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Saturation deficit and deer density affect questing activity and local abundance of *Ixodes ricinus* (Acari, Ixodidae) in Italy

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ABSTRACT

The wood tick *Ixodes ricinus*, one of the most common arthropod-borne disease vectors, is of increasing relevance for human and animal health in Europe. The aim of this study was to determine the relative contribution of several abiotic and biotic factors potentially affecting questing activity and local abundance of *I. ricinus* in Italy, considering the scale at which these factors interact with the host-seeking ticks. Within EDEN, a large-scale EU collaborative project on eco-epidemiology of vector-borne diseases, we collected questing ticks for three consecutive years using a standard protocol at eleven sites in the Italian Alps and Apennines. A total of 25 447 *I. ricinus* were collected. All sites showed the same annual pattern of tick activity (bimodal for nymphs and unimodal for larvae and adults), although the abundance of nymphs was statistically different between sites and years. A Generalized Linear Mixed Model and a Linear Mixed Model fitted to data for nymphs, showed that while the principal variables affecting the local abundance of questing ticks were saturation deficit (an index combining temperature and relative humidity) and red deer density, the most important variable affecting questing nymph activity was saturation deficit. As for the timing of seasonal emergence, we confirmed that the threshold temperature at this latitude for larvae is 10 °C (mean maximum) while that for nymphs is 8 °C.

1. Introduction

The wood tick, *Ixodes ricinus* (Linnaeus, 1758), is widespread throughout Europe and North Africa (Gray et al., 2002; Estrada-Peña et al., 2006), and is the main vector of a number of pathogens of public health importance that cause human and veterinary disease with increasing incidence throughout Europe (Parola and Raoult, 2001; Goodman et al., 2005; Kunze, 2007; Vorou et al., 2007; Lipsker and Jaulhac, 2009; Samuels and Radolf, 2009). Since the risk of tick-borne infection in humans is dependent on tick abundance, tick infection prevalence and the extent of exposure to questing ticks (Sumilo et al., 2007; Randolph et al., 2008; Hubálek, 2009; Godfrey and Randolph, 2011), identifying the factors affecting the local questing tick abundance is crucial to developing preventive strategies and public health interventions.

Many factors are already known to influence *I. ricinus* phenology (i.e. the variation in abundance of the three developmental stages over time and space), including climate, microclimate, habitat suitability, and host availability (Estrada-Peña et al., 2006; Medlock et al., 2008; Randolph, 2008, 2009; Daniel et al., 2009; Gray et al., 2009; Danielová et al., 2010; Gilbert, 2010). Temperature and relative humidity also affect tick survival and behaviour (e.g. MacLeod, 1935, 1936; Lees and Milne, 1951; Daniel and

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Dusbábek, 1994; Gray, 2002; Hubálek et al., 2003), but more recently it has been shown that saturation deficit (an index integrating temperature and relative humidity to give a measure of the drying power of the atmosphere; see below) influences questing behaviour, and consequently, local questing tick abundance and contact rates with potential hosts (Perret et al., 2000, 2004; Burri et al., 2007; Gern et al., 2008; Knap et al., 2009). Ungulate hosts, especially deer, are known to promote amplification and dispersion of adult ticks (Hudson et al., 2001; Perkins et al., 2006), so that within suitable tick habitats, tick abundance is strongly affected by large ungulate population density (Wilson et al., 1984, 1990; Deblinger et al., 1993; Hudson et al., 2001; Perkins et al., 2006; Rosà et al., 2007; Rizzoli et al., 2009).

While most of our knowledge about tick phenology is based on studies carried out in the UK, Ireland and Switzerland (e.g. UK: Randolph et al., 2002; IRE: Gray, 2008; CH: Morán Cadenas et al., 2007), empirical data from southern Europe are relatively rare (Estrada-Peña et al., 2004, 2006). Furthermore, the effect of the interaction of abiotic (climate) and biotic (host) factors on tick phenology has been poorly investigated, especially at a regional scale. Therefore, the aim of this study was to determine the relative effects of specific climatic variables and population density of the most common ungulate host species (roe deer, *Capreolus capreolus* and red deer, *Cervus elaphus*) on the abundance of *I. ricinus* at eleven sites in Italy where ticks are endemic and recognized as a public health problem. Tick data were obtained from a longitudinal three-year survey on the eco-epidemiology of tick-borne diseases as part of the European FP6 project EDEN (http://www.eden-fp6project.net).

2. Materials and methods

2.1. Study sites

Eleven study sites from four mountainous Italian Regions (Alps: Veneto (6 sites), Friuli Venezia-Giulia (2), Trentino Alto-Adige (2); Apennines: Emilia-Romagna (1); see Fig. 1) were selected to include similar, suitable tick habitat, and different ungulate densities (Table 1), where 'suitable' habitat includes mixed deciduous vegetation (mainly beech, *Fagus sylvatica*) and coniferous woodland

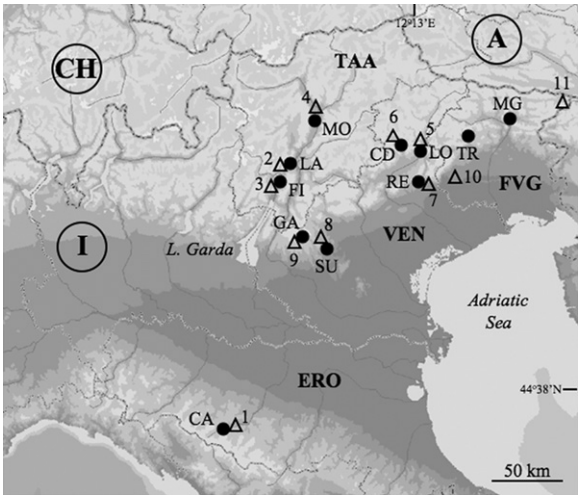

Fig. 1. Tick (*I. ricinus*) sampling sites and meteorological stations in the regions of the Italian Alps and Apennines included in this study (ERO = Emilia Romagna; FVG = Friuli Venezia-Giulia; TAA = Trentino Alto-Adige; VEN = Veneto). Sampling sites (closed circles): CA = Caslina (RE); CD = Candaten (BL); FI = Filari (TN); GA = Gauli (VR); LA = Lamar (TN); LO = Losego (BL); MG = Moggio (UD); MO = Monticolo (BZ); RE = Lago Revine (TV); SU = Sudiro (VI); TR = Tramonti di Sotto (PN) and meteorological stations (open triangles): 1 = Carpineti (RE); 2 = Terlago (TN); 3 = Cavedine (TN); 4 = Bolzano; 5 = Belluno; 6 = Agordo (BL); 7 = Vittorio Veneto (TV); 8 = Valdagno (VI); 9 = Boscochiesanuova (VR); 10 = Aviano (PN); 11 = Tarvisio (UD). Created with ©Microsoft Encarta.

(fir, *Abies alba*, spruce, *Picea abies* and pines, *Pinus* spp.). Most of the sites were located between 500 and 700 m above sea level (a.s.l.), although the lowest site was at 143 m a.s.l. (Sudiro, VI), and the highest was 858 m a.s.l. (Gauli, VR).

2.2. Climatic data

Although ticks respond to microclimate, macroclimatic records also give reasonable estimates of the gross seasonal and annual differences experienced by ticks in different areas; therefore, we used datasets of climatic variables from the closest meteorological stations to the monitored tick collection sites (data from online sources http://www.ilmeteo.it and http://www.arpa.emr.it, or kindly contributed as mentioned in the 'Acknowledge-

Table 1
Ungulate densities at nine tick sampling sites in the Italian Alps and Apennines between 2006 and 2008 (Roe = roe deer, *Capreolus capreolus*; Red = red deer, *Cervus elaphus*; na = not available).

Site	Roe deer			Avg_Roe	Red deer			Avg_Red
	2006	2007	2008		2006	2007	2008	
Candaten	17.8	18.0	17.4	17.7	1.3	2.7	2.7	2.2
Caslina	31.0	25.0	16.0	24.0	na	na	na	na
Tramonti	2.9	2.9	3.1	3.0	0.3	0.4	0.6	0.4
Filari	9.5	10.0	10.7	10.1	0.0	0.0	0.0	0.0
Gauli	1.1	1.3	1.2	1.2	na	na	na	na
Lago Revine	13.6	13.1	14.1	13.6	1.3	1.5	1.8	1.5
Lamar	7.8	7.7	8.0	7.8	1.9	2.0	2.0	2.0
Losego	14.4	14.5	14.7	14.6	1.9	2.8	3.2	2.6
Moggio	3.2	3.3	3.9	3.4	1.9	2.3	2.7	2.3
Monticolo	7.5	7.5	7.5	7.5	0.5	0.5	0.5	0.5
Sudiro	9.0	5.0	na	7.0	na	na	na	na