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## Original article

## Factors responsible for *Ixodes ricinus* nymph abundance: Are soil features indicators of tick abundance in a French region where Lyme borreliosis is endemic?

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## ABSTRACT

In Europe, the hard tick *Ixodes ricinus* (Acari: Ixodidae) is the main vector of Lyme borreliosis spirochetes (*Borrelia burgdorferi* sensu lato group). A field study was conducted to evaluate the abundance of *Ixodes* nymphs in the French region of Alsace, where Lyme borreliosis is endemic, and to determine whether environmental factors such as soil moisture and composition may be associated with nymph abundance. In the ten sites studied, ticks were collected by drag sampling from March to October in 2013 and 2014. Temperature, relative humidity, saturation deficit, soil pH, humus composition and type of vegetation were recorded at each site. The abundance of *I. ricinus* was highly variable from one site to another. Inter-annual variations were also observed, since the nymph abundance were higher in 2013 than in 2014. This study shows that humus type can be indicative of nymph abundance. Three types of humus were observed: (1) moder, (2) mull, and (3) mull-moder humus. One of them, moder humus, which is characterized by a thick layer of fragmented leaves, was found in multivariate analyses to be strongly associated with the nymph abundance. This study demonstrates that factors such as saturation deficit do not suffice to explain the differences in nymph abundance among sites. The composition of the soil and especially the type of humus should also be taken into consideration when assessing acarological risk.

## 1. Introduction

In Europe, the hard tick, *Ixodes ricinus*, is the main vector of Lyme borreliosis spirochetes (*Borrelia burgdorferi* sensu lato group), which are responsible for the most frequent vector-borne disease occurring in the Northern Hemisphere (Stanek et al., 2012). For public health reasons, Lyme borreliosis has recently attracted considerable attention (Gray et al., 2009; Rizzoli et al., 2014). In France, Lyme borreliosis is endemic in the Alsace region (Létrilliart et al., 2005; Vandenesch et al., 2014) and some of the cantons (French administrative divisions) in this region are known to have both a high incidence of Lyme borreliosis and high nymphal *I. ricinus* densities (Ferquel et al., 2006).

*I. ricinus* ticks spend a large part of their lives off their hosts (Humair

and Gern, 2000; Kurtenbach et al., 2006). Transmission of *B. burgdorferi* s. l. occurs via the inoculation of tick saliva containing *Borrelia* into the hosts on which they are feeding (Stanek et al., 2012). Humans are considered accidental hosts for ticks. The risk of tick-borne infection in humans depends on the conjunction of several parameters including the tick abundance and their questing activity, the prevalence of the pathogens in ticks and the human activity. These parameters are indicators to the level of human exposure to questing ticks, which has been called the acarological risk (Estrada-Peña et al., 2012; Mannelli et al., 2003; Medlock et al., 2013). Field studies have been conducted in both the USA and Europe to elucidate the occurrence of this disease in human populations. It is mainly the nymphal *Ixodes* stage that transmits Lyme borreliae to humans (Falco et al., 1999). Most field studies have

Abbreviations: GPS, global positioning system; RH, relative humidity; SD, saturation deficit; T, temperature; ONF, Office National des Forêts; AER, applied econometrics in R; GLM, generalized linear model; MASS, modern applied statistics with S; SE, standard error; AIC, Akaike Information Criterion

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therefore focused on the nymphal ecological niches (Dobson and Randolph, 2011; Estrada-Peña, 2001).

In several field studies, the factors affecting *I. ricinus* phenology have been assessed in order to predict the abundance of questing nymphs (Estrada-Peña, 2003; Estrada-Peña, 2001; Jore et al., 2014; Randolph et al., 2002). Biotic factors such as tree species, landscape fragmentation, the composition of the vegetation and the ungulate densities also contribute importantly to the dynamics of *I. ricinus* populations and their size (Brownstein et al., 2005; Li et al., 2012; Pfäffle et al., 2013; Tack et al., 2012). Abiotic factors such as temperature, relative humidity and saturation deficit have long been known to be associated with the survival and behavior of *I. ricinus* (Perret et al., 2000; Randolph and Storey, 1999; Schulz et al., 2014; Tagliapietra et al., 2011). As a humid environment is essential for tick survival, some soil features such as the presence of leaf litter in particular play a key role in tick abundance patterns (MacLeod, 1935; Milne, 1946; Tomkins et al., 2014). Other soil features such as particle size distribution and soil structure have been less frequently investigated in terms of their impact on *I. ricinus* ticks (Gilot et al., 1975; Glass et al., 1994; Guerra et al., 2002; Vourc'h et al., 2016). The porosity of the soil structure is known to have a major impact on water retention processes (Medlock et al. 2008). In this study, we explored the effect of certain soil features such as the humus status, with its potential microbial activity (biotic

factors) and particle size (abiotic factors), on the *I. ricinus* nymphal abundance.

## 2. Methods

### 2.1. Sites

The present study sites were located in both rural and suburban areas in northern, southern, eastern and western Alsace at various altitudes (Fig. 1). Since eight of these sites were previously studied by Ferquel et al. (2006) in 2003–2004, these sites were again included in this study. The two sites in suburban areas were selected in order to measure the nymph abundance in areas with a high human population density. In 2013 and 2014, all ten sites were visited every month. Altitude, longitude and latitude were recorded with a GPS apparatus (GPS Garmin 62 °) (Fig. 1).

Most of the sites carried mull humus, but two sites (Appenthal and Sattel) carried moder humus, and two other sites (Murbach and Chene Voltaire) carried mull-moder humus. Soil acidity ranged between 4.6 in the most acidic case (at Murbach) to 6.5 in the most basic case (at Dannemarie). The soil occurring at more than half of the sites consisted of a combination of sand and silt. Two sites (Murbach and Dannemarie) showed a silt-like texture.

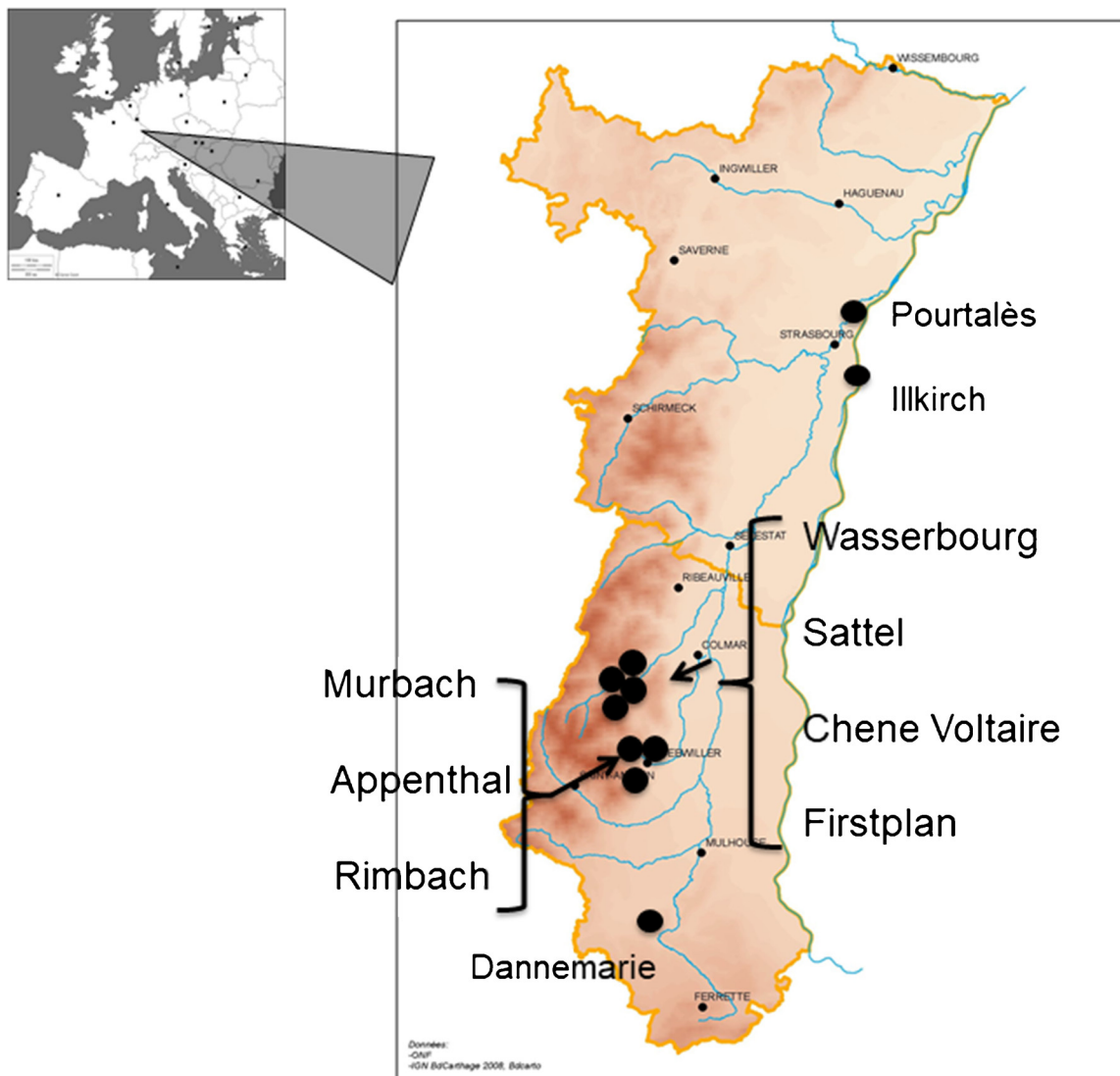


Fig. 1. Sites studied in the Alsace region (France) in 2013 and 2014.

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