreline length
178 (1.9%) were included in the final models. The variables were selected based on their univariate and
179 multivariate contribution in the Maxent modelling (Phillips et al., 2006; Phillips and Dudík, 2008).
180 Moreover, multicollinear variables were removed ($R_s = |>0.7|$, (Dormann et al., 2013)). However, we
181 included both annual mean temperature and latitude ($R_s = -0.974$) in the final model, because the
182 latter variable described a geographical gradient important for model accuracy. Exclusion of latitude

would have weakened the model accuracy, especially in central coastal areas compared to the observation data (see also Laaksonen et al., 2017). The Area under the curve (AUC) value indicates the probability that a randomly chosen presence site is ranked above a random background site (Phillips and Dudík, 2008). In this study, the original tick observation data were randomly divided to calibration (70%) and evaluation (30%) data sets. The average of calibration and evaluation AUC was 0.842 and 0.840, respectively. Following Swets (1988), model accuracy of our exercise was good (good if $0.8 < \text{AUC} < 0.9$). Modelling of tick distribution in the study area was carried out with the Maxent 3.3.3k version.

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2.3. Analyzing the exposure to ecosystem disservice

2.3.1 Overlay between the probability value of ticks, residential areas and free-time residences

To evaluate the amount of possible tick contacts in the outdoor environment around residential areas and free-time residences, we used overlay analysis of modelled tick distributions, population of Finland and the location of free-time residences (Fig. 3). Population was estimated using the Official Statistics Finland's (2015b) grid database raster layer of 250x250-m resolution. We aggregated data at a resolution of 1-km² to correspond to the resolution of the modelled tick distribution. We calculated the risk separately for the entire population and grid cells which include information only on children between 7 and 14 years of age. The locations of free-time residences across Finland were obtained from Statistics Finland (Official Statistics of Finland, 2015a) and also aggregated to the resolution of 1-km².

203

204 *Figure. 3. A schematic figure of the stages of the study. Modelled tick distribution map was used as a*
 205 *background data for the further overlay and accessibility analysis.*

206

207 2.3.2. The movement of children in everyday environment and the risk of tick exposure

208 The spatial accessibility approach was used to indicate children's movement between residential
 209 areas and schools. Accessibility was assessed as travel cost estimates of the fastest routes between
 210 residential locations (origins) and nearest comprehensive schools (destinations) through a road
 211 network. The residential pattern of the children between 7 and 14 years of age was selected to
 212 represent the points of origin for travel to school. The resolution of residential locations of children
 213 was 250x250-m (Official Statistics of Finland, 2015b). We used the centroids of each grid cell as the
 214 spatial reference of origins during accessibility analysis. The locations of the schools (destinations)
 215 have been obtained from Statistics Finland (2015c).

216

217 School roads were calculated using GIS -based least-cost path analysis (see Ala-Hulkko et al., 2016).
 218 The least-cost path between the origin and destination can be calculated in a GIS, when the spatial
 219 data of relevant travel cost estimates (e.g. travel speed or time) for the graph model of a road
 220 network are available. In practice, route formulation in GIS relies mainly on Dijkstra's (1959) algorithm
 221 and its heuristic applications (ESRI, 2010). Origins, travel destinations and the road network can be
 222 analytically considered as either a graph or a weighted graph when some attributes are added to the

vertices connecting nodes (see Miller and Shaw, 2001). The shortest route to school was estimated according to topological and geometric information provided by Digiroad for the year 2016 (Finnish Transport Agency, 2016). We added 25% to the travel cost estimate for regional roads and local main streets to direct the analysis to calculate the shortest route along walking and cycling tracks if possible (again, only routes less than five kilometers were considered in our analysis). As children typically walk or bicycle to school, we made calculations more realistic by removing road types such as motorways, carriageways, slip roads and ferries from the analysis. To illustrate children's risk to tick exposure, we added the maximum value of tick probability to each analyzed route (Fig. 3 and Fig. 4).

Figure 4. Simplified illustration of the data used to calculate the shortest route between home and school. The potential risk to tick exposure when children walk or bicycle between different locations were estimated based on modelled tick probability values (see Fig. 2). **A-D** Overview of the typical school routes across the study area: (A) in the City of Oulu, (B) in the City of Tampere, (C) in the City of Turku and (D) in the City of Espoo in Greater Helsinki. Photos: Terhi Ala-Hulkko (A, B), Susanna Greus (C) and Jan Hjort (D).

2.3.3. The amount of children's activity in high-risk tick exposure areas

The results of the earlier accessibility analysis of the shortest routes between home and school (hereafter, school trips) have been used to estimate the activity level of children across the whole study area. Activity was measured by calculating the total length of all school trips in each 1-km² grid cell. More precisely, we counted how many kilometers of school trips accumulated on the grid cell when all children whose school trip goes through the grid cell are taken into account. For example, if school trip of three children go through a particular grid, and first two ones walk the same 500-m and third one 300-m in a grid cell, the total length is therefore 1300-m. We take into account only high EDS risk grid cells where probability of tick presence exceeded a value of 0.5.

2.3.4. Evaluating the amount of possible LB and TBE cases

After assessing the probability of encountering ticks, we evaluated how many of those whose residential area, location of free-time resident or school trip exceeded the tick probability value of 0.5 have potential to get either LB or TBE, followed by results of Laaksonen et al. (2017). They reported that *I. ricinus* and *I. persulcatus* ticks 16.9% were positive for *B. burgdorferi* s.l., and 1.6% were positive for TBE. The prevalence of *B. burgdorferi* s.l. was consistent with the recent study of Laaksonen et al. (2018). It is a recognized problem that people may have had a tick bite at unregistered time and place, and LB or TBE is diagnosed later. Owing to the lack of information about the location of actual tick contacts in Finland, we assume that people have the potential to be exposed to tick bite in areas where modelled probability of tick presence is more than 0.5.

3. Results

3.1. Residential areas and free-time residences

Based on the Maxent models (Fig. 2), overlay analysis of residential areas, free-time residences and tick probability values, ticks have three clusters in Finland, where they have higher-than-average probability to cause harm: on the coasts of the Baltic sea, around the City of Kuopio and between the cities of Tampere and Kouvola. Comparing the overlay of residential areas and free-time residences to probability values of ticks indicated that the risk of tick exposure in residential environments and vacation homes is relatively low (Fig. 5A). When Finns recreate at residential environments or near free-time residences, they have a 0.32 probability of encountering ticks on average (the probability of presence value is based on Maxent models, see Material and methods). In particular, near free-time residences ticks cause a moderate threat to people. Only 20% of free-time residences are

268 located in the environments where the probability of being exposed to ticks is more than 0.5. In
 269 residential areas, the probability of tick presence raised slightly as 35% of the population have a
 270 greater than 0.5 probability of encountering ticks. A risk of getting a LB from tick bite at residential
 271 areas is 7.4% and around free-time residences 4.7%. TBE risk is 0.7% and 0.4%, respectively (Fig. 5B).
 272 In our results, there were no notable differences between the residential areas of the whole
 273 population and grid cells which include information only on children between 7 and 14 years of age
 274 (Fig. 5).

276 *Figure 5. (A) Cumulative percentage of population (y-axes) in relation to probability of tick exposure (x-axes)*
 277 *during a school trip, residential area (population = whole population in study area, children = only grid cells*
 278 *including information on children) and free-time residences. (B) Amount (%) of those whose residential area,*
 279 *location of free-time resident or a school trip exceeded the tick probability value of 0.5 have potential to get*
 280 *either Lyme borreliosis (LB) or tick-borne encephalitis (TBE). The pathogen prevalence of ticks was based on the*
 281 *study of Laaksonen et al. 2017.*

282 **3.2. Risk of tick exposure during a school trip**

283 Our study contains overall 443,217 children and we analyzed nearly 78,000 school trips across the
284 study area. The highest risk of tick bite during a school trip is found along coastal areas and in major
285 cities in Central Finland (Fig. 6). In particular, Southern and Southwestern Finland population centers
286 are located in high-risk areas and all children have a considerably high risk (> 0.5 probability) of
287 encountering ticks compared to within inland cities (Fig. 6). In the City of Tampere (population of
288 231,853 in year 2017, (Statistics Finland, 2017)), for example, children have only a 0.4 probability of
289 encountering ticks on average (Fig. 6B), whilst in the City of Turku (population of 189,699 in year
290 2017) the risk is 0.7 (Fig. 6C). Moreover, ticks are distributed more evenly along the coast of the Baltic
291 Sea, which can be seen as the higher probability values on routes to school around this region.
292 Distribution hot spots for ticks are more sporadic in inland areas and high exposure risk school trips
293 are more regional. Generally, 47% of children have at least a 0.5 probability of encountering ticks in
294 Finland when they walk to school and 8,9% of them have a risk of getting LB. TBE risk is around 0.8%
295 (Fig. 5B and 6A). When comparing possible tick exposure to overlay analysis, ticks have a higher risk
296 of causing harm to children during school trips than in children's home environments (Fig. 5).

Figure 6. Maps: Shortest routes from residential areas (children in the 7 to 14 age group) to comprehensive schools at the national and local level (Turku and Tampere). Route to school indicates the highest probability value (ranging from 0 to 1) for tick exposure during a school trip. A-C: Cumulative percentage of children (y-axes) in relation to probability value of tick presence (x-axes) when moving from home to the nearest comprehensive school in the whole study area (A). Cumulative percentage of children in relation to probability value of tick presence in the city areas of Tampere (B) and Turku (C).

3.2 The activity of children in high-risk tick exposure areas

To indicate the amount of human activity and hence the magnitude of tick exposure risk at a national scale, we calculated the total length of all school trips in each 1-km² grid cell. The sum of all school trips was over 8 million kilometers and more than 30% of school trips went along routes where the probability of encountering ticks was over 0.5 (Fig. 7A). The total length of school trips in each 1-km² grid cell, where the probability of encountering tick is above 0.5, is depicted in maps in Figure 7. The greatest peaks of activity level were found in coastal areas, especially around population centers

where the total length of school trips can rise above 10,000-km in a single grid cell. This gives a good overview of the amount of children’s activity in high-risk areas at 1-km² resolution.

Figure 7. Maps: Total length of school trips (km) for 1-km² grid cells where tick probability value is more than 0.5. Total length indicates the activity level of children in each grid cell where they have a relatively high probability of encountering ticks. Total length means how many kilometers of school trips are made in total in each grid cell when all children whose school trip goes through the grid are taken into account. (A) A cumulative share of all school trips made in Finland (y-axes) versus the probability value of tick presence (x-axes). School trips of lower than 0.5 probability of tick presence were also included in the calculations of cumulative percentage.

322 4. Discussion

323 The central focus of this study was to assess the suitability of accessibility analysis in mapping the
324 potential risk of EDS (here ticks) at a national scale. Based on a simple overlay analysis, the risk of tick
325 encounters is relatively low in residential environments and at vacation homes. When we take the
326 movement of people into consideration through a GIS-based accessibility analysis (as we did in the
327 case of children) the probability of encountering ticks increased. Our results show that 47% of
328 children have at least 0.5 probability of encountering ticks during school trips and nearly 9% of them
329 have potential of getting LB. In order to complete the overall picture of tick exposure, the accessibility
330 results enable us to evaluate the magnitude of tick exposure risk by calculating the total length of
331 school trips for high-risk areas. Based on the tick distribution model and accessibility analysis, we
332 found the greatest threat of encountering tick is in coastal cities. This result was consistent, for
333 example, with the findings of Laaksonen et al. (2017, 2018), who found highest tick distributions in
334 the coastline and around Finnish Lakelands, but also in urbanized areas in southern Finland. The used
335 tick probability model gives a good basis for the modelling of the probability of tick presence.
336 However, for the future studies, more detailed information for example on the tick host animals'
337 distribution and tick environmental requirements at different scales are needed.

338 4.1. The risk of tick exposure in the study area

339 As ticks have become more abundant in urban and suburban areas, the risk of potential tick-borne
340 infectious diseases has increased enormously during the past decades. Especially, increased mobility
341 of humans may promote new tick encounters in developed environments (Rizzoli et al., 2014). It has
342 been emphasized that relatively low tick densities can be an important source of human pathogen
343 exposure in urban and suburban environments if high numbers of people use these areas. Even
344 maintained city parks and vegetation-flanked walkways have been reported to be high-risk areas of
345 possible contacts between humans and ticks (Rizzoli et al., 2014; Sormunen, 2018). Therefore, more
346 attention should be paid to the fact that people have a higher potential to be in contact with
347 environments suitable for ticks when they travel across different environments. Our results show that
348 overlay between residential areas, free-time residences and probability of tick presence
349 underestimate the possible risk of tick exposure. As people recreate in different outdoor
350 environments during the day, it is important to assess the risk by using more specific methods, such
351 as accessibility analysis, instead of simple overlay analysis. Our results demonstrate that ticks have a

352 higher risk to cause harm to children during school trips than in residential areas when we take
353 various environments into account.

354 Our study approach obtained complementary information on tick exposure to people. The amount
355 of potential EDS contacts, and thus the number of exposed children, was measured by calculating the
356 shortest route to school for all children. Von Döhren and Haase (2015) have suggested that EDS
357 studies should evaluate the number of people who are affected by EDS or even assess the ecosystem
358 probability to produce potential EDS in more detail to establish a comprehensive overview of the net
359 effects of ecosystem functions for human well-being. In addition to this, we received information on
360 the total length of school trips in each high-risk (tick probability >0.5) grid cell, which indicates the
361 activity level of people in those areas. This information gives a good overview of areas where the
362 highest tick exposure is present and produces valuable information to support decision-making. This
363 information also informs people of areas where movement should be avoided or where tick
364 inspections should be carefully conducted after outdoor movement, especially when ticks are at their
365 highest activity peaks. As long as we do not have vaccines or other preventive treatments against
366 tick-borne diseases apart from TBEV, human protection must rely mostly on avoiding risk areas or
367 increasing the awareness of infectious ticks (Sormunen, 2018). Thus far, tick risk areas are identified
368 mainly on the knowledge of tick sampling or predictive modelling with GIS (Sormunen, 2018).
369 However, adding the information on how tick abundance and distribution are spatially connected
370 with the movement of people can improve our understanding of the amount of people who have
371 higher probabilities of encountering infectious ticks. This information is crucial for pre-assessment
372 and identification of public health strategies for tick control and minimizing tick-borne diseases. Early
373 diagnosis of borreliosis would result in economic gain and reduced human suffering (Henningsson et
374 al., 2010).

375 When studying ticks as an EDS, some critical aspects need to be considered. For example, tick
376 exposure risk can vary during the time of year. This means that, ticks are usually seeking blood meal
377 hosts in mid-March to early November in northern Europe (Sormunen, 2018). In addition, all ticks are
378 not infected as overall prevalence of *B. burgdorferi s.l.* is 16.9% and TBE 1.6% in Finland (Laaksonen
379 et al., 2017). The study of Laaksonen et al. 2017, also observed that the above mentioned pathogens
380 prevalence is often higher for adults than for nymphs. It is noteworthy that most of the crowdsource-
381 based tick samples were adults (Laaksonen et al. 2017). Although the probability to face infecting
382 ticks is relatively low, the highest incidence rates of pathogens is concentrated in coastal areas of

Finland, where the population density is also highest. Urban ticks may potentially form a larger threat to human welfare than previously thought, as the activity level of human is higher in built-up areas. Our study provides a rough estimate to actual tick contacts, because it is based on the assumption that people would have potential to be in contact with environments suitable for ticks while walking or bicycling. However, as mentioned earlier, fairly low tick densities can be a relevant source of potential infections in urban and suburban environment if high amount of people are using these areas (Rizzoli et al., 2014; Sormunen, 2018). Furthermore, Cayol et al. 2018 have observed that the abundance of ticks were positively associated with human population density around their study sites located in Central Finland.

4.2. Possibilities of accessibility analysis in EDS research

Ticks have proven to be a good example of an EDS that has a direct negative impact on human well-being. However, mapping health outcomes is challenging, as concepts or methods used to measure EDS are still poorly developed in the literature (Blanco et al., 2019; Shackleton et al., 2016; Von Döhren and Haase, 2015). The use of spatial accessibility methods can provide a promising tool to evaluate the harms EDS can cause to human health, as demonstrated in our exercise. Our findings further suggest that taking the movement of people from one place to another into consideration likely gives a more accurate picture of the overall EDS exposure risk compared to the analysis where we evaluate only the overlay of EDS risk areas and residential areas. This is because through the accessibility analysis, we can take into account a wider range of potential environments that may include the risk of encountering EDS.

The present study focused on ecosystems which are reservoirs for disease vectors, but also other EDS, where exposure risk is easy to verify, can be assessed through accessibility analysis. For example, it is possible to estimate the potential effects of ecosystems that harbor species harmful to humans due to their release of allergenic pollen and spores, their toxicity or irritant properties. Also nature-related fears and risks, such as fear of wild animals, natural darkness and crimes connected with urban parks (see Lyytimäki, 2014; Vaz et al., 2017; Von Döhren and Haase, 2015) can be linked with the movement of people.

Widely applied accessibility analysis can offer a novel approach to assess both benefits and negative effects of ecosystems on human well-being. For example, to benefit from cultural ecosystem services, such as recreation, people need to be able to access those areas (Ala-Hulkko et al., 2016). These

recreation opportunities provide an attraction to move from a place where people are living to a place that provides services. EDS are not, in general, considered an attraction, but can be located in the same area with ecosystem services. Meanwhile, the same ecosystem function may be perceived as an ecosystem service and disservice, depending on individual and social perceptions, demographics and economic realities (e.g. Escobedo et al., 2011; Saunders and Luck, 2016; Shackleton et al., 2016; Vaz et al., 2017), making the evaluation of net benefits more complicated. For example, an aesthetically pleasing and comfortable forest environment for someone can be a source of allergens or fear of natural darkness for someone else. In addition, when people are moving from a place to another, the probability of encountering EDS on the way increases, especially if people walk, as in the case of school trips. To enable efficient health policies, biodiversity policies and management, it is important to know what kind of potential harm, as well as benefit, ecosystems can produce to people. As several studies have recommended (Lyytimäki et al., 2008; Schaubroeck, 2017; Vaz et al., 2017) both harms and benefits should be explicitly recognized and dealt with in planning processes.

However, there are certain critical aspects need to be included when considering EDS in ES research. For example, Blanco et al. (2019) argued that EDS may influence people's action more than ES do. If a particular ecosystem provide both ES and EDS, people behavior is often driven by their perceptions of EDS (see Blanco et al., 2019 and references therein). This means that people may start to spend less time or even avoid the areas that produce EDS, reducing the major benefits of ES. The study of Berry et al. (2018) observed that people spent less time outdoor recreation in order to avoid tick infections in Northeast United States. Because every ecosystems may provide either ES and EDS depending on the context (Saunders and Luck, 2016) and a wide variation on how EDS influence people behavior may be expected (Blanco et al., 2019), we need further studies with more focus on both EDS and ES to develop a full picture of the relationship of ecosystems and human well-being.

5. Conclusions

In this study, we analyzed in a novel way how EDS, namely probability of tick presence, is spatially connected with the free-time activity of people in Finland. We investigated which kinds of threats ticks represent to people in residential areas and around free-time residences. Furthermore, we used GIS-based spatial accessibility analysis to illustrate tick exposure risk in children's (between 7 to 14 years of age) everyday environment. The specific objective of this study was to assess the applicability

443 of spatial accessibility analysis to map the risk of EDS exposure at a national scale. Based on our
444 results, we draw two main conclusions. **First**, the approach was well-suited for indicating the areas
445 where children have a relatively high probability of encountering potentially infectious ticks. By using
446 spatial accessibility analysis, we can evaluate the amount of potential EDS contacts and thus the
447 number of exposed children, but also the activity level of people in high-risk areas. **Second**, our results
448 show that taking people movement into consideration gives a more accurate picture of the overall
449 tick exposure risk compared to the overlay analysis of EDS and population density, which
450 underestimate the possible risk. Our findings produce valuable information to support decision-
451 makers by allowing them to optimize investments, such as vaccinations, but also inform people of
452 specific areas where movement should be avoided or tick inspections should be done carefully after
453 outdoor activities. Accessibility analysis can provide a promising approach enabling efficient
454 biodiversity policies and management when it is important to understand exposure potential to
455 harmful aspects of ecosystems, as well as their benefits in order to increase human wellbeing.

456

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458

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625

626 **Supplementary Information**

627

628 **Table S1.** List of environmental variables used in modelling the distribution of ticks in Finland.

ENVIRONMENTAL VARIABLES	UNIT	ORIGINAL RESOLUTION	TIME	SOURCE	MODEL RESOLUTION	MEAN (MIN-MAX)*
Topography						
Elevation (mean)	m	25m	-	DEM	1-km ²	150 (1–1250)
Topographical wetness index (mean)	-	25m	-	DEM	1-km ²	13 (4–29)
Radiation (mean)	kJ/cm ² /a	25m	-	DEM	1-km ²	0.5 (0.2–0.7)
Climate						
Growing degree days (>5°C)	GDD	1km	1980-2010	FMI	1-km ²	1064 (224–1541)
Mean temperature	°C	1km	1980-2010	FMI	1-km ²	2 (-3–7)
Annual precipitation	mm/a	1km	1980-2010	FMI	1-km ²	607 (379–761)
Geographical location						
X-coordinate	-	-	-	-	1-km ²	3450272 (3065500– 3733500)
Y-coordinate	-	-	-	-	1-km ²	7115479 (6631500– 7779500)
Vegetation						
EVI, Enhanced vegetation index (mean)	-	250m	2010-2015	NASA (TERRA/ MODIS)	1-km ²	0.4 (-0.03–0.7)
Land cover						
Coniferous forest	% / km ²	20m	2012	CORINE	1-km ²	13.1 (0–96.3)
Deciduous forest	% / km ²	20m	2012	CORINE	1-km ²	3.7 (0–98.3)
Mixed forest	% / km ²	20m	2012	CORINE	1-km ²	42.2 (0–100)
Cultivated field	% / km ²	20m	2012	CORINE	1-km ²	16.6 (0–100)
Shoreline	m / km ²	20m	2012	CORINE	1-km ²	936 (0 – 13707)
Wetland	% / km ²	20m	2012	CORINE	1-km ²	10.3 (0–100)

629 Abbreviations: FMI, Finnish Meteorological Institute; DEM, Digital Elevation Model; NASA, TERRA/MODIS
630 satellite image; CORINE, CORINE land cover classification. *All environmental variables were aggregated at a
631 resolution of 1-km² for distribution modelling. Descriptive statistics were calculated at 1-km² resolution.