

Tick-borne encephalitis in Sweden and climate change

Elisabet Lindgren, Rolf Gustafson

Summary

Background The incidence of tick-borne encephalitis (TBE) in Sweden has substantially increased since the mid-1980s. During the same period the climate has become milder and ticks have become more abundant. We investigated whether there is a link between the change in climate and the increase in incidence of TBE.

Methods Since the late 1950s all cases of encephalitis admitted in Stockholm County have been serologically tested for TBE. We analysed the period 1960–98 with multiple regressions. The number of days per season with temperatures of known importance for tick prevalence and pathogen transmission were studied. 2 years of temperature data were related to each TBE incidence rate to account for the tick's long life-span.

Findings Increases in disease incidence was significantly related ($R^2=0.58$; $p<0.0001$) to a combination of two consecutive mild winters, temperatures favouring spring development (8–10°C) and extended autumn activity (5–8°C) in the year prior to the incidence year, and temperatures allowing tick activity (5–8°C) early in the incidence year.

Interpretations The findings indicate that the increase in TBE incidence since the mid-1980s is related to the period's change towards milder winters and early arrival of spring. Other factors may have influenced TBE incidence such as more people in endemic locations, and increases in host animal populations; factors which are partly climate related. Access to TBE vaccination since 1986 and increased awareness of ticks might have caused an underestimation of the links found. Our findings also suggest that the incidence of other tick-borne zoonoses might have been affected by the milder climate.

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Department of Systems Ecology, Natural Resources Management, Stockholm University, Stockholm SE-10691, (E Lindgren MD); and Department of Immunology, Microbiology, Pathology and Infectious Diseases, Division of Clinical Immunology, Karolinska Institutet at Huddinge University Hospital, Stockholm, Sweden

(Prof R Gustafson MD)

Correspondence to: Dr Elisabet Lindgren (e-mail: elisa@system.ecology.su.se)

Introduction

There has been a global warming trend during the last two decades of the 20th century, with the years 1990, 1995, and 1997 having the highest mean temperatures ever registered in the northern hemisphere.^{1,2} In Sweden, the change towards a milder climate has been suggested to have contributed to latitude shifts in the northern distribution limit of the *Ixodes ricinus* tick and a general increase in tick population density between the early and the mid-1990s.³

I ricinus is the main vector for Lyme borreliosis and tick-borne encephalitis (TBE) in Europe. Climate restricts latitude and altitude distribution of ticks and influences disease incidence and seasonality.^{3–5} A certain number of days per season with temperatures influencing tick survival development, and activity^{6–9} and are necessary to sustain and increase tick prevalence.^{3,4,8} Thus, changes in climate will have direct effects on tick prevalence. Indirectly, both the tick population size and the virus-infected proportion of ticks will be affected by climate influences on the year-round survival of host and reservoir animals.⁵

Ticks may survive freezing temperatures (well below –7°C) and become active when night temperatures rise above 4–5°C.^{6–9} The life span of a tick can be more than 3 years depending on climatic conditions, and includes three blood-sucking stages: larvae, nymphs, and adults.⁶ All three tick stages may be infected as TBE virus is transmitted transovarially in about 1%.¹⁰ However, nymphs are the major contributors to infection in human beings.

Since 1984, incidence of TBE has increased substantially in Stockholm County in central Sweden. The area is highly endemic, and has had a TBE surveillance programme since the late 1950s.¹⁰ All cases of encephalitis admitted to hospital are serologically tested for antibodies against TBE virus and patients positive for TBE infection are interviewed and reported to a national epidemiological TBE registry. We studied whether the increase in TBE incidence (1960–98) was related to the number of days per season with temperatures of known bioclimatic interest for vector abundance and pathogen transmission.

Methods

Tick prevalence in the incidence year (t) depends on climatic conditions during at least 2 years.^{3,5} Thus, each TBE incidence rate was analysed in relation to temperature variables during 2 consecutive years, year (t) and the year before it (t-1). Details about the expected size of nymph and tick populations as a result of the temperatures have not been studied, and the temperatures were therefore used directly as potentially explanatory variables. The main analyses included 18 explanatory variables, with three variables for the winter, spring, and autumn respectively, for the year (t) and (t-1). The variables consisted of the number of days with temperatures within the following ranges: <–10°C, –10°C to –7°C, –7°C to 0°C, 5°C to 8°C, 8°C to 10°C, and >10°C. Ground temperatures (ticks hibernate in the ground during the winter season), depend on the amount

of snow.¹¹ Two different air temperature ranges ($<-10^{\circ}\text{C}$ and -10°C to -7°C) were therefore included. We did a separate analysis in which winter variables were substituted by the number of days with different snow depths (<20 cm, $20-40$ cm, >40 cm) when temperatures were either $<-10^{\circ}\text{C}$ or -10°C to -7°C . The variable -7°C to 0°C represents mild winters with temperatures that do not impair tick survival. 5°C is a threshold for both tick activity and for the start of the vegetation season, with increased food supply for host animals.^{5,6,8,9} Tick metamorphosis and egg hatching require temperatures between 8°C and $10-11^{\circ}\text{C}$.^{6,8} We also analysed summer temperatures $>10^{\circ}\text{C}$.

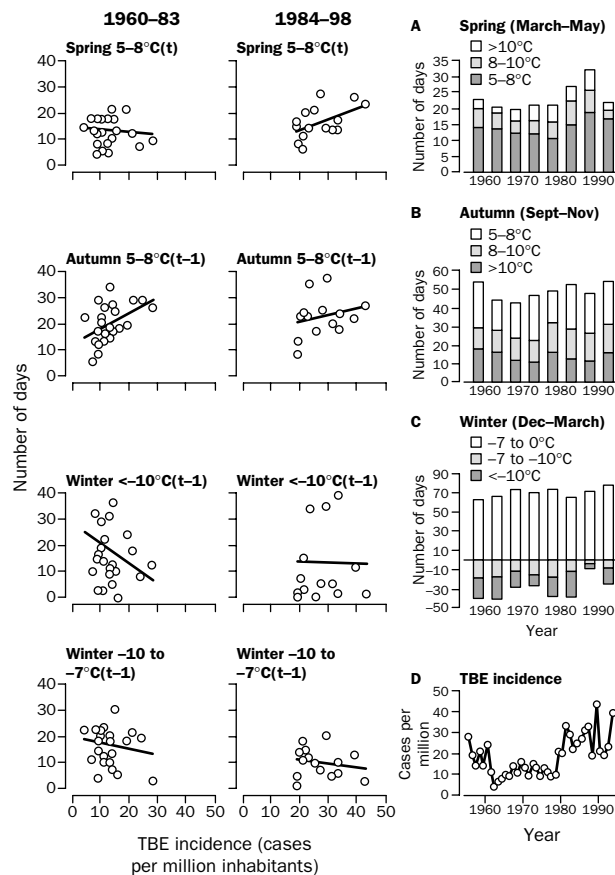
We obtained daily minimum temperature and daily centimetre snow-depth data from November, 1958, to October, 1998, for Stockholm County from the Swedish Meteorological and Hydrological Institute. Data on the annual number of TBE cases from 1960 to 1998 in Stockholm County was collected from the Swedish Institute for Infectious Disease Control. The incidence rate was calculated as number of cases per million inhabitants.

Multiple-regression analyses were done with backward and best subset selection methods, with TBE incidence as the dependent variable and temperature as the independent variables. Spearman's rho was calculated to investigate whether the independent variables were mutually correlated.

Results

TBE incidence was significantly linked to a combination of five variables (table). In going from 18 to five explanatory variables, by means of the backward selection method, the R^2 value was only reduced from 0.73 to 0.58 (with $p<0.0001$ for $R^2=0.58$). An increase in TBE incidence was related to two mild consecutive winter seasons (table: variable A and B), temperatures favouring spring development ($8-10^{\circ}\text{C}$) and extended autumn activity ($5-8^{\circ}\text{C}$) in year $t-1$ (variable C and D), and temperatures allowing tick activity ($5-8^{\circ}\text{C}$) early in the incidence year (variable E). The snow analyses showed the same significant combination of spring and autumn variables but with both positive and negative coefficients for the colder temperatures. Medium cold days (-10°C to -7°C) with deep snow cover (>40 cm) had a positive correlation ($p<0.02$) with TBE incidence. Very cold days ($<-10^{\circ}\text{C}$) with >40 cm snow had a negative correlation ($p<0.02$) and so did days with less snow ($20-40$ cm) at medium cold temperatures (-10°C to -7°C ; $p<0.001$). R^2 was reduced from 0.75 to 0.61 ($p<0.001$) in going from 22 to seven variables. There were no significant links between daily minimum summer temperatures and TBE incidence, and these variables were therefore excluded from the main analyses. Multiple-regression analyses with best subset selection confirmed the above links.

The average number of days at each temperature during 5-year periods for the different temperature range is shown in the right histograms of the figure. The spring seasons arrived earlier and were on the average warmer in 1960-83, compared with 1984-98 before (except for the



Analysed temperatures and TBE incidence

The four charts to the left show the plotted relation between TBE incidence and the number of days with different temperature variables. A, B, and C show average number of days per 5 year periods with the different spring, autumn, and winter temperatures used in our analyses. D shows the annual TBE incidence between 1960 and 1998 in Stockholm County.

years 1995-97, which also showed a decrease in TBE incidence rates). Autumn season temperatures showed no consistent difference between the two periods. Winter seasons became considerably milder after the mid-1980s, except for 1986 and 1987. However, these two winters had by far the deepest and longest lasting snow depths registered in the Stockholm area during the whole study period (1960-98).

The figure shows TBE incidence in relation to the number of days at each temperature. The slope increases substantially from $r^2=0.007$ for the 1960-83 period to $r^2=0.3$ in 1984-98 for the variable spring $5-8^{\circ}\text{C}$ (t), whereas for the same periods the r^2 decreases from 0.2 to 0.07 for autumn $5-8^{\circ}\text{C}$ ($t-1$). The $r^2=0.1$ for the winter variable $<-10^{\circ}\text{C}$ ($t-1$) in the 1960-83 period, but 0.0004 in 1984-98. We found no difference in r^2 between the periods when TBE incidence is plotted against the number of days with temperatures within the range -10 to -7°C , compared with the difference in the absolute number of days at each temperature for the same variable.

Discussion

Our results indicate that the increase in TBE incidence since the mid-1980s in Stockholm County is related to the period's change towards milder winters and early arrival of spring. The highest TBE incidence ever reported in Sweden occurred in 1994, with a three-fold increase in the peak compared with the average number of annual cases. In the same year a peak in TBE cases was reported also

Variable	B coefficient	T†	p
(A) -10 to -7°C ($t-1$)	-0.5	24.0	0.0001
(B) -7 to 0°C (t)	0.1	1.6	0.1
(C) spring $8-10^{\circ}\text{C}$ ($t-1$)	0.3	1.7	0.3
(D) autumn $5-8^{\circ}\text{C}$ ($t-1$)	0.6	4.2	0.0001
(E) spring $5-8^{\circ}\text{C}$ (t)	0.5	2.3	0.03

Model summary: $R^2=0.58$; $p<0.0001$. †T=B/Standard error of B.

Regression model summary for the period 1960-98

from Bayern and Baden-Württemberg, Germany, with 142 cases instead of the usual average of 11 cases per year.¹² In Stockholm County the year 1994 was preceded by five very mild winters and the early arrival of the spring season for 7 consecutive years. Such conditions are favourable for the tick vector, and host and reservoir animals.

The combination of temperature variables that were related to TBE incidence has biological relevance for the tick, particularly the nymph. Cold winter temperatures would have more of a negative effect in year $t-1$, when the more cold-sensitive larvae hibernates, than in year t . This effect is seen in our results. In the spring ($t-1$) the larvae develop into nymphs if temperatures are favourable—ie, between 8°C and 10°C. An extended autumn ($t-1$) increases the chance of survival. Temperatures allowing the nymphs to be active early in the spring of the incidence year (ie, 5–8°C) increase the risk for TBE incidence. Deep snow cover may increase ground temperatures where ticks hibernate sometimes by several degrees depending on the air temperatures.¹¹ Our results confirm this effect.

The effect on TBE incidence from several climate-dependent factors are indirectly acknowledged in our analyses model through their direct and indirect effect on tick prevalence, and hence TBE prevalence. Changed weather conditions could also have an effect on out-door activities of human beings and hence the risk of tick bites. Ticks are not active during warm sunny days, nor during rainfall.⁵ However, in spring and autumn the extended tick activity periods commonly coincide with extended periods of outdoor activity, such as, for example, a longer forest mushroom picking season and picnics.

Several non-climate-dependent factors might have influenced the link between increased incidence of TBE and temperature. The number of summer cottages has increased in endemic locations, resulting in an increased population at risk. However, a TBE vaccine became available in 1986. More than 200 000 inhabitants out of 1.6 million have been vaccinated in Stockholm County, which has probably led to a decrease in the number of cases (about 12% in 1998). Host and reservoir animal populations especially, and small and medium sized mammals, such as roe deer, have increased since the mid-1980s as a result of favourable conditions created by the milder winters and the longer vegetation periods. An additional increase in the roe deer population occurred during the 1980s as a result of decreased red fox predation due to a scabies infestation of the fox population. This factor might have contributed to an overestimation of the links found in Stockholm County. However, although important, the roe deer is only one of many host animals. Since the emergence of Lyme borreliosis in the late 1970s much attention has focused on tick-borne diseases. This increased awareness has not affected our incidence data because the TBE surveillance programme has been collecting data since the late 1950s. However, higher awareness of ticks has promoted individual preventive measures such as encouraging people to cover up when visiting highly endemic locations, and changing gardening practices to reduce

ground litter and thick grass. These factors might have contributed to less tick bites.

Our findings are in accordance with climatic changes seen in Europe during the past decades. The spring vegetation season has advanced by 12 days on average in latitudes 45–70° N) between 1960 and the mid-1990s.¹³ During 1980s and 1990s, northern European winter temperatures became milder and minimum temperatures increased proportionally more than maximum.¹³ Our results suggest that the milder climate in Sweden has contributed not only to increases in TBE incidence, but also to increases in the incidence of other diseases transmitted by *I ricinus*, such as Lyme borreliosis and human ehrlichiosis.^{14,15}

Contributors

Elisabet Lindgren collected data, designed the study, did the statistical analysis and outcome assessment, and wrote the paper. Rolf Gustafson collected data, did the outcome assessment, and wrote the paper.

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