TICK-BORNE DISEASES RISK MODEL FOR SOUTH BOHEMIA (CZECH REPUBLIC)

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Abstract

Tick-borne diseases (TBD) like Lyme borreliosis or tick-borne encephalitis (TBE) belong to most important health threats in the Northern Hemisphere. The Czech Republic is one of the countries with highest incidence of TBD. Particularly the region of South Bohemia, with an annual average of 26 TBE cases per 100 000 inh. has been for a long time a high-risk area (mean annual TBE incidence for the whole country is 6.4 cases per 100 000 inh.). Concerning the TBD preventive measures, one of the key issues is the knowledge of disease risk distribution in time and space. Moreover, such knowledge may be helpful in revealing background mechanisms actually determining the distribution. Habitat suitability models based on remote sensing or GIS data are increasingly employed in spatial epidemiology of vector-borne diseases. We propose a model system for estimation of TBD risk based on assessment of habitat suitability for the vector – *Ixodes ricinus* tick. Land cover data (CORINE Land Cover 2006) and digital elevation model were employed for the prediction of tick activity, the main component of the biological risk of TBD. The model was validated on a dataset of field-collected data on tick activity and further on actual number of clinical cases of tick-borne encephalitis. A map of biological risk and a map of risk of TBD case occurrence were produced. Areas of high and low biological risk were identified. Areas of high biological risk were scattered mainly along the river valleys, whereas low risk areas were represented by mountainous part of the region. Highest numbers of TBD cases were predicted in surroundings of large setllements or in areas of maximum biological risk.

Keywords: GIS, cartographic model, Lyme borreliosis, tick-borne encephalitis

1 INTRODUCTION

Diseases transmitted by ticks – tick-borne diseases (TBD) belong to so called emerging diseases. These are diseases caused by new or altered disease agents, diseases occurring in a new context or with different intensity. An increase in the number human cases of TBD is reported from a number of European countries in last decades. Moreover, dramatic changes in the distribution of the disease cases in time and space are observed (Randolph 2001, Süss et al. 2004, Materna et al. 2008, Gray et al. 2009).

Because of this dynamic nature of emergent infections, tools for disease risk assessment and monitoring are needed. In vector-borne diseases epidemiology various models are used for prediction of disease risk. Concerning the training datasates and model outputs, the risk is usually calculated based on epidemiological dat (numbers of disease cases) (e.g. Beneš et al. 2005), vector data (presence/absence, abundance) (e.g. Eisen et al. 2006, Schwarz et al. 2009), pathogen data (prevalence of pathogens, density of infected vectors) (e.g. Rizzoli et al. 2002) or on combination of above mentioned (e.g. Daniel et al. 2006). Such data are used for identification of environmental factors closely correlated to the risk of exposure. Subsequently highely correlated factors serve as predictors of exposure risk (Ostfeld et al. 2005). Each of the above-mentioned approaches influences the final model output and has certain advantages and disadvantages (summarized by Eisen and Eisen 2008).

Regarding the transmission of TBD to human, the tick *Ixodes ricinus* is the most important species in Europe. It may transmit a number of disease agents including two most widespread: tick-borne encephalitis virus and Lyme borreliosis spirochetes. This tick is mostly restricted to forested areas and prefers heterogeneous broad-leaved or mixed forests with dense undergrowth and leaf litter providing sufficient humidity. In natural foci, the pathogens circulate among ticks and their vertebrate hosts (Süss 2003; Humair et al. 2000).

Numerous woodland fragments scattered among pasture and agricultural areas, appropriate climatic and biotic conditions in the South Bohemian Region provide an especially pertinent environment for *I. ricinus* populations. An average of 160 human cases of tick-borne encephalitis and 154 cases of Lyme borreliosis occur annually in the region (data provided by the National Institute of Public Health, Prague).

The aim of our study is to assess the biological risk of TBD infection – i.e. the probability of encountering a tick in a particular area. The level of the risk depends mainly on the level of tick activity. The prevalence of pathogens was not included, because its influence on total TBD risk is minor and *I. ricinus* ticks in South Bohemia transmit multiple pathogens with variable prevalence rate. Using the habitat modeling approach a simple vector based model for assessment of tick activity was developped. Association of certain environmental variables with the biological demands of ticks was used for estimation of expected tick activity. The major advantages of this vector-based model are: risk assessment independent on human behaviour and independent on particular tick-borne pathogen.

2 DATA AND METHODS

Ticks are highly dependent on certain abiotic (e.g. temperature, relative air humidity) and biotic (e.g. host availability) environmental factors. These factors are numerous, often interact with each other and often are difficult to reveal and monitor. Therefore, usually complex habitat characteristics like NDVI, brightness or greennes are employed (Eisen et al. 2006, Šumilo et al. 2006). In our model, vegetation land cover was used as complex descriptor of a given area (encompassing soil type, climate, to certain extend composition of tick host fauna). Because of the partially mountainous character of the region altitude had to be included as a second predictor. The relationship between elevation and tick population activity is well described and the climatic and biotic condition covariate with altitude.

2.1 INPUT DATA, TRANSFORMATION

Input layers were transformed into a raster grid with uniform pixel size. Regarding the computational capacity, resolution of some of the input data and the purpose of the study, the pixel size was set 50 x 50 m.

In the biological risk model, the layers were classified according to the probability of tick occurrence (based on empirical experience and literature). Intervals covering the whole range of the factor were set and rescaled to 0 – 1 scale (0 – minimum risk, 1 – maximum risk). The values of the risk index for individual categories are shown in Table 1.

2.1.1 Vegetation cover

Vegetation cover influences the probability of *I. ricinus* occurrence and level of activity essentially (Nosek and Krippel 1974). The relationship between the habitat type and distribution of the ticks was repeatidly empirically verified. Association of tick with certain habitats is commonly applied in TBD modeling studies (Daniel and Kříž 2002, Daniel et al. 2006, Eisen et al. 2006, Šumilo et al. 2006). The data on vegetation cover were obtained from CORINE Land Cover 2006 (CLC 2006) project of European Environment Agency were used (EEA, 2006). The resolution of the input data allowed us to identify even small habitat fragments, which are known to be important reservoirs of ticks. No remarkable changes in land cover are expected to occur since 2006. From a variety of land cover classes CLC 2006, only some are present in the surveyed area and only some are suitable for the survival of *I. ricinus* ticks. These classes were assigned a risk index based on own field experiments and literature (Daniel and Kříž 2002, Schwarz et al. 2009). In other classes, the probability of tick encounter is minimal, therefore these classes were merged in a single category "other". Water courses and bodies exclude the occurrence of living ticks completely and thus were assigned a zero risk. The list of CLC 2006 vegetation cover categories and assigned risk indices is shown in Table 1.

2.1.2 Elevation

Altitude influences the activity of ticks and therefore was used as a second factor entering the biological risk model. The range of altitudes in the surveyed area is 330 to 1378 meters above sea level. The risk indices were inferred from the relationship between tick activity and elevation from our own field collected data and data from literature (Jouda et al. 2004; Materna et al. 2005, 2008; Danielová et al. 2010; Gilbert et al. 2010). Most studies focused on higher altitudes of 400 to 1160 m a. s. l. The activity of *I. ricinus* populations decreases rapidly in the interval of 500-850 m a. s. l. In the range 850-1160 m the activity decreases more steadily approaching the minimum values at 800-1000 m. Therefore, the risk index was assigned maximum value from zero to 500 m a. s. l. From 500 to 850 m a. s. l. the risk is decreasing continually. Above 850 m a. s. l. the index is assigned a constant value of minimum but existing risk of 0.05. The elevation values were derived from contour lines in Arc ČR500 database.

Table 1. Risk index assignment

Layer	Category	Risk index [0-minimum;1-maximum]
Vegetation cover [Corine Land Cover 2006 classification]	1.4.1. Green urban areas	0.25
	2.3.1. Pastures	0.20
	2.4.3. Land principally occupied by agriculture	0.40
	3.1.1. Broad-leaved forest	0.80
	3.1.2. Coniferous forest	0.50
	3.1.3. Mixed forest	1.00
	3.2.1. Natural grassland	0.20
	3.2.4. Transitional woodland shrub	0.60
	5.1.1. Water courses	0.00
	5.1.2. Water bodies	0.00
	other	0.05
Elevation [m a. s. l.]	< 500	1.00
	501 – 850	decreasing from 1.00 to 0.05
	> 851	0.05

2.2 MODEL CONSTRUCTION

The model was compiled in ESRI ArcGIS 9.3 software. Tools and logics of map algebra were used for linking up individual map layers. Before final calculation in Single Output Map Algebra tool, necessary transformation steps including joining and cutting the input data, raster transformation and reclassification of the data (Fig. 1) were conducted. Various possibilities of the integration of individual input layers were tested in order to pick up the best representation of the real relationships among the factors.

In the proposed model the level of tick activity results from integraction of two predictors – altitude and vegetation cover. Biologically, extremely low suitability in one or another factor results in low risk regardless on the level of the second factor. For example, the occurrence of ticks is excluded in water areas independently on altitude. Similarly, very low tick activities occur in altitudes above 1000 m a. s. l., despite potentially suitable vegetation cover. On the other hand, high suitability of both factors potentiates the risk in a multiplicative manner. This behaviour was represented in the model by multiplication of the two input layers. Moreover, the final ouput value remained 0 for minimum risk and 1 for maximum risk.

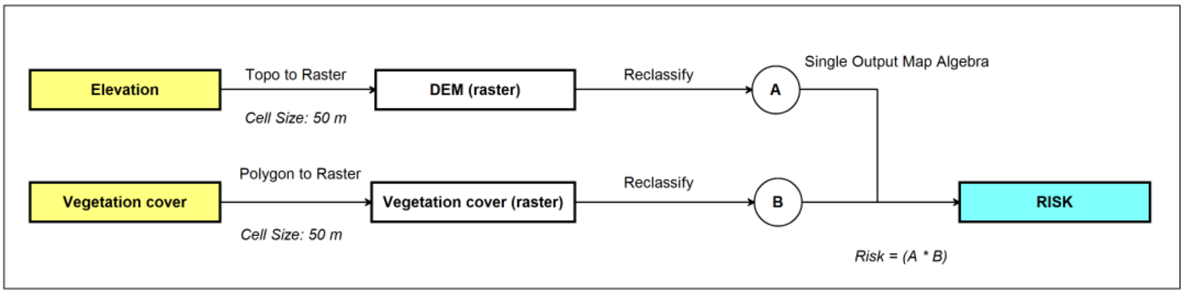

Fig. 1. The scheme of the biological risk model

2.3. MODEL VALIDATION

The efficiency of the model to predict tick activity was evaluated using the field-collected data. A network of 30 testing sites evenly distributed over the surveyed area was established (location indicated in Fig. 2). In each study site, the tick activity was estimated 3 times per season (May, June, September), regarding the typical seasonal pattern of *I. ricinus*. The ticks were sampled by a commonly used flagging method. The activity was calculated as a mean number of ticks per 100 m^2. In each sampling event 600 m^2 were flagged (compare Vassalo et al. 2000). The estimated activity of ticks was compared with the model output by Spearman rank order correlation test STATISTICA 9.1 software (StatSoft. Inc., USA).

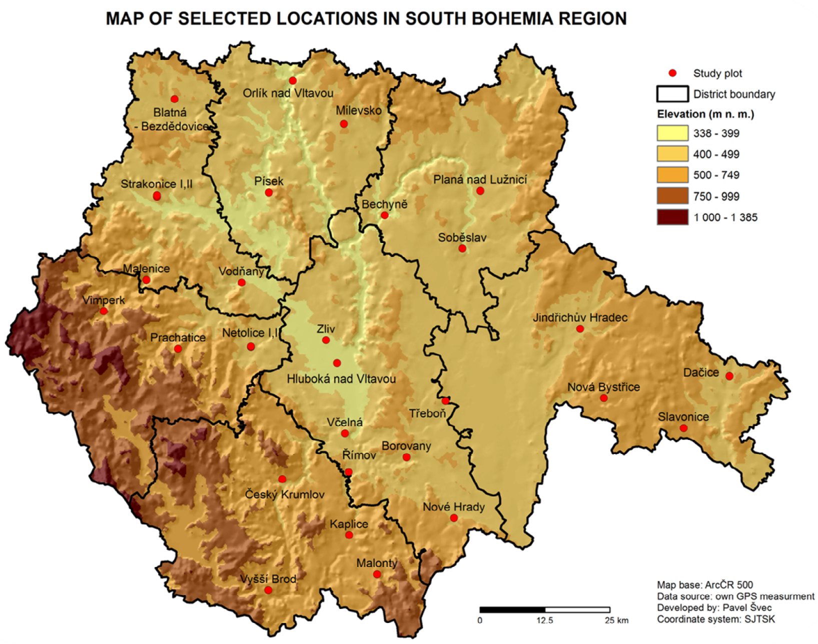

Fig. 2. Distribution of testing localities

Occurence of a disease case as a realisation of the biological risk is strongly influenced by human activity. Therefore, estimate of human activity was included in the model. The level of human occurrence was inferred from the number of inhabitants. Because of highly active tourist traffic particularly in the Region of South Bohemia tourist activity data were included. Data on number of inhabitants at the level of municipality were used (compare Estrada-Pena and Venzal 2007). The data were acquired from the Czech Statistical Office (valid to 1.1.2009) and expressed as population density per km^2 (range 1.23 - 1708.29).

No direct data on the number of tourists were available in sufficient resolution. Therefore, numbers of accomodation beds were used as a rough estimate of tourist activity. The data were obtained from The Atlas of Tourism of the Czech Republic (Vystoupil et al. 2006) and recalculated per km^2 (range 20 - 411).

Total human activity was obtained as a sum of number of inhabitants and number of tourists. All people were considered as susceptible to TBD infection and thus potential disease cases. The biological risk (activity of ticks) was multiplied by the level of human activity (probability of human occurence) resulting in a probability of disease case occurrence (Fig. 3). The model output was compared with the actual number of tick-borne encephalitis (TBE) cases per municipality and the correlation was statistically tested by the means of Spearman correlation ranking test. TBE was selected because of its precise case definition and reliable reporting system. Total numbers of disease cases for the 2001-08 period were acquired from the Institute of Public Health, Prague, Czech Republic.

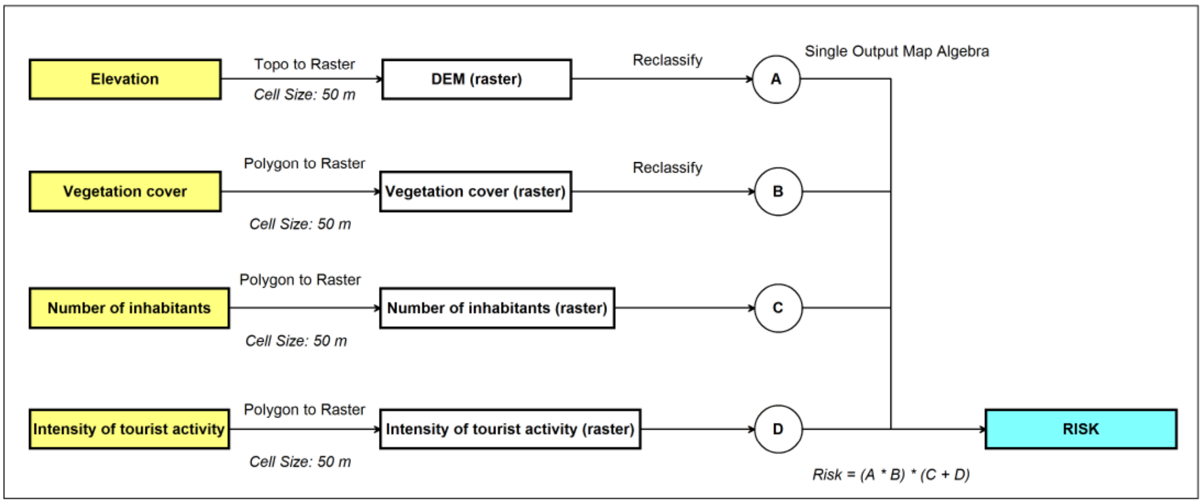

Fig. 3. The scheme of the model of disease case occurence

3 RESULTS

The biological risk model was transferred to a map output (Fig. 4). The biological risk represents the predicted activity of ticks.

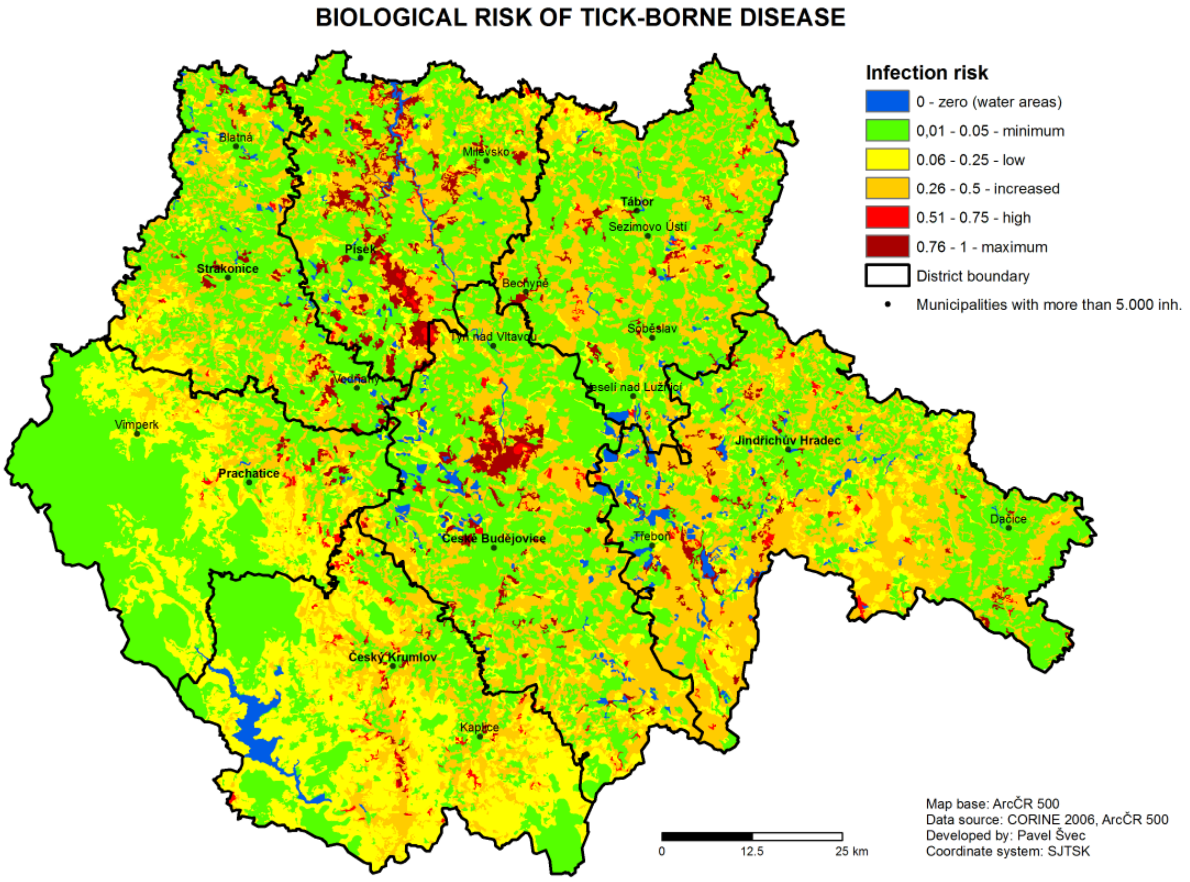

Fig. 4. Biological risk of tick-borne diseases

The majority of the surveyed area falls in low risk categories. The largest compact area of minimum risk is located in the southwestern mountainous part of the region (Šumava Mountains). The maximum and high-risk areas are scattered along the valeys of the rivers Vltava, Otava and Blanice from the center of the region northwards. Large area of increased risk stretches from the town Třeboň southwards and westwards to the border. The summary of the proportional representation of the individual risk categories over the whole area is shown in Table 2.

Table 2. Proportional representation of risk categories

Risk category	Proportion of pixels [%]
zero (0)	2.0
minimum (0.01 - 0.05)	19.1
low (0.06 - 0.25)	45.2
increased (0.26 - 0.5)	29.7
high (0.51 - 0.75)	1.0
maximum (0.76 - 1)	3.0

The model output was compared with the data on tick density assessed in 30 testing sites dispersed over the Region of South Bohemia (Fig. 2). Significant correlation was confirmed in Spearman rank order correlation test ($p<0.05$) and Pearson correlation test ($r = 0.36$, $p<0.05$) between risk predicted by model and mean density of ticks.

After addition of human activity to the model, the output was compared with the total number of TBE cases (2001-08). A strong correlation was confirmed by Spearman rank order correlation test ($p<0.05$) and Pearson correlation test (r = 0.76, p<0.01) between risk predicted by model and total number of disease cases. A map of risk TBD case occurrence was constructed (Fig. 5).

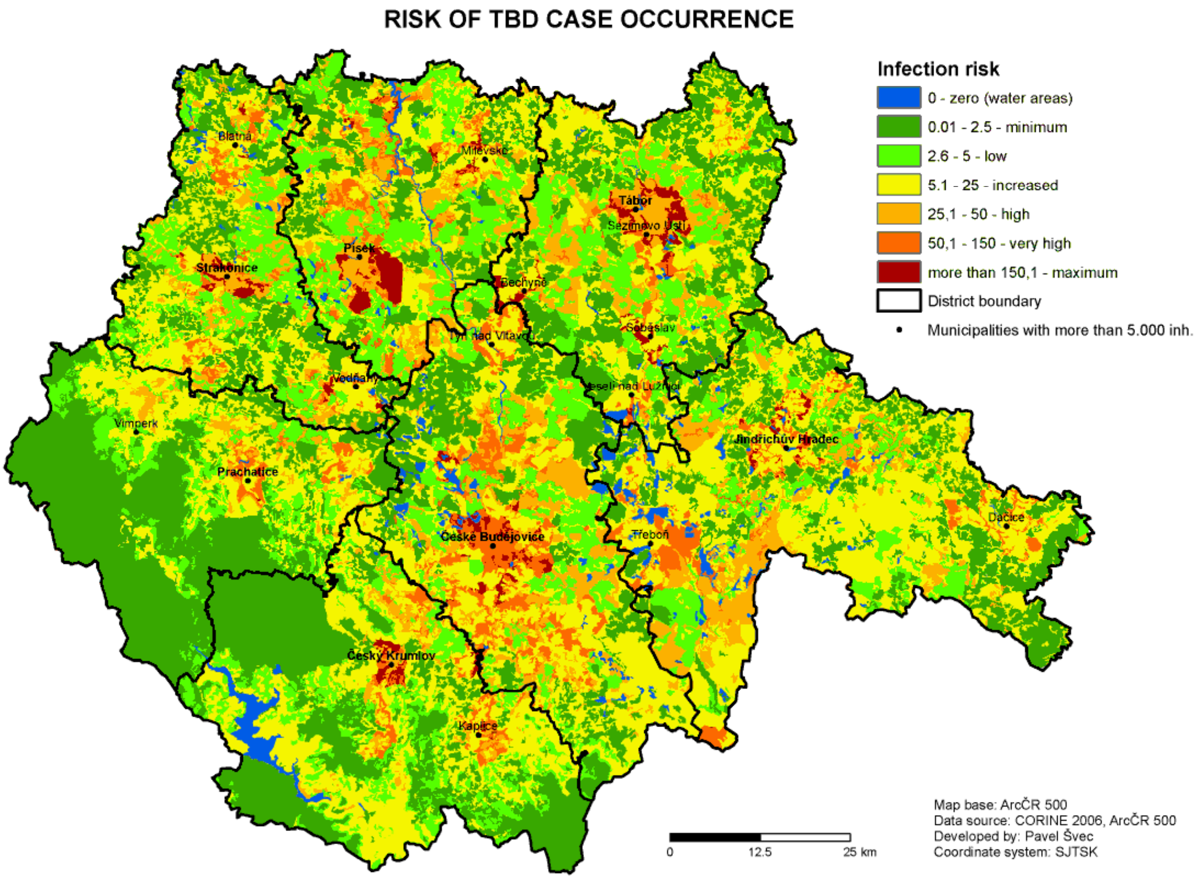

Fig. 5. Map of risk TBD cases occurence

The high-risk areas shifted considerably into the surrounding of larger settelements. Two high-risk areas remained in sparsely populated areas of the region: near Orlik dam (northern part of the region) and between the towns České Budějovice and Týn nad Vltavou.

4 DISCUSSION AND CONCLUSIONS

For modelling of vector-borne diseases distribution various factors are evaluated as possible predictors: macro-, microclimatic conditions, type of vegetation cover, level of urbanization etc. (Šumilo et al. 2006, Eisen et al. 2006, Estrada-Pena and Venzal 2007). In our case, a simple model predicting suitable habitats of ticks based on vegetation cover and elevation was developed. The data from CORINE Land Cover 2006 seemed sufficient for our purpose in the respect of resolution as well as number and composition of vegetation cover categories. This source was also used in the study of Šumilo et al. (2006). According to numerous experimental data, the activity of ticks is influenced by elevation (e.g. Materna et al. 2008). Altitude plays a particularly important role in our model because it allows us to classify the mountainous regions correctly as low risk areas, although the vegetation cover might be suitable.

The predictions produced by the model were significantly correlated with the actual tick activity. The valleys of large rivers were considered the areas of increased risk. This migth be possibly due to presence of deciduous and mixed forests as well as relatively low altitude. By contrast the Šumava mountain range was classified as low risk area, apparently due to high elevation. Indeed, the tick activity in this region is considerably lower when compared with the rest of the region (Danielová at al. 2002, 2006).

Human activity was included to the model, to be able to compare the model output with actual number of tick-borne encephalitis cases. Although the distribution of TBE in nature is highly focal and influenced by other factors besides simple tick activity (Danielová 2002), high degree of correlation was found. The probable reason is high correlation of human activity with number of disease cases. The high-risk areas were concentrated in the surroundings of larger settlements, indicating again the importance of human population density. The tourist activity seems to play an important role in the recreational areas of Orlik and Lipno dam and in the area of Třeboň. Nevertheless, in the map of risk TBD case occurrence some sparsely populated areas remained classified as high risk. These areas co-incided with areas of maximum biological risk. These facts indicate that high numbers of clinical cases may be caused either by high human activity or by high tick activity in poorly inhabited areas.

Concerning the overall proportional representation of different risk categories, minimum to increased risk categories cover 94 % of the area under survey. Only 4 % of the pixels were assigned to high or maximum risk indicating, that the biological risk is almost homogenously spread over the whole region with only several small areas reaching the extreme values.

The model of biological risk has a technical limitation in its resolution. In the map outputs is the lack of resolution presented in the case of smaller water courses, which are not depicted. Similar situation will be in the case of small areas of different vegetation type than the surrounding areas. However, the probability of survival of a stable tick population in a fragment of suitable habitat smaller than the model resolution 50x50 m is negligible. Therefore, we consider the resolution of the model still sufficient, although not perfect.

When compared with disease case based models, the proposed model has several advantages. Due to the vegetation cover layer is the identification of the risk areas more accurate by the model. Furthermore, the number of cases does not include the cases without any clinical signs, cases that do not occur because of immunity acquired by previous infection or vaccination. In regions with high vaccination rate, the risk for an unvaccinated person may be actually much higher than predicted from disease case mapping.

The presented model is one of the working versions and will be further optimized. The possibility of integration of climatic data, field-collected data on tick activity and pathogen prevalence will be considered. The predictors and their combinations will be selected by their statistical evaluation on a trining dataset. The human activity model could be refined by data on urbanization and land use (Estrada-Pena and Venzal 2007).

Acknowledgement:

The authors would like to thank for the data kindly provided by the Region of South Bohemia, Faculty of Economics and Administration, MU Brno, National Institute of Public Health, Prague and for collaboration to Dr. Danielová and Dr. Daniel. The research is co financed by the European Development Fund of the European Union, by the Region of South Bohemia and by following grants: SP/2010184 and GAČR 206/09/H026.

REFERENCES

Randolph, S.E. (2001) The shifting landscape of tick-borne zoonoses: tick-borne encephalitis and Lyme borreliosis in Europe. Phil. Trans. R. Soc. Lond. B. 386: 1045-1056.

Süss, J., Schrader, C., Falk, U., Wohanka N. (2004) Tick-borne encephalitis (TBE) in Germany – epidemiological data, development of risk areas and virus prevalence in field-collected ticks and in ticks removed from human. Int. J. Med. Microbiol. 293 Suppl 37: 69-79.

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 Krkonoše Mts., Czech Republic). Int. J. Med. Microbiol., 298, S1, 25-37.

Gray, J.S., Dautel, H., Estrada-Pena, A., Kahl, O., Lindgren, E. (2009) Effects of climate change on ticks and tick-borne diseases in Europe. Interdiscip. Perspect. Infect. Dis. 2009:593232.

Beneš, V., Bodlák, K., Moller, J., Waagepetersen, R. (2005) A case study on point process modeling in disease mapping. Image. Anal. Stereol. 24: 159-168.

Eisen, R.C., Eisen, L., Lane R. S. (2006) Predicting density of *Ixodes pacificus* nymphs in dense woodland in Mendoncino county, California, based on geographic information systems and remote sensing versus field-derived data. Am. J. Trop.Med. Hyg. 74:632-640.

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.

Rizzoli, A., Merler, S., Furlanello, C., Genchi, C. (2002) Geographical information system and bootstrap aggregation (bagging) of tree-based classifiers for Lyme disease risk prediction in Trentino, Italian Alps. J. Med. Entomol. 39: 485-492.

Daniel, M., Zítek, K., Danielová, V., Kříž, B., Valter. J., Kott, I. (2006) Risk assessment and prediction of *Ixodes ricinus* tick questing activity and human tick-borne encephalitis infection in space and time in the Czech Republic. Int. J. Med. Microbiol., 296 Suppl. 40: 41-47.

Ostfeld, R.S., Glass, G.E., Keesing, F. (2005) Spatial epidemiology: an emerging (or re-emerging) discipline. Trends Ecol. Evol., 20, s. 328-336.

Eisen, R.J. and Eisen L. (2008) Spatial modeling of human risk of exposure to vector-borne pathogens based on epidemiological versus arthropod vector data. J. Med. Entomol. 45: 181-192.

Süss, J. (2003) Epidemiology and ecology of TBE relevant to the production of effective vaccines. Vaccine: 21:S1 19-35.

Humair, P.-F. and Gern, L. (2000) The wild hidden face of Lyme borreliosis in Europe. Microbes Infect. 2: 915-922.

Šumilo, D., Bormane, A., Asoklien, L., Lucenko, I., Vasilenko, V., Randolph, S. (2006) Tick-borne encephalitis in the Baltic States: Identifying risk factors in space and time. Int. J. Med. Microbiol., 296, 76-79.

Nosek, J. and Krippel, E. (1974) Mapping of ixodid ticks. Report Inst. Geogr. Czechoslov. Acad. Sci., 111, 9-19.

Daniel, M. and Kříž, B. (2002) Klíšťová encefalitida v České republice. SZÚ. Praha.

EEA 2006 (European Environment Agency), http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-clc2006-100-m-version-12-2009, 29.10.2010.

Jouda, F., Perret, J., Gern, L. (2004) *Ixodes ricinus* density and distribution and prevalence of *Borrelia burgdorferi* sensu lato infection along an altitudinal gradient. J. Med. Entomol., 41, 162–169.

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 Krkonoše Mts. (Czech Republic). Cent. Eur. J. Pub. Hlth., 13, 24-28.

Danielová, V., Daniel, M., Schwarzová, L., Materna, J., Rudenko, N., Golovchenko, M., Holubová, J., Grubhoffer, L., Kilian P. (2010) Integration of a tick-borne encephalitis virus and *Borrelia burgdorferi* sensu lato into mountain ecosystems, following a shift in the altitudinal limit of distribution of their vector, *Ixodes ricinus* (Krkonoše Mountains, Czech Republic). Vector Borne Zoonotic Dis., 10, 223-230.

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.

Vassalo M., Pichon B., Cabaret J., Figureau C., Pérez-Eid C. (2000): Methodology for sampling questing nymphs of *Ixodes ricinus* (Acari: Ixodidae), principal vector of Lyme disease in Europe. J. Med. Entomol. 37: 335-339.

Estrada-Pena, A. and Venzal, J.M. (2007) A GIS framework for the assessment of tick impact on human health in changing climate. Geospatial Health 2, 157-168.

Vystoupil, J., Holešinská, A., Kunc, J., Maryáš, J., Seidenglanz, D. Šauer, M., Tonev, P., Viturka M. (2006) Tourism Atlas of the Czech Republic. Ministerstvo pro místní rozvoj ČR, Praha.

Danielová, V., Holubová, J., Daniel, M. (2002) Tick-borne encephalitis virus prevalence in *Ixodes ricinus* ticks collected in high risk habitats of the South-Bohemian region of the Czech Republic. Exp.Appl.Acarol. 26:145-151.

Danielová, V., Rudenko, N., Daniel, M., Holubová, J., Materna, J., Golovchenko, M., Schwarzová, L. (2006) Extension of *Ixodes ricinus* ticks and agents of tick-borne diseases to mountain areas in the Czech Republic. Int.J.Med.Microbiol. 296, Suppl. 1: 48-53.

Danielová V. (2002) Natural foci of tick-borne encephalitis and prerequisites for their existence. Int. J. Med. Microbiol. 291, Suppl. 33: 183-186.