Geographic Information Systems in Epidemiology – Ecology of Common Vole and Distribution of Natural Foci of Tularaemia

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Received February 7, 2002
Accepted June 19, 2002

Abstract

Pikula J., F. Treml, M. Beklová, Z. Holešovská, J. Pikulová: *Geographic Information Systems in Epidemiology – Ecology of Common Vole and Distribution of Natural Foci of Tularaemia.* Acta Vet. Brno 2002, 71: 379-387.

KORMAP geographic information system (GIS) was used to analyse the distribution and selected environmental factors related to population levels of *Microtus arvalis* (a potential reservoir host of *F. tularensis*) in the Czech Republic and the relation between *M. arvalis* populations and natural foci of tularaemia in the European hare. Maximum population levels of *M. arvalis* were in areas from 200 to 399 m above sea, of 40 to 60 days of snow cover annually and of 10 °C of mean annual air temperature. Warm and moderately warm climatic regions differed in the mean *M. arvalis* population level with high statistical significance ($t = 4.97$, $P = 0.01$). *M. arvalis* did not occur in the cold climatic region and areas of less than 4 °C of mean annual air temperature. The highest and lowest population densities were found in geographic areas of 1800 to 2000 h and up to 1600 h of annual sunshine duration, respectively. *M. arvalis* population density correlates with high statistical significance with the elevation above sea, annual sunshine duration and mean annual air temperature. It was, however, found that there is no correlation between *M. arvalis* levels and numbers of natural foci of tularaemia in the European hare ($r = 0.0765$, $n = 396$, $t = 1.5228$). In other words, tularaemia seems to be independent of *M. arvalis* population density. GIS are suitable for the State Veterinary Administration and they are becoming part of decision-making as knowledge on the geographical aspects of diseases including the distribution of reservoir hosts is essential for disease control.

Microtus arvalis, geography of occurrence, population levels, environmental factors, Czech Republic, tularaemia

Recently, there has been a growing number of applications of geographic information systems (GIS) in epidemiology and public health (McDermott 1995). Data for the GIS may be gathered using standard screening methods throughout a distinct territory as well as remote sensing from satellites (Dale et al. 1998). GIS databases offer new analytic opportunities for disease assessment and prevention (Croner et al. 1996). They have been used to identify risk factors of zoonotic diseases over large geographic areas such as environmental variables associated with the disease (Glass et al. 1995) and breeding habitats of disease vectors (Dale et al. 1998). It is also possible to use GIS to test epidemiological hypotheses about patterns of disease occurrence (Hungerford 1991; Marshall 1991).

In the Czech Republic it was only Zeman (1997) and Pikula (1996) who used the GIS methods in epidemiological and epizootiological studies. Zeman (1997) employed retrospective epidemiological data to obtain risk maps and analysis of spatial distribution of tick-borne encephalitis and Lyme borreliosis. Pikula (1996) analysed the population density and geographic distribution of the European hare (*Lepus europaeus*) under various ecological conditions in relation to natural foci of tularaemia in the Czech Republic. Recently, there has been a renewed interest in reservoir host (rodent) ecology as the so-called

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”new-emerging” infectious diseases occur. In this respect it is necessary to study the geographic distribution of the host defining the maximum range the disease can occur, range of the pathogen distribution within the range of the host, associations between the geographic distribution of the host and pathogen within specific habitats, population density of the host, and ecological requirements of reservoir hosts of zoonotic diseases. Such characteristics as overcrowding occasions of small rodents, their seasonal dynamics, migration, activity throughout the day and survival rates can influence the valence of natural foci of diseases (Rosický and Kratochvíl 1953).

It was, therefore, the aim of the study to employ GIS for the evaluation of ecological distribution of the selected reservoir host, the common vole (*Microtus arvalis*), of such zoonoses as hantavirosis (Daneš et al. 1991), leptospirosis (Treml and Nesňalová 1993) and tularaemia (Hubálek et al. 1996; Hoflechner-Poltl et al. 2000) in the Czech Republic. Another objective was to analyse the population levels and geographic distribution of the common vole under various ecological conditions in relation to natural foci of tularaemia in the Czech Republic.

Materials and Methods

In order to evaluate the ecology of distribution of the common vole we used geographic computer databases on spatial distribution of environmental factors including the following maps:

1. Hypsometric geographic map of the Czech Republic schematically divided into areas characterised by the elevation above sea of up to 200 m, 200-399 m, 400-599 m, 600-799 m, 800-999 m and over 1000 m.

2. Climatic map of the Czech Republic encompassing such climatic areas as: 1 = a warm and dry district with mild winter and longer duration of sunshine; a warm and dry district with mild winter and shorter duration of sunshine; a warm and moderately dry district with mild winter; 2 = a warm and moderately dry district with cold winter; 3 = a warm and moderately damp district with mild winter; a warm and moderately damp district with cold winter; 4 = a moderately warm and dry district with mild winter; a moderately warm and dry district, mostly with mild winter; 5 = a moderately warm and moderately damp district with mild winter of the hilly country; a moderately warm and moderately damp district with cold winter of valleys; a moderately warm and moderately damp district of highlands; 6 = a warm and moderately damp district with mild winter in hilly country and on plains; a moderately warm and damp district with cold or cool winter in valleys; a moderately warm and damp district in highlands; 7 = a moderately warm and very damp district in hilly country; 8 = a moderately cold district; 9 = a cold district of mountains; a chilly district of mountains. Larger climatic units in the Czech Republic, i.e. warm climatic regions, moderately warm climatic regions and cold regions include the above districts 1 to 3, 4 to 8 and 9, respectively.

3. Map of the Czech Republic showing snow cover in different areas lasting for 40-60 days, 60-120 d, 120-180 d, 180-200 d in a year.

4. Map of the Czech Republic showing annual mean precipitation schematically divided into areas characterised by precipitation levels of 450-700 mm, 700-1000 mm, 1000-1400 mm and 1400-1800 mm.

5. Sunshine duration map of the Czech Republic schematically divided into areas characterised by annual mean sunshine lasting up to 1600 h, 1600-1800 h, 1800-2000 h and 2000-2200 h.

6. Map of the Czech Republic depicting areas differing by annual mean air temperature schematically divided into categories of 10 °C, 8-10 °C, 6-8 °C, 4-6 °C, 2-4 °C and 0-2 °C.

For the description of the above-mentioned databases, which were updated, see the paper by Pikula and Beklová (1987).

7. Database on long-term quantitative geographic distribution of the common vole in the Czech Republic (years 1971 to 2000). For the description of the source data see Zapletal et al. (2000). There were areas where the common vole was absent (0) and other ones where it reached low (1), medium (2) or high (3) population levels. By analysing environmental factors in these categories we can outline which conditions are more or less suitable for the species.

8. Database including the mean spatial distribution of natural foci of tularaemia in the European hare during years of 1971 to 2000 in the Czech Republic. Source data were obtained from Monthly reports on infectious diseases in animals by the State Veterinary Administration of the Czech Republic (1971-2000) and saved as a mean of natural foci of tularaemia in unit areas of the database during the 30-year study period.

Analytical tools of the KORMAP GIS program (cf. Pikula and Beklová 1987) were employed to evaluate the databases. We can imagine the evaluation as employing a multi-dimensional (layered) map in which each geographic area of a given size is characterised by a set of variables (attributes). The evaluation of relationship between the elevation above sea (an independent variable) and the population level of the common vole (a dependent variable) is presented hereinafter in the text as an example of data processing. Comparing the two databases we got a frequency table (Table 1).

Table 1
Frequency table of correlation between the elevation above sea and the common vole population levels in the Czech Republic. The table contains numbers of unit areas of 3.825 × 6.375 km where the two evaluated variables attain the mentioned value.

	Elevation above sea					
Common vole population level	up to 200 m	200-399 m	400-599 m	600-799 m	800-1000 m	over 1000 m
Low (1)	12	36	74	47	5	1
Medium (2)	68	253	203	63	4	-
High (3)	10	72	35	18	-	-
Mean	1.98	2.10	1.88	1.77	1.44	1.00

Figures in Table 1 express the number of unit areas where the two evaluated variables attain the mentioned value. For example, it was found that there were 12 unit areas up to 200 m of elevation where the long-term population level of the common vole was low. Unit areas in this evaluation cover the area of 3.825 times 6.375 km. The size of unit areas may be called the resolution and influences the precision of the evaluation. The smaller the unit area, the greater the precision of evaluation. Areas from which the common vole was absent and which are not important for this species (e.g., forests or water bodies) were not included into the frequency table.

The frequency table was then further used to compute the coefficient of correlation and means of population level for each value of the factor evaluated as it is presented in Results and Tables. Differences were tested by Student´s *t*-test using the Statistica software (StatSoft, Inc.).

Results

Population levels of the common vole in dependence on the elevation above sea are summarised in Table 2.

Table 2
Mean common vole population levels in areas of different elevation above sea in the Czech Republic

	Population level of the common vole		
Areas characterised by the elevation above sea	Mean	Number of unit areas	Standard deviation
up to 200 m	1.98	90	0.49
200-399 m	2.10	361	0.54
400-599 m	1.88	312	0.58
600-799 m	1.77	128	0.68
800-999 m	1.44	9	0.50
over 1000 m	1.00	1	0.00

Table 3
T-test values of comparisons between individual mean values from Table 2
(t = value of the t-test, *P* = level of significance, N = non-significant differences)

Area of elevation above sea	200-399 m		400-599 m		600-799 m		800-999 m	
	t	*P*	t	*P*	t	*P*	t	*P*
up to 200 m	1.92	N	1.63	N	2.65	0.01	3.15	0.01
200-399 m			5.07	0.01	4.96	0.01	3.63	0.01
400-599 m					1.61	N	2.25	0.05
600-799 m							1.43	N

The common vole reached its maximum population density in areas from 200 to 399 m above sea. The coefficient of correlation between the elevation above sea and the common vole population level (r = -0.1936, t = 5.91, n = 901) was highly statistically significant at the level of 0.01. It means that the higher the elevation above sea, the lower the population level.

Differences between mean numbers of the common vole population levels in individual areas characterised by the elevation above sea evaluated by the *t*-test are summarised in Table 3.

Table 4
Mean common vole population levels in individual climatic areas in the Czech Republic

	Population level of the common vole		
Climatic districts	Mean	Number of unit areas	Standard deviation
1	2.15	144	0.50
2	-	-	-
3	2.00	27	0.00
4	2.06	157	0.53
5	1.93	371	0.54
6	1.82	112	0.70
7	1.59	64	0.72
8	1.96	26	0.76
9	-	-	-

Population levels of the common vole in different climatic areas are summarised in Table 4.

The highest population level of the common vole was in the climatic district No. 1, while the lowest population level in the climatic district No. 7.

Warm climatic regions and moderately warm climatic regions, including district 1-3 and 4-8, were characterised by the mean common vole population levels of 2.13 and 1.92, respectively. The difference of the mean population level between these two regions is highly statistically significant (t = 4.97, P = 0.01). The common vole does not occur in the cold region in the Czech Republic.

Population levels of the common vole in dependence on the snow cover duration in a year are surveyed in Table 5.

The highest population levels were found in areas characterised by 40 to 60 days of snow cover duration in a year. The difference between the mean common vole population level in areas of 40-60 and 60-120 days of snow cover duration is highly significant (t = 4.54, P =

Table 5
Mean common vole population levels in individual areas characterised by snow cover duration in a year in the Czech Republic

	Population level of the common vole		
Snow cover duration in a year	Mean	Number of unit areas	Standard deviation
40- 60 days	2.03	560	0.53
60-120 days	1.84	338	0.65
120-180 days	2.00	2	0.82
180-200 days	-	-	-

0.01). There were only 2 unit areas of 120-180 days of snow cover duration in the Czech Republic, so the mean level of the common vole in this area was not statistically compared with other values.

Population levels of the common vole in dependence on the mean annual precipitation are listed in Table 6.

The relation between the mean annual precipitation and the common vole population level was not significant (r=-0.0357, t=1.0720, n= 901). Differences between mean values of the common vole in areas characterised by the mean annual precipitation were also not significant in all possible combinations of Table 6 values.

Table 6
Mean common vole population levels in individual areas characterised by mean annual precipitation in the Czech Republic

	Population level of the common vole		
Mean anuual precipitation in mm	Mean	Number of unit areas	Standard deviation
450-700	1.96	687	0.55
700-1000	1.95	201	0.69
1000-1400	1.75	12	0.60
1400-1800	1.00	1	0.00

Population levels of the common vole in areas of different sunshine duration in a year are summarised in Table 7.

Table 7
Mean common vole population levels in areas characterised by different sunshine duration in a year in the Czech Republic

	Population level of the common vole		
Sunshine duration in hours	Mean	Number of unit areas	Standard deviation
up to 1600	1.38	24	0.48
1600-1800	1.80	441	0.56
1800-2000	2.15	432	0.55
2000-2200	2.00	4	0.00

The highest and lowest population levels were found in geographic areas characterised by 1800 to 2000 h and up to 1600 h of sunshine duration in a year, respectively. The correlation between the sunshine duration in a year and the population level was highly significant (r = 0.3318, t = 10.5467, n = 901, P = 0.01). Differences in the mean population level of the

Table 8
T-test values of comparisons between individual mean values from Table 7 (t = value of the t-test, P = level of significance)

Area of sunshine duration in hours	1600-1800		1800-2000	
	t	P	t	P
up to 1600	3.6	0.01	6.72	0.01
1600-1800			9.32	0.01

common vole in individual areas characterised by sunshine duration were found to be highly significant (Table 8).

Population levels of the common vole in dependence on the mean annual air temperature are summarised in Table 9.

Table 9
Mean common vole population levels in areas characterised by mean annual air temperature in the Czech Republic

	Population level of the common vole		
Mean annual air temperature	Mean	Number of unit areas	Standard deviation
10 °C	2.50	4	0.50
8-10 °C	2.06	305	0.53
6-8 °C	1.91	516	0.58
4-6 °C	1.86	76	0.72
2-4 °C	-		-
0-2 °C	-		-

The highest population levels were found in the geographic areas characterised by the mean annual air temperature of 10 °C. The common vole was absent from areas characterised by the mean annual air temperature of less than 4 °C. The coefficient of correlation between the mean annual air temperature and the population level is highly significant ($r = 0.1355$, $t = 4.1009$, $n = 901$, $P = 0.01$). Differences in the mean population level of the common vole in individual areas characterised by mean annual air temperature were in some combinations significant, highly significant or non-significant (Table 10).

Table 10
T-test values of comparisons between individual mean values from Table 9 (t = value of the t-test, *P* = level of significance, N = non-significant differences)

Area of mean annual air temperature	8-10 °C		6-8 °C		4-6 °C	
	t	*P*	t	*P*	t	*P*
10 °C	1.65	N	2.03	0.05	1.75	N
8-10 °C			3.78	0.01	2.27	0.05
6-8 °C					0.58	N

It can be concluded that other environmental factors, which are dependent on the elevation above sea, such as annual precipitation, duration of snow cover in a year, sunshine duration in a year, mean annual air temperature and climatic areas influence the quantitative distribution of the common vole in a similar way because they are largely dependent on the elevation above sea.

Relation between population levels of the common vole and numbers of natural foci of tularaemia

Correlation analysis was used to test the relation *between* population levels of the common vole and the numbers of natural foci of tularaemia throughout the territory of the Czech Republic. For this purpose we used the database on long-term quantitative geographic distribution of the common vole in the Czech Republic and the database including the mean spatial distribution of natural foci of tularaemia in the European hare during years of 1971 to 2000. There was not found a correlation between the common vole levels and numbers of natural foci of tularaemia in the European hare (r = 0.0765, n = 396, t = 1.5228). In other words, tularaemia seems to be independent of the population level of common vole.

Discussion

Numerous GIS programs are currently available. As they differ in their abilities and for they have been used to study different topics, it is hard to compare the results we obtained with data of other authors. The same GIS program, i.e. KORMAP, was used to analyse the population density and geographic distribution of the European hare (*Lepus europaeus*) under various ecological conditions in relation to natural foci of tularaemia in the Czech Republic (Pikula 1996). This author found that the occurrence of tularaemia in the Czech Republic is European hare population density dependent with high statistical significance of correlation (r = 0.4431, n = 395, t = 9.7972, *P* = 0.01). The higher the population density of the European hare, the higher the number of natural foci of tularaemia in a given area. As far as the common vole is concerned, the statement of population density (level) dependence is not true even though the patterns in the geographic distribution and ecological valence of both the common vole and the European hare are similar. When comparing the patterns of geographic distribution of the common vole and European hare including population levels over the territory of the Czech Republic, a close correlation is noted (r = 0.12, t = 3.45, n = 891, *P* = 0.01). There are, however, some differences in the geographic distribution of the two species which might explain the differences in the relation of natural foci of tularaemia to their population densities or levels. The common vole reaches its maximum population level in areas from 200 to 399 m above sea, whereas in the European hare it is the area up to 200 m above sea that its population is the highest. Both species have the highest population level in the climatic region No. 1 (i.e., a warm and dry district with mild winter and longer duration of sunshine; a warm and dry district with mild winter and shorter duration of sunshine; a warm and moderately dry district with mild winter), while the lowest population level of the common vole and the European hare was found in the climatic region No. 7 (i.e., a moderately warm and very damp in hilly country) and 8 (a moderately cold district), respectively. In both species compared the highest population levels were found in areas characterised by 40 to 60 d of snow cover duration in a year. Considering the relation between the mean annual precipitation and the population level, in the common vole it is non-significant. On the other hand, in the European hare the results (r = -0.4346, t = 14.4187, n = 895, *P* = 0.01) mean that the correlation is highly significant. The highest and lowest population levels of both the species studied were found in geographic areas characterised by 1800 to 2000 h and up to 1600 h of sunshine duration in a year, respectively. The correlation between the sunshine duration in a year and the population level is highly significant at the level of 0.01 in both species (the respective values in the common vole and European hare being r = 0.3318 and 0.2129, t = 10.5467 and 6.5110, n = 901 and 895). The highest population densities of both species were found in the geographic areas characterised by mean annual air temperature of 10 °C. Both species are absent from areas characterised by the mean annual air temperature of less than 4 °C. In the common vole the coefficient of correlation between the mean annual air temperature and the population level is highly significant (r = 0.1355, t = 4.1009, n = 901, *P* = 0.01). The same is true in the European hare where r =-0.4867, t = 16.6469, n = 895, *P* = 0.01. There are certainly other factors, apart from the distribution patterns of the two species, that influence their role in the natural foci of tularaemia distribution and persistence in the Czech Republic. These are the factors as, for example, population oscillations, fluctuations, migration, species susceptibility to infection. Analysis of these other factors in relation to natural foci of tularaemia is, however, theme for further detailed studies.

The scale of maps is another point of view that has to be considered when using GIS data processing. One thing in this respect is the availability of data scaled down to the smallest possible area, the other one is the tremendous work of collecting, storing and processing such data. Data on geographic distribution and population levels of the common vole are gathered by field workers of the State Plant Protection Administration within districts (Zapletal et al. 2000). For the purpose of evaluation by the GIS KORMAP program they were saved in unit areas of 3.825 times 6.375 km and as such presented some generalisation to the prevailing value of the phenomenon studied. The smaller the unit area, the greater the precision of evaluation and the more difficult data collection, storage and processing. Evaluation of the geographic distribution of the common vole in this paper considers the whole territory of the Czech Republic. Zeman (1997), for example, using the GIS mapped the risk of tick-borne encephalitis and Lyme borreliosis in a smaller area, i.e. the Central Bohemian region of the Czech Republic, obtaining thus more precise results. This author, however, did not consider the geography of distribution of reservoir hosts (small mammals) of the two mentioned diseases.

The common vole is an important pest of crops in the Czech Republic, the occurrence of which is monitored by the State Plant Protection Administration (Zapletal et al. 2000; Zapletal et al. 2001). Population levels and occasions of overcrowding of reservoir hosts including the common vole are important factors that may influence the prevalence of density-dependent infectious diseases. Knowledge on the quantitative distribution of hosts can thus be used in human and veterinary epidemiology. The non-analytical, especially the display possibilities of GIS, as well as the analytical ones, are suitable for the State Veterinary Administration. GIS can and should be applied to animal disease control.

Geografické informační systémy v epidemiologii – ekologie hraboše polního a rozšíření přírodních ohnisek tularémie

S využitím geografického informačního systému KORMAP bylo analyzováno rozšíření hraboše polního ve vztahu k vybraným faktorům prostředí a výskytu přírodních ohnisek tularémie zajíce polního v České republice. Nejvyšší populační úroveň byla zjištěna v oblastech od 200 do 399 metrů nadmořské výšky, charakterizovaných 40-60 dny trvání sněhové pokrývky v roce a s průměrnou roční teplotou vzduchu 10 °C. Klimatické oblasti teplá a mírně teplá se liší průměrnou populační úrovní hraboše polního s vysokou statistickou průkazností (t = 4,97; P = 0,01). Hraboš polní se nevyskytuje v klimaticky chladné oblasti a v oblastech charakterizovaných průměrnou roční teplotou vzduchu pod 4 °C. Nejvyšší populační úroveň je v geografické oblasti charakterizované 1800-2000 hodinami slunečního svitu v roce, kdežto nejnižší v oblastech do 1600 hodin slunečního svitu. Populační hladiny hraboše polního korelují s vysokou statistickou průkazností s nadmořskou výškou, délkou trvání slunečního svitu v roce a průměrnou roční teplotou vzduchu. Bylo nicméně zjištěno, že mezi populační hladinou hraboše polního a početností ohnisek tularémie zajíce polního v dané geografické oblasti není korelace (r = 0,0765; n = 396; t = 1,5228). Zdá se tedy, že výskyt a početnost ohnisek tularémie je nezávislý na početnosti populace hraboše polního. Znalosti geografických aspektů nemocí včetně rozšíření rezervoárových hostitelů jsou důležité pro jejich tlumení, proto jsou geografické informační systémy vhodné i pro účely Státní veterinární správy, neboť se mohou stát součástí rozhodovacího procesu.

Acknowledgements

This work was supported by the Internal Grant Agency of Veterinary and Pharmaceutical University Brno (Research Project No. 16/2000/FVHE) and the Grant Agency of the Czech Republic (Research Project No. 524/00/1122)

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