



The use of multi-criteria evaluation for the selection of study plots for monitoring of *I. ricinus* ticks – Example from Central Europe

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ABSTRACT

Research projects in the field of eco-epidemiology of tick-borne diseases often require extensive sampling of arthropod vectors in the field. The aim of our study was to use geographical information systems (GIS) to select appropriate sampling sites of *Ixodes ricinus* ticks in central European habitat for further ecological studies of vector-borne pathogens (tick-borne encephalitis virus and *Borrelia burgdorferi* sensu lato). The model area was the Czech-German borderland (the region of South Bohemia and two regions in Germany: the Upper Palatinate and Lower Bavaria) where numerous human tick-borne encephalitis cases are reported annually. We prepared the sampling site design as a multi-criteria evaluation (MCE) task. In the GIS environment, we conducted MCE with a set of environmental, socio-economic and epidemiological data (altitude, vegetation cover, number of tick-borne encephalitis cases recorded in the past, tourist activity). The MCE classified the surveyed area into two classes: suitable for tick collection and unsuitable for tick collection. Subsequently, 50 tick sampling sites were randomly selected in the suitable area: 30 in South Bohemia (Czech Republic) and 20 in the Upper Palatinate and Lower Bavaria regions (Bavaria, Germany). The sampling sites were identified and surveyed in the field. The presence of ticks was confirmed by flagging at each of the selected plots. The described MCE system represents a versatile tool for semi-randomized design of tick sampling sites for research projects in the field of tick-borne pathogen ecology as well as for tick-borne pathogen surveillance programs run by local health authorities.

1. Introduction

Rapid development in the field of geographic information systems (GIS) and increasing availability of remote-sensing and other geo-referenced data have allowed the spread of GIS-based methods into new areas. Employed in processing, visualization and analysis of spatial data, GIS have become an integral part of various epidemiological and infection risk assessment studies (Kistemann et al., 2002; Ostfeld et al., 2005; Eisen and Eisen, 2011; Juhásová et al., 2017). The causative agents of vector-borne diseases are transmitted by hematophagous arthropods. Considering the close association of arthropod vectors with specific environmental conditions, GIS represents a perfect tool for the analysis of vector-borne disease distribution patterns (Kalluri et al., 2007). Tick-borne diseases represent a serious threat to public health. In the Northern Hemisphere, the two most widespread are Lyme

borreliosis (LB), caused by several genospecies of bacteria of the *Borrelia burgdorferi* sensu lato complex, and tick-borne encephalitis (TBE), caused by tick-borne encephalitis virus (TBEV) (Heyman et al., 2010). TBEV and to a certain degree also *B. burgdorferi* s.l. display a certain level of natural nidality: they circulate in more or less geographically defined natural foci among vector ticks and their vertebrate (reservoir) hosts. In epidemiological surveillance of tick-borne diseases, estimates of vector activity and pathogen prevalence in the field are used to predict the risk of infection (Thompson and Etter, 2015). Selection of proper testing plots in the field is crucial to ensure an objective risk assessment valid in different habitats and climatic conditions. In order to generate representative data for the purposes of risk assessment studies, the selection of sampling plots should be as random as possible. At the same time, specific habitat requirements of the ticks, requirements and the purposes of the study and proportional representation of

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different habitats must be taken into consideration.

Multi-criteria decision analysis MCDA (Malczewski, 1999, 2006; Vial et al., 2017), which MCE is a part of, is a decision support approach widely used in GIS (Carver, 1991). Analysis of multiple criteria allows assessment of complex systems with the result displayed as a single consensual output. Individual criteria enter the system as separate layers. Each cell or polygon is subsequently evaluated considering the values of each of the individual layers. Various methods are used for the integration process leading to a single output layer. For example Boolean overlay uses logical operators (AND, OR, NOT, XOR), weighted linear combinations (WLC) allow parametrization of input layers, whereas ordered weighted averaging (OWA) allows parametrization of mean type aggregation operators (Carver, 1991; Chen et al., 2001; Malczewski, 2000).

We present a multi-criteria evaluation system of semi-randomized selection of testing plots with the usage of Boolean overlay for monitoring tick populations for epidemiological purposes. Our study was aimed at selection of collection sites for regular monitoring and sampling from *Ixodes ricinus* tick populations.

2. Materials and methods

The area under study was the Czech-German borderland (particularly the region of South Bohemia in the Czech Republic, and the regions of Upper Palatinate and Lower Bavaria, in Germany) (Fig. 1). The area is geographically, climatically and biologically considerably heterogeneous, ranging from Danube valley to the highest sections of the Šumava/Bavarian forest mountain range (280–1456 m a. s. l.). The climate zone is temperate with average annual temperature ranging between 3–9 °C and average annual rainfall reaching 640–1600 mm per year with a strong influence of altitude on both. The total area under survey comprised 30 077 km² (10 056 km² in the Czech Republic and 20 021 km² in Germany). Arable land prevails in the area with fragments of coniferous, broad-leaved and mixed forests. More than 140 cases of TBE are registered annually in South Bohemia (National Institute of Public Health, Prague) and over 130 cases in Bavaria (Robert-Koch Institute, Berlin).

Areas considered suitable for collecting had to meet the following criteria (Table 1): altitude and the vegetation cover suitable for the tick *I. ricinus*, past records of TBE cases in humans, and the presence of tourist activity. We used various types of data sources to obtain

Table 1

Parameters for area to be classified as suitable for tick sampling by multi-criteria evaluation process (CORINE Land Cover category: 243 land principally occupied by agriculture, with significant areas of natural vegetation, 311 broad-leaved forest, 312 coniferous forest, 313 mixed forest, 324 transitional woodland-shrub).

Criterion	Condition
Altitude	< 750 m a. s. l.
Vegetation cover	CORINE category 243, 311, 312, 313, 324
Number of cases of TBE	25% of highest values
Tourist activity	40 % of highest values

information on each of the criteria. Basic topographic data were obtained from geographic databases ArcCR 500 (ArcDATA Prague) and Vektor 500, ATKIS® Basis DLM (Bayerische Vermessungsverwaltung). The data on vegetation cover were derived from CORINE Land Cover (CLC) 2006 (EEA, 2006). The numbers of human TBE cases were provided by the National Institute of Public Health, Prague for South Bohemia. The epidemiological data for the regions of Upper Palatinate and Lower Bavaria were obtained from the Robert-Koch Institute and local public health authorities. The criterion of past records of TBE cases was included because of well-developed diagnostics, accurate case definition and reliable reporting system of TBE on the contrary to LB. Characteristics of human activity were derived from numbers of inhabitants (Czech Statistical Office; Federal Statistical Office Germany). The intensity of tourism was estimated from the data on accommodation capacities per km² (Vystoupil et al., 2006; Bayerisches Landesamt für Statistik und Datenverarbeitung).

The analysis was conducted in ArcGIS software; interpolation algorithms were calculated using Spatial Analyst extension, the random selection procedure was done using “Create Random Points” tool. The data were transformed before entering the analysis (Fig. 2), converted to WGS 1984 coordinate system and transformed from the vector format to a raster with a pixel size of 250 m (with regard to the size of the area under survey, the purpose of the survey and the resolution of the input data). Tabular data were joined to the layer of administrative division at the municipal level. The data on TBE occurrence were available as the point of assumed infection at the municipal level. Considering the specific pattern of the distribution of TBE cases and uncertainty in the localization of the disease transmission, the data



Fig. 1. Location of the area of interest in the Czech Republic and Germany.

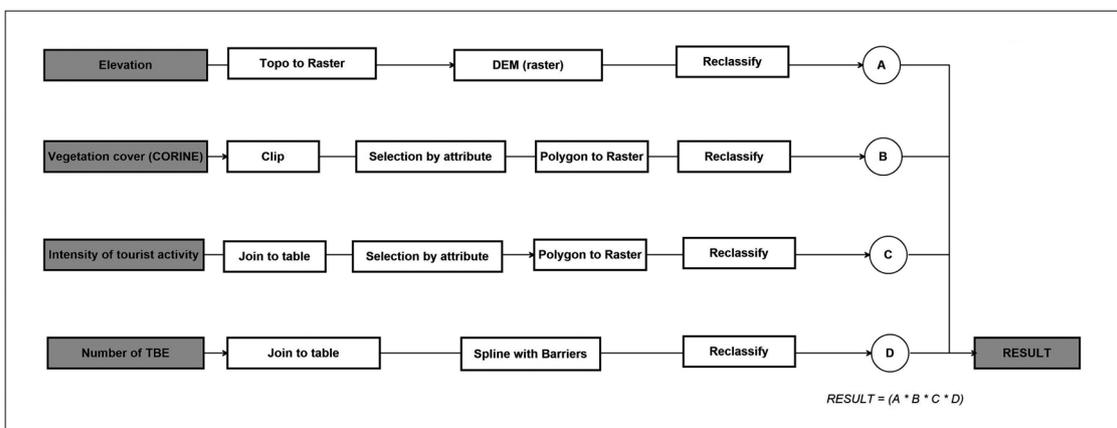


Fig. 2. Steps of data transformation and scheme of multi-criteria evaluation during the reclassification. The conditions listed in Table 1 were applied.

were interpolated from the point layer of municipalities to a raster. Different interpolation algorithms were tested, the focal feature of TBE distribution was best represented by using “Spline with Barriers”.

A simple bivariate response (suitable/unsuitable) was requested, therefore the Boolean MCE approach was used for integration of the individual layers. Each layer was converted to a bit mask following the criteria listed in Table 1 (values 1 - suitable or 0 - unsuitable). Based on our own experience from field and literature data (e.g. Daniel and Křifž, 2002; Schwarz et al., 2009) the limits for the classification were set as follows. Positive classification was assigned to pixels with values for altitude < 750 m a. s. l.; vegetation cover of one of following: 243 land principally occupied by agriculture, with significant areas of natural vegetation, 311 broad-leaved forest, 312 coniferous forest, 313 mixed forest, and 324 transitional woodland-shrub; occurrence of TBE - 25% of the pixels with highest numbers of diseases cases; tourist activity - 40% of the pixels with highest values of tourist activity. The resulting consensual layer was obtained by integration of the individual bit mask layers. The calculation was conducted by “Raster Calculator” tool using Boolean overlay method with logical operator AND (Fig. 3). The final product in 250 m resolution was obtained as the result of the MCE process. The area under the survey was classified into two categories (Fig. 4): area suitable for tick sampling (all criteria met) and area unsuitable for tick sampling (at least one criterion not met).

Subsequently, a randomized selection procedure was run to pick up 25 potential collection areas in the region of Upper Palatinate/Lower Bavaria and 35 in the region of South Bohemia. Each of the pre-selected

sites was zoomed on a topographic map. We checked the conditions of the vegetation cover and traffic accessibility of the site manually. We digitally marked proposed testing plots (2 plots per pre-selected site) and maps were created in the scale of 1 : 25 000 for every individual site. Proposed testing plots were surveyed in the field. In case one of the pre-selected spots was suitable for the tick collection, it was marked in-field using a GPS device. Concerning ecological variability and statistical significance on one hand and financial and logistic issues on the other, the final target number of localities was set to 50 (30 plots located in South Bohemia and 20 in regions of Upper Palatinate/Lower Bavaria).

3. Results and discussion

A total of 297.8 km² (0.99%) of the area under survey was evaluated as suitable for selection of *I. ricinus* collection. A larger portion of the area was classified as suitable in Bavaria (1.27%, 254.3 km²) than it was in South Bohemia (0.44%, 44.3 km²). Out of the 60 localities preselected by the above-described procedure, 50 study sites (30 in South Bohemia, 20 in Bavaria) were finally selected for the monitoring of local tick populations (Fig. 4).

The average altitude of selected localities was 448 m a s. l. in Bavaria and 520 m. a s. l. in South Bohemia. The most common categories of CLC 2006 were 243 land principally occupied by agriculture, with significant areas of natural vegetation (40%), 312 coniferous forest (30%), and 313 mixed forest (25%) in Bavaria. The proportional

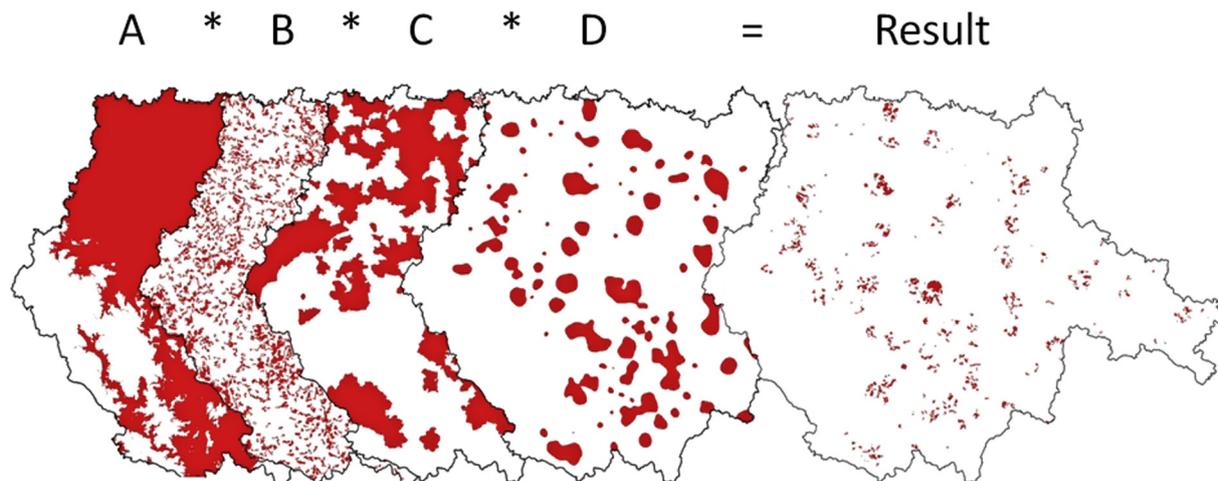


Fig. 3. Scheme of multi-criteria evaluation process of calculation using Boolean overlay method with logical operator AND. Red - areas suitable for tick sampling, white - areas unsuitable for tick sampling. Criteria: A – altitude, B – vegetation cover, C – tourist activity, D – number of TBE cases (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

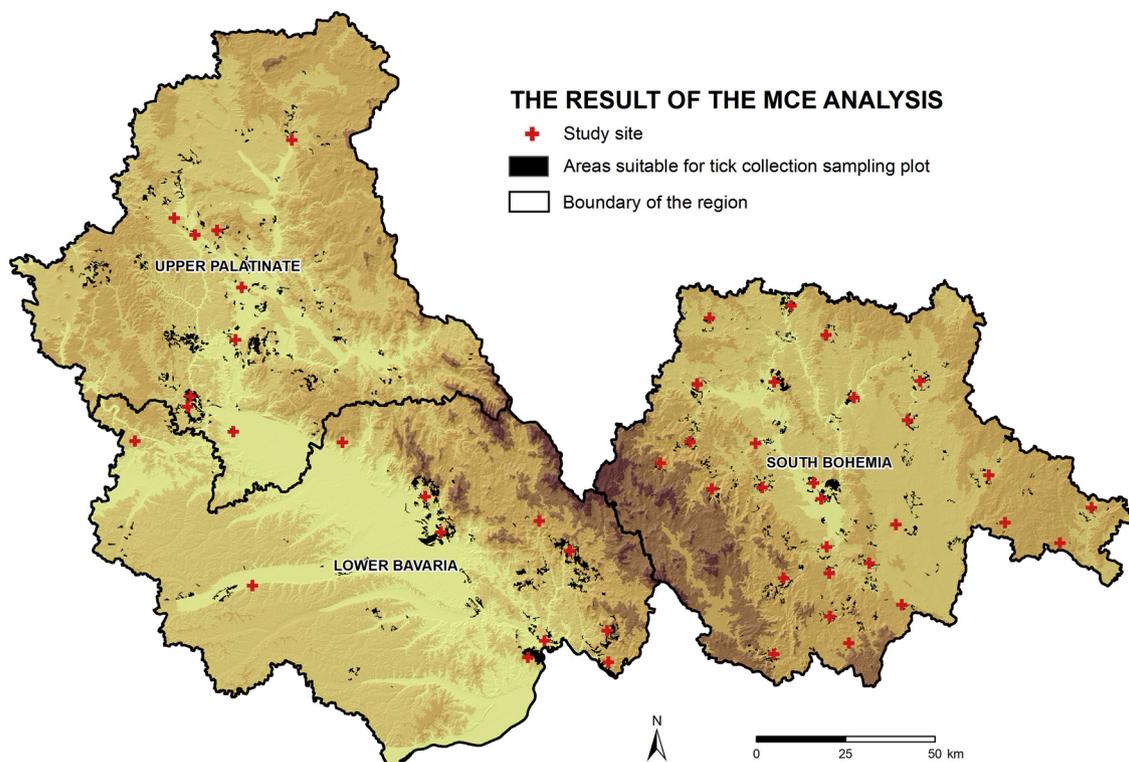


Fig. 4. Area classified as suitable for tick sampling (black - all criteria met) and area unsuitable for tick sampling (hollow - at least one criterion not met).

representation was different in South Bohemia: 313 mixed forest (50%), 312 coniferous forest (37%), 243 land principally occupied by agriculture, and with significant areas of natural vegetation (7%).

In 2008 and 2010 the activity of *I. ricinus* ticks was estimated at these study sites. The presence of *I. ricinus* was confirmed at all 50 sites. In 3 collection periods (spring, summer, autumn) altogether 28 862 ticks (27 032 nymphs, 879 females and 951 males) were collected. The ticks were present in each of the collection periods. The activity of tick populations on the individual study plots and different sampling periods ranged from 2.3–110.8 ticks/100 m² in South Bohemia (Hönig et al., 2015) and from 2.3–74.1 in Bavaria (Zubriková, unpublished data). The mean prevalence of the agents of LB and TBE respectively reached 12.1% (1 356/11 182), 0.32% (64/20 057) for the Czech Republic (Hönig et al., 2015); 12.8% (509/3 968), and 0.26% (23/8 805) for Bavarian regions (partial data presented in Vögerl et al., 2012; Hönig et al., 2015).

Based on the results of the extensive field sampling and laboratory analysis of the tick populations we have constructed a model for prediction of *I. ricinus* tick host-seeking activity; LB spirochete and TBEV prevalence; and LB spirochete/TBEV infected tick activity, using commonly available environmental data (Hönig et al., 2019). Using GIS tools we have integrated the results of the research including the risk models in map outputs. The risk maps are available to the public through an interactive internet-based map portal available at <http://gis.vsb.cz/klistata/>. The map portal uses the technology of ArcGIS for Server (ESRI).

The distribution of tick-borne disease cases as well as of the infection risk is highly focal and therefore difficult to predict with high spatial accuracy (Cortinas et al., 2002; Eisen and Eisen, 2008). We used an MCE process for consideration of the criteria influencing the distribution of ticks (vegetation cover, altitude) as well as epidemiological relevancy of the study (distribution of TBE cases, tourist activity). CORINE 2006 project has proven to be a suitable source of information on the vegetation cover. It provides data classified into a few categories, which can be easily evaluated for their ability to support tick populations. Some discrepancy between the CORINE classification and the in-

field reality was observed, but were rare. Application of various vegetation indices (NDVI, EVI, etc.) may be an alternative, although the association between the index values and presumable tick presence/absence may be more complex (Bisanzio et al., 2008). The altitude, or more specifically altitude associated changes in climatic conditions, influences the activity of tick populations (Materna et al., 2008; Gilbert, 2010).

For the success of the planned study (estimation of tick-borne pathogen prevalence in ticks; Hönig et al., 2015; Zubriková, unpublished data) the availability of certain minimum amount of ticks was crucial. The current altitudinal limit of distribution of *I. ricinus* certainly exceeds the constraint defined in MCE (Materna et al., 2005, 2008; Stünzner et al., 2006). However, low tick activities would prevent reaching the minimum number of tick samples needed for reliable prevalence analysis. The distribution of TBE cases was used as an indicator of tick, human, and pathogen activity in the area. Evidence of TBE human cases was more suitable for our purposes because of its well defined focal distribution in comparison to LB (Zeman and Januška, 1999). Furthermore, LB has an imperfect case definition and is not notifiable in all German federal states (Wilking and Stark, 2014). Apart from the TBEV infection acquired by tick bite, humans may be infected also by consumption of unpasteurized milk or milk products (summarized by Offerdahl et al. (2016)). Such cases may be included in the database, although they have no direct association with ticks. Nevertheless, the frequency of such cases is low, compared to tick-borne infections. Only 64 of 7288 TBE cases recorded for the whole Czech Republic in 1997–2008 were alimentary infections (Kříž et al., 2009). In Germany human TBE cases have been reported since the 1960s, but the statistics have become more reliable and comprehensive in 2001 when a new infection law came into practice. Since 2001 approximately 200–400 human cases were reported each year (<https://survstat.rki.de/>). Most human cases are reported from the states Bavaria and Baden-Württemberg. Oral transmission of TBEV is not considered as epidemiologically important in Germany (Rieger et al., 1998). Since 2001 only one report described 2 human cases of TBE after consumption of raw goat milk in 2016, in the State Baden-Württemberg (Brockmann et al., 2018). Thus,

we are convinced the inclusion of alimentary infections does not significantly bias the analysis. Another limitation of the use of TBE case records can be high vaccination rate, which may result in underestimation of the actual risk. In South Bohemia approximately 1/3 of the residents are vaccinated (Kollaritsch et al., 2011), compared to 40% in Bavaria (Erber and Schmitt, 2018).

Recently, crowd-sourcing based approaches are increasingly employed in the field of vector-borne diseases (Garcia-Martí et al., 2017; Laaksonen et al., 2017). For example, a database of reported human tick bites could be an alternative source of human-tick encounter data. Unfortunately, no such project is currently running in the area under survey. Generation of a suitable database would therefore require a robust reporting system and a powerful information campaign. Taking together, a reliable TBE disease case reporting system is a valuable input in our MCE-based tool for tick sampling locality selection.

Numbers of TBE cases also reflect, to a certain level, the intensity of human occurrence in a particular area. Alternatively, numbers of inhabitants (including a buffer zone of spread of activity of residents around the large settlements) could be used to select for epidemiologically relevant areas. As TBE in the Czech Republic is largely associated with outdoor activities and hence traveling and tourism (Křifž et al., 2012), we have attempted to include the extent of tourist activity in our analysis. We have used accommodation capacity numbers as an indirect quantitative indicator, as it is the only available.

A simple Boolean overlay approach was used for the integration of the individual input layers resulting in the bivariate output. This approach is considered as the pessimistic scenario (Jiang and Eastman, 2000), requiring every single criterion to be met. The result then provides a strict and high certainty identification of the suitable areas, whereas some principally useful areas may be missed in the “unsuitable” class. A more complex approach based on WLC (Jiang and Eastman, 2000; Basnet et al., 2001) or OWA (Jiang and Eastman, 2000; Rinner and Malczewski, 2002) could be used as an alternative. These approaches provide a measurement of suitability on a continuous scale (suitability map), which is not categorized only in a bivariate output (Malczewski, 2000). Nevertheless, in our case the bivariate output was sufficient, in order to identify potential sampling area. MCDA/MCE methods are used in a wide variety of research fields (Malczewski, 2006) including the health and epidemiology (Thompson and Etter, 2015) and also particularly vector-borne diseases (Tran et al., 2013; Rousseau et al., 2017; Vial et al., 2017) in last few years.

We have used a MCE-GIS system for objective semi-randomized selection of testing plots for an eco-epidemiological study. The use of our approach provides a reduction of the extent of the field work, informed and structured selection of the study sites, and thus easier evaluation of the collected data and their transformation to a risk model.

The system was developed for the conditions of Central Europe. Therefore, the application of the system in different geographical areas may require adjustment of the limits, addition of other vegetation types, searches for locally specific data sources, etc. Nevertheless, this approach brings general ideas of input data (e.g. substitution temperature instead of altitude), parameters (limits), and their adjustment. Moreover, MCDA/MCE analysis is also independent of used GIS software and can be integrated in any commercial or non-commercial software.

This article aimed to show, how MCDA/MCE can help to design a set of tick sampling sites. In our study, the main objective was to collect a sufficient amount of biological samples from several different habitats, known to support high population densities of the ticks. Furthermore, we wanted to characterise the prevalence and diversity of the two selected causative agents of human disease (tick-borne encephalitis virus and *B. burgdorferi* s.l. spirochetes). Nevertheless, the system is very versatile in the terms of input data and their processing, thus it may be adapted to other purposes like risk habitat modelling, epidemiological studies etc. The presented system is particularly suitable for

surveillance of ticks and tick-borne pathogens by local public health institutions. It allows objective assessment of the target area without detailed previous knowledge of the spatial distribution of ticks and tick-borne pathogens.

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References

- Basnet, B.B., Apan, A.A., Raine, S.R., 2001. Selecting suitable sites for animal waste application using a raster GIS. *Environ. Manag.* 28, 519–531.
- Bisanzio, D., Amore, G., Ragagli, C., Tomassone, L., Bertolotti, L., Manelli, A., 2008. Temporal variations in the usefulness of normalized difference vegetation index as a predictor for *Ixodes ricinus* (Acari: ixodidae) in a *Borrelia lusitaniae* focus in Tuscany, Central Italy. *J. Med. Entomol.* 45, 547–555.
- Brockmann, S.O., Oehme, R., Buckenmaier, T., Beer, M., Jeffery-Smith, A., Spannenkrebs, M., Haag-Milz, S., Wagner-Wiening, C., Schlegel, C., Fritz, J., Zange, S., Bestehorn, M., Lindau, A., Hoffmann, D., Tiberi, S., Mackenstedt, U., Dobler, G., 2018. A cluster of two human cases of tick-borne encephalitis (TBE) transmitted by unpasteurized goat milk and cheese in Germany, May 2016. *Euro Surveill.* 23 (15) pii = 17-00336.
- Carver, S.J., 1991. Integrating multi-criteria evaluation with geographical information systems. *Int. J. Geogr. Inf. Sci.* 5 (3), 321–339.
- Chen, K., Blong, R., Jacobson, C., 2001. MCE-RISK: integrating multicriteria evaluation and GIS for risk decision-making in natural hazards. *Environ. Model. Softw.* 16, 387–397.
- Cortinas, M.R., Guerra, M.A., Jones, C.J., Kitron, U., 2002. Detection, characterization, and prediction of tick-borne disease foci. *Int. J. Med. Microbiol.* 291 (Suppl. 33), 11–20.
- Daniel, M., Křifž, B., 2002. Klíšťová encefalitida v České republice. SZÚ, Prague, Czech Republic 64 p.
- EEA (European Environment Agency), 2006. <https://www.eea.europa.eu/data-and-maps/data/clc-2006-raster-4> (Accessed 20 February 2008).
- Eisen, R.J., Eisen, L., 2008. Spatial modeling of human risk of exposure to vector-borne pathogens based on epidemiological and versus arthropod vector data. *J. Med. Entomol.* 45, 181–192.
- Eisen, L., Eisen, R.J., 2011. Using geographic information systems and decision support systems for the prediction, prevention, and control of vector-borne diseases. *Annu. Rev. Entomol.* 56 (1), 41–61.
- Erber, W., Schmitt, H.J., 2018. Self-reported tick-borne encephalitis (TBE) vaccination coverage in Europe: results from a cross-sectional study. *Ticks Tick-Borne Dis.* 9 (4), 768–777.
- Garcia-Martí, I., Zurita-Milla, R., Swart, A., van den Wijngaard, K.C., van Vliet, A.J.H., Bennema, S., Harms, Harms, M., 2017. Identifying environmental and human factors associated with tick bites using volunteered reports and frequent pattern mining. *T. GIS.* 21 (2), 277–299.
- Gilbert, L., 2010. Altitudinal patterns of tick and host abundance: a potential role for climate change in regulating tick-borne diseases. *Oecologia* 162, 217–225.
- Heyman, P., Cochez, C., Hofhuis, A., van der Giessen, J., Sprong, H., Porter, S.R., Losson, B., Saegerman, C., Donoso-Mantke, O., Niedrig, M., Papa, A., 2010. A clear and present danger: tick-borne diseases in Europe. *Expert Rev. Anti. Ther.* 8 (1), 33–50.
- Hönl, V., Švec, P., Halas, P., Vavrušková, Z., Tykalová, H., Kilian, P., Vetišková, V., Dornáková, V., Štěrbová, J., Šimonová, Z., Erhart, J., Štěrba, J., Golovchenko, M., Rudenko, N., Grubhoffer, L., 2015. Ticks and tick-borne pathogens in South Bohemia (Czech Republic) – spatial variability in *Ixodes ricinus* abundance, *Borrelia burgdorferi* and tick-borne encephalitis virus prevalence. *Ticks Tick. Dis.* 6 (5), 559–567.
- Hönl, V., Švec, P., Marek, L., Mrkvíčka, T., Zubriková, D., Wittmann (Vögerl), M., Masař, O., Szturcová, Růžek, D., Pfister, K., Grubhoffer, L., 2019. Model of risk of exposure to Lyme borreliosis and tick-borne encephalitis virus-infected ticks in the border area of the Czech Republic (South Bohemia) and Germany (Lower Bavaria and Upper Palatinate). *Int. J. Environ. Res.* 16 (7), 1173.
- Jiang, H., Eastman, J.R., 2000. Application of fuzzy measures in multi-criteria evaluation in GIS. *Int. J. Geogr. Inf. Sci.* 14, 173–184.
- Juhásová, L., Králová-Hromadová, I., Zelenáková, M., Blištan, P., Bazsalovicsová, E., 2017. Transmission risk assessment of invasive fluke *Fascioloides magna* using GIS-modelling and multicriteria analysis methods. *Helminthologia* 54 (2), 119–131.
- Kalluri, S., Gilruth, P., Rogers, D., Szczur, M., 2007. Surveillance of arthropod vector-

- borne infectious diseases using remote sensing techniques: a review. *PLoS Pathog.* 3 (10), e116.
- Kistemann, T., Dangendorf, F., Schweikart, J., 2002. New perspectives on the use of Geographical Information Systems (GIS) in environmental health sciences. *Int. J. Hyg. Environ. Health* 205, 169–181.
- Kollaritsch, H., Chmelfik, V., Dontsenko, I., Grzeszczuk, A., Kondrusik, M., Usonis, V., Lakos, A., 2011. The current perspective on tick-borne encephalitis awareness and prevention in six Central and Eastern European countries: report from a meeting of experts convened to discuss TBE in their region. *Vaccine* 29, 4556–4564.
- Křif, B., Beneš, Č., Daniel, M., 2009. Alimentary transmission of tick-borne encephalitis in the Czech Republic (1997–2008). *Epidemiol. Mikrobiol. Imunol.* 58, 98–103.
- Křif, B., Malý, M., Beneš, Č., Daniel, M., 2012. Epidemiology of tick-borne encephalitis in the Czech Republic 1970–2008. *Vector Borne Zoonotic Dis.* 12, 994–999.
- Laaksonen, M., Sajanti, E., Sormunen, J.J., Penttinen, R., Hänninen, J., Ruohomäki, K., Sääksjärvi, I., Vesterinen, E.J., Vuorinen, I., Hytönen, J., Klemola, T., 2017. Crowdsourcing-based nationwide tick collection reveals the distribution of *Ixodes ricinus* and *I. persulcatus* and associated pathogens in Finland. *Emerg. Microbes. Infect.* 6 (5), e31.
- Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, Inc, New York.
- Malczewski, J., 2000. On the use of weighted linear combination method in GIS: common and best practice approaches. *T. GIS.* 4, 5–22.
- Malczewski, J., 2006. GIS-based multicriteria decision analysis: a survey of the literature. *Int. J. Geogr. Inf. Sci.* 20 (7), 703–726.
- Materna, J., Daniel, M., Danielová, V., 2005. Altitudinal distribution limit of the tick *Ixodes ricinus* shifted considerably towards higher altitudes in central Europe: results of three years monitoring in the Krkonose Mts. (Czech Republic). *Cent. Eur. J. Public Health* 13, 24–28.
- Materna, J., Daniel, M., Metelka, L., Harčarik, J., 2008. The vertical distribution, density and the development of the tick *Ixodes ricinus* in mountain areas influenced by climate changes (the Krkonose Mts., Czech Republic). *Int. J. Med. Microbiol.* 298 (Suppl. 1), 25–37.
- Offerdahl, D.K., Clancy, N.G., Bloom, M.E., 2016. Stability of a tick-borne flavivirus in milk. *Front. Bioeng. Biotechnol.* 4, 40.
- Ostfeld, R.S., Glass, G.E., Keesing, F., 2005. Spatial epidemiology: an emerging (or re-emerging) discipline. *Trends Ecol. Evol.* 20, 328–336.
- Rieger, M.A., Nübling, M., Kaiser, R., Tiller, F.W., Hofmann, F., 1998. FSME-Infektionen durch Rohmilch-welche Rolle spielt dieser Infektionsweg? Untersuchungen aus dem südwestdeutschen FSME-Endemiegebiet. *Gesundheitswesen.* 60 (6), 348–356.
- Rinner, C., Malczewski, J., 2002. Web-enabled spatial decision analysis using ordered weighted averaging (OWA). *J. Geogr. Syst.* 4 (4), 385–403.
- Rousseau, R., McGrath, G., McMahon, B.J., Vanwambeke, S.O., 2017. Multi-criteria decision analysis to model *Ixodes ricinus* habitat suitability. *Ecohealth* 14 (3), 591–602.
- Schwarz, A., Maier, W.A., Kistemann, T., Kampen, H., 2009. Analysis of the distribution of the tick *Ixodes ricinus* L. (Acari: ixodidae) in a nature reserve of western Germany using geographic information systems. *Int. J. Hyg. Environ. Health* 212, 87–96.
- Stünzner, D., Hubálek, Z., Halouzka, J., Wendelin, I., Sixl, W., Marth, E., 2006. Prevalence of *Borrelia burgdorferi* sensu lato in the tick *Ixodes ricinus* in the Styrian Mountains of Austria. *Wien. Klin. Wochenschr.* 118, 682–685.
- Thompson, P.N., Etter, E., 2015. Epidemiological surveillance methods for vector-borne diseases. *Rev. Sci. Technol. Off. Int. Epiz.* 31 (1), 235–247.
- Tran, A., Ippoliti, C., Balenghien, T., Conte, A., Gely, M., Calistri, P., Goffredo, M., Baldet, T., Chevalier, V., 2013. A geographical information system-based multicriteria evaluation to map areas at risk for Rift Valley fever vector-borne transmission in Italy. *Transbound. Emerg. Dis.* 60 (Suppl. 2), 14–23.
- Vial, L., Ducheyne, E., Filatov, S., Gerilovych, A., McVey, D.S., Sindryakova, I., Morgunov, S., Pérez de León, A.A., Kolbasov, D., De Clercq, E.M., 2017. Spatial multi-criteria decision analysis for modelling suitable habitats of *Ornithodoros* soft ticks in the Western Palearctic region. *Vet. Parasitol.* 249, 2–16.
- Vögerl, M., Zubriková, D., Pfister, K., 2012. Prevalence of *Borrelia burgdorferi* s. l. In *Ixodes ricinus* ticks from four localities in Bavaria, Germany. *Berl. Munch. Tierarztl. Wochenschr.* 125, 401–406.
- Vystoupil, J., Holešinská, A., Kunc, J., Maryáš, J., Seidenglanz, D., Šauer, M., Tonev, P., Viturka, M., 2006. Tourism Atlas of the Czech Republic. Ministry of regional development, CZ, Prague, Czech Republic.
- Wilking, H., Stark, K., 2014. Trends in surveillance data on human Lyme borreliosis from six federal states in eastern Germany, 2009–2012. *Ticks Tick. Dis.* 6 (3), 219–224.
- Zeman, P., Januška, J., 1999. Epizootiologic background of dissimilar distribution of human cases of Lyme borreliosis and tick-borne encephalitis in a joint endemic area. *Comp. Immunol. Microbiol. Infect. Dis.* 22, 247–260.