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REVIEW ARTICLE

Review of ticks attacking domestic dogs and cats, and their epidemiological role in the transmission of tick-borne pathogens in Poland

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Abstract

Introduction. Progressive climate change plays a major role in the expansion of tick populations, as well as the transmission of tick-borne disease pathogens (TBPs) to humans and animals throughout the world. Zoonoses are a growing environmental problem of great importance for public health. In Poland, domestic dogs and cats are mainly infested by *Ixodes ricinus*, *Ixodes crenulatus*, *Ixodes hexagonus*, *Ixodes rugicollis* and Dermacentor reticulatus ticks from the Ixodidae family. Other tick species, such as I. apronophorus and Haemaphysalis concinna, recorded sporadically on domestic dogs or cats, may expand their range in the future and successfully infest pets. Individual cases of infestations in Poland with foreign tick species, such as Rhipicephalus sanguineus, are known and may soon be recorded more frequently.

Objective. The aim of this review is to summarize the occurrence and identification of tick species and TBDs that are present or are likely to spread in Poland, which, given the medical and veterinary importance of ticks, may help in the development of public health strategies.

Review Methods. A comprehensive literature review of publications and own research and data analysis was performed, obtained from reports and scientific descriptions on the epidemiology of tick-borne diseases.

Brief description of the state of knowledge. The ecology of ticks and hosts in urban and suburban environments is critical for quantifying the parameters necessary for an initial risk assessment, and identifying public health strategies to control and prevent TBDs. In the future, these species may expand their range of occurrence and their host, becoming common members of the Polish tick fauna.

Summary. Anaplasma, Babesia, Borrelia and Rickettsia spp. are the major TBPs in Poland, and their prevalence is usually higher in dogs than cats.

Keywords

Poland, tick-borne diseases, domestic cats, domestic dogs, Ixodidae

INTRODUCTION

In recent years, there has been a significant increase in the incidence of tick-borne diseases (TBDs) [1]. This is thought to be the result of a number of factors, including progressive climate change, that affect the range and abundance of ticks. Climate and environmental changes are contributing to the expansion of the range of tick species to higher latitudes and higher altitudes. Seasonal tick activity lengthens as temperatures rise, promoting the spread of TBDs to new areas. Elevated temperatures increase tick survival and their range of hosts, which results in longer seasons during which people and animals can be exposed to tick attacks. Additionally, global warming may alter the spread of TBDs. Climate determines the geographical distribution of ticks, their density and their pathogenicity, leading to an increasing frequency of contacts among humans and animals. Changes in biotopes are associated with deforestation, reforestation, and the increased rate of urbanization [1]. The presence of tick hosts in cities and suburban areas carries the risk of potentially increased exposure to tick infestations and the spread of TBDs [1].

Understanding the ecology of ticks and their hosts in urban and suburban environments is critical for quantifying the parameters necessary for an initial risk assessment and identifying public health strategies to control and prevent TBDs. Socio-demographic factors, agriculture and wildlife management, deforestation and reforestation are known to have key impacts on biotope transformations, thus affecting tick host communities and rates of tick infection [2]. In general, urban and suburban habitats have less biodiversity in wild species compared to natural ecosystems. In addition, animal populations in urban areas may show genetic differences from wild populations of the same species [2]. In this way, urbanization can alter the biology and density of tick and host populations and can lead to increased transmission of pathogens between vectors and urban-adapted hosts [2]. The increasing presence of wild animals in urban environments can lead to increased exposure and risk of infestation by dangerous parasites in humans and pets. The increasing

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pace of urbanization is related to human mobility, long-distance trade, and interactions with nature by humans and companion animals, which could change epidemiological conditions in urban and suburban areas [3]. The circulation of pathogens and transmission of diseases in nature are determined by the range of a vector (tick) and the presence of animals belonging to the natural source (reservoir) of the etiological factors (e.g., small rodents, deer, and birds) in an ecosystem. Geographical distribution and degree of tick density, the population density of birds and mammals infected with pathogens, and the local properties of the biotopes themselves are also significant [2].

Poland is located in Central Europe in the zone of moderate warm transitional climate, with a mountain climate in the higher parts of the country. Each tick species has preferred environmental conditions for its development that determine its distribution. Throughout Poland, the most common tick species affecting domestic cats (*Felis catus*) and dogs (*Canis lupus familiaris*) is *Ixodes ricinus* (Linnaeus, 1758). It has also been shown that domestic animals can be infested by *I. hexagonus* (Leach, 1815), *I. crenulatus* (Koch, 1844), *I. rugicollis* (Schulze and Schlottke, 1929), and *Dermacentor reticulatus* (Fabricius, 1794) [4, 5, 6, 7, 8, 9, 10, 11, 12].

Cases of infestations with *Rhipicephalus sanguineus* (Latreille, 1806) in Poland that have come from Southern European countries have been reported [13, 14]. Domestic dogs and cats can additionally be infested by other tick species, such as *I. persulcatus* (Schulze, 1930), *Haemaphysalis punctata* (Canestrini and Fanzago, 1878), and *H. concinna* (Koch, 1844) [5].

In a study conducted by Kantar Public in 2017 [15], it was noted that 62.0% of the people surveyed who were living in rural areas and small towns had a domestic dog or cat, while 30.0% of those living in urban environments also had a domestic dog or cat. Various pathogens are responsible for human and animal diseases, including viruses, bacteria, and protozoa, which can be detected in ticks collected from dogs and cats. Domestic animals play an important role in the circulation of pathogens. Global warming and hydrological changes are accompanied by changes in the fauna of ticks, population size, and dynamics of activity in different areas [16].

The One Health concept refers to the protection of human health through the interaction of animal health protection and the consideration of environmental influences on human and animal health [17]. In the context of the present review, this concept draws attention to the role that human companion animals, especially dogs and cats, play in the transmission of infectious diseases in humans and animals, and to the fact that ticks are important in the pathogen cycles of tick-borne diseases (TBP) [1].

The aim of this review was to summarize the occurrence and identification of tick species and TBDs in domestic dogs and cats that are present or are likely to spread in Poland which, given the medical and veterinary importance of ticks, may provide advice to public health strategies (Tab. 1).

MATERIALS AND METHOD

A comprehensive literature review of the available publications and own research and data analysis was performed to gather information from reports and scientific descriptions on the occurrence of ticks in Poland and the epidemiology of TBDs. The literature search was conducted using PubMed and Google Scholar with the use of key words: tick dogs Poland, tick cats Poland, tick-borne pathogen in domestic dogs/cats Poland, conference abstracts, and specialist monographs.

TICK SPECIES ATTACKING DOMESTIC CATS AND DOGS IN POLAND

Ixodes ricinus. Recognized as the species of the greatest medical and veterinary importance among parasitic arthropods, and is the most common tick species in Poland [18]. It is a polyxenic parasite, and its host can be any terrestrial vertebrate that occurs in its habitat naturally as well as incidentally. *I. ricinus* is involved in the transmission of many pathogens, such as tick-borne encephalitis virus (TBEV) and *Borrelia burgdorferi* sensu lato (causative agent of Lyme borreliosis), as well as *Rickettsia slovaca*, *R. helvetica*, *Coxiella burnetii*, *Anaplasma phagocytophilum*, *Babesia canis*, *B. microti*, *B. capreoli*, *B. ovis*, *B. divergens*, and *Theileria mutans* [19].

During a long-term study between 2002 and 2014 in southern Poland (Lesser Poland Province), 908 *I. ricinus* ticks were collected from 1,500 domestic dogs, which amounted to an infestation rate of 29.8% [8]. In contrast, in a study of 500 domestic cats in the same province, 477 *I. ricinus* ticks were collected (96.0% of the animals were infested), including 368 females, 108 males, and one nymph. Ticks were collected in the greatest numbers during the spring peak of activity [10]. In 2017–2018, ticks were collected from 10 domestic cats and 88 domestic dogs, from which were identified 119 *I. ricinus* females among eight of the cats and 82 of the dogs [20].

In a study by Pawełczyk et al. [21], 23 *I. ricinus* were collected from domestic dogs and cats in 2013 in the Silesian Province (south-west Poland). Asman et al. [22] confirmed the occurrence of *I. ricinus* in 28 domestic dogs and 26 domestic cats in the same province. In 2017–2018, 861 *I. ricinus* were collected from 130 cats and 33 dogs in Lesser Poland and the Silesian Provinces. Pet infestations were most common in April and May, while the presence of these ticks was found least frequently in February and September. In the Lesser Poland Province, a total of 459 *I. ricinus* were collected from 168 domestic dogs and 47 domestic cats, including 392 females, 37 males, and 30 in copula. In contrast, 402 *I. ricinus* were collected from 171 dogs and 83 cats in the Silesian Province, including 351 females, 10 males, 40 in copula, and one nymph [23].

In the western part of the country (Lower Silesian Province), *I. ricinus* predominated in ticks collected from 373 dogs and 78 cats, with 88.6% of the ticks belonging to this species. In another study evaluating 689 dogs and 162 cats, 1,272 *I. ricinus* were found (dominated by females), which accounted for 87.4% of all ticks collected. The highest number of *I. ricinus* was collected from dogs (,005 specimens), along with 267 *I. ricinus* from cats [24, 25].

A multi-year study (2009–2016) in north-eastern Poland (Warmian-Masurian Province) demonstrated the predominance of *I. ricinus* (60.14%) in domestic dogs, with the highest prevalence being females (1,283 ticks), followed by nymphs (1,243 ticks) [14]. Between 2016–2018, 423 *I. ricinus* (81.0%) were collected from 272 dogs in the same area, including 413 females and 10 males [12].

Table 1. Summary of information on ticks affecting dogs and cats in Poland and their veterinary significance

Tick species	Host (dog/cat)	Place of harvest (province)	Pathogens
Ixodes ricinus	dogs, cats	Southern Poland (Lesser Poland, Silesian Province) **[8, 10, 20, 21, 22, 23]** Western Poland (Lower Silesian Province) **[24, 25, 26]** South-eastern Poland (Subcarpathian Province) **[7, 27, 28]** Eastern Poland (Lublin Province) **[11]** North-eastern Poland (Warmian-Masurian Province) **[12, 14]** Central Poland (Masovian Province) **[4]**	*Anaplasma phagocytophilum* **[6, 12, 20, 34]** *Rickettsia* spp., *R. helvetica, R. monacensis* **[9, 65]** *Babesia microti*, *B. venatorum*, *B. canis*, *B. gibsoni* **[9, 20, 21, 53, 60]** *Borrelia burgdorferi* s.l., *B. burgdorferi* s.s. **[11, 12, 24, 34, 53]** *Toxoplasma gondii* **[20, 22]** *Bartonella* spp. **[52]** *Candidatus* Neoehrlichia mikurensis **[9]** Co-infection: *A. phagocytophilum* and *B. microti* **[9, 21, 53]** *Rickettsia* spp. and *A. phagocytophilum* **[9]** *Cand.* N. mikurensis, *A. phagocytophilum* and *Rickettsia* spp. **[9]** *Cand.* N. mikurensis, *A. phagocytophilum* and *Babesia* spp. **[9]** *B. microti* and *B. burgdorferi* s. l. **[53]** *B. microti* and *T. gondii* **[22]** *Rickettsia* spp. and *Cand.* N. mikurensis **[9]** *Rickettsia* spp. and *Babesia* spp. **[9]** *Cand.* N. mikurensis + *Babesia* spp. **[9]**
Ixodes hexagonus	dogs, cats	Southern Poland (Lesser Poland, Silesian Province) **[8, 23, 30]** South-eastern Poland (Subcarpathian Province) **[7, 27]** Eastern Poland (Lublin Province) **[11]** Western Poland (Lower Silesian Province) **[9, 24, 25]** Central Poland (Masovian Province) **[26]**	*Anaplasma phagocytophilum* **[9]** *Babesia microti* **[20, 53]** *Borrelia burgdorferi* s.l. **[11, 24]** *Rickettsia* spp. **[9]** *Toxoplasma gondii* **[20]** *Cand.* N. mikurensis **[9]**
Ixodes crenulatus	dogs, cats	Southern Poland (Lesser Poland, Silesian Province) **[23, 32]** South-eastern Poland (Subcarpathian Province) **[7]**	*Rickettsia* spp. **[32]**
Ixodes rugicollis	dogs, cats	South-eastern Poland (Subcarpathian Province) **[7]**	No data
Ixodes apronophorus	cat	Southern Poland (Silesian Province) **[23]**	No data
Dermacentor reticulatus	dogs, cats	Southern Poland (Lesser Poland, Silesian Province) **[8, 23]** Western Poland (Lower Silesian Province) **[9]** Eastern Poland (Lublin Province) **[11, 28, 41]** North-eastern Poland (Warmian-Masurian Province) **[12, 13, 26]** Central Poland (Lodz, Masovian Provinces) **[4, 26]**	*Anaplasma phagocytophilum* **[11, 41, 55]** *Babesia canis* **[6, 34, 59]** *Borrelia burgdorferi* s.l., *B. garinii*, *B. afzelii* **[12, 24]** *Rickettsia* spp., *R. raoultii* **[9]** Coinfection: *B. canis* and TBEV **[58, 70]**
Rhipicephalus sanguineus	dogs	Northeastern Poland (Warmian-Masurian Province) **[13]** Central Poland (Masovian Province) **[14]**	No data
Haemaphysalis concinna		Central-Western Poland (Greater Poland and Lower Silesian Province) **[45]**	No data

In central Poland (Masovian Province), studies were also carried out on the occurrence of ticks in domestic animals. In a two-year collection (200–2005), a total of 519 ticks from 316 domestic dogs were found, with 209 ticks belonging to the *I. ricinus* species [4]. In a study by Mierzejewska et al. [26] in western and northern Poland, *I. ricinus* was not the dominant tick species affecting domestic dogs, but it was the dominant species in cats.

In the eastern part of the country, 136 *I. ricinus* were collected from 65 dogs and 119 cats in 2015–2017, accounting for 73.9% of all ticks. Ticks were located on the neck (48.1%) and around the mouth (17.1%), paws (14.9%), abdomen (10.5%), and back (9.4%) [11]. The high proportion of ticks found on the head has been confirmed by other studies [7, 23, 27]. Domestic dogs from south-eastern Poland (Subcarpathian Province) were also dominated by *I. ricinus*; 153 females and 58 males were collected from 40 dogs, for a prevalence of 47.56% [27]. Siuda et al. [7] confirmed the occurrence of this species in domestic dogs in Subcarpathian Province. In a three-year study (2017–2019), 223 *I. ricinus* (44.5%) were collected from 24 domestic dogs and 98 dogs from a shelter. This species was not dominant in that part of the country [28].

Ixodes hexagonus. This species lives in upland and lowland areas, in nests, burrows, and host cavities. It can also be found in close proximity to dog kennels that are near human homes [19]. The most common hosts of this parasite are hedgehogs (*Erinaceus europaeus*), weasels (Mustelidae), foxes (*Vulpes vulpes*), domestic dogs and cats (Canidae, Felidae), rodents (Rodentia), and deer (*Capreolus capreolus*). *I. hexagonus* rarely attacks humans [19, 29].

I. hexagonus is involved in the transmission of pathogens such as *Borrelia burgdorferi* s. l., *R. helvetica*, *R. conorii*, *Anaplasma phagocytophilum, Babesia* spp. [19].

In southern Poland, a study conducted between 2002–2014 in the Lesser Poland Province (Małopolska) found 30 *I. hexagonus* collected from 1,500 domestic dogs [8]. Conversely, between 2004–2015, only seven specimens, including six nymphs and one male, were recorded from more than 500 domestic cats. Thirty-six *I. hexagonus* were collected in mountain areas from two cats and six dogs, including 15 larvae, 13 nymphs, and eight females [11]. Another study found one specimen from a domestic dog in the Silesian Province [30]. In Lesser Poland and Silesian Provinces, 107 *I. hexagonus* (3.9%) were collected from 1,209 dogs and 399 cats in 2017–2018, including 59 females, two males, 43

nymphs, and three larvae. The highest number of ticks was collected in February and July from dogs and in September and April from cats; single specimens were also observed in August and September [23].

In south-eastern Poland, 25 *I. hexagonus* were collected from 40 dogs, including three nymphs, 21 females, and one male [27], in addition to single cases described by Siuda et al. [7] and Roczeń-Karczmarz et al. [11].

In the western and central parts of the country, the occurrence of this species has also been confirmed. In a study by Król et al., 9.2% of the ticks found on domestic dogs and cats were *I. hexagonus*. Another study found that 9.4% of the ticks (i.e., 137 specimens, including 32 females, 98 nymphs, and seven larvae) collected from seven cats and 37 dogs, were *I. hexagonus* [9, 24, 25]. Mierzejewska et al. [26] described the occurrence of three females of this species in one domestic dog in central Poland.

Ixodes crenulatus. A species found in habitats ranging from lowlands to mountain areas which is suspected to be widespread throughout Poland, but rarely recorded due to difficult access to its feeding grounds, which include rodent and other mammal burrows and caves. This tick has been reported to parasitize marmots (Marmota), hedgehogs (Erinaceidae), weasels, badgers (Mustelidae), moles (Talpinae), rats (Muridae), hamsters (Muroidea), foxes, dogs (Canidae), sheep (Caprini), domestic cats (Felidae), horses (Equidae), and occasionally – humans [7, 19].

To date, *I. crenulatus* has been found to be a reservoir and vector of *Yersinia pestis* (plague bacillus) in rodent populations and TBEV in forest animal populations [19]. It is also an important vector of *Borrelia burgdorferi* s. l., which can cause paralysis in hosts in areas where *I. ricinus* is not present [31]. The role of this species in the transmission of TBPs in Poland is not fully understood.

In 2004–2005, single specimens of *I. crenulatus* were observed on domestic dogs and cats in south-eastern Poland (Subcarpathian Province) [7]. In 2017, in southern Poland (Silesian and Lesser Poland Provinces), a total of 23 tick specimens were collected from six domestic dogs and six domestic cats, including one larva, four nymphs, and 18 females. The highest number of ticks was collected in July, and the lowest number of ticks was collected in March and June [23, 32]. *Rickettsia* spp. were detected in the molecular tests conducted for TBPs [32].

Ixodes rugicollis. The natural habitat of *I. rugicollis* is usually burrows, mammalian hiding places, and low humidity habitats. The preferred hosts of this species are predatory mammals, mainly of the weasel family (Mustelidae) and foxes (Canidae) [19]. The medical and veterinary significance of *I. rugicollis* has not been studied.

In 2004–2005 in southeastern Poland (Subcarpathian Province), after 80 years, its occurrence on cats and dogs was confirmed in the town of Torki, near Przemyśl. Six females and one nymph of *I. rugicollis* were collected from three cats [7].

Ixodes apronophorus. A hygrophilous tick which lives in moist nests and burrows of mammals, in wet meadows, muddy areas bordering rivers and lakes, as well as in islets with sedge clumps and reed beds, near bird nests, and in the burrows of small mammals. The main hosts are rodents and small mammals, including mice (Muridae), voles (Cricetidae), shrews (Soricidae), beavers (Castoridae), birds (Aves), and occasionally reptiles (Reptilia).

In April 2017, one female *I. apronophorus* was collected from a domestic cat in south-western Poland (Silesian Province) [23].

Dermacentor reticulatus. A species that exists mainly in wooded or bushy valleys of rivers, streams, and drainage channels, in mixed swamp forests, mid-forest glades and meadows, clearings and bushy pastures on small hills, and within marshes covered with grey willow [33]. It is a vector for *B. burgdorferi* s. l. and TBEV [34, 35]. *D. reticulatus* is also a vector for *Babesia* spp., *Rickettsia* spp., *A. phagocytophilum*, and *Theileria equi* [34, 36]. *D. reticulatus* is the main vector for *B. canis,* the etiological agent of canine babesiosis, the most important infectious disease of dogs in regions of Poland endemic for *D. reticulatus* [37].

The hosts of this tick species are mainly large mammals, such as dogs, foxes (Canidae), horses (Equidae), wild boar (Suidae), elk (Cervidae), deer (Ruminantia), and bison (Bovinae), less frequently birds and reptiles, and occasionally humans [19].

The rapid expansion of *D. reticulatus* in many European countries has also affected the occurrence of this tick species in Poland. Until the 1990s, the range of *D. reticulatus* was limited to eastern Poland; however, recent studies have shown that the tick is expanding its range into the central and western areas of the country [35]. Buczek et al. and Zając et al. point to the influence of climatic and environmental factors on the occurrence of *D. reticulatus* in eastern Poland [38, 39, 40].

The highest incidence of attacks on domestic dogs by *D. reticulatus* is reported in central Poland. Between 2003–2005, 210 ticks (64.6%) were collected from 108 domestic dogs, including 194 female and only 16 male ticks [4]. During a long-term study (2009–2016) in north-eastern Poland, 1,668 specimens of *D. reticulatus* (39.71%) were found on domestic dogs, including 997 nymphs and 671 females. In the same area, 99 specimens of *D. reticulatus* (19.0%) (62 females and 37 males) were collected from 272 domestic dogs in the Warmian-Masurian Province between 2016–2018 [12, 13]. In 2012–2013, *D. reticulatus* was also the dominant species in domestic dogs (86.0%) from areas of central and northeastern Poland. In domestic cats, only two females of this species were collected [26]. In 2013 and 2014, 46 *D. reticulatus* were collected in western Poland, including 31 females and 15 males from two cats and 34 domestic dogs [9]. In eastern Poland, during three years of study, 278 adult *D. reticulatus* were collected from 122 dogs, which accounted for 55.5% of all ticks collected, with 184 ticks collected from shelter dogs and 94 from domestic dogs [28]. In the same area, 152 ticks of this species, collected from dogs, were later identified [41]. In a later study between 2015–2017, 45 *D. reticulatus* were collected from domestic dogs and cats, which accounted for 24.5% of all ticks collected [11]. In the area of southern Poland, single cases of this species have been found thus far. Three female *D. reticulatus* ticks were collected from three domestic dogs in 2017–2018 in the Silesian Province [23]. In the Lesser Poland Province, one female *D. reticulatus* was collected from a domestic dog in a study conducted between 2002–2014 [8].

Rhipicephalus sanguineus. This is the most common tick species in the world. It is primarily a parasite of dogs, but it can also use other hosts, including carnivores (Carnivora), ungulates (Ungulata), lagomorphs (Lagomorpha), and very rarely humans. It serves as a tick of very high medical and veterinary importance due to its transmission of many TBPs, including *Anaplasma* spp., *Babesia* spp., *Coxiella* spp., *Hepatozoon* spp., and *Rickettsia* spp. [19].

In sporadic cases, *R. sanguineus* has been imported to Poland from southern European countries. The current climatic conditions in the country are not conducive to the development of this tick, but this does not exclude the possibility of nesting in homes where there are dogs. Szymański described one of the few cases of this species being imported to Poland [14]. A Polish family and an Italian family were on holiday with their dogs in the Mazurian Lake District in the northern part of Poland. Most likely during playtime and walks, ticks from the Italian family dog were transferred to the Polish family dog. After returning home (in Central Poland), a female tick broke away from the host dog and laid eggs in the family's apartment, from which larvae developed [14]. A study in northeastern Poland also showed two cases of *R. sanguineus* importation, probably from other European countries, including three females from domestic dogs in 2011 and two females in 2012 [13].

Haemaphysalis concinna. Lives in humid river valleys, overgrown lakeshores, reed thickets, and marshy habitats. The most important hosts are cervids (Cervidae), domestic cattle, sheep (Bovidae), domestic dogs and cats (Canidae and Felidae), birds, and reptiles [19]. It is a vector and reservoir of pathogens such as *Borrelia* spp., *Babesia* spp., *Rickettsia* spp., *Coxiella* spp., *Brucella* sp., and TBEV [19, 42].

The first data on the occurrence of this species in Poland were provided by Neumann (1911). The collection of ticks was supposed to have come from a deer; however, no further information is available [29]. Later, this species was observed in north-western Poland (West Pomeranian Province) at the edge of a forest [43]. In 2018, *H. concinna* was found in western Poland and in the Lower Silesian and Greater Poland Provinces [44]. Single cases have also been reported on a domestic dog that accompanied wandering researchers [45]. This species has also been observed in the south-east of the country, in the Subcarpathian Province [46].

This species is known for its ability to survive in different habitats and climatic zones [47]. Changing weather and climate conditions may create favourable conditions for the spread of this species across Poland.

TICK-BORNE PATHOGENS OF CATS AND DOGS AND THEIR EPIZOOLOGICAL ROLE IN POLAND

Because of the variety of clinical signs, diagnosing TBDs in domestic dogs and cats can be difficult. All these diseases are focal infections due to the presence of vectors carrying the pathogens; in Poland, these are mainly *I. ricinus*, *D. reticulatus*, and *I. hexagonus*.

Anaplasma phagocytophilum. Gram-negative bacteria that are pathogenic intracellular microorganisms. They can attack white blood cells, causing granulocytic anaplasmosis, which was formerly referred to as granulocytic ehrlichiosis. The diagnosis of anaplasmosis is difficult, as the symptoms of the disease are not specific, and include fever, lethargy, anorexia, anaemia, arthritis, vomiting, and diarrhea [48].

Feline granulocytic anaplasmosis is relatively rare, but cases have been reported in Europe, including in Sweden, Finland, Denmark, Ireland, the UK, Italy, Germany, and Switzerland [49]. In Poland, infection with this *Rickettsia* has been described in cats from south-western, eastern, and central Poland. The first case of anaplasmosis in a cat was described by Adaszek et al. in eastern Poland. In a subsequent study by Adaszek et al., the presence of *A. phagocytophilum* in the same area was confirmed in three cats [50]. In Poland, the literature data on this subject are limited, as the presence of the etiological agent of this disease has been reported only in north-western and eastern Poland [48, 51]. Many individuals do not show clinical signs of infection; therefore, only single cases of this disease have been found in Poland.

In a study conducted in north-western Poland, 192 blood samples from healthy dogs and dogs with symptoms of Lyme disease were analyzed. Two samples were positive for *A. phagocytophilum* [48]. In dogs with suspected Lyme disease, the presence of *A. phagocytophilum* was detected in 14.0% of cases; single co-infections of *A. phagocytophilum* and *Bartonella* have also been described, and single cases in dogs considered asymptomatic have been reported [52].

In central Poland, the presence of the pathogen was detected in the DNA of ticks collected from domestic dogs; however, this represented a small percentage of infected parasites (2.9%) [34]. A single case of *A. phagocytophilum* in ticks collected from domestic dogs was described by Welc-Falęciak et al. (Fig. 1) [6].

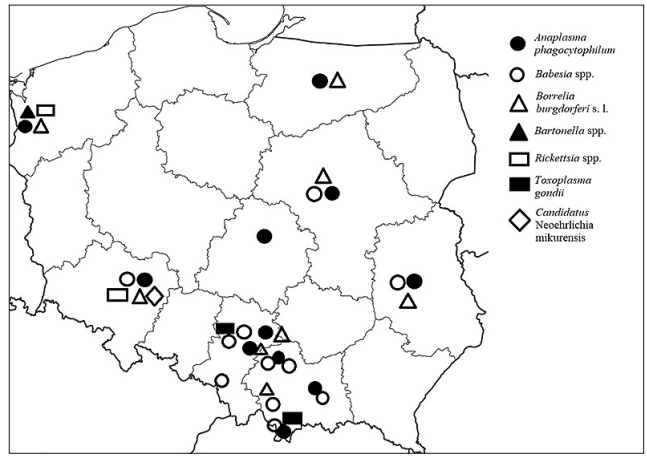

Figure 1. Occurrence of tick-borne pathogens *Ixodes ricinus* in domestic dogs and cats in Poland

In 2017–2018, surveys were conducted on domestic dogs and cats in southern Poland for selected TBPs, in which 3.8% of ticks were infected with *A. phagocytophilum* (Fig. 1) [20]. Own studies from the Silesian and Lesser Poland Provinces showed a similar result of 4.0%-4.7%. One co-infection of *A. phagocytophilum* and *B. microti* was also found (Fig. 1) [53]. A similar result (4.4%) in the Silesian Province was obtained by Pawełczyk et al. [21] and one co-infection of *A. phagocytophilum* and *B. microti* was identified (Fig. 1). In a study by Kramer et al. [54], 3,094 serum samples were collected from dogs in 16 provinces and tested for circulating antibodies to *A. phagocytophilum*. The highest percentage of

positive samples was reported in southern Poland (Lesser Poland and Silesian Provinces) and in the centre of the country.

In western Poland, the prevalence of *A. phagocytophilum* was 21.3% among *I. ricinus* and 8.1% among *I. hexagonus* [9]. Several co-infections have also been demonstrated in female *I. ricinus*, with *Rickettsia* spp. and *A. phagocytophilum*, *Rickettsia* spp. and *Candidatus* Neoehrlichia mikurensis, *Rickettsia* spp and *Babesia* spp., *Cand.* N. mikurensis and *Babesia* spp. and one triple-infection *Rickettsia* spp., *Cand.* N. mikurensis and *A. phagocytophilum* (Fig. 1) [9]. In a study of domestic dogs in north-western Poland, Michalski et al. demonstrated a low percentage of *I. ricinus* ticks (0.96%) infected with this pathogen (Fig. 1) [12].

In eastern Poland, the percentage of ticks in dogs infected with *A. phagocytophilum* was 8.0% (Fig. 1) [55]. Similar results were obtained by Pańczuk et al. [41] out of 152 *D. reticulatus*, 13 had *A. phagocytophilum* in their DNA (8.6%) (Figure 2). Roczeń-Karczmarz et al. [11] showed 6.6% infected ticks in dogs (Fig. 1).

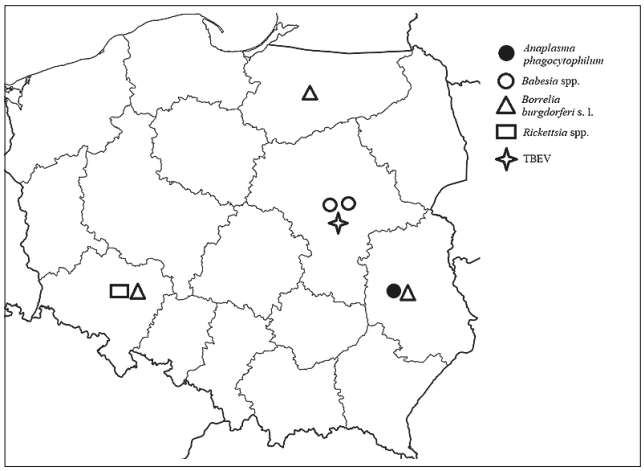

Figure 2. Occurrence of tick-borne pathogens *Dermacentor reticulatus* in domestic dogs and cats in Poland

***Babesia* spp.** Protozoa that cause babesiosis. In Poland, babesiosis is mainly caused by *B. canis* in dogs, *B. felis* in cats, and *B. microti* in humans [56]. Canine babesiosis, although well-recognized by veterinarians, presents many problems in diagnosis and treatment. The symptoms of the disease are non-specific at first, with fever, apathy, and decreased appetite, but pale mucous membranes, and haemoglobinuria can develop over time. The disease has been described throughout Europe [56].

Studies by Adaszek et al. have shown that eastern and central Poland are most at risk of canine babesiosis, but progressively more cases of the disease are being reported in the western provinces [6, 57]. The first case of this disease in cats was described by Adaszek et al. [57], which demonstrates the appearance in our latitude of new etiological factors of diseases currently not present in Poland.

In south-eastern Poland, in the Lesser Poland Province, as much as 47.0% of *I. ricinus* ticks on domestic animals were infected with this parasite, while this percentage was lower in the Silesian Province (22.5%). One co-infection with *B. microti* and *B. burgdorferi* was demonstrated. Additionally, the presence of *B. microti* in *I. hexagonus* was confirmed (Fig. 1) [53].

Pawełczyk et al. [21] confirmed that a significant percentage of ticks in dogs in the Silesian Province were infected with *B. microti* (87.0%), with one co-infection of *A. phagocytophilum* and *B. microti* (Fig. 1). The results of Asman et al. revealed that *B. microti* dominated among the pathogens examined in tick DNA; in dogs, the percentage was 67.85%, and in cats – 15.40%. In addition, *B. microti* and *T. gondii* co-infections were found (Fig. 1) [22]. In the Lesser Poland Province, 24.5% of *B. microti* were found in *I. ricinus* and *I. hexagonus* ticks in dogs and cats (Fig. 1) [20].

In western Poland, the prevalence of *Babesia* spp. in *I. ricinus* was 9.0% (*B. microti* and *B. venatorum*). Co-infections were found with *Rickettsia* spp. + *Cand.* N. mikurensis, *Rickettsia* spp. + *Babesia* spp., and one case of *Cand.* N. mikurensis + *Babesia* spp. (Fig. 1, 2) [9].

A study by Bajer et al. [33] on sled dogs from different regions of Poland, showed the presence of *B. canis* in 11 dogs (four with clinical babesiosis and seven asymptomatic, 8.7%). Several cases have also been described in central Poland [37]. Additionally, researchers described for the first time a co-infection with *B. canis* and TBEV in dogs that had returned from a dog sled competition in Estonia [58]. In central Poland, *D. reticulatus* has been confirmed to be involved in the transmission of *B. canis* in dogs. The presence of DNA of this pathogen was detected in 11.0% of ticks of this species (Fig. 2) [34]. Welc-Falęciak et al. [6] also described cases of *B. canis* (25.3%) in *D. reticulatus* collected from dogs (Fig. 2). In a study by Mierzejewska et al. [59] the presence of *B. canis* was detected in 20.7% of *D. reticulatus* females examined (Fig. a forest 2).

In eastern Poland, the presence of *B. microti* was demonstrated in the blood of 102 dogs, and *B. gibsoni* was also identified for the first time in Poland [60], indicating that infections with this pathogen should be taken into account in the diagnosis of canine diseases [61].

***Borrelia burgdorferi* s. l.** A Gram-negative bacteria that causes Lyme disease. The disease is usually manifested by inflammation of the extremities, usually joints, malaise, fever, lack of appetite, and limping. Numerous cases of canine Lyme disease have been reported throughout Europe. In cats, many cases are asymptomatic [62]. Lyme disease in dogs is a disease of great importance in veterinary practice, and it has now been found in north-western Poland and in the Lublin Province of eastern Poland [62, 63]. Lyme disease in cats has not yet been established in clinical trials in Poland.

Blood polymerase chain reaction (PCR) testing for *B. burgdorferi* DNA in 15 dogs naturally exposed to ticks was conducted in north-western Poland, and six results turned out to be positive for the infection [64]. PCR testing for this pathogen showed that 31 dogs were positive [48]. *B. burgdorferi* sensu stricto was found in blood samples from 98 dogs [62].

In the southern part of the country, a low percentage of *B. burgdorferi* s. l. in ticks was found in dogs and cats. In the Lesser Poland Province, it was 2.0% of *I. ricinus* ticks, and in the Silesian Province – 4.7% (Fig. 1) [53].

In western Poland, domestic dogs and cats showed a higher percentage of *Borrelia* spp. in *I. ricinus* (22.5%); additionally, the pathogen was shown in *I. hexagonus* (1.5%) and *D. reticulatus* (2.0%) (Fig. 1, 2) [24].

Out of 400 dogs in eastern Poland, *B. burgdorferi* was reported in 11.0% (Fig. 1) [55]. A study by Roczeń-Karczmarz

et al. [11] showed the presence of this pathogen in the DNA of ticks collected from dogs in 10.5% of *I. ricinus* and *I. hexagonus* (Fig. 1). Michalski et al. [12] described a higher presence of this pathogen in *I. ricinus* DNA (35.7%), while it was 14.1% in *D. reticulatus*. *B. garinii* and *B. afzelii* were isolated in the study (Fig. 1, 2). In contrast, Pańczuk et al. [41] demonstrated the presence of *B. burgdorferi* in only one of their examined ticks (0.7%) (Fig. 1).

A study by Zygner et al. [34] in central Poland showed a low percentage of *B. burgdorferi,* 6.2% in *I. ricinus* ticks. Additionally, *B. afzelii* was found for the first time in dogs in this region. One case of this pathogen has been described in studies on canine blood samples. Kramer et al. [55] reported the highest prevalence of *B. burgdorferi* in dogs in Łódź Province (Fig. 1).

***Rickettsia* spp.** *Rickettsia* are Gram-negative internal parasitic bacteria that can cause typhoid fever, Q fever, and spotted fever, among other diseases. Disease symptoms are non-specific due to the symptoms being similar to anaplasmosis, Lyme disease, and babesiosis, which makes diagnosis very difficult [51].

In the northwestern region, *R. helvetica* DNA was isolated from *I. ricinus* ticks collected from dogs infected with Lyme disease (Fig. 1) [65]. In the west of the country, a high percentage of ticks infected with *Rickettsia* spp. (30.6%) was shown; for *D. reticulatus* it was 60.9%, for *I. ricinus* – 50.4%, and for *I. hexagonus* – 2.2%. *R. raoultii* was detected only in *D. reticulatus*, while *R. helvetica* and *R. monacensis* were found in *I. ricinus* (Fig. 1, 2) [9].

***Toxoplasma gondii*.** A pathogenic protozoan that causes toxoplasmosis. The disease is usually asymptomatic, but it can have severe manifestations in animals, including neurological problems, vomiting, diarrhea, and weight loss [66]. The role of ticks in the circulation of this pathogen in nature is not yet fully understood. Sroka et al. and Asman et al. showed that ticks may be involved in the spread of this pathogen, and that the prevalence of this protozoan was highest in females [22, 66]. Further studies on the occurrence of *T. gondii* in ticks in Poland are necessary.

In a study in southern Poland (Lesser Poland Province), *T. gondii* was detected in domestic dogs and cats in 4.5% of *I. ricinus* and *I. hexagonus* (Fig. 1) [20]. In the area of the Silesian Province, also in southern Poland (Fig. 1), Asman et al. [22] demonstrated a significant proportion of *T. gondii* in ticks collected from domestic dogs (96.42%), while it was as high as 100.0% in cats (Fig. 1).

***Bartonella* spp., *Cand*. N. mikurensis, TBEV.** *Bartonella* is a Gram-negative intracellular bacterial parasite that causes bartonellosis. It is usually asymptomatic in domestic cats and dogs. Characteristic signs of the disease can include lymphadenopathy, swollen spleen, and inflammation of the bile ducts, liver, myocardium, joints, and kidneys [66]. In Poland, one case of *Bartonella* spp. in *Ixodes* ticks has been described, in which 1.0% of this pathogen was found in dogs with symptoms of Lyme disease (Fig. 1) [52].

Cand. N. mikurensis is a Gram-negative bacterium that causes neoerlichiosis, with disease symptoms similar to ehrlichiosis described previously [68]. In Poland, this bacterium was detected overall in 8.1% of female *I. ricinus* and nymph *I. hexagonus* collected from dogs and cats (Fig. 1) [9].

TBEV is a virus belonging to the Flaviviridae family that causes tick-borne encephalitis with meningitis. The first signs of the disease in animals include high body temperature and increased heart rate, and some animals progress to develop photophobia, seizures, and paralysis of the limbs [69]. In a study of sled dogs, Bajer et al. confirmed a case of TBEV in a dog for the first time in Poland (Fig. 2) [70].

CONCLUSIONS

Of the 19 species of ticks permanently present in the Polish fauna, *I. ricinus*, *I. hexagonus*, *I. crenulatus*, *I. rugicollis*, and *D. reticulatus* are the species that are known to infest domestic dogs and cats in the country. Other tick species, such as *I. apronophorus* and *H. concinna*, that are sporadically recorded on domestic dogs or cats may expand their range in the future and successfully infest domestic animals. It is suspected that due to current environmental and climatic changes, incidents of host-associated infestations of foreign tick species, such as *R. sanguineus*, may soon be recorded more frequently in Poland. Moreover, in the future, they may expand their range of occurrence and their hosts and permanently appear in the Polish tick fauna. The One Health concept highlights the emergence of TBPs in animals and humans, including granulocytic anaplasmosis, babesiosis, Lyme disease, and rickettsiosis, as well as the emergence of new disease entities that are difficult to diagnose and not fully recognized as vectors in ticks, including *T. gondii*, *Bartonella* spp., *Cand*. N. mikurensis, and TBEV (Tab. 1). Currently, climate change is playing a significant role in increasing tick populations and in the transmission of pathogens to humans and their companion animals. It can be expected that new species will appear in Poland, attacking domestic dogs and cats, and that there may be an increase in the frequency of attacks by ticks in explored and unexplored areas.

Given the increasing prevalence of TBDs in humans and pets and the very complex issues associated with their correct diagnosis and effective treatment, it seems reasonable to believe that prevention is one of the most important tools for effectively reducing disease and protecting human and animal health from TBDs. Modern strategies to mitigate this risk should be developed.

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