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## 2.2. Climate impacts on tick populations

# Climate change and ticks: measuring impacts

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## 1. Expert Opinion

### 1.1. Introduction

Changes in the abundance and distribution of ticks and increases in the incidence of tick-borne disease in Europe, that result from climate change, are issues of very real and immediate concern (Rose *et al.*, 2016). Climate projections suggest that Europe will experience an increase in high temperature extremes, droughts and heavy precipitation events, but with considerable variation across the continent: the majority of published assessments suggest that temperatures may increase by 1°C to 4°C per century (IPCC, 2013). Such changes would be expected to have direct effects on ticks, acting on tick development and survival, mediated by the physiological adaptations of the tick species in question, and indirect effects, acting through host availability and the presence of suitable habitat. However, any changes in tick population dynamics or tick-borne disease incidence will inevitably depend on the interactions between a wide range of factors, and outcomes are likely to be complex and non-linear. Hence, the specific consequences of climate change on components of the system may be hard to isolate (Gray *et al.*, 2009). Nevertheless, substantial changes have been predicted and, it is argued, may already be evident (Beugnet and Marié, 2009).

In terms of direct effects, warming might be expected to increase development rates and extend the seasonal periods during which conditions are favourable for survival and pathogen transmission. However, this will be strongly dependent on precipitation: drier, hotter conditions in summer will reduce survival and activity for the most abundant tick species found in Europe, such as *Ixodes ricinus*, while the opposite will be the case in winter in parts of north western Europe that experience warmer wetter winters. Analysis of the effects of hotter summer temperatures indicated that it resulted in a transfer of *I. ricinus* ticks between development cohorts, resulting in increased questing activity and therefore increased disease transmission in late autumn and early spring (Gray 2008). Similarly changing rainfall patterns may affect the feeding patterns. If unusually dry conditions occur early in the season when ticks are questing (April-June), nymphal ticks may be more likely to feed on small rodents nearer the ground and increase the rodent reservoir of pathogens such as *Borrelia burgdorferi* s.l. and tick-borne encephalitis (TBE) virus (Randolph and Storey 1999),

whereas if dry conditions occur later in the season (June-August) then the ticks may starve for want of sufficient hosts prior to the winter when questing usually stops (Randolph *et al.* 2002; Randolph 2004). Climate changes may also facilitate range expansion and it has been suggested that the impacts of climate change are likely to be greatest at the edge of the range of environmental tolerances for particular species (Lindgren *et al.*, 2000; Gray *et al.*, 2009). In addition, it is more likely that tropical and sub-tropical species will establish at higher latitudes and altitudes. For example, predicted changes could result in the permanent establishment of the more desiccation tolerant species, *Rhipicephalus sanguineus*, in many locations where it is currently unable to establish and is found only in heated or sheltered buildings such as kennels (Gray *et al.* 2009). Changes in phenology will vary greatly across climatic zones; in some regions sharp changes between seasons may serve to synchronise tick populations. Alternatively, in parts of northern and north-western Europe warmer wetter winter conditions might make populations more heterogenous, removing distinct peaks in the tick season, increasing the proportion of tick population questing at any one time, but increasing the rates of starvation (Gilbert *et al.*, 2014).

In terms of indirect effects, climate change will have a range of particularly important impacts on the availability of habitat suitable for tick or their hosts; these effects may be natural or anthropogenic. In parts of Europe there are large-scale plans for wetland creation to mitigate the effects of climate change on biodiversity loss. Initiatives are also being undertaken to promote biodiversity-enhancement, to increase woodland management for biodiversity and to link fragments of existing biodiverse-rich habitat to increase habitat connectivity (Bailey, 2007). This has led to increases in wildlife populations and expansion of their distributions, particularly deer (Stigum *et al.*, 2019), which are important reproduction hosts, and rodents which are important reservoirs of a range of disease pathogens, such as for Lyme borreliosis. For example, over the last 20-30 years populations of roe deer, *Capreolus capreolus*, have expanded in areas of increased tick abundance (Tälleklint and Jaenson 1998; Scharlemann *et al.*, 2008) and their incursion into peri-urban areas is becoming more common (Jameson and Medlock, 2010) increasing the human risk of exposure to tick bites in these areas.

The compounded effects of climate on tick abundance and changes in phenology will also affect the transmission of pathogens and the increase in temperature and extreme weather events predicted under most climate change scenarios, are likely to affect the incidence of tick-borne disease in many parts of Europe (Gray *et al.*, 2009).

## 1.2. Evidence and its limitations

Despite extensive discussion, unambiguous links between climate change and changes in tick abundance, phenology and disease incidence are difficult to demonstrate. This is, in part, because, of the complexity of the interacting drivers, as discussed above. In addition, good empirical studies of the effects of climate on tick populations are rare, partly due to the long timescales that are required to demonstrate long-term changes that map to the expected rates of climate change. Hence, many existing studies suffer from the fact that the duration of the time series is too short, or frequency and quality of sampling effort may not have been consistent throughout the decades required. As a result, conclusions drawn from many of these studies need to be interpreted with some caution.

It is not the intention to present an assessment of the literature on this subject here, but two studies in particular highlight the rigour required to provide good evidence. Between 1977 and 2011, questing *I. ricinus* were monitored in the Tula region of eastern Russia by Korotkov *et al.* (2015). Three sites were situated in coniferous-deciduous forests and a fourth site was in the forest-steppe zone. In these zones, twenty to forty 1 kilometre transects were set up, and questing *I. ricinus* ticks were collected from vegetation every 10 metres along the transect. For the initial 14 years, the recorded tick abundance was at 0.1 to 0.9 specimens per 1 kilometre transect - the lower limit of the sensitivity of the methods used. However, during the following 21 years there was a substantial increase in tick abundance; in some floodplain areas tick abundance reached around 18 specimens per 1 km of transect, and around 5 specimens per 1 km transect in the xerophilic woods. The abundance of small and large wild mammals was monitored; fluctuations in these potential hosts were small and their numbers remained relatively constant. Despite this, an overall increase in tick abundance was observed over the 35-year span of the study. Correlation analysis showed a significant association between climate variables and the abundance of questing *I. ricinus*. As a result, it was concluded that the increase in tick abundance was mainly as result of both climate and anthropogenic changes in the environment rather than changes in host abundance.

Similarly, Žygutienė (2009) conducted a study in Lithuania into the changing patterns of *I. ricinus*, between 1991 and 2008 and sampled many areas of Lithuanian woodland. In the Klaipeda region from 1995 to 2008, the density of ticks during the spring peak of activity increased three-fold from 19 ticks per 1 kilometre to 57 ticks per 1 kilometre. In addition, the duration of the tick biting season was extended: by 2007 the last ticks were collected in mid-December and the first of the 2008 season were found in mid-March. In association there was a significant rise in morbidity due to TBE between 1997 and 2008 in Lithuania. It was concluded that the abundance of *I. ricinus* numbers is increasing, their seasonal period of activity is extending, and this is leading to the increase in the

prevalence of tick-borne disease (Žygutienė, 2009). However, while this latter study highlights the extensive nature of the surveillance needed to demonstrate changes, interestingly, this author considered that changes in wild host abundance had a greater influence on tick numbers and disease risk than climate, but that weather conditions may influence human risk from tick-bites through increased exposure.

As highlighted by Žygutienė (2009), when considering tick-borne disease incidence, in particular, it is important to appreciate that underlying changes in vector abundance may be only one possible driver, and must be distinguished from changes in behaviours that increase host exposure and disease incidence, greater awareness amongst public and medical professions compounded by changes in social and economic conditions (Godfrey and Randolph, 2011), improved surveillance, improved communications among the infectious disease community, and better diagnosis. These may all lead to increases (or decreases) in tick-borne disease incidence without any necessary change in vector abundance. Climate mediated changes may also affect land use patterns and population movement and this in turn allows for increased transmission of vector-borne diseases (Godfrey and Randolph, 2011). A change in the perception of disease risk may lead to changes in approach to intervention, with perhaps a greater willingness to treat prophylactically or to intervene with treatment earlier. This is likely to further complicate the identification of long-term associations between climate and reported tick-borne disease incidence.

### 1.3 Novel tools: metabolic rate measurement for detecting the impact of climate on ticks

Given the difficulty of inferring the effects of climate on ticks through measurement of seasonal patterns of abundance alone, novel approaches that are able to detect climate mediated impacts directly will be of value. One approach is through the analysis of metabolic rate.

Tick nutrition is derived from the blood-meal and sufficient must be obtained to allow larvae and nymphs to undergo development to the next life-cycle stage, and eventually initiate repeated questing until another host is located. For adults, accumulated metabolic reserves must also provide the resources for reproduction (Obenchain and Oliver, 1973). The longer ticks can survive between blood-meals, the higher the chance of encountering a new host. However, the rate of metabolite resource depletion is strongly affected by temperature and precise measurement of the rates of depletion may allow insights into the effects of climate on tick activity and the more exact determination of feeding patterns.

The study of metabolite use patterns has been greatly facilitated by the spectrophotometric techniques developed by van Handel (1985a, b) and recent studies have demonstrated these

methods can be used also to determine the entire energy budget of individual ticks (Alasmari and Wall, 2020). The primary immediate energy source for ticks is glucose, which is stored in a hydrated polymeric form, glycogen, but this is rapidly depleted (Moraes *et al.* 2007). Carbohydrate can be used to replenish glycogen reserves. Lipids also play key roles in tick metabolism, both as an energy source and structurally. Lipid is stored primarily in the form of triglycerides in adipocytes, the main fat body cell, and additionally as cytoplasmic lipid droplets. Lipid analysis alone has been used to infer feeding patterns in field-derived cohorts of *I. ricinus* (Randolph *et al.*, 2002; Abdullah *et al.*, 2018) but when measured in conjunction with other metabolites, a more comprehensive picture can be formed. Proteins are essential for muscle development and the synthesis of cuticle, hormones and enzymes, synthesis of egg yolk, and the production of sperm and gonadal proteins (Kongsuwan *et al.*, 2010). Proteins may also be metabolised as a long-term energy reserve (Williams *et al.* 1986). Among ticks collected from the field, clear differences in metabolite concentrations between life cycle stages are apparent – largely associated with differences in the relative amounts of protein compared to glycogen (Fig. 1). For ticks collected in late spring and early summer in the south west of England, in nymphs, glycogen was found to represent around 40% of the total mass of metabolites, followed by carbohydrate, and protein (at around 25% each). In contrast, in females, glycogen comprised only 19% and in males 12% of the mass of metabolites, whereas protein represented 53% of the mass in females and 61% in males (Alasmari and Wall, 2020). These differences were considered to reflect differences in the feeding history of the preceding life cycle stage the previous year, with the nymphs collected at that time of year having more substantive reserves compared to the adults.

Further analysis of the rates of metabolite loss suggested that complete resource depletion would occur at between 45-70 days at temperatures of 25-30 °C and 200 days at 5 °C, assuming humidity was sufficiently high not to result in desiccation. The lower thresholds for metabolic activity were estimated to be between -10 °C and -5 °C, which probably reflects the lower lethal temperature for *I. ricinus*. The thermal sensitivity of metabolic rate, often described by an organism's  $Q_{10}$ , is the magnitude of change in metabolic rate for a 10 °C change in temperature. In insects  $Q_{10}$  values range from 1.5 to 3, with a mode of 2.5 (Woods *et al.*, 2003). In *I. ricinus*,  $Q_{10}$  values of 1.5 for nymphs, 1.71 for males and 1.63 for females have been recorded (Alasmari and Wall, 2021). These relatively low values reflect the low metabolic rate that helps to increase tick survival during the extended inter-feed intervals. It has previously been suggested that ixodid ticks have a metabolic rate which is typically 13% below that of most arthropods (Lighton and Fieldon, 1995).

Hence, a more detailed understanding of the pattern of metabolite use and depletion, particularly in responses to temperature, may provide tools that allow the likely impacts of climatic change on ticks to be assessed directly, allowing subtle changes in seasonal activity and feeding patterns to be detected (Alasmari and Wall, 2021). However, in the future, this approach may need to take account of the possibility that such relationships are likely to be affected by saturation deficit and daylength (Belozarov, 2009).

## 2. Prediction

Ticks and tick-borne disease are important worldwide, in terms of both mortality, morbidity and animal welfare – such impacts are likely to become more problematic in the future. Because of their lengthy off-host life-cycle stages ticks are highly sensitive to climate change as their life-history processes such as development and survival are temperature- and moisture-dependent. It has been suggested that changes in the phenology and distribution of tick species have been observed in recent years, but relatively few robust studies have undertaken collection over sufficiently long time periods to demonstrate changes unequivocally; such studies are essential. The complex interactions between tick development and mortality, environmental change, and host behaviour can make accurate predictions of future changes difficult. Clearer data and more exact predictions will emerge in the future as new tools to allow a more exact understanding of the effects of the environment on ticks emerge. Future changes in exposure and risk must be considered more comprehensively in climate impact assessments since the nature and timing of these interactions may change with altered climate. However, given the complexity of the systems in question, in the short term, preparation for the unexpected and unpredicted outcomes is the essential take-home message from this expert opinion. Finally, and critically, although there is potential for climate change to result in an increase in tick abundance and tick-borne disease incidence, strategic changes to exposure also provide an opportunity to mitigate impacts of climate change (Rose *et al.*, 2016).

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Figure 1. The percentage mass for different categories of metabolite in individual *Ixodes ricinus* nymphs, males or females collected from the field in 2017 between March to May by blanket-dragging (redrawn from Alasmari and Wall, 2020).

