REVIEW

What Makes Ticks Tick? Climate Change, Ticks, and Tick-Borne Diseases

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Over the past decades, tick-borne encephalitis (TBE), Lyme Borreliosis (LB), and other tick-borne diseases (TBDs) have become a growing public health problem in Europe and other parts of the world.[1,2]

In Europe, 90% to 95% of all tick bite incidences in humans are caused by *Ixodes* (I) *ricinus* (in Eastern Europe by *persulcatus*). Neglecting the large number of unreported cases, 100,000 to 150,000 of these incidences become manifest as LB and between 10,000 and 15,000 as TBE. TBE virus (TBEV) is endemic in regions of 27 European countries and the number of risk areas has increased every year.[2] TBEV is also endemic in some parts of Japan, China, and Mongolia. Hence, there are severe health problems for inhabitants and travelers.

TBE is predominantly reported in humans and seldom in dogs and horses. Recently, a clinical case of TBE was described in a monkey after natural exposition.[3]

The reason for this development is not quite clear, but it can be stated for certain that global warming causes some of these dramatic changes.[4] Recent stringent data were discussed in this article. However, there are additional factors to be considered, such as social and political changes in agricultural production and in leisure time and an increase in traveling, which in turn leads to a higher exposition rate.

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What Makes Ticks Tick?

As all parasites do, ticks as hematophagous ectoparasites strive:

1. For the best conditions to start and finish their life cycle (egg, larvae, nymphs, and adult stages). What is important for the tick is a high humidity of >85%. In addition, host questing is only possible at temperatures >7°C.
2. To find a host and take a blood meal. The blood meal can take place in competent hosts or in incompetent hosts, ie, humans.
3. To transmit pathogens without killing the host.

Among others, three main factors make ticks tick: weather, climate, and host. In addition to humidity, temperature, and the availability of hosts, the entire ecosystem and, most importantly, certain microclimate conditions, which induce the formation of natural foci, are decisive.

Ticks analyze their surroundings by means of the so-called Haller's organ, a highly complex sense organ located in the first pair of legs.

Hosts are detected by:

1. their shadow;
2. their body heat;
3. their odor; and
4. vibrations caused by their movement.

Hard ticks spend most of their lifetime isolated from passing vertebrates; however, they require a blood meal to proceed to their next life stage.

Some sensory and behavioral requirements help ticks:

1. to limit water loss;
2. to absorb humidity. *I ricinus* is not able to drink water; it can only absorb moisture from the air;
3. to restrict movements to particular times of the day;
4. to use sensitive thermoreceptor cells to find a refuge with appropriate microclimate conditions for survival;
5. to use chemosensors to find hosts; and
6. to use chemosensilla on the legs and mouthparts of the tick with receptor cells.

The duration of the blood meal of *I ricinus* depends on the tick's life stage. It may range from 2 days in larvae up to 10 days in adult females.

The ingested blood is concentrated three to five times, and surplus water is secreted into the host.

This is the process, which is decisive for transmission of all pathogens to the host via the tick's salivary glands by means of a pump mechanism.

In a female, eg, a 200-fold increase in body mass can occur during the blood meal, which requires highly complicated physiological and structural–anatomical processes in the background to prevent the tick from bursting.

During the first days of the blood meal, the cuticula and the epithelium of the intestine increase in size to be able to absorb the blood. Only within the last 12 to 24 hours, morphological changes occur in the tick.

I ricinus is the vector of 95% of all tick-transmitted pathogens in Europe,[5] although there is no doubt that *Borrelia burgdorferi* sensu lato and the TBEV are the most important human pathogens in this context. Ticks carry a lot of more pathogens, which they can also transmit.

The following bacteria and parasites have been detected.[6]

Borrelia burgdorferi s.l., *Coxiella burnetii*, *Babesia divergens/Babesia microti*, *Ehrlichia chaffeensis*, *Bartonella henselae*, *Francisella tularensis*, *Anaplasma phagocytophilum*, some Rickettsia species, and others.

The number of human pathogenic viruses detected in *I ricinus* is also very high.

The most important virus family is the flaviviridae, followed by bunya-, reo-, orthomyxo-, and togaviridae.[7]

Of course, the most significant virus of these is the TBEV but the Crimean-Congo hemorrhagic fever virus, the Omsk hemorrhagic fever virus, and the West Nile fever virus are also of importance. These pathogens almost exclusively cause hemorrhagic fever or Central Nervous System infections.[7]

Climate Change and TBDs

Within the past 20 to 30 years, we have observed a steady increase in the incidence of TBDs, which we attributed to the climate change already a long time ago. Meanwhile, hard data are available, which provide clear evidence for this association and this makes ticks tick!

A humidity rate of >85%, air temperatures of >6°C to 7°C, and a large number of blood-delivering hosts are the basic requirements to make ticks "happy." Unfortunately, these three basic requirements for the well-being of ticks are changing for the worst in many areas in Europe, including Germany.

The temperature and humidity conditions of March through May are particularly important for the transmission of tick-borne meningoencephalitis.[8] Due to the already detected climate changes throughout Germany on the long-time average, it can be expected that this is also true for other periods of the year. Hence, the question needs to be answered, which changes occurred in the period from March to April during the past decades. Within this period, the most favorable conditions for the spread of ticks could be found in the southwest of Germany with relatively high temperatures of 9°C to 11°C (Figure 1a) and precipitation values of up to 550 mm (Figure 1b). If we look at the development of both meteorological parameters (Figure 1c and d), a further northward extension of these favorable conditions for ticks can be observed. With up to approximately 2°C, temperatures in the north and northeast for instance showed a much stronger increase than those in the rest of the investigation area. Precipitation also increased except for some regions in Saxony and Brandenburg. The values range between 25 and 75 mm. These continuously improving conditions have already now most evidently led to an extension of the area of circulation of *Dermacentor reticulatus*. Dautel and colleagues[9] wrote that "The results of both studies show that *D reticulatus* presently occurs at far more sites than previously known in Germany and thus most likely has expanded its range." Süss and colleagues[10] were able to prove the same trend for the spread of TBE in Germany. The question of how long this trend will continue in the future is still open.

The goal was to calculate scenarios that are most likely to occur in the near future. For this purpose, a

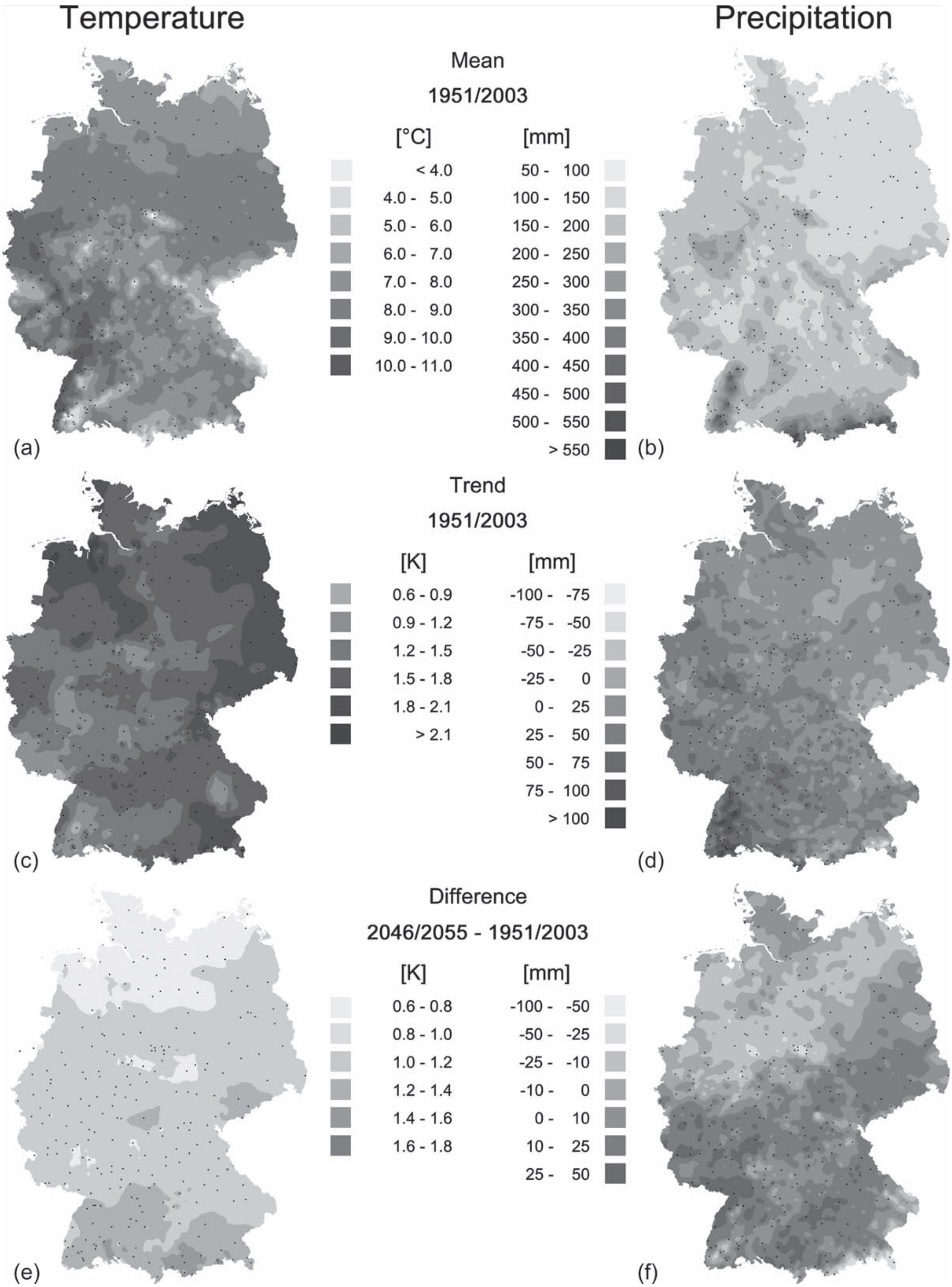

Figure 1 (a) Mean air temperature in March, April, May, 1951/2003; (b) mean sum of precipitation in March, April, May, 1951/2003; (c) trend of the mean air temperature in March, April, May, 1951/2003; (d) trend of the mean sum of precipitation in March, April, May, 1951/2003; (e) mean temperature change in March, April, May, 2046/2055 to 1951/2003; and (f) mean precipitation change in March, April, May, 2046/2055 to 1951/2003.

statistical regional climate model was developed[11] that enables us to develop plausible scenarios for Germany as a whole that according to the validation results have a maximum error rate of 10% in the simulation of the recent climate. According to the A1B scenario of the Intergovernmental Panel on Climate Change (IPCC), which describes the "business as usual" situation in consideration of the technological progress, the mean temperature in Germany will increase between 0.6°C and 1.8°C over the next 50 years. The lowest increase will be in the North and the highest in the South (Figure 1e). This means that the temperature conditions for ticks will continue to improve in large parts of Germany, especially in those areas that are already strongly affected. As to precipitation, however, the situation looks much more differentiated (Figure 1f). Whereas in the southern parts of Germany, the living conditions are again improving due to a further increase in precipitation, the decrease of precipitation in nearly all parts of northern Germany has a damping effect on the development of ticks.

The strongest increase in the average temperatures is seen especially in the northern hemisphere, in certain regions of Europe and North America, as well as in North Africa.

Ticks require high humidity to run their biological program. Therefore, the increase in average rainfall quantities makes them even happier than global warming alone. The strongest average increase in rainfall quantities is seen in regions with high tick activity.

Based on a more regional level, the situation remains the same. In southern Germany, the highest incidence of TBDs was observed. These are also the regions with the strongest increase in average temperatures over the past 50 years.

Over the past 50 years, the rainfall quantities in southern Germany have also increased, which is another factor that has improved the living conditions of ticks.

Climate change leads to better conditions for the everyday life of ticks.

Some of the recently gained scientific facts, which provide evidence for this association, are as follows:

1. Winter activity of ticks (reported from Germany and Sweden).[12–21]
2. Acceleration of life cycle and increase in population density (reported from Latvia).[13]
3. Occurrence of ticks at higher altitudes in the mountains (reported from the Czech Republic).[14]
4. Northward movement of ticks in Europe (reported from Sweden,[15–17] Norway,[18] Germany,[19] and other countries).
5. Higher incidence of TBDs (reported from all European risk countries).[1,2]

All these facts put pressure on public health, especially in the field of travel medicine.

Winter Activity of Ticks

A distinct sign of changes in the environment is the fact that host searching *I ricinus* were frequently found in the field in Germany in November and December 2006, and again in January 2007, a fact that could not be noted in previous years.

Reliable data, which prove that during the entire winter of 2006/2007 *I ricinus* in Germany were able to quest for hosts, were reported.

With a special study setup, the working group of Dautel and colleagues[12] was able to prove the winter activity of ticks between September 14 and March 2. Forty-eight wooden rods arranged in a 6 × 8 grid were mounted into a stainless steel reservoir of approximately 1 m^2 containing a 10 cm layer of leaf litter from oak and beech covered with wire netting. Laboratory-bred ticks were put into this reservoir. Two hundred four nymphs and 196 adults were used.

Host-questing ticks climb up the wooden rods, stretch out their front legs, and can thus be counted with regard to their host-seeking activity. To permit the analysis of their activity at night, they were additionally marked with fluorescing plastic particles.

During the whole observation period from September 14 to March 2, active ticks were detected! This means that we have a completely new ecological situation and that the temperature-dependent classical winter rest of ticks did not take place.

To verify these experimental data, free-living ticks were collected in the surroundings of this study setup on January 15 and February 5 and 19, 2007, using a flag. Questing ticks (in the wild) were detected on all 3 days. This confirms the results of the study setup. Ticks were very active in central Germany during the entire winter of 2006/2007, which also led to the occurrence of disease cases within this time period.

The Czech Republic reported an entirely different epidemiological situation. About 500 incidences of more than 1,000 reported cases of TBE in 2006 were acquired in the last third of the year 2006, representing a completely different state yet again.

Recent results of Daniel and colleagues confirm a long-term effect of winter climate on the incidence of TBE and LB in the subsequent seasons of the year in Bohemia, Czech Republic.[20]

Climate Change Leads to an Acceleration of the Ticks' Life Cycle

The duration of the developmental cycle from the egg via the larval and the nymphal stage to the adult stage depends on (1) temperature conditions, (2) the seasonal timing of questing, and (3) the availability of hosts, and ranges between 2 and 5 to 6 years depending on the availability of hosts and the weather conditions.

An increase in temperature up to a certain level leads to:

1. an acceleration of the ticks' developmental cycle;
2. an extension of the ticks' developmental cycle;
3. an increase in egg production;
4. an increase in population density; and
5. a shift of risk areas.

Investigations on the population density of *I ricinus* and *I persulcatus* carried out by the working group of Bormane and colleagues[13] in Latvia between 1991 and 2002 clearly showed a steady population density increase.

Recent studies of Gray[22] suggest that in northern temperate regions of Europe, global warming may cause changes in the seasonal patterns of TBDs. High summer temperatures can cause a mass transfer of ticks between development cohorts resulting in increased activity and therefore increased disease transmission in late autumn and early spring.

Occurrence of Ticks in Higher Altitudes in the Mountains

Investigations carried out by Materna and colleagues[14] from the Czech Republic demonstrated that *I ricinus* have reached higher altitudes in the mountains.

In the Krkonoše Mountains, the average temperature increased by 1.4°C between 1960 and 2005.

This means that *I ricinus*, which previously could be found up to an altitude of 800 m above sea level, now occur at altitudes as high as 1,100 m and more above sea level. Besides this, *I ricinus* also carry TBEV[23–25] at these higher altitudes.

Northward Movement of Ticks in Europe

Another consequence of climate change might be the northward movement of ticks and pathogens in Europe.

Three concrete examples were given in the following.

Previously, the occurrence of the tick *D reticulatus*, which is among others responsible for the transmission of *Babesia canis* to dogs, was restricted to the Mediterranean region. Recently, it has been detected as far north as northern Germany.[9]

The working group of Lindgren and colleagues[15] in Sweden was able to document the northward movement of the *I ricinus* population in Sweden within the short period of 10 years. Long-term field studies carried out by Eisen[26] on the Rocky Mountain wood tick, *D andersoni* in Colorado, United States, show that climate warming results in rapid and detectable changes in the spatial pattern of distribution and abundance of this tick. This tick is an important vector for human pathogens in the United States (ie, Colorado tick fever virus, *Rickettsia rickettsii* [Rocky Mountain Spotted Fever]) and also the cause for tick paralysis.

Further signs are the first occurrence of TBE in the southern most corner of Norway[18] and the spread to central Sweden, new foci in Central Europe, eg, in Switzerland and Austria.[27]

These four factors, which are certainly accompanied by others, lead to an increased incidence of TBD.

Higher Incidence of TBDs

From 1974 to 2003, an average increase in the incidence of TBE of 400% could be registered in all TBE countries all over Europe.[10] The only exception is Austria, where 90% of the population could be vaccinated against TBE, which led to a decrease of TBE cases from annually 600 to 700 to currently 50 to 100. The risk for unvaccinated tourists traveling to Austria is significant. The TBE incidence in unvaccinated patients increased.[27]

Most surprising was the fact that in the Czech Republic, in Switzerland, in Poland, and in Germany, another increase in the TBE incidence by 137.5% was found within the relatively short period between 2002 and 2006.

It is even more striking that between 2005 and 2006 alone, an incidence increase of another 30% could be observed in all European TBE countries.

Maximum incidence increases of 73% in the Czech Republic and 81% in Switzerland clearly demonstrate how substantial the ecological changes are.

Also, as an example, the development of the TBE incidence in Germany from 1993 to 2006 shows a substantial increase. The mean annual number of TBE cases between 1993 and 2002 was 185 cases. In 2005, 431 and in 2006, 546 TBE cases were reported! And, in the first 21 weeks of 2007, 30 TBE cases in Germany were reported, 15 more than by week 21 of 2006.

If we look at geographically small areas in Germany, such as the Odenwald region, we see the same picture with regard to the increase in TBE incidence.

Not only the number of TBE cases increases steadily but also the size of the TBE risk areas in Germany. In 1998, Germany had 63 risk areas and in 2007, we have already reached as many as 129.

Small new risk foci have also developed in France, Switzerland, and Austria. In Sweden, TBE hotspots emerge in the western part of the country.[28]

In the United States, the number of registered cases of Lyme disease increased from 9,000 in 1991 to 23,000 in 2006, but the actual number may be more like 60,000 to 100,000 cases.[29] In Germany, we estimate the number of Lyme disease cases to range between 60,000 and 80,000 per year. In Europe, Russia, and Siberia, 15,000 TBE cases per year are registered; however, we can assume that the number of unregistered cases is very high.

The prevalence of the different pathogens in ticks is also very high. Investigations carried out in Austria by the working group of Stanek[30] showed that only 25% of 864 *I ricinus* ticks were pathogen free and 32% carried more than one pathogen.

So far, there are very limited data on co-infections, which will certainly keep us busy in the future, also in the clinical field.[31]

However, in addition to climate change, other factors from the social, political, and economic field have to be mentioned, which contribute to the increasing TBD problem, especially higher exposition rates to tick bites for various reasons.

Such factors are as follows:

1. More use of the environment leads to *higher exposure*.[32] In "rich" countries, inhabitants have more leisure time, retired people are healthy and active, and they collect mushrooms, berries, and also firewood. In "poor" countries, unemployment is a great problem and inhabitants collect firewood, mushrooms, and berries to improve their economic conditions.
2. Change in farming leads to higher exposure. Other factors are farm holidays (drinking of unpasteurized milk might cause alimentary TBE), agricultural land set aside because of EU subsidies leads to fallow, and scrublands that in turn increase the number of hosts for ticks.
3. Better conditions in economy. Factors are, for instance, reduced air pollution, reduced toxicity, and more specialized pesticides, which make life easier for some hosts like rodents.
4. The rate of vaccination against TBE is too low in most of the countries with a TBE risk, and travelers are not sufficiently informed about the risks in the countries.
5. Increasing public awareness for the problems of TBD.
6. With increasing travel to areas of high TBE endemicity, travelers are at considerable risk for travel-associated TBEV infection.[33]

Summary of these examples for a direct connection between climate change, ticks, and TBDs.

Climate, weather, host finding, microclimate, and the whole ecosystem make ticks tick these days.

Recent climate change has improved the living conditions of ticks substantially.

One of the consequences is an increased distribution of ticks and a rise of the TBD incidence rate.

It is believed that the number of life cycles of ticks will increase within the next few years, and as a result of this, the geographical distribution of ticks will expand and the population density will increase.

So, seek advice on possible dangers before traveling, and, if necessary, get a vaccination (against TBE). The decision pro or contra a TBE travel vaccination should be mainly influenced by the planned activities of the travelers (contact with nature) and not only by the destination.[34]

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Declaration of Interests

The authors state that they have no conflicts of interest.

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