



The impact of land use and climate on tabanid assemblages in Europe



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ABSTRACT

Land use and climate are important drivers of the diversity and abundance of insects. Tabanids (Diptera: Tabanidae) are haematophagous cosmopolitan flies that are pests to humans and livestock as well as mechanical vectors of animal disease agents such as *Besnoitia besnoiti* and the equine infectious anaemia virus. Given growing concerns about tabanid-borne diseases in Europe, there is a need to assess how land use and climate affect tabanid assemblages on the European scale. To investigate this, we used a dataset including 38 tabanid samples from 7 European countries to determine the geographical distribution of 79 tabanid species, and a dataset restricted to 32 samples from 4 countries to examine the relationship between tabanid assemblages and climatic and land-use variables. We also investigated the impact of the sampling method on findings. On the European scale, a non-metric multidimensional scaling (NMDS) ordination revealed that tabanid assemblages were spatially ordered along a marked gradient from Eastern to Western Europe. A model-based analysis of the multivariate tabanid abundance data showed that both climatic and landscape variables, but not sampling method, had a significant additive effect on mean abundance. Using linear mixed-effects models, we found that the Shannon diversity index decreased from 2.5 to 0.5 when the percentage of pastureland in a 2-km buffer around the sampling site increased from 0 to 80% and the annual mean temperature decreased from 16 to 4 °C, while Pielou's measure of species evenness decreased from 0.94 to 0.18 with an increase in the percentage of pastureland. We found that the community proportion of the two most common European species, *Tabanus bromius* and *Haematopota pluvialis*, was significantly associated with the sampling method. Our results indicate that the distribution and incidence of tabanid-borne diseases may be heavily influenced by changes in land use and climate and highlight the importance of environmental changes on insect vector populations.

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1. Introduction

Land uses that alter habitat structure and heterogeneity, as well as resource availability, may have varying effects on arthropod communities. For example, grazing can have an impact on both a small spatial scale, e.g. through grazing intensity, and on a large spatial scale, e.g. through habitat fragmentation (Benton et al., 2002; Sjödin et al., 2008; Kleijin et al., 2009; Joern and Laws, 2013; Foster et al., 2014; Kormann et al., 2015; Van Klink et al., 2015). Pastureland for grazing has often been shown to negatively affect the diversity and abundance of arthropods such as beetles, moths,

spiders, grasshoppers (O'Neill et al., 2003; Borges and Brown, 2004; Grandchamp et al., 2005; Littlewood, 2008).

Climate is typically a strong indicator of broad-scale species richness; this pattern may be explained by several hypotheses including the energy hypothesis (Hawkins et al., 2003). This climate-based hypothesis claims that energy availability generates and maintains richness gradients; it assumes that at higher temperatures, winter mortality is lower, and growth and reproduction are greater, leading to larger populations (Hawkins et al., 2003). This relationship between temperature and species richness is highly variable across a wide range of taxa and at different scales (Field et al., 2009). For invertebrates, temperature (i.e. energy) is strongly linked to species richness in cooler climates, while precipitation (i.e. water availability) is more critical in warmer climates (Hawkins et al., 2003). Several studies on European insects such as butterflies or

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dung beetles have highlighted the strong influence of climatic variables, especially temperature, on species richness at a large scale (Lobo et al., 2002; Hawkins et al., 2003).

A number of studies have shown that land use and climate are important drivers of the diversity and abundance of arthropods (Tscharrnke and Greiler, 1995; Hawkins et al., 2003; Field et al., 2009; Kormann et al., 2015; Van Klink et al., 2015). To date, studies of environmental responses (including to land use and climate) have mainly been carried out on arthropod herbivores or pollinators (O'Neill et al., 2003; Grandchamp et al., 2005; Littlewood, 2008; Sjödin et al., 2008); few have focused on micropredators such as haematophagous insects, despite their biting nuisance to humans and livestock, and their role as pathogen vectors (Borges and Brown, 2004; Purse et al., 2012).

Tabanids (Diptera: Tabanidae) are haematophagous cosmopolitan flies that are pests of both humans and livestock. In Europe, tabanids are divided into three subfamilies (Chrysopsinae, Pangoniinae and Tabaninae), comprising 14 genera and more than 170 species (Chvála et al., 1972). By virtue of their diversity and adaptability, tabanids have colonized a wide range of habitats, such as forests, pastures and wetlands, from sea level to alpine altitudes. Although tabanids are mainly livestock pests, their biology and ecology are only partially linked to livestock farming. In contrast to other livestock pests such as horn flies or stable flies, tabanid larvae develop in natural breeding sites (e.g. in rivulets/streams, stagnant water bodies or under forest litter) and not in faeces or manure. Tabanid adults, both males and females, need carbohydrates for flight and a few species are exclusively nectar-feeders (Kniepert, 1980). Tabanid females are opportunistic blood feeders, blood being essential for egg maturation. Most tabanid species preferentially feed on large domestic ungulates (e.g. cows or horses) as well as on wild ungulates (e.g. red deer or wild boar) (Baldacchino et al., 2014b). As a result, tabanid females can mechanically transmit animal disease agents such as *Besnoitia besnoiti* (the agent of bovine besnoitiosis) and the equine infectious anaemia virus (Baldacchino et al., 2014a). Mechanical transmission occurs when the disease agent is transmitted without amplification or development within the vector via contaminated blood on mouthparts. Compared to other arthropod vectors such as mosquitoes or ticks, tabanids have received little study. However, there are growing concerns about tabanid-borne diseases, especially bovine besnoitiosis. This disease is currently spreading in Europe and having an economic impact on herd health management (Alvarez-García et al., 2013; Cortes et al., 2014). Consequently, it is important to understand the factors that affect the geographical distribution of tabanid populations, especially at a large scale.

In this study, we investigated for the first time how environmental variables affect tabanid assemblages on the European scale. To this end, we analysed a dataset that included 38 tabanid samples from 7 European countries, from sea level to alpine altitudes. We characterized the geographical distribution of tabanid fauna at this broad scale and examined the relationship between tabanid assemblages and climate and land use, including the surface area of pastureland, forest and inland water bodies. We hypothesized that (i) an increase in temperature might increase tabanid diversity, and (ii) an increase in pastureland might decrease tabanid diversity and favour eurytopic species. We also tested the influence of the sampling method in our models since the use of different traps could affect the number of tabanid species and specimens collected.

2. Material and methods

2.1. Tabanid data (response variables)

We established a tabanid database from 38 samples, including 2 original samples and 36 previously published datasets. The

sampling was conducted on 22 sites in 7 European countries (Bulgaria, Croatia, France, Germany, Serbia, Spain and Switzerland) between 1971 and 2013 (Fig. 1; See Table A1 in Appendix A in Supplementary materials). The altitude ranged from sea level to 1915 m above sea level. Some sites were sampled over several years, leading to temporal pseudo-replication, which was considered in the statistical analysis (see below) (Crawley, 2007).

Studies on arthropod assemblages may be affected by the sampling method (Littlewood, 2008). In our study, the most frequent sampling method was trapping, using various traps, including the canopy trap, the malaise trap, the Manitoba trap and the Nzi trap (See Fig. B1, B2, B3 and B4 in Appendix B in Supplementary materials); some collections were made using a net around an ungulate. Moreover, most of the data came from Croatia and France: while Nzi traps were systematically used in France, malaise and canopy traps were used in Croatia (Fig. 1). Nzi and canopy traps are made from coloured fabrics, which are visually attractive cues for tabanids, whereas malaise traps intercept flying insects indiscriminately (Mihok and Mulye, 2010). Since different traps may result in variation in the number of species and specimens collected (Baldacchino et al., 2014a), we took the trapping method into account as an effect in the statistical analysis (see below).

2.2. Environmental data (explanatory variables)

We considered two categories of environmental variables in the analysis: climatic and land use variables (See Table A1 in Appendix A in Supplementary materials). We obtained climatic variables from the WorldClim database (<http://www.worldclim.org/bioclim>). Each site was characterized by the annual precipitation and mean temperature, and precipitation and mean temperature in the wettest/driest/warmest/colest quarter (defined as one of the following three-month periods: January–March, April–June, July–September or October–December). Land use variables were defined by the surface area of pastureland, forest and inland water bodies in a 2-km radius around the sampling location. This radius was selected based on tabanids' dispersal capacity – smaller species have a poor dispersal capacity, but larger species such as *Hybomitra* sp. have a mean daily flight range of around 1 km (maximum 2 km) (Konstantinov, 1993). We obtained land cover data from the Corine Land Cover 2006 raster data (<http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2>).

2.3. Statistical analysis

To identify potential geographical patterns in tabanid distribution, we performed a non-metric multidimensional scaling (NMDS) ordination using Bray–Curtis dissimilarities on the fauna dataset of 38 samples without including any explanatory variables using the R package 'vegan' (R Core Team, 2014; Oksanen et al., 2015). This enabled the recognition of spatial gradients across tabanid communities through comparisons of pairwise similarities, or distance, between all samples.

To investigate the influence of environmental variables on tabanid assemblages, we excluded the 6 samples collected between 1971 and 1978 since the Corine Land Cover raster data was generated in 2006, and significant land use changes may have occurred during the last 50 years. Thus, we restricted the following analysis to the 32 samples collected between 1993 and 2013 (Table 1).

We tested the correlation among the explanatory variables using the Pearson's correlation test and excluded variables with an absolute value of Pearson's coefficient >0.7 . We ended up with three climatic variables (annual mean temperature, mean

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