INFLUENCE OF CLIMATE WARMING ON TICK-BORNE ENCEPHALITIS EXPANSION TO HIGHER ALTITUDES OVER THE LAST DECADE (1997–2006) IN THE HIGHLAND REGION (CZECH REPUBLIC)

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SUMMARY

The steep rise in the incidence of tick-borne encephalitis (TBE) in the 1990s and its subsequent high level in the Czech Republic are not even over the whole territory. It is manifested markedly in the Czech-Moravian Highland region. In the decades of 1971 through 1992, TBE incidence in the Highland Region did not reach the countrywide average. The rise has been noted only since 1997; in the year 2006 TBE incidence in that administrative region was more than double the countrywide average. Analysis of the situation have not found any socio-economic shifts or land-use changes, or in the numbers of game animals, that could have had an effect on TBE incidence. The rise of infections in localities 500 m above sea level (a.s.l.) and more was markedly steeper than that below that altitudinal limit. At those altitudes there has been found an increase in average monthly temperatures exceeding countrywide averages namely in the period of maximum *Ixodes ricinus* activity (May–August). Detailed analysis of meteorological conditions and comparison with a long-term study of the influence of modifications of the mountain climate in the Krkonoše Mts. on *I. ricinus* tick distribution and the pathogens transmitted by them, have led to the conclusion that likewise in the Czech-Moravian Highland a marked warming had influenced the local population of the vector *I. ricinus,* caused an activation of foci of TBE, increased contacts of humans with the vector, consequently giving rise to an apparent increase in the incidence of human cases of TBE.

Key words: tick-borne encephalitis, vertical distribution, climate modification

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INTRODUCTION

One of the reasons for the steep increase in human cases of tick-borne encephalitis (TBE) in the early 1990s manifested itself in the Czech Republic was its occurrence in locations above sea level exceeding the former recognized limit of vertical distribution of the vector *Ixodes ricinus* at 750 m a.s.l. (1). Those altitudinal shifts, demonstrated by comparison with historical data following up the problem (2, 3), have a causal connection with climate changes observed in that period (4, 5). There are also parallel findings of Scandinavian authors (6, 7) pointing out the shift of TBE vector occurrence to higher geographic altitudes.

The vertical shift of the vector and pathogens transmitted by it to new mountain areas formerly free of their presence, has been analyzed repeatedly. However, thus far there has not been given sufficient attention to the problem of whether and how the phenomenon of climate modification causing changes in its altitudinal distribution has made its own at lower altitudes near the formerly recognized limit of 750 m a.s.l. The majority of registered human cases occurred at lower altitudes and by far did not reach the upper limit of occurrence of the vector *I. ricinus.* Zeman and Beneš (8) performed a statistical analysis of the theoretical vertical distribution of TBE in the Czech Republic over the years 1971 through 2000.

The steep increase in TBE incidence in the Czech Republic, which with certain variation remains at a high level over the past two decades (9) is not evenly spread. Beside the South Bohemian Region where there is registered the greatest number of cases (EPIDAT, National Institute of Public Health, Prague), there has recently occurred a rise in the Highland Region exceeding the countrywide average. In the year 2006, TBE incidence of 24/100 000 in the latter administrative region was closely aligned with the value in the South Bohemian Region (27/100,000).

Our endeavour is to contribute to the elucidation why and how such a situation occurs. It has to be stated beforehand that in the given region there did not take place any changes in land-use or in socio-economic conditions that could lead to the forming of a population group under risk. Likewise, the numbers of cleft-hoof game (foremost roe deer) that in other areas played an important role in the increase of TBE incidence (10) have not undergone any changes that could have had any influence in our case. Therefore, we focused on an analysis of other environmental factors. As the majority of the territory of the Highland administrative region belongs orographically to the system of the Czech-Moravian Highland, we have undertaken to verify the working hypothesis that the cause of the increase in TBE incidence observed namely in the cadastres of municipalities located more than 500 m a.s.l. (according to the probable place the infection occurred) is the influence of climate warming that is more obvious in mountainous country and exceeds the countrywide average. The conclusions are compared with the mountainous region of Krkonoše where there were made similar analyses, namely a five-year follow-up of *I. ricinus* tick occurrence in two vertical trans-sections (600–1300 m), which shared an increasing tendency in their vertical distribution. Laboratory examination of all ticks found demonstrated the presence of virus up to the altitude of 1100 m a.s.l. and that of *Borrelia burgdorferi* sensu lato up to 1270 m a.s.l. (11, 12). A long-term field experiment studying tick development at various altitudes a.s.l. demonstrated an apparent effect of climate warming on altitudinal changes (13).

MATERIAL AND METHODS

Data on TBE occurrence were obtained from the National Epidemiological Register. Data on the altitude of localities of acquired infection are determined by the average value of the lowest and highest location in the given locality. The highest altitude in the Czech-Moravian Highland in which the Highland administrative region is located is at the summit of Javořice Hill (837 m). The lowest located area aside of river valleys is the south-eastern part of the District of Třebíč. Temperature data from the Czech-Moravian Highland were obtained from the meteorological station of the Czech Hydrometeorological Institute (CHMI) in Svratouch (49° 44' latitude and 16° 2' longitude, 737 m a.s.l.) and data for comparison from Krkonoše from the meteorological station of CHMI in Harrachov (50° 46' latitude, 15° 26' longitude, 670 m a.s.l.) and another 4 stations in the area of that mountain range (650–1315 m a.s.l.).

For the evaluation of the average annual and monthly temperatures the least-squares multiple linear regression method was used (14).

The regression line shows a trend of the average monthly and annual temperatures during the period 1961–2005 and 1961–2006, respectively.

The sum of monthly and annual temperature anomalies from 30-year average temperature normals of 1961–1990 was used to reveal long-term changes (positive or negative trends) in data sets. The values from the meteorological stations Svratouch and Harrachov are compared with the average values of the Czech Republic (available up to 2000). Average monthly and annual temperatures for the Czech Republic were calculated from homogenized data sets of all meteorological stations covering the period 1848–2000. The climagram depicting the countrywide exceptional situation in the year 2006, elaborated by the CHMI, Prague from data of 22 meteorological stations representing the area of major TBE incidence in the Czech Republic at altitudes from 158 m to 536 m a.s.l., shows the monthly temperature deviations in °C from the 30-year average of monthly temperatures either in a positive or negative shift on axis *x* and in analogy deviations of monthly precipitation totals on axis *y* in %.

Data on the numbers of cleft-hoof game were obtained from the data base of the Czech Ministry of Agriculture.

RESULTS

In the year 2006 there was registered an extremely great number of human TBE cases (1,029) in the Czech Republic, i.e. the highest number found since the registration of laboratory-confirmed cases had been started in 1971. Of that number, 126 cases were found in the Highland Region with an incidence of 24 per 100,000 of the population, that being the second highest to the South Bohemian Region (27/100,000) reporting the highest numbers of cases on a long-term basis. In 2006 only in 4 out of 14 regions incidence of TBE exceeded the countrywide average,

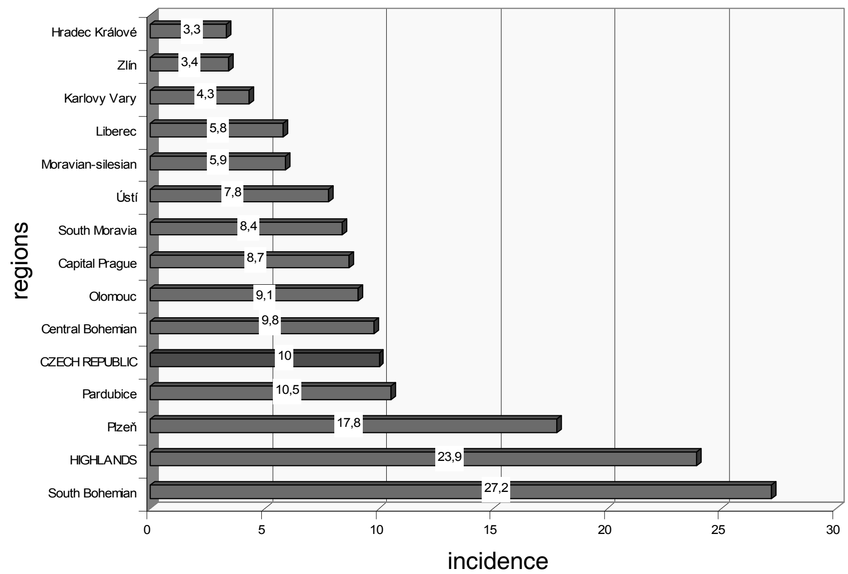

Fig. 1. *Incidence of tick-borne encephalitis per 100,000 of the population by administrative regions in 2006.*

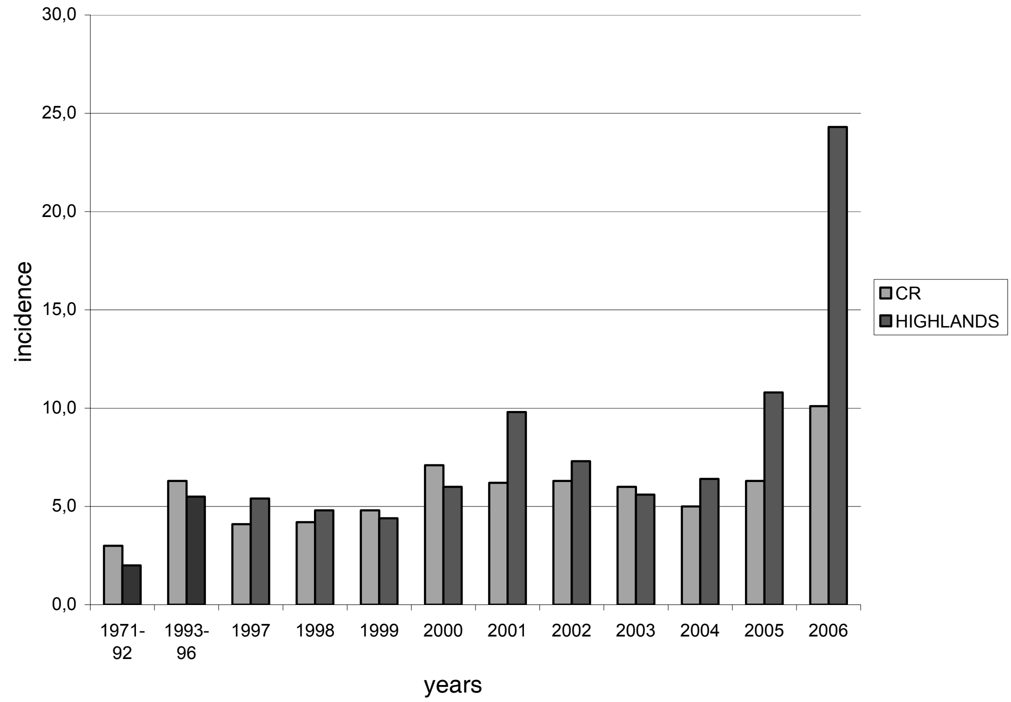

Fig. 2. *Incidence of tick-borne encephalitis per 100,000 of the population in the last decade (1997–2006) and in the preceding years in the Highland Region in comparison with the whole Czech Republic.*

with the Pardubice Region approximating that average (Fig. 1). In preceding decades over 1971–1992 the incidence of TBE in the districts of the Highland Region did not reach the countrywide average, and even shortly thereafter in the period of the steep rise in the number of cases in the whole Czech Republic, no such above-average increase was observed. The beginning of the above-average increase in this disease was noticed only during the last decade in the years 1997, 1998, 2002, more markedly in 2001 and then repeatedly over 2004 through 2006. However, in the year 2006 the incidence exceeded more than twice the countrywide average (Fig. 2). The marked increase in incidence in the last decade (1997–2006) in comparison with the previous one (1987–1996) in each district is depicted in Fig. 3. Although the absolute numbers in districts located higher up (Jihlava, Havlíčkův Brod, Pelhřimov), are lesser than in districts located at altitudes lower than 500 m a.s.l. (Třebíč, Žďár), the rise in the former is of a several-fold magnitude higher. The distribution of cases by districts in the Highland Region is presented in Table 1. By comparison of the numbers of TBE cases below 500 m a.s.l. and above 500 m a.s.l. in the course of the last decade the overall rise in the number of TBE cases in localities above 500 m a.s.l. is markedly steeper than in localities below 500 m a.s.l. (Fig. 4). Thus, the spread of TBE to higher altitudes above sea level is evident. The connection of this phenomenon with the observed climate warming is apparent from the following temperature analyses.

The increase of the global average annual ambient air temperature over the last 100 years is said to be 0.74 °C. In the Czech Republic at the meteorological station Klementinum (Prague) the temperature rise over the past 240 years is reported to be only 0.8 °C. Of course, the rise in temperatures does not take place evenly not only globally over the world but also in the framework

Table 1. *Area, numbers of inhabitants, municipalities and tick-borne encephalitis cases in the Highland Region and its districts*

Region District	Area in km^2	Number of inhabitants	Number of municipalities	Number of tick-borne encephalitis cases	
				bellow 500 m a.s.l.	above 500 m a.s.l.
Vysočina Region	6 925	518 325	730	122	316
Havl. Brod	1 265	94 919	120	26	49
Jihlava	1 180	108 261	121	4	90
Pelhřimov	1 290	72 684	120	0	23
Třebíč	1 518	117 310	173	76	36
Žďár n. Sázavou	1 672	125 141	196	16	118

Table 2. *Annual and monthly increase of temperature averages (°C) in the spring-summer season in the Krkonoše Mts. and the Czech-Moravian Highlands since 1961*

Area	Year	May	June	July	August
Krkonoše Mts. 1961–2005	1.3–1.4	3.5	2.0	2.0	2.5
Svratouch 1961–2006	1.5	2.8	1.3	2.5	2.6

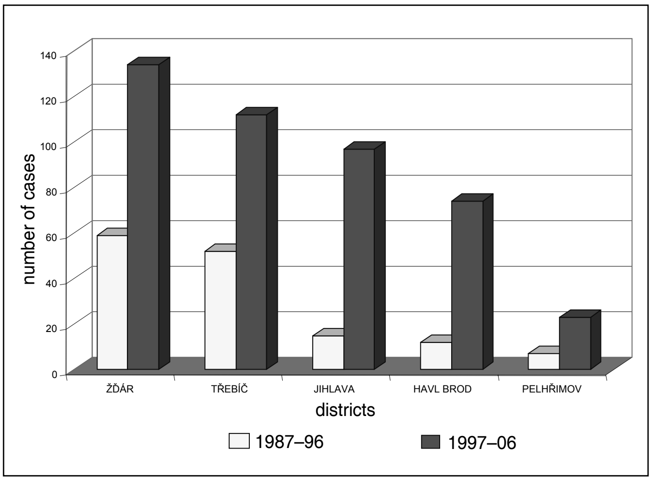

Fig. 3. *Number of tick-borne encephalitis cases in districts of the Highland Region in the last decade (1997–2006) and the preceding one (1987–1996).*

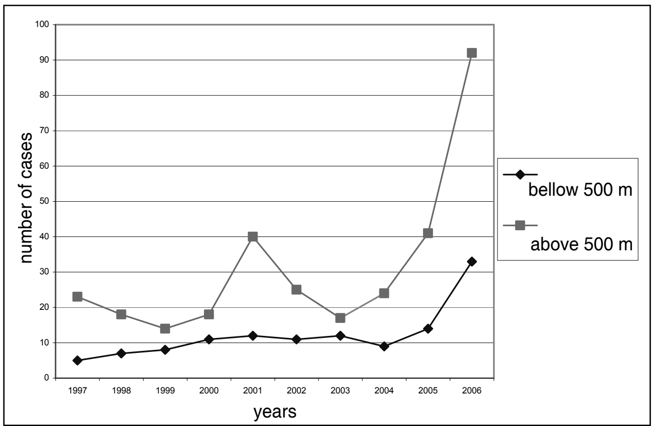

Fig. 4. *Number of tick-borne encephalitis cases in the Highland Region below 500 m (n = 122) and above 500 m a.s.l. (n = 316) in the years 1997–2006.*

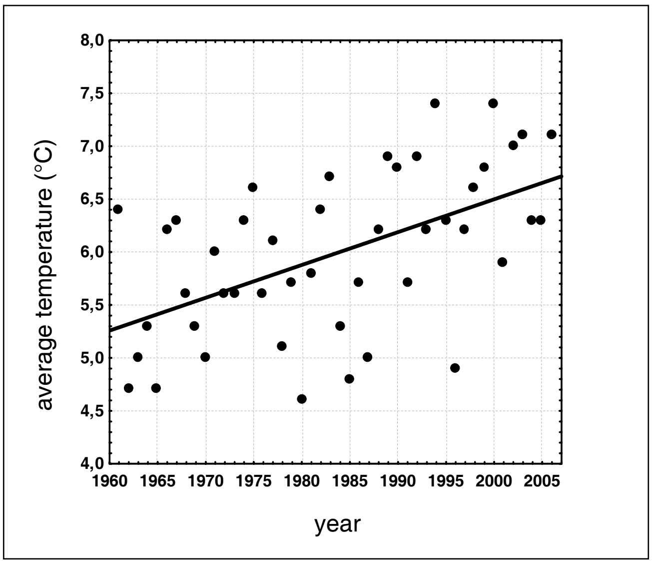

Fig. 5. *Average annual air temperature at Svratouch over the period 1961–2005 with a linear trend.*

*Regression equations for the average monthly and annual temperatures, where y is a value of the average monthly temperature (as the dependent variable) and x is a year (as the independent variable). The x coefficients (the regression coefficients) reveal a warming per year (in degrees Celsius), r is the correlation coefficient, p is the statistical significance level. YEAR: y = -55.49 + 0.0310*x, r = 0.5410; p = 0.0001.*

of the Czech Republic, and thus it can influence the biocenosis in various areas differently. A detailed analysis revealed that the increase in temperature is greater at higher altitudes. Only since 1961 has the average annual temperature risen in the Czech-Moravian Highland by 1.5 °C (Svratouch) (Fig. 5) and by 1.3–1.4 °C in the Krkonoše Mts. (data from 5 weather stations) (11). At the same time, however, in the spring and summer months (Fig. 6), i.e. in the period of the greatest *I. ricinus* tick activity, the average monthly temperatures increases even by 1.1–2.8 °C in the Czech-Moravian Highland and by 2–3.5 °C in the Krkonoše Mountains (Tab. 2). All the monthly (except June) and annual averages have a statistically significant trend towards higher temperatures at the statistical significance level of $p \leq 0.05$.

At an average vertical temperature gradient in the summer season of about 0.6 °C/100 m, the systematic temperature change by 1.1–2.8 °C in the Czech-Moravian Highland corresponds to environmental conditions formerly found at altitudes lower by 200–450 m. By comparing the periods 1961/1990 and 1991/2006 it came to light that the months of January through August in the years 1991/2006 were warmer than in the years 1961–1990 (Fig. 7). The increase in average monthly ambient air temperatures over the 46 years under follow-up was not even. Changes in temperature trends in the course of that period are synoptically illustrated by curves of the sum of monthly anomalies from the 30-year normal over the period of 1961–1990. Autumn months on a long-term basis do not show any statistically significant trend, nor did those curves reveal any marked change (not shown). On the other hand, spring and especially summer months show a steep rise in the temperature trend, namely since the beginning of the 1990s (Fig. 8). Up to the beginning of the 1990s the curves of values from Svratouch in those months are almost the same as the average values for the Czech Republic. Approximately since the mid-1990s warming at Svratouch in the summer months is a bit more rapid than the countrywide average. A similar situation has been recorded at the Harrachov meteorological station.

Since 1992 each of the successive year (except for 1996) was warmer than the preceding one (Fig. 9). Since 1995 there are apparent a bit higher values in the Czech-Moravian Highland and the Krkonoše Mts. than the countrywide average, which means a somewhat higher temperature increase in the localities under follow-up in comparison with the whole country. Of course, also

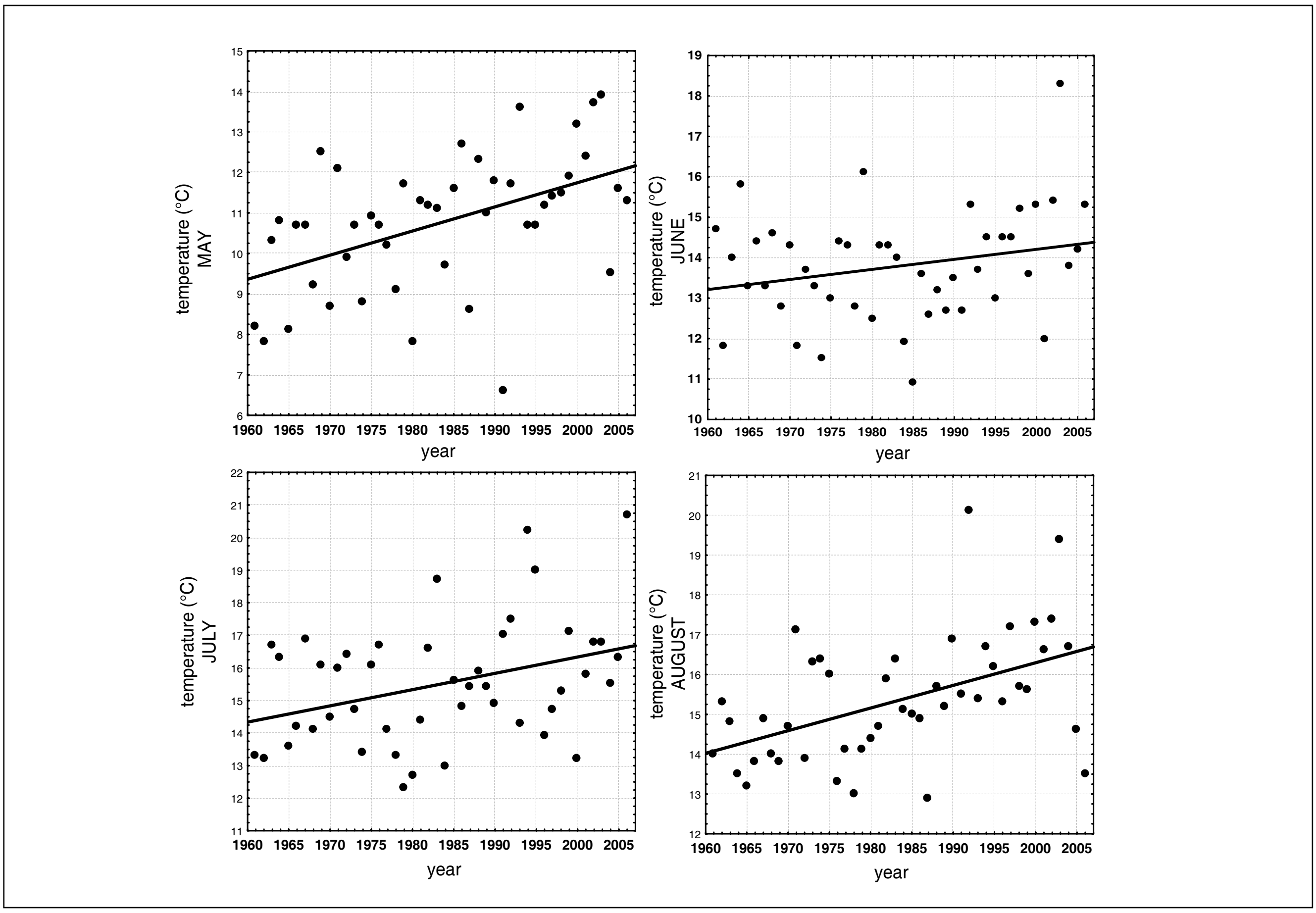

Fig. 6. *Average monthly (May, June, July, August) air temperature at Svratouch over the period 1961–2005 with a linear trend. For explanatory notes see Fig. 5.*

*MAY: y = -107.46 + 0.0596*x, r = 0.4815; p = 0.0007;*
*JUNE: y = -35.44 + 0.0248*x, r = 0.2433; p = 0.1032;*
*JULY: y = -83.62 + 0.0500*x, r = 0.3560; p = 0.0152;*
*AUGUST: y = -97.39 + 0.0568*x, r = 0.4879; p = 0.0006.*

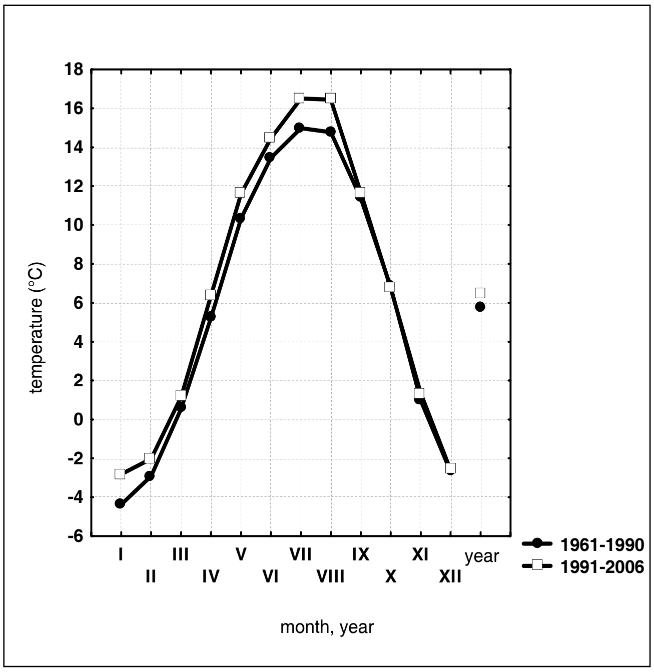

Fig. 7. *Average monthly and annual air temperature at Svratouch over 2 periods (1961–1990, 1991–2006).*

the curves of the sum of temperature deviations from normal differ in each month. For instance, in January the curves rise steeply and the decrease in 1996 is much lesser at Svratouch than is the countrywide average (not shown). Likewise, the months of May through August show a steep increase in temperature deviations from the normal, and since 1993 have been somewhat greater at the meteorological stations in Svratouch and Harrachov in comparison with the countrywide average. Autumn months do not show any such trend in temperature anomalies. Significant for TBE occurrence are namely late spring and summer from the point of view of the development and activity of ticks, and January and February from the point of view of *I. ricinus* tick host survival, especially of small mammals positively influencing the numbers of engorged larvae development stages of ticks in early spring.

DISCUSSION

The presented results demonstrate the influence of ambient air temperature on TBE occurrence in concrete conditions of the Highland Region. The temperature increase in the spring and summer seasons in locations at higher altitudes induce climatic

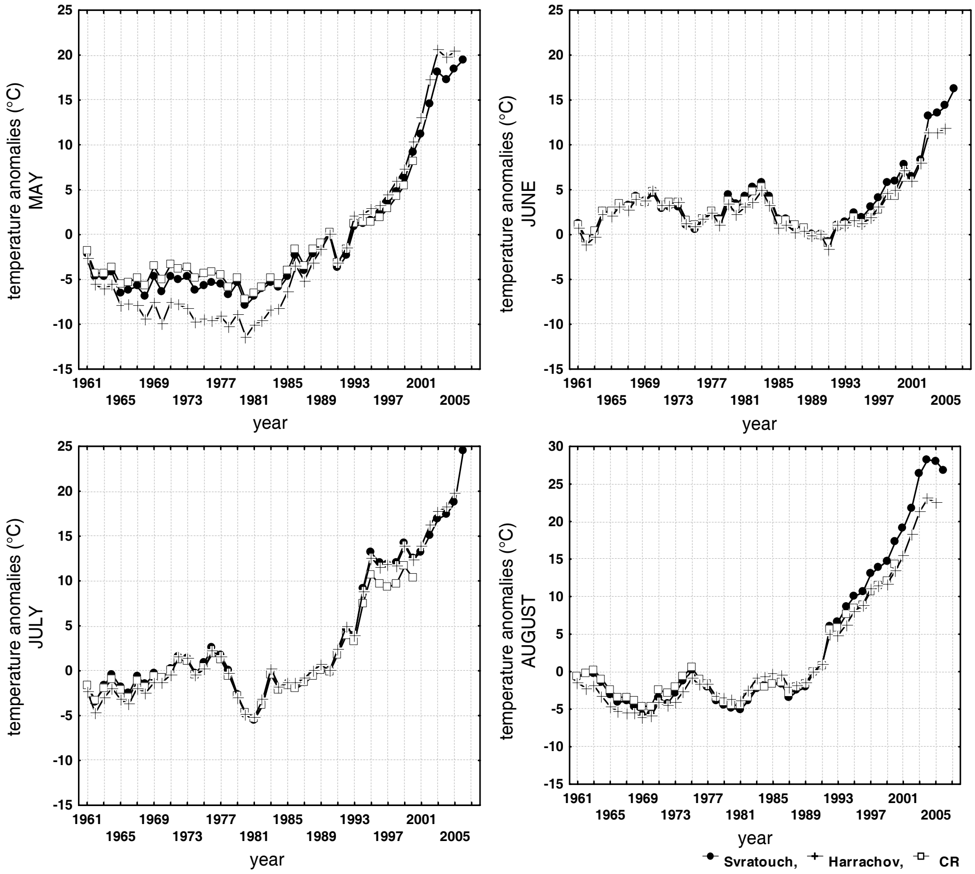

Fig. 8. Sum of monthly air temperature anomalies relative to 1961–1990 monthly normals.

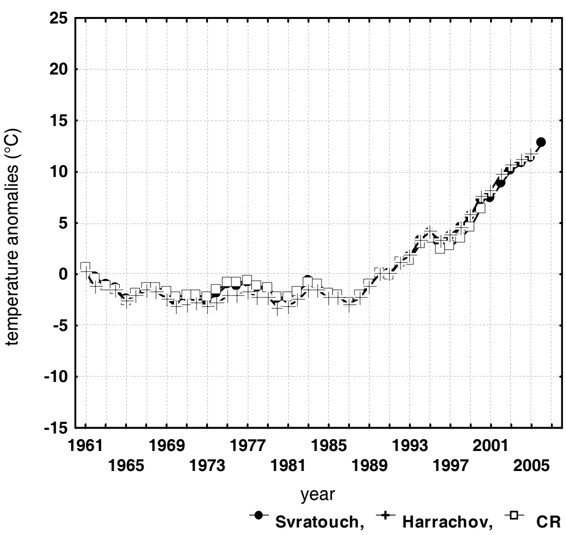

Fig. 9. Sum of annual air temperature anomalies relative to 1961–1990 annual normals.

conditions corresponding to those found at lower altitudes in previous years. Thereby a more rapid and successful ontogenetic development is facilitated in ticks as well as an increased population density and easier circulation of the virus is made. At the same time the temperature increase in January and February allows a more comfortable survival of small mammals over the winter. Thereby larger numbers of hosts for the spring wave of ticks are ensured. Likewise, there is a better survival of large game animals of whom roe deer are hosts to adult ticks that are considered to be one of the important factors in TBE virus circulation in theriodical natural foci of infection and their transport to wider areas. Nevertheless, a planned regular culling regulates the number of game animals. Since the year 2002, in the Highland Region there has not occurred any substantial increase in cleft-hoof game numbers, namely of roe deer that could have explained the steep increase in TBE in those years (Fig. 10).

Increased ambient air temperatures affect not only ticks but also the whole biocenosis that is necessary for the formation of a natural focus. Nevertheless, while a short-term temperature change in locations of regular and numerous tick occurrence is manifested in their density over a short time horizon (4), for the spread of ticks and TBE to new locations particularly at higher altitudes, a longer span of time with increased temperatures is necessary. A certain time lag (Fig. 2) deems necessary for the formation of a stable tick population and a natural focus of TBE. The influence of meteorological conditions manifests itself not only in the terms of effect on biocenotic elements of virus circulation in a natural focus, but indirectly also on human activities and contact with nature as was shown in 2006 which was extraordinary as to the TBE incidence. The above-average warm months of May, June, July, September and October on the one hand, and the cool August with above-normal precipitation (see climagram in Fig.

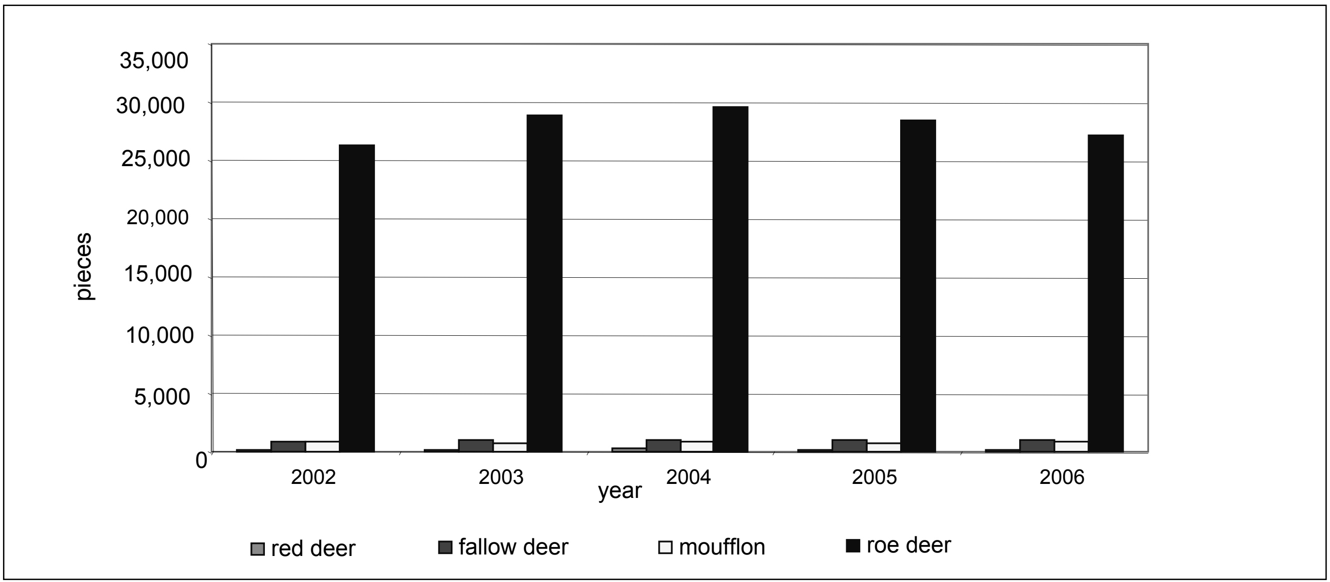

Fig. 10. *Spring stock numbers of cleft hoof game in the Highland Region in the years 2002/2006.*

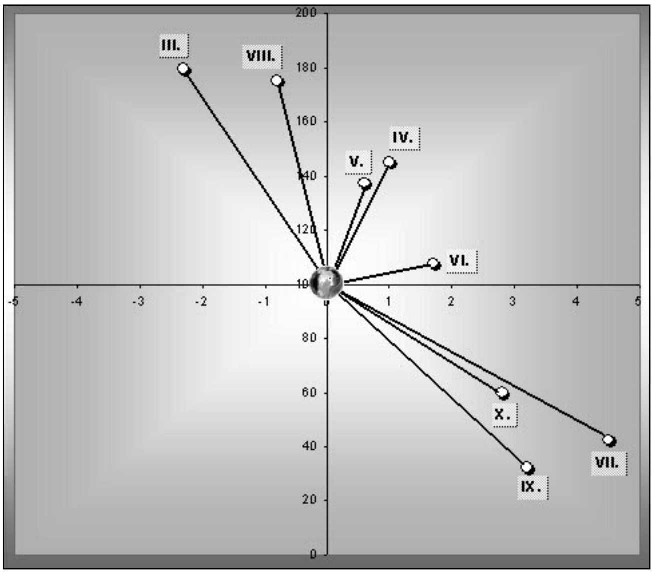

Fig. 11. *Climagram of the March–October period in 2006 Czech Republic.*

x-axis: deviations of monthly average air temperatures in °C from the 30-year average of monthly temperatures;
y-axis: deviations of monthly sums of precipitation in % from the 30-year average of monthly sums of precipitation.
Point of axes intersection represents 30-year averages.

11) on the other, caused not only great tick activity but also an abundant crop of mushrooms in the latter half of summer and in the autumn. The latter was reflected in human recreational activities such as mushroom picking which is a nationwide hobby in the Czech Republic. That situation has directed large numbers of people to habitats favourable for mushroom growth as well as for ticks and TBE virus circulation. That resulted in an enormous number of human cases of TBE in that year (15).

For the rise in TBE morbidity in the Highland Region in the past decade socio-economic factors could not be considered to have any influence as the unemployment rate in that region did not reach the countrywide average (Statistical Yearbook of the Czech Republic). For that matter, the influence of that factor on TBE incidence in the Czech Republic has already been disproved earlier (16).

Long-term follow-up of the shift of the altitudinal limit of *I. ricinus* distribution and the subsequently demonstrated spread of TBE to higher locations in the area under study are a sound basis for a prognosis of further long-term development of their overall distribution in central Europe. Recently published prognoses of climate changes by the end of the 21st century (17) mention a 3–3.5 ^{o}C rise in the average annual ambient air temperature on the territory of the Czech Republic with a continuing level of precipitation or its moderate increase. Those are values that can at present be observed in the spring-summer months at higher altitudes, already, causing an increased occurrence of the vector *I. ricinus* which is a thermophilic and hygrophilic species.

It is interesting to compare results of the present study with data from the Swiss Alps where at present a temperature increase by about 1.5 ^{o}C has been observed which is double of the global average. By 2050 there is expected an increase of 3 ^{o}C in summer (17), the value found in the Czech mountain area under study.

The significance of tick-borne diseases (TBD) at the close of the 21st century is further stressed by projected favourable climatic conditions for summer tourism on the territory of the Czech Republic, classified in the category "very good" (17). That is the basis for an assumed increased European interest in Czech tourist and recreation spots, which however, at present are already getting under risk of TBD.

CONCLUSIONS

There has been demonstrated a rise in the incidence of TBE in the Highland Region over the last 10 years (1997–2006) markedly exceeding the average increase in this disease in the Czech Republic observed from 1993. In the years 1961–2006 there has been found an increase in average ambient air temperatures in the Czech-Moravian Highland (the Svratouch meteorological station) by 1.5 °C, ranging from 1.3–2.8 °C in the spring and summer months, which in view of the altitudinal gradient of 0.6 °C/100 m corresponded to a shift towards environmental conditions formerly prevailing in localities at altitudes lower by 200–450 m a.s.l.

The increase in ambient air temperature, however, has manifested itself only since the beginning of the 1990s. Approximately since the mid-1990s there has been found an gradually rising trend in temperature deviations above the 30-year normal level (1961–1990) in the summer months recorded at the meteorological station Svratouch in the Czech-Moravian Highland in comparison with the average in the Czech Republic.

Increased temperatures influence on the one hand the period of activity and subsequent density of the *I. ricinus* tick, and on the other hand the whole biocenosis providing easier host seeking namely in the spring season. Under certain specific circumstances it may also influence human recreational activities and increase the probability of contact with ticks. It should be stressed that TBE in the Czech Republic is a infection predominantly linked with recreational activities.

Acknowledgements
The authors thank Dr. J. Valter, CSc. and Ing. I. Kott for providing the climagram. The study was supported by the GAČR fund under project No. 310/06/1546.

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Received and accepted December 4, 2007