Biodiversity, dilution effect and tick-borne diseases: analysis of the relationship between prevalence of pathogens, tick and host diversities along a landscape gradient

BIODILUTIQUE

BIOSEFAIR Metaprogram

Project summary: 2021 – 2024

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The links between biodiversity and health represent a frontier in science where the concept of the dilution effect plays a central yet still debated role. Tick-borne diseases, which are often zoonotic, provide a particularly relevant pathosystem for exploring this concept. The Biodilutique project explored the links between the biodiversity of host and tick communities and the diversity of pathogens transmitted by these ticks, with a particular focus on bacteria of the genus Borrelia responsible for Lyme disease. We investigated the roles of woodland, grassland and cropland on the diversity of vertebrates and ticks, as well as on the prevalence of the pathogens they carry, across 62 landscape patches (32 each year, including 2 – located within a large forest massif – were common to both years) distributed across two landscape gradients of woodland and grassland proportions within the Plaine & Val de Sèvre Workshop Area.

In the springs of 2022 and 2023, we collected 4,546 ticks, of which 4,386 were found on vegetation, 71 on small mammals and 89 on birds. In total, 7 tick species were identified, of which 90.1% were *Ixodes ricinus*, a generalist species capable of biting humans, and 9.2% were *Ixodes frontalis*, a species specialising in birds (passerines – Turdidae and Corvidae – and Columbidae).

Captures of small mammals (n=271) revealed the presence of six species, the three most abundant being the common shrew (50.2%), the wood mouse (34.2%) and the field vole (10%). Analysis of data from camera traps (n=723 videos) set up in the windows revealed the presence of 10 species of wild mammals and various species of birds (see detailed results). The highest tick densities were observed in the largest wooded areas, whereas smaller wooded areas, particularly those located in less wooded patches and less connected to other wooded areas, had lower or even zero densities.

Analysis of tick DNA revealed an overall prevalence of *Borrelia* of 8.2% (of which 3.2% were *Borrelia* whose main reservoirs are birds and 2.2% whose main reservoirs are small mammals). These ticks collected from vegetation also carried zoonotic pathogenic bacteria as well as protozoa (see detailed results). Analysis of DNA extracted from biopsies of small mammals (n=80) revealed the presence of bacteria and protozoan (see detailed results). Among the *I. ricinus* ticks collected from birds (n=66), 51.5% were infected with *B. garinii* or *valaisiana.*

A multi-host, multi-pathogen mechanistic model was developed. A sensitivity analysis shows a very strong effect of roe deer density; roe deer are incompetent hosts for the multiplication of Borrelia but play an important role in tick population dynamics. Birds appear to play a greater role than small mammals as reservoirs for these pathogens.

A PhD thesis co-funded by Biosefair is continuing this research.

Detailed results

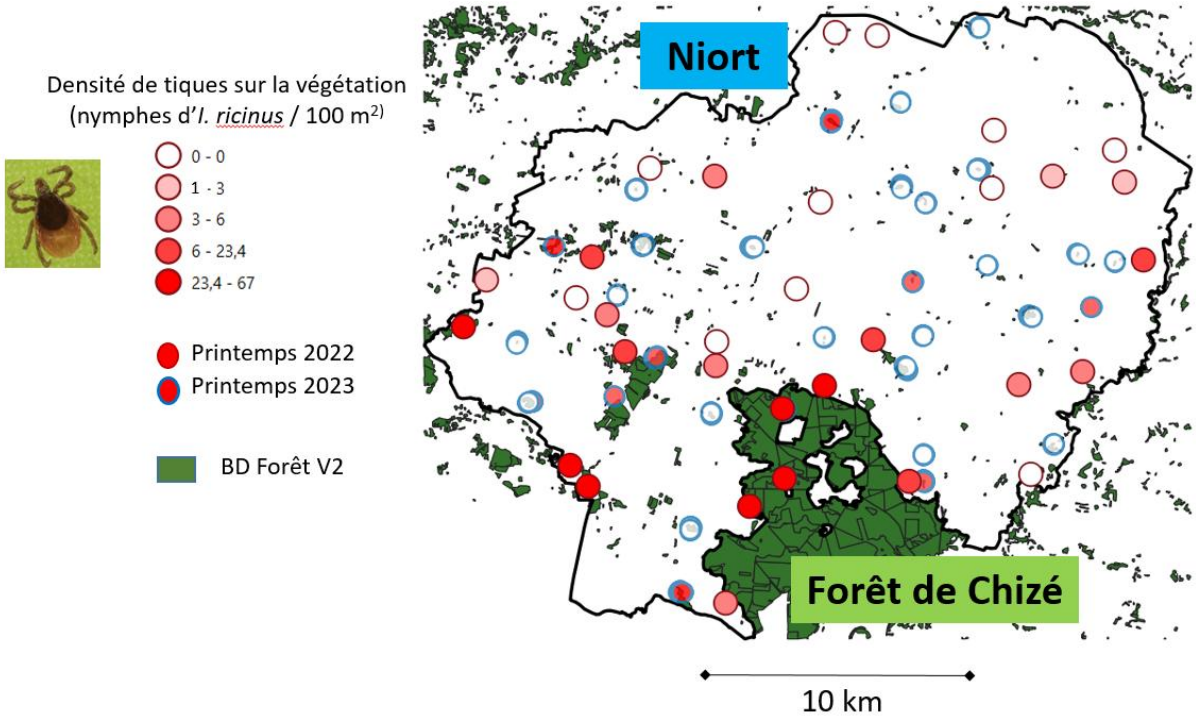
Sampling strategy

In order to investigate the effect of afforestation size and the surrounding landscape context on the species richness of vertebrate tick hosts, as well as on tick density and pathogen

prevalence, 62 one-hectare plots were selected in the Sèvre plain and valley study area. These plots were selected to decouple the proportion of forested areas and grassland, so that the effect of these two explanatory variables could be analysed separately.

Field collection and monitoring

Collections in the spring of 2022 and 2023 yielded 4,546 ticks, of which 4,386 were found on vegetation, 71 on small mammals and 89 on birds. Ticks on vegetation were found in 29 of the 62 sampled plots. Tick density was highest in the largest forest areas (Forêt de Chizé, Bois de la Crignolée, Bois de la Foye, Bois du Fief Dupont, Bois des Touches) in the south-west of the study area, whereas densities were lower in the north-eastern half of the study area, where the proportion of woodland in the landscape and its connectivity are also lower



Seven species of ticks were collected, of which 90.1% were *Ixodes ricinus*, a generalist tick and the main vector of Lyme disease in humans, and 9.2% were *I. frontalis*, a tick specialising in birds (particularly passerines).

In total over the two years, 261 small mammals were captured in the 62 transects:

- 50.2% were red-backed shrews (*Crocidura russula*),
- 34.5% were wood mice (*Apodemus sylvaticus*),
- 10% were common voles (*Microtus arvalis*),
- 4.2% were field voles (*Microtus agrestis*),
- 3 were bank voles (*Myodes glareolus*), and 2 were house mice (*Mus musculus*).
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From these small mammals, 71 ticks were collected, including 66 larvae and 1 nymph of *I. ricinus,* 1 larva and 1 nymph of *I. acuminatus* and *Dermacentor marginatus*.

As for the birds, out of the 277 individuals captured across 21 different species, 94 ticks were collected from 26 individuals of 8 different species (15 blackbirds, 3 song thrushes, 2 dunnocks, 2 robins, 1 nightingale, 1 Cetti's warbler, 1 whitethroat, 1 subalpine warbler). These

ticks comprised 66 nymphs, 10 larvae and 2 females of *I. ricinus*, 5 nymphs and 6 females of *I. frontalis*, 3 nymphs of *Ixodes sp*., 1 nymph of *Haemaphysalis punctata* and 1 of *Hyaloma marginatum.*

Analysis of the footage from the camera traps installed in the 62 windows yielded 728 videos in which the animal that triggered the trap could be identified. These were mainly roe deer (39.8%, observed in almost all windows), followed by European hares (19.1%), birds (18.3%), red foxes (7.4%), mustelids (pine martens or stone martens: 3.4%), lagomorphs (hares or rabbits: 22), cats (22) and domestic dogs (16), wild rabbits (12), European badgers (4), hedgehogs (3), wild boars (2), red squirrels (1).

Characterisation of pathogens

Following DNA extraction from the ticks, pathogen testing was carried out by the BIPAR Joint Research Unit (ANSES, ENVA, Maisons-Alfort) using microfluidic chip-based qPCR.

1,010 ticks of the species *Ixodes ricinus* collected from vegetation in the 29 tick-infested areas were analysed. These revealed an overall prevalence of *Borrelia spp*. of 8.22%. Characterisation down to species level revealed that the most common species was *B. afzelii* (2.18%; main reservoir = small mammals), followed by *B. garini* (1.88%; main reservoir = birds), *B. burgdorferi* sensu stricto (1.68%), *B. valaisiana* (1.19%; main reservoir = birds), *B. myamotoi* (0.79%), whilst *B. lusitaniae, finlandensis* and *turdi* together accounted for a lower prevalence (0.6%). Pathogenic bacteria of the genera *Rickettsia* (7.62%, of which 5.15% due to *R. helvetica*), *Anaplasma* (*A. phagocytophilum*: 3.56%), *Ehrlichia* (*E. sp*.: 1.29%), *Neoehrlichia* (*N. mikurensis*: 0.5%) were also observed, as well as Apicomplexa protozoa (*Babesia venatorum*: 2.48%, *B. divergens*: 0.5%, *Hepatozoon spp*.: 0.1%).

Of the ticks (*I. ricinus*) collected from birds (n=66), 51.5% were infected with *B. garinii* or *valaisiana*.

Modelling and data analysis

A mechanistic multi-host, multi-pathogen model comprising small mammals and birds as hosts, which are competent hosts for *Borrelia afzelli* and *B. garinii* respectively, as well as roe deer as an incompetent host, was developed to explore in silico the consequences of variations in the abundance of these hosts on the tick-borne risk (estimated by the density of infected nymphs) associated with these two species.

Despite a longer duration of infection for *B. garinii* in birds, higher densities of small mammals result in a greater risk for *B. afzelli*. A sensitivity analysis of the R0 and acarological risk values estimated after 5 years of simulation shows a very strong effect of roe deer density, which, whilst an incompetent host for Borrelia reproduction, plays a significant role in tick population dynamics.

Whilst a decreasing gradient in the prevalence of *Borrelia* between eastern and western France is increasingly recognised, it therefore appears that the prevalence of these bacteria in the Plaine and Val de Sèvres study area is relatively high. Birds appear to play a greater role than small mammals as reservoirs for these pathogens (cf. *B. garinii* and *valaisiana versus B. afzelli*).

Regarding data analysis, a PhD thesis, half-funded by MP Biosefair, began in autumn 2025. The research focuses on the influence of wooded areas and their spatial arrangement within the landscape on the tick-borne risk associated with the two aforementioned *Borrelia* species.

The objectives of this work, for which we have recruited Manon Guillaumin, are, on the one hand, to statistically analyse the respective effects of the size of wooded areas and their spatial arrangement and, on the other hand, to develop a dynamic model that will ultimately enable the simulation of the effect of landscape characteristics (connectivity, fragmentation) on risk.

Project outcomes

This study has, for the first time, described the spatial variations in tick density and the prevalence of tick-borne pathogens across the Plaine et Val de Sèvre Study Area, in relation to vertebrate biodiversity and landscape composition. It has identified areas with higher tick densities, particularly in the south-west of the study area, where precautionary measures could be put in place for people visiting these wooded areas, whether for work or leisure.

Scientific implications

Research into the role of biodiversity in relation to ticks and tick-borne diseases could be extended to other landscapes and regions in France or Europe where the regional pool of vertebrate host species differs. During the course of the project, the issue of woodland dynamics, particularly concerning (increasing) copses resulting from natural reforestation following the abandonment of areas within agricultural plots that are difficult to farm (e.g. flood-prone), emerged as a relevant consideration. Furthermore, in order to incorporate the component of acarological risk linked to human exposure, collaborations with colleagues working in public health or the humanities and social sciences would be particularly useful. Investigations into the links between human, animal and environmental health are continuing in the Plaine et Val de Sèvre Workshop Zone, notably through an ambitious transdisciplinary project on ‘Territorial Health:

(https://za-plaineetvaldesevre.com/recherches/ecohealth/).