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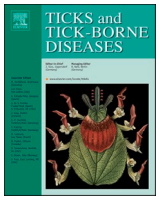

Original article

Ticks in the metropolitan area of Berlin, Germany

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ABSTRACT

A high-resolution city map showing the geographic distribution of 12 tick species (Acari: Argasidae, Ixodidae) that have been recorded from the metropolitan area of Berlin, Germany is presented. A total of 237 tick locations was mapped. These include ten ixodid tick species: *Dermacentor reticulatus, Haemaphysalis concinna, Hyalomma rufipes, Ixodes ricinus, Ixodes canisuga, Ixodes hexagonus, Ixodes arboricola, Ixodes frontalis, Ixodes trianguliceps* and *Rhipicephalus sanguineus* sensu lato. The two tick species *Hy. rufipes* and *R. sanguineus* s.l. are not endemic to Berlin. *Hyalomma rufipes* ticks are introduced in Europe with migratory birds from Africa every spring. *Rhipicephalus sanguineus* s.l. are introduced to Central Europe with dogs that had travelled to or were imported from countries where this tick is endemic. In Germany, they are able to develop and reproduce inside heated buildings. Occurrences of two soft tick species, the pigeon tick *Argas reflexus* and the short-legged bat tick *Carios vespertilionis* were also mapped. Other tick species that are likely to be endemic to Berlin and its environs, but for which documented findings or geographical coordinates are lacking, are mentioned. These include the long-legged bat tick *I. vespertilionis* and the marten tick *I. rugicollis* documented in Brandenburg, the federal state surrounding Berlin. It can be assumed that if appropriate field studies are carried out, these tick species will also be found in the metropolitan area of Berlin. The high-resolution mapping of all tick species found in a city (like Berlin) forms the basis for further investigations into the impact of climate change and changing land use on ticks and tick-borne diseases, precisely in those habitats where most people will live in the future.

1. Introduction

Field research on ticks (Ixodida: Argasidae, Ixodidae) has a long tradition in Berlin. Examples of relevant research on different tick species concern the guide to species identification of nest-dwelling ticks such as *Ixodes canisuga, Ixodes hexagonus, Ixodes rugicollis* and *Ixodes arboricola* (Schulze and Schlottke, 1929), the occurrence of the brown dog tick *Rhipicephalus sanguineus* sensu lato introduced from the Mediterranean (Centurier et al., 1979; Hoffmann, 1981), the host relationships of sub-adult stages of *I. hexagonus* (Matuschka et al., 1990) and *Ixodes ricinus* Matuschka et al. (1991), ticks collected from red foxes (Schöffel et al., 1991), the occurrence of *Argas reflexus*, a tick species exclusively found in human buildings with domestic pigeons (*Columba livia domestica*) nesting nearby (Dautel et al., 1991), the control of *A. reflexus* in Berlin buildings (Scheurer and Dautel, 1994), the seasonal dynamics of *A. reflexus* (Dautel et al., 1994), the winter activity of *I. ricinus* in a Berlin forest (Dautel et al., 2008), the collection of *I. ricinus* and *Ixodes trianguliceps* from urban rodents (Maaz, 2018), the seasonal activity of *Dermacentor reticulatus* (Kohn et al., 2019), and the finding of questing *Ixodes frontalis* larvae (Kahl et al., 2019).

Several studies on the occurrence of tick-borne pathogens in Berlin have also been published. Examples are the detection of the tick-borne encephalitis (TBE) virus in questing *I. ricinus* ticks and the serological detection of antibodies against TBE virus in roe deer (*Capreolus capreolus*) (Kahl and Radda, 1988), the finding of *Borrelia burgdorferi* sensu lato in *I. ricinus* ticks (Kahl et al., 1989), and a study on pathogens in questing *I. ricinus* nymphs resulting in the detection of *Anaplasma phagocytophilum, Borrelia afzelii, Borrelia garinii, Borrelia valaisiana, B. burgdorferi* s.s., and *Rickettsia helvetica* (Pichon et al., 2006). Canine vector-borne pathogens in ticks collected from dogs were investigated by Schreiber et al. (2014). In addition to the pathogens listed above, *Babesia capreoli, Babesia microti, Babesia venatorum, Borrelia miyamotoi, Rickettsia monacensis, Rickettsia raoultii*, and *Candidatus* Neoehrlichia mikurensis were detected in ticks collected in or close to Berlin.

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The specifics of ticks and tick-borne diseases in urban areas, reflecting the studies listed above, have been discussed in detail by Dautel and Kahl (1999) and Uspensky (2014). Despite all this extensive research, there is still no high-resolution map showing the distribution of all species of ticks found in the metropolitan area of Berlin. Many of the tick findings mapped here are therefore not included in publications on the global distribution of ticks, since historical German-language literature is difficult to obtain (Hoffmann, 1981; Negrobov and Borodin, 1964; Schulze and Schlottke, 1929). This gap is closed with the present work.

2. Materials and methods

Berlin, the capital of Germany, is located at the geographical coordinates 52.52° N/13.40° E. It has approximately 3.7 million inhabitants, and approximately 10% of its surface is covered by forest. The warm temperate climate with precipitation in all seasons is classified after Köppen–Geiger as a Cfb climate (Kottek et al., 2006). Fig. 1 shows the seasonal cycles of the monthly temperature and precipitation observations in Berlin with an annual mean temperature of 10.2 °C and an accumulated precipitation of 606 mm/year. Georeferenced locations of ticks published in Rubel et al. (2021, 2014) were used and supplemented by newly compiled tick locations. These data come from the authors themselves or from the literature.

Data of tick species compiled by Rubel et al. (2014) were obtained by the following authors: 14 *D. reticulatus* (Dautel et al., 2006), 10 *I. ricinus* (legit, i.e. collected by Olaf Kahl, 2014), 2 *D. reticulatus* (Menn, 2006), 1 *Haemaphysalis concinna* (leg. Hans Dautel, 2010), 7 *I. ricinus* and 4 *D. reticulatus* (Hagedorn, 2013), 9 *I. ricinus* (Gupta et al., 1995), 12 *I. ricinus* (Estrada-Peña et al., 2013). Data of tick species compiled by Rubel et al. (2021) were obtained by the following authors: 1 *A. reflexus* (leg. Olaf Kahl, 1978), 1 *I. hexagonus* (leg. Hans Dautel, 2003), 11 *D. reticulatus*, 10 *I. ricinus* and 2 *I. hexagonus* (Schreiber et al., 2014), 1 *I. canisuga* and 1 *I. hexagonus* (Liebisch and Walter, 1986), 3 *D. reticulatus* (Kohn et al., 2019), 1 *C. vespertilionis* (Walter and Kock, 1985), 6 *R. sanguineus* s.l. (Hoffmann, 1981), 2 *A. reflexus* (Dautel et al., 1991), 1 *I. canisuga* and 1 *I. hexagonus* (Cornely and Schultz, 1992), 28 *D. reticulatus* (Naucke, 2007), 3 *I. frontalis* (Kahl et al., 2019), 1 *R. sanguineus* s.l. and 2 *A. reflexus* (leg. Hans Dautel, 2017), 3 *I. ricinus* and 3 *D. reticulatus* (Kahl et al., 2021).

The present study deals also with some rarely observed tick species. These include, for example, the short-legged bat tick *Carios vespertilionis*, for which a Europe-wide dataset of georeferenced locations was recently published by Sándor et al. (2021). Further tick locations were extracted from some of the studies already cited above (Hoffmann, 1981; Schreiber et al., 2014), which were not digitized by Rubel et al. (2021, 2014) but are here added to compile a high-resolution map of Berlin. The authors' unpublished data from 1978–2020 were also used. In total, 97 new tick locations were digitized for the Berlin map, which can be traced back to the following authors: 1 *I. arboricola* (Schulze and Schlottke, 1929), 8 *R. sanguineus* s.l. (Hoffmann, 1981), 1 *I. ricinus*, 5 *I. hexagonus* and 5 *I. canisuga* (Schöffel et al., 1991), 1 *C. vespertilionis* (Walter, 1992), 1 *C. vespertilionis* (Hoffmeister et al., 2008), 8 *A. reflexus* (Dautel et al., 1999), 1 *C. vespertilionis* (Scheffler, 2013), 4 *D. reticulatus*, 6 *I. ricinus* and 10 *I. hexagonus* (Schreiber et al., 2014), 2 *I. trianguliceps* and 4 *I. ricinus* (Maaz, 2018), 8 *I. ricinus* (leg. Hans Dautel, 1995–2018), 1 *D. reticulatus*, 1 *I. frontalis* and 3 *Hyalomma rufipes* (leg. Ard Nijhof, 2018), 3 *D. reticulatus* and 23 *I. ricinus* (leg. Olaf Kahl, 1978–2020).

The tick locations in the metropolitan area of Berlin were mapped with the R software (R Development Core Team, 2021) using the OpenStreetMap data from Stamen (https://stamen.com).

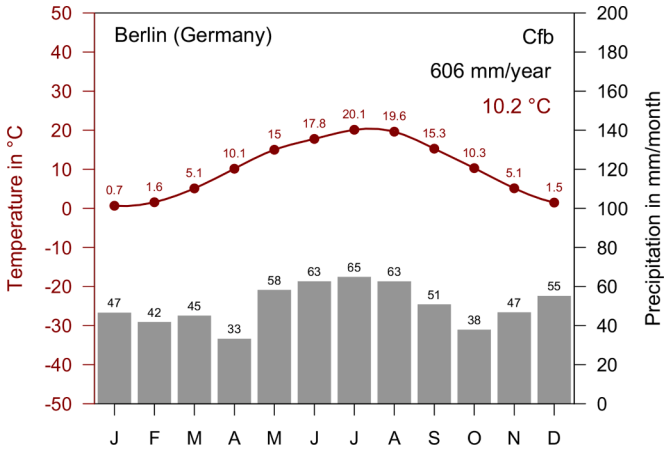

Fig. 1. Climate diagram representative for the metropolitan area of Berlin, Germany. Climate classification after Köppe–Geiger Cfb, annual mean temperature 10.2 °C, accumulated precipitation 606 mm/year (period 1986–2010).

3. Results and discussion

The final result of this work is a distribution map of 12 tick species with altogether 237 tick locations in the metropolitan area of Berlin (Fig. 2). The following ten ixodid tick species were mapped: *D. reticulatus, Ha. concinna, Hy. rufipes, I. arboricola, I. canisuga, I. frontalis, I. hexagonus, I. trianguliceps, I. ricinus*, and *R. sanguineus* s.l. In addition, occurrences of the two soft ticks *A. reflexus* and *C. vespertilionis* were mapped. Except for *Ha. concinna* (leg. Hans Dautel, 2010) and *Hy. rufipes* (leg. Ard Nijhof, 2019), which had been found some kilometres outside the city of Berlin (Fig. 2), all other mapped tick species have also been found within the city's political boundaries. It must also be mentioned that *Hy. rufipes* and *R. sanguineus* s.l. are definitely not endemic to Berlin.

The two most frequently documented species are *I. ricinus* with 94 locations and *D. reticulatus* with 73 locations. *Ixodes ricinus* is by far the most commonly found tick species in Berlin and its environs when flagging vegetation or when collecting ticks from suburban and urban rodents. *Ixodes ricinus* larvae and nymphs were collected from black-striped field mice (*Apodemus agrarius*), wood mice (*Apodemus sylvaticus*), yellow-necked mice (*Apodemus flavicollis*), field voles (*Microtus agrestis*), common voles (*Microtus arvalis*) and bank voles (*Myodes glareolus*) trapped at four study sites in Berlin (Maaz, 2018). In that study, 99.2% of the ticks collected were *I. ricinus*, infesting 56% of the rodents with an average of 9.4 immature ticks per infested rodent. *Ixodes ricinus* has been found in all city forests and some city parks, and also occurs in gardens, cemeteries and comparable green areas, as observed in other European cities (Rizzoli et al., 2014). It has apparently benefitted from the change of park policy in the 1980s in former Berlin (West) from removing all the leaf litter in the late autumn to leaving the leaf litter in the shrubbery of parks. Only 0.7% of the ticks were vole ticks *I. trianguliceps* found on *A. flavicollis* and *M. glareolus*. *Ixodes trianguliceps* was also found in Brandenburg, the federal state surrounding Berlin, on *A. flavicollis* and *M. arvalis* (Negrobov and Borodin, 1964). This tick species is therefore likely to be much more widespread in and around Berlin than the two locations shown on the map suggest. The remaining 0.1% of ticks on rodents were immature *D. reticulatus*, but it has to be borne in mind that the latter are only active in the summer. *Dermacentor reticulatus* is less a forest than a steppe inhabitant. Suitable habitats exist abundantly in the close environs of former Berlin (West), also in and close to the former border area. *Dermacentor reticulatus* (adults) were already flagged from vegetation in eastern Germany by Kahl et al. (1992). However, the presumably first findings of *D. reticulatus* in and around Berlin were only made in the year 2000 by Dautel and Kahl (unpublished). Today, this tick species is abundant, locally even very abundant in and around Berlin. The fact that there are 73 locations of *D. reticulatus* in the map (Fig. 2) might be favoured by the existence of many water bodies with their adjacent forests, parks or steppe-like open landscapes, that provide sufficient humidity and also warm summer

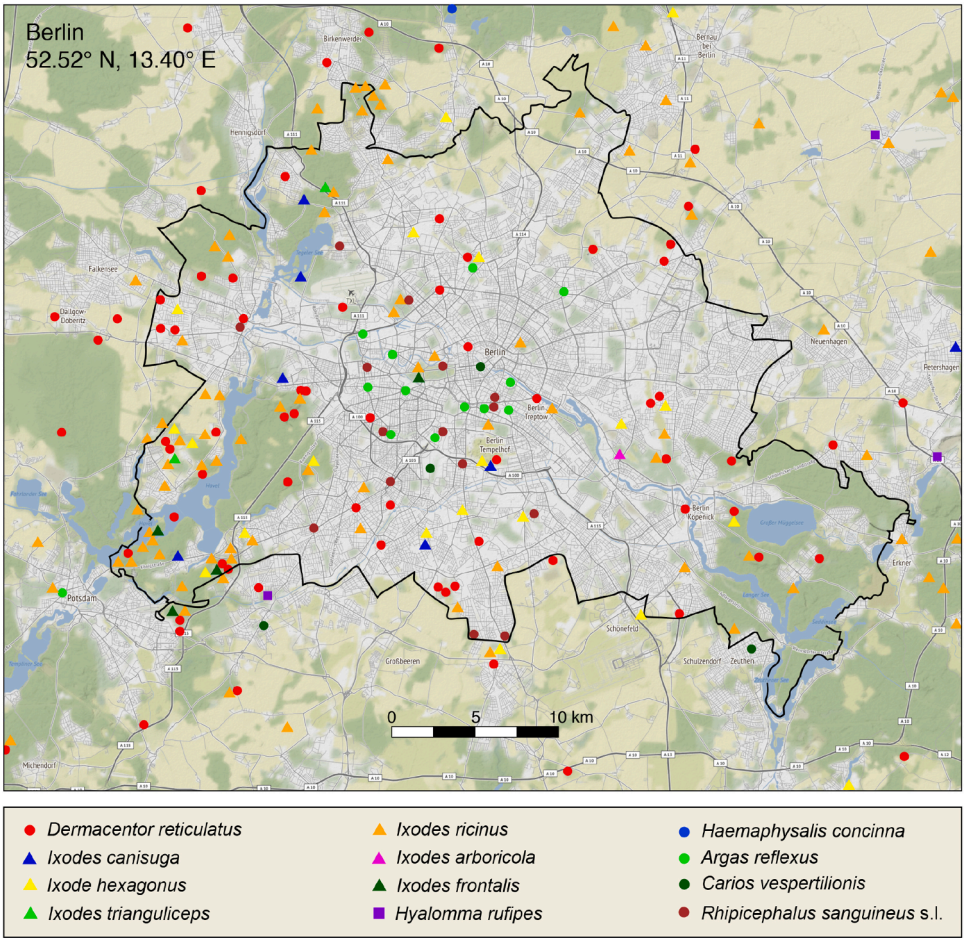

Fig. 2. Recorded locations of 12 tick species in the metropolitan area of Berlin, Germany.

conditions to speed up the development of engorged larvae and nymphs of *D. reticulatus*. These often recreational areas are used intensively by dog owners for their walks, and adult *D. reticulatus* are frequently found on dogs as documented by Dautel et al. (2006) and Schreiber et al. (2014). Adult *D. reticulatus* were also collected from roe deer (*Capreolus capreolus*) at one location in Berlin (Dautel et al., 2006).

With 15 mapped locations, the brown dog tick *R. sanguineus* s.l. is also one of the most frequently documented tick species in Berlin. The old study by Hoffmann (1981) was restricted to former Berlin (West). *Rhipicephalus sanguineus* s.l. usually come to Central Europe with dogs taken from touristic travelling or by importations and are able to develop and reproduce inside houses. It can survive the winter in Germany only indoors and may occur permanently in houses or animal shelters if not eliminated by professional pest controllers. An unpublished recent indoor outbreak of this exotic and widespread tick species (leg. Hans Dautel, 2017) documents that *R. sanguineus* s.l. is still introduced today.

A tick that has also often been found in houses especially in the 1980s and 1990s is the soft tick *A. reflexus*. In the 1990s, a total of 188 buildings infested with that pigeon tick was identified in Berlin by Dautel et al. (1999). Geographic coordinates are known from 13 locations of this tick, which are associated with the occurrence of domestic pigeons (*Columba livia domestica*) and rock pigeons (*Columba livia livia*). Both pigeon subspecies belong to the present city fauna of Berlin. *Argas reflexus* was a serious pest in Berlin (West) in the 1970s and 1980s. Numerous buildings that had been neglected for many years after World War II housed high numbers of pigeons and with them *A. reflexus*, which are extremely resistant against high and low temperatures, against dryness, and they are also capable of fasting for several years. People, not necessarily the owners, decided to take possession of these houses and renovated them. They expelled the pigeons from these houses and moved in. However, nobody thought of the long-lived pigeon ticks that still lived in the buildings, and they attacked the human inhabitants of these houses after some years of living without their natural hosts. The nocturnal bites and in some cases also resulting allergies (Type IV hypersensitivity) posed a heavy stress and even risk for the involved people, and in many cases expensive control measures had to be taken (Dautel and Kahl, 1999; Dautel et al., 1991). With the gradual technical improvement of houses, the significance of *A. reflexus* as a human pest distinctly decreased in the late 1990s and 2000s and seems to be low up to now.

The second species of soft tick reported from Berlin is the short-legged bat tick *C. vespertilionis*, formerly known as *Argas vespertilionis* (Mans et al., 2021). The four mapped locations of *C. vespertilionis* refer to findings on rearmice, *Vespertilio murinus* (Hoffmeister et al., 2008; Walter and Kock, 1985), serotine bats, *Eptesicus serotinus* (Walter, 1992), and common noctules, *Nyctalus noctula* (Scheffler, 2013).

Tick species associated with carnivores and/or insectivores are *I. canisuga* and *I. hexagonus*. Although only seven locations of *I. canisuga* have been documented, this tick species might be widespread in the mapped area. The main host of *I. canisuga*, the red fox (*Vulpes vulpes*), is known as a domiciliated species in Berlin. Schöffel et al. (1991) estimated the number of foxes living in the former Berlin (West) at 400–600. The fox population, which has risen sharply in recent decades, is now estimated at around 2000 individuals for the entire metropolitan area of Berlin. From this study, 27% of the foxes examined were infested with *I. ricinus*, 18% with *I. hexagonus* and 15% with *I. canisuga*. A total of five locations with red foxes infested with *I. canisuga* and just as many

locations of red foxes infested with *I. hexagonus* were mapped according to Schöffel et al. (1991). Further locations with *I. canisuga* collected from dogs and rarely from cats have also been documented (Cornely and Schultz, 1992). The latter study describes that *I. hexagonus* was mostly collected from dogs. There is also a study concerning the occurrence of *I. hexagonus* on hedgehogs in an area where the spirochaetal agents of Lyme borreliosis have repeatedly been detected in nymphal and adult *I. ricinus*. In this study, *I. hexagonus* was found on all 51 captured hedgehogs (Matuschka et al., 1990). However, no location information suitable for mapping was given. Since Berlin, with its forests, parks and vast garden areas, offers good habitats for the European hedgehog (*Erinaceus europaeus*), *I. hexagonus* might be much more widespread than the 20 mapped locations suggest.

Tick species associated with birds are *I. frontalis* and *I. arboricola*. At three locations the passerine tick *I. frontalis* was recently flagged from the vegetation (Kahl et al., 2019). Here, four locations were mapped along with one unpublished finding (leg. Ard Nijhof, 2016). Two findings of the tree-hole tick *I. arboricola*, which parasitizes small passerine birds, are known from Schulze and Schlottke (1929). However, only the location of one specimen, found on a tree trunk, could be mapped. For the second finding on a tawny owl (*Strix aluco*) no geographical coordinates were provided.

Finally, three locations of *Hy. rufipes* were mapped. All these ticks were found on horses, which agrees with findings from other areas of Germany. *Hyalomma rufipes* (as well as *Hyalomma marginatum*) are introduced to Europe with migratory birds each spring, but the engorged nymphs that drop off from these birds are seemingly able to develop to the adult stage only in exceptionally warm summers in Central Europe, for example in 2018 (Chitimia-Dobler et al., 2019). The findings in the metropolitan area of Berlin also date from 2018 and are located just a few kilometres outside the city in Werneuchen (northeast of Berlin), Rüdersdorf (east of Berlin) and Kleinmachnow (south of Berlin). There are numerous riding stables and equestrian centres in the mentioned regions.

Up to 1987, many tortoises were imported to Germany from the former Yugoslavia and Greece and officially sold in pet shops, which is now prohibited by law. Ticks not endemic in Germany have been frequently imported via these and other reptiles. *Hyalomma aegyptium*, the dominant tick on tortoises of the genus *Testudo*, was found several times on unspecified tortoises in a pet shop in Potsdam (Negrobov and Borodin, 1964). These findings of Mediterranean ticks were not considered here.

It seems that there is documented evidence not for all tick species endemic to Berlin. This includes, for example, the long-legged bat tick *I. vespertilionis*. There are no current studies in Germany on this cave-dwelling tick species, whose males are often found on the walls of caves, grottes, mines, subterranean vaults, cellars or other bat roosts (Neumann, 1916). It is much more difficult and expensive to look for larvae, nymphs and females on bats. Four specimens of *I. vespertilionis* were collected from the lesser noctule (*Nyctalus leisleri*) in the Zehernsdorf forest, 30 km south of Berlin (Negrobov and Borodin, 1964). Schmidt (1987) documented another location, 65 km north-east of Berlin in the Melzow forest. There *I. vespertilionis* was found on Nathusius' pipistrelle (*Pipistellus nathusii*). Both the lesser noctule bat and the Nathusius' bat are woodland bats that inhabit tree holes. They are also known to be infested with *I. vespertilionis* (Ševčik et al., 2010). Their findings are not yet mapped in the *Atlas of Ticks in Germany* (Rubel et al., 2021), but will be added with the first data update.

A finding of *I. rugicollis* on a European pine marten (*Martes martes*) in or close to Berlin was mentioned by Schulze and Schlottke (1929). An exact location is missing, which is why this finding could not be mapped. Since further findings of *I. rugicollis* on pine marten and feral minks (*Neovison vison*) are documented south of Berlin (Christian, 2002; 2010), this nest-dwelling tick species may also occur in the mapped area (Fig. 2).

In Central Europe, there are only few recent studies on tick species such as *I. rugicollis, I. arboricola, I. trianguliceps, I. vespertilionis* or *C. vespertilionis*, which have to be collected from wild animals, some of which are strictly protected. Conversely, there are more and more species of ticks that were hardly known until recently, such as *Hy. marginatum* and *Hy. rufipes*, whose increased occurrence is attributed to climate change. *Ixodes ricinus, I. hexagonus* or *D. reticulatus* collected from domestic animals such as dogs and cats, on the other hand, are increasingly documented in the context of citizen science projects.

The high-resolution mapping of all tick species found in a city (like Berlin) forms the basis for further investigations into the impact of climate change and changing land use on ticks and tick-borne diseases, precisely in those habitats where most people will live in the future.

4. Conclusions

A first high-resolution map of Berlin depicting 237 locations with 12 species of ticks was presented here. The locations of two other tick species, *I. vespertilionis* and *I. rugicollis* could not be mapped. Thus, it can be concluded that at least 14 tick species are established in or around Berlin or at least occur there sporadically. Some of the listed species bite people and may transmit pathogens, other species live a rather hidden life. Quite a number of vertebrates (e.g. foxes) have reached a very high abundance in Berlin and in its environs, and ticks may take advantage from the high availability of certain host species there. The difference in the number of tick findings between the eastern and the western parts of Berlin, might be caused by differing search efforts.

Digital data are available to the scientific community in the *Atlas of ticks in Germany* (Rubel et al., 2021). New data presented here will be supplemented with the next update to provide a consistent, non-redundant database for Germany.

CRediT authorship contribution statement

Franz Rubel: Conceptualization, Methodology, Data curation, Software, Visualization, Writing – original draft, Writing – review & editing. **Hans Dautel:** Data curation, Writing – review & editing. **Ard M. Nijhof:** Data curation, Writing – review & editing. **Olaf Kahl:** Data curation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

Authors declare that they have no conflict of interest.

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