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Wildlife reservoirs for vector-borne canine, feline and zoonotic infections in Austria

Georg G. Duscher [a,*], Michael Leschnik [b], Hans-Peter Fuehrer [a], Anja Joachim [a]

[a] Institute of Parasitology, Department of Pathobiology, University of Veterinary Medicine Vienna, Veterinaerplatz 1, A-1210 Vienna, Austria
[b] Small Animal Clinic, Department for Companion Animals, University of Veterinary Medicine Vienna, Veterinaerplatz 1, A-1210 Vienna, Austria

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ABSTRACT

Austria's mammalian wildlife comprises a large variety of species, acting and interacting in different ways as reservoir and intermediate and definitive hosts for different pathogens that can be transmitted to pets and/or humans. Foxes and other wild canids are responsible for maintaining zoonotic agents, e.g. *Echinococcus multilocularis*, as well as pet-relevant pathogens, e.g. *Hepatozoon canis*. Together with the canids, and less commonly felids, rodents play a major role as intermediate and paratenic hosts. They carry viruses such as tick-borne encephalitis virus (TBEV), bacteria including *Borrelia* spp., protozoa such as *Toxoplasma gondii*, and helminths such as *Toxocara canis*.

The role of wild ungulates, especially ruminants, as reservoirs for zoonotic disease on the other hand seems to be negligible, although the deer filaroid *Onchocerca jakutensis* has been described to infect humans. Deer may also harbour certain *Anaplasma phagocytophilum* strains with so far unclear potential to infect humans. The major role of deer as reservoirs is for ticks, mainly adults, thus maintaining the life cycle of these vectors and their distribution. Wild boar seem to be an exception among the ungulates as, in their interaction with the fox, they can introduce food-borne zoonotic agents such as *Trichinella britovi* and *Alaria alata* into the human food chain.

1. Introduction

Austria is a comparatively small Central European country with a high biodiversity and abundant mammalian wildlife. At the interface of wildlife habitats and human activities, a range of pathogens can be transmitted from wild to domestic animals and to humans (Fig. 1). This concerns both established populations of mammals, like deer, fox or wild boar, and invasive alien species like the racoon dog, the racoon and the golden jackal. Latter group of species are also referred as "neozoans", so called if they are alien species and introduced to a region after 1492 (Kowarik and Starfinger, 2003). Wild animals may serve as indicators for the presence of parasites; however, transmission risks to domestic animals or humans are usually subject to speculation.

Wildlife may also be reservoirs for arthropod-borne infections that can be transmitted to domestic animals and/or humans. Among these, for example *Anaplasma phagocytophilum, Borrelia burgdorferi* s.l. and tick-borne encephalitis virus (TBEV) transmitted by *Ixodes ricinus* are endemic in Austria and are all related to wildlife reservoirs.

A lot of discussion surrounds the possible introduction of the Brown Dog Tick, *Rhipicephalus sanguineus*, into Central Europe. It represents the most important vector of canine tick-borne diseases worldwide and has been introduced several times into animal shelters in Austria in the past.

We here summarize the current knowledge on the possible role of wildlife in the transmission of zoonotic parasites and arthropod-borne pathogens to domestic animals and humans in Austria as an example of a Central European country with diverse habitats from lowlands to alpine regions with different faunas and abundant contact between wild animals and humans and their pets.

2. Wildlife animals as reservoir for zoonotic pathogens and vector-borne parasites

2.1. Wild canids

2.1.1. Red foxes (Vulpes vulpes)

Foxes obviously play a key role in the interface between wildlife, pets and humans. Reasons for this include the increasing population density of foxes, their susceptibility to relevant pathogens, their hunting preference for small mammals which leads to frequent ingestion of intermediate hosts, and their wide distribution and vicinity to human settlements as a consequence of their

* Corresponding author. Institute of Parasitology, Department of Pathobiology, University of Veterinary Medicine Vienna, Veterinaerplatz 1, Vienna A-1210, Austria. Tel.: +43 1 250772211; fax: +43 1 250772290.
E-mail address: georg.duscher@vetmeduni.ac.at (G.G. Duscher).

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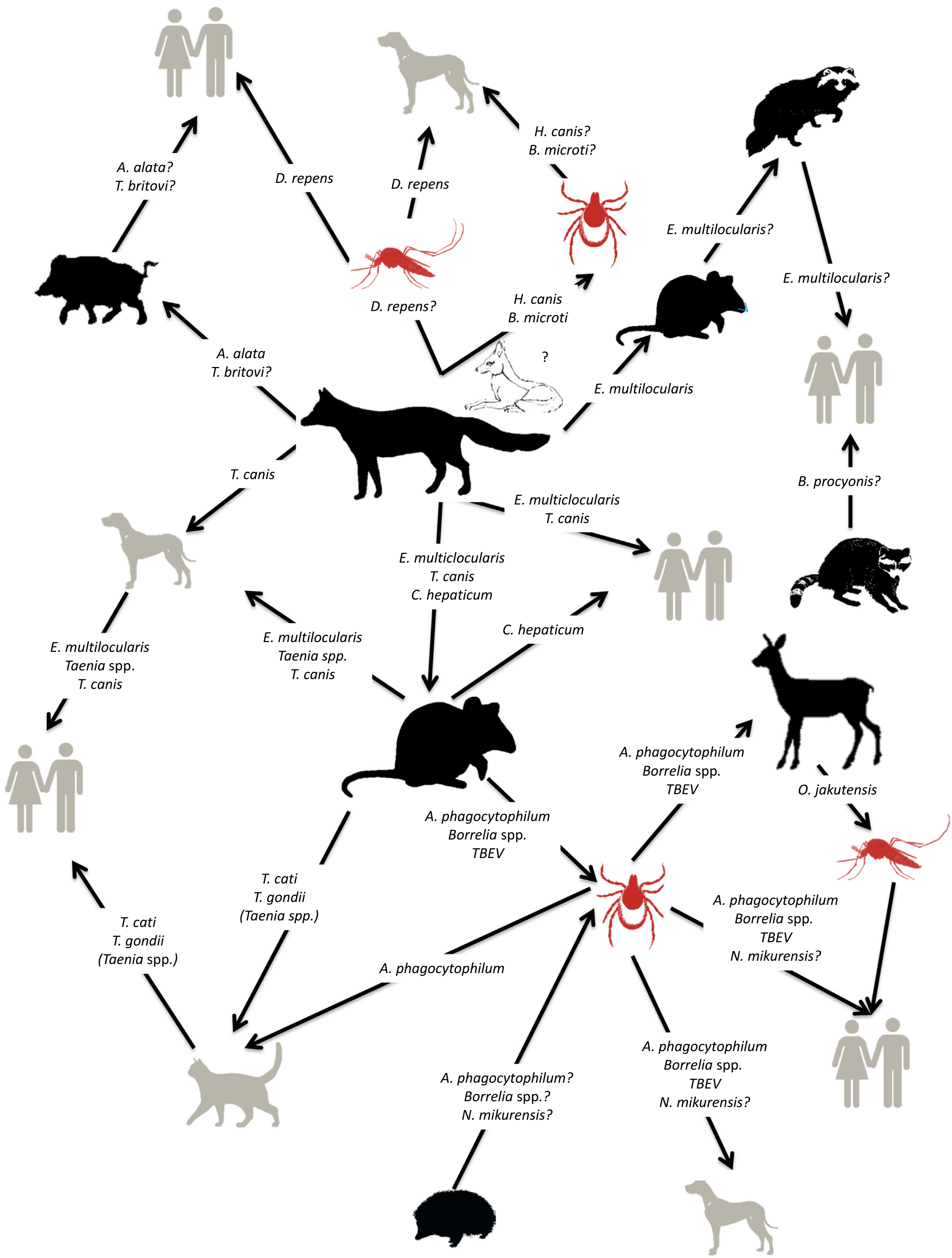
A. alata?
T. britovi?
D. repens
D. repens
H. canis?
B. microti?
E. multilocularis?
E. multilocularis?
D. repens?
H. canis
B. microti
?
A. alata
T. britovi?
E. multilocularis
T. canis
B. procyonis?
E. multiclocularis
T. canis
E. multiclocularis
T. canis
C. hepaticum
C. hepaticum
E. multilocularis
Taenia spp.
T. canis
E. multilocularis
Taenia spp.
T. canis
A. phagocytophilum
Borrelia spp.
TBEV
O. jakutensis
A. phagocytophilum
Borrelia spp.
TBEV
T. cati
T. gondii
(Taenia spp.)
T. cati
T. gondii
(Taenia spp.)
A. phagocytophilum
Borrelia spp.
TBEV
N. mikurensis?
A. phagocytophilum
A. phagocytophilum
Borrelia spp.
TBEV
N. mikurensis?
A. phagocytophilum?
Borrelia spp.?
N. mikurensis?

synanthropic lifestyle (Wandeler et al., 2003; Deplazes et al., 2004; Duscher et al., 2005, 2006; Torina et al., 2013). The red fox was the main reservoir for sylvatic rabies in Central Europe, which was very common and a threat to human and animal health before the oral fox vaccination campaign which started in the 1980s in Austria (Müller et al., 2009). Due to the intensive surveillance and baiting, rabies is now considered eradicated from Austria. However, spillover from neighbouring countries may still occur, and the surveillance system in Austria is still in place. The vaccination against rabies is held responsible for the increasing fox population in Central Europe (Romig et al., 1999; Chautan et al., 2000; Deplazes et al., 2004; Duscher et al., 2006). Especially in cities such as Zurich (Switzerland), an increased population of foxes is being reported (Hofer et al., 2000; Wandeler et al., 2003; Deplazes et al., 2004; Mackenstedt et al., 2014). In Austria we confirmed this trend, albeit at a slower speed (Duscher et al., 2006). Higher fox densities and closer relationships to human dwellings consequently increase the contact rates among foxes and between foxes, pets and humans (Romig et al., 1999; Duscher et al., 2006). Therefore the foxes are held responsible for harbouring and transmitting a wide range of vector-borne and zoonotic diseases in Europe, including in Austria.

Most prominent is the occurrence of the small fox tapeworm, *Echinococcus multilocularis* (Duscher et al., 2006). Foxes become infected by ingestion of metacestodes in infected intermediate rodent hosts. The adult worms produce numerous eggs which are shed with the faeces. Foxes tend to use their faeces as marks on elevated positions, e.g. on stones at river banks (Duscher, 2011), supporting the distribution of eggs and the contact with them for the infection of intermediate and accidental hosts such as humans. Around 2–13 cases of human alveolar echinococcosis caused by *E. multilocularis* are reported annually in Austria (Schneider et al., 2013), mostly with an unknown geographic source of infection. Prevalences in foxes are around 4% on average with higher rates in the western part (Duscher et al., 2006). In dogs, prevalences are probably below 0.1% (Dyachenko et al., 2008), although systematic data for Austria are lacking. Beside their known role as definitive hosts, dogs also can become infected as intermediate hosts due to egg ingestions (Mätz-Rensing et al., 2002; Weiss et al., 2008); sporadic cases are reported by veterinary practitioners (Anja Joachim, unpublished data).

Another metazoan parasite present in Austrian foxes is *Toxocara canis* (Suchentrunk and Sattmann, 1994): it was found in 42.9% of 307 foxes originating from several regions of Austria. Similar results with 48% of 629 foxes sampled in Lower and Upper Austria were obtained (Georg G. Duscher, unpublished data). This nematode is responsible for human cases of various forms of toxocariasis such as visceral or ocular larva migrans, neurotoxocariasis etc. in humans (Macpherson, 2013). Reports of human cases in Austria are rare, but a serological study revealed 6.3% of 1046 examined people with previous contact to this roundworm (Poeppl et al., 2013). Estimations suggest several hundred cases of undiagnosed overt cases per year (Auer, 2011). In addition, the fox reservoir is also important in maintaining the *T. canis* population in dogs.

Foxes are also known as carriers of *Trichinella britovi* in Austria. About 2% of the foxes, mainly with higher prevalences in the alpine region, harboured larvae of this nematode (Krois et al., 2005). In Europe it is the most prevalent *Trichinella* species (Pozio and Zarlenga, 2013). As a consequence of the expanding wild boar population into regions with red foxes, a potential risk is arising due to overlapping habitats of wild boar and infected foxes (Duscher et al., 2005). Scavenging on infected dead foxes by wild boar may consequently lead to human infections by consumption of undercooked wild boar meat; however, so far no case of human *Trichinella* infection from this source has been reported from Austria. Reasons therefore are various such as overlooked cases, the disability to identify the origin of infection, traditional dining habitats of inhabitants or even negligible risk. But the risk of *Trichinella* infections from wild boar was discussed after findings of larvae and some seropositive animals in a fenced area (Edelhofer et al., 1984). This finding was later revised because no muscle larvae were found and further evidence from other animals was lacking, and it was assumed that the positive case was introduced from Russia. Cross-reactivity was assumed for the serologically positive cases (Edelhofer et al., 1996). Human *Trichinella* infections have been recorded in Austria but are usually considered to be imported (Auer, 2005). Nevertheless, based on several changes in the recent past such as the increasing of fox population (Duscher et al., 2006) and of overlapping areas of foxes with wild boars (Duscher et al., 2005), together with changing the cooking habits to raw or undercooked meals, transmission of *Trichinella* is favoured.

A similar route via wild boar meat could be taken by the trematode *Alaria alata* (Duscher, 2011). Foxes harbour the adult stages of this helminth. The eggs develop in the water and infect snails as first intermediate hosts, followed by amphibians as second intermediate hosts. Several animals such as snakes and wild boar are discussed as paratenic hosts (Möhl et al., 2009). By ingestion of the metacercariae, the natural definitive host, the fox, becomes infected and the life cycle is completed. A fatal human case was reported in relation to an infection with a closely related species, *A. americanum* (Freeman et al., 1976); human infections in Austria have not been recorded so far. Similar to *Trichinella*, drawing conclusions about actual risk is almost impossible due to the lack of reliable diagnostic tools in humans and integral data of this parasite in definitive, paratenic and intermediate hosts. But in this case undercooked wild boar represents a potential treat of this zoonosis.

Foxes might also act as carriers of vector-borne zoonotic *Dirofilaria* spp. (Lok, 1988). Mosquitoes transmit these filaroids among canids and to felids (McCall et al., 2008). Beside cutaneous lesions induced by *Dirofilaria repens*, a cardio-pulmonary manifestation evoked by *Dirofilaria immitis* is known to occur in Austria, with the latter only as imported cases so far (Duscher et al., 2009; Silbermayr et al., 2014). Both species are responsible for human diseases, usually

Fig. 1. Role of wildlife (in black: red fox, wild boar, racoon dog, racoon, hedgehog, roe deer, and rodents; in white: golden jackal) in the transmission of various pathogens to cats, dogs and humans (in grey) directly or via arthropod vectors (in red: ticks, mosquitoes).

A. alata: Alaria alata
A. phagocytophilum: Anaplasma phagocytophilum
B. procyonis: Baylisascaris procyonis
C. hepaticum: Calodium hepaticum
D. repens: Dirofilaria repens
E. multilocularis: Echinococcus multilocularis
H. canis: Hepatozoon canis
N. mikurensis: Candidatus Neoehrlichia mikurensis
O. jakutensis: Onchocerca jakutensis
T. britovi: Trichinella britovi
T. canis: Toxocara canis
T. cati: Toxocara cati
T. gondii: Toxoplasma gondii
TBEV: tick-borne encephalitis virus

with cutaneous and ocular locations due to *D. repens* and pulmonary lesions due to *D. immitis* (Simón et al., 2009). In Austria imported infections with both species have been documented in dogs and humans. However, in both dogs and humans some cases have been determined as autochthonous (Auer and Susani, 2008). *D. repens* was found in mosquitoes in Austria for the first time in 2012, and can now be considered as endemic in Austria, presumably invaded from the eastern neighbouring countries (Silbermayr et al., 2014).

Foxes are also carriers of tick-transmitted protozoa such as *Babesia microti*-like pathogens, also known as *Babesia annae, Theileria annae* or "*Babesia* sp. from Spanish dog" (Criado-Fornelio et al., 2003). Those piroplasmids are known to cause diseases in dogs with azotaemia, haemolytic anaemia, renal failure and mortality (Camacho et al., 2004, 2005). In Austria 50% of 36 foxes were positive for this pathogen (Duscher et al., 2014). The vector ticks are thought to be *Ixodes hexagonus* (Camacho et al., 2003) as well as *I. ricinus* and *Ixodes canisuga* (Najm et al., 2014a). Their zoonotic potential is not known. Further studies are required to define the complete intermediate and final host range of *B. microti*-like pathogens.

Foxes also harbour another apicomplexan, *Hepatozoon canis*. This tick-transmitted pathogen, unlike any other, needs to be ingested by the vertebrate host (Baneth et al., 2003). Generally this happens during grooming or by ingestion of ticks on prey. Similar to *H. americanum*, vertical transmission from bitches to their progeny has been described (Murata et al., 1993), and transmission via infected prey tissue, e.g. rodents containing meronts, is also discussed (Johnson et al., 2009; Hornok et al., 2013). The zoonotic potential of this pathogen seems to be negligible. The main vector tick of *H. canis, R. sanguineus*, is not considered endemic in Austria (Estrada-Peña et al., 2012), although sporadically, imported ticks can be found (Prosl and Kutzer, 1986; Duscher and Leschnik, 2011). Nevertheless, *H. canis* is reported from areas where the main vector tick is also missing, e.g. Germany or Hungary (Gärtner et al., 2008; Farkas et al., 2014; Najm et al., 2014b). In Austria about 58% of 36 foxes in eastern areas were positive for this pathogen (Duscher et al., 2014). Other tick species that are endemic in these countries as well as in Austria, such as *Dermacentor* or *Haemaphysalis* species, might also act as vectors, as suggested for *Haemaphysalis longicornis* and *Haemaphysalis flava* in Japan and *Amblyomma ovale* and *Rhipicephalus microplus* in Brazil (de Miranda et al., 2011; Otranto et al., 2011; Hornok et al., 2013). Recent studies found *I. ricinus* to be unsuitable as vector (Giannelli et al., 2013). Similar to *B. microti*-like pathogens, transmission by competent ixodid vectors still has to be confirmed in further studies. Interestingly, sporadic imported cases, but neither endemic *B. microti*-like infections nor *H. canis* cases, could so far be diagnosed in dogs from Austria. As diagnosis of *H. canis* in the patent phase is easily made by microscopic detection of large gamonts formed in white blood cells of dogs, it appears highly unlikely that this infection has been overlooked in dogs in the past. It is currently unknown why this infection circulates in foxes but not in dogs, as both can frequently be infested with ticks of the same genera and species (Duscher et al., 2013a).

Foxes and other wild carnivores might also play a role in the maintenance of a sylvatic cycle of *Toxoplasma gondii* infection (Karbowiak et al., 2010) as 35% of Austrian foxes tested positive by serology (Wanha et al., 2005); however, systematic data on the sylvatic and domestic cycles, e.g. in peri-urban areas, are missing.

2.1.2. *Golden jackal (*Canis aureus*)*

Data on the distribution of golden jackals in Austria are scarce. The animals are believed to migrate from southern Europe, e.g. Croatia or southern Hungary, to northern latitudes including Austria (Arnold et al., 2012; Duscher et al., 2013b). Single individuals are sighted occasionally, and sometimes road kills occur. Recently a golden jackal was involved in a car accident in Vienna. Although the jackal was not infested with *R. sanguineus*, it was infected with *H. canis* (Duscher et al., 2013b). The origin of the infection remains a mystery due to the inability to determine the origin of the jackal. It is unclear if wild jackals, including individuals introduced to Austria or migrating into the country, could establish new parasite populations transmissible to domestic dogs, but this has to be suspected due to the close phylogenetic relationship between the jackal and the domestic dog.

Besides their suspected role in the transmission of pathogens like *H. canis*, the jackals themselves seem to have an impact on the ecology and spread of diseases, because if they expand they are in competition with foxes which they displace (Majláthová et al., 2007; Duscher et al., 2013b). Consequently foxes are moving to new areas, thus contributing to the spread of fox-borne infections. Golden jackals are also known to harbour *Ehrlichia canis, Leishmania donovani, T. gondii, Ancylostoma caninum, Echinococcus granulosus* and several canine viruses (Shamir et al., 2001) and they are assumed to have an impact on spreading these pathogens (Hamel et al., 2012).

2.1.3. *Racoon (*Procyon lotor*) and racoon dog (*Nyctereutes procyonoides*)*

Those two species are neozoa in Austria but have adapted to their new habitats, particular to the lowlands, quite well (Lampe, 2009). Their distribution and numbers are in the focus of ongoing research by using sightings, car hits, photo trapping and traps (www.enok.at). So far, their numbers in Austria seem to be lower than those reported from Germany where they already come close to the vicinity of human settlements. Racoon dogs (family: Canidae) are known to harbour *E. multilocularis, Trichinella spiralis, T. canis* and *A. alata* (Thieß et al., 2001; Kapel et al., 2006). Additionally they are a known reservoir for *Leishmania* sp. (Xu et al., 1982). Racoons (family: Procyonidae) are carriers of *Baylisascaris procyonis* (Thompson, 2013). This worm is of major concern due to its zoonotic character evoking visceral, ocular or neural larva migrans (Auer, 2011; Thompson, 2013).

In Austria all racoons and racoon dogs shot or found dead are sampled and investigated, but due to their low number, it has so far not been possible to determine the actual risk arising from these invasive species in Austria. Yet none of the aforementioned pathogens could be detected.

2.1.4. *Polecat (*Mustela putorius*)*

Polecats in Europe harbour two different parasites, a trematode and a nematode, in their nasal sinuses. Both make an impressive appearance by dissolving the bone structure, probably during the feeding process. The trematode, *Troglotrema acutum*, is transmitted via two intermediate hosts, a water snail and a frog (Vogel and Voelker, 1978). Incidentally, this parasite was found in foxes, badgers, martens and mink in several countries (summarized in Duscher et al., in press). The nematode, *Skrjabingylus nasicola*, is transmitted via terrestrial molluscs and maybe small mammals as paratenic hosts (Kierdorf et al., 2006).

These parasites seem to gain importance due to the increased popularity of keeping ferrets, the domestic form of the polecat, as pets.

2.1.5. *Martens: beech marten (*Martes foina*), pine marten (*Martes martes*)*

Although martens are often discussed and investigated as a potential carrier of *E. multilocularis*, this could not be confirmed to our knowledge. One beech marten from Lower Austria was found to harbour *Hepatozoon* sp., which could not be further classified (Weinberger and Duscher, 2014).

2.2. Rodents

Rodents are probably the key factor in the maintenance of transmission cycles for zoonotic and vector-borne diseases in Austria. They are intermediate hosts for several parasites (e.g. *E. multilocularis*) and therefore responsible for maintaining the sylvatic cycle. Additionally, small rodent mammals are paratenic hosts for *T. canis* and other nematodes of domestic carnivores (Macpherson, 2013).

These animals are not only important intermediate and paratenic hosts, but they are also responsible as interface to pets and humans due to their "urban lifestyle" in many species (Paziewska et al., 2010). Cats and dogs frequently ingest rodents, whereby any sylvatic cycle is changed to a domestic and even synanthropic one, increasing the risk for pets and humans.

In Austria rodents act as intermediate hosts of several cyclophyllid cestodes of zoonotic importance of which *E. multilocularis* is the most important one for human health. Several vole species and other murids are known as intermediate hosts in Central Europe. Although human cases of alveolar echinococcosis and high prevalences in red foxes are documented for Austria, there is virtually no information about this parasite in Austrian rodents (Auer and Aspöck, 1991; Duscher et al., 2006). Several studies examined the murid fauna in Austria for the presence of this parasite (e.g. Pampas, 1994). However, it took until 2010 to detect DNA of this parasite in one liver specimen out of 102 of a common vole (*Microtus arvalis*) (Führer et al., 2010).

Other cestodes with rodents as intermediate hosts and Felidae, Canidae and Mustelidae as definitive hosts are *Taenia crassiceps* and *Taenia taeniaeformis*. Metacestodes of *T. crassiceps* are located in the peritoneal and pleural cavities, muscle and subcutaneous tissues and rarely in the eye or brain. *T. crassiceps* is of zoonotic importance and mainly documented in immunosuppressed patients. In Austria metacestodes of this cestode were documented from muskrats (*Ondatra zibethicus*), snow voles (*Chionomys nivalis*) and water voles (*Arvicola terrestris*; 2/98 specimen) (Pfaller and Tenora, 1972; Führer et al., 2010; Fuehrer et al., 2012). *T. taeniaeformis* is rarely zoonotic and of low importance for human medicine (summarized in Fuehrer et al., 2012). In Austrian rodents metacestodes (Cysticercus fasciolaris) of this parasite were found in the livers of snow voles (*C. nivalis*), common voles (*M. arvalis*; 22/318) and water voles (*A. terrestris*; 30/98) (Pfaller and Tenora, 1972; Führer et al., 2010).

Rodents in general are well known as hosts of several nematodes of zoonotic importance. However, with the exception of *Calodium hepaticum* (syn. *Capillaria hepatica*), there is virtually no knowledge about the role of rodents as hosts of zoonotic nematodes in Austria (e.g. *Toxocara* spp.). Within a study conducted in the most western province Vorarlberg, Arvicolinae were examined for the presence of *Trichinella* spp. (microscopy) and *T. canis* (PCR) but parasites were not detected (Führer et al., 2010).

C. hepaticum is a globally distributed zoonotic nematode parasitizing livers of Muroidea as main hosts but also numerous other mammals. This parasite had been observed in more than 180 mammalian species (including humans) and more than 90 rodents of the superfamily Muroidea (Fuehrer et al., 2011; Fuehrer, 2014a, 2014b). More than 70 cases of hepatic capillariosis have been documented worldwide (Fuehrer et al., 2011). In Austria two employees of the zoological garden in Vienna were serologically positive for this parasite but presented no symptoms (Juncker-Voss et al., 2000). However, the true burden of animal and human infections with this parasite is not known. Due to its biology the parasite is mainly detected at necroscopies and biopsies and there are no commercial serological detection kits available.

Within the superfamily Muroidea, *C. hepaticum* was documented in Austria in field voles (*Microtus agrestis*), common voles (*M. arvalis*), water voles (*A. terrestris*), house mice (*Mus musculus*), brown rats (*Rattus norvegicus*) and long-tailed field mice (*Apodemus sylvaticus*) with prevalences from 0.9% (common voles) to 43% (house mice) (Ryldo, 1966; Frank, 1977; Juncker et al., 1998; Führer et al., 2010). Furthermore this parasite was found in Austria in non-rodent animals, common shrews (*Sorex araneus*), European hares (*Lepus europaeus*) and mountain hares (*Lepus timidus*) (Kutzer and Frey, 1976; Frank, 1977; Eder, 2008). A spurious infection (=pseudoinfection with eggs in the faeces) was reported from a Pallas' cat in a zoological garden (Basso et al., 2005).

Knowledge about the protozoan parasite fauna in rodents in Austria is rather limited, although some parasites are of zoonotic importance. *T. gondii* is of major zoonotic significance and is transmitted to cats as the definitive host. Rodents of different species harbour extraintestinal stages of the parasite as reservoir hosts (Turčeková et al., 2014) and can transmit it to carnivorous and omnivorous wildlife as well as to the definitive host, such as cats, by predation. Systemic infection in rodents may lead to a reduction of fear behaviour towards natural predators, leading to an augmented rate of predation and consequently to an increase in parasite multiplication (Gonzalez et al., 2007). Although approximately 33–40% of the Austrian human population are infected with *T. gondii*, one of the most important ways of transmission (consumption of pseudocysts in raw meat) seems not to draw responsibility for infection (Aspöck et al., 2002). Yet data on meat are limited and only pork was investigated closer. Raw pork appears to be a rare source of infection because on the one hand there is no tradition of consuming raw pork meat in Austria and on the other hand the seroprevalence of *T. gondii* in conventionally farmed pigs has decreased in the last two decades from 13.7% to less than 1% (Edelhofer, 2004). This leads to the assumption that other sources of infection, including the ingestion of oocysts excreted by infected cats, is the main source of infection for humans in Austria. Rodents are of prime importance for the maintenance of the sylvatic cycle of *T. gondii* and as indicators for the grade of environmental contamination with zoonotic parasites by carnivores (Reperant et al., 2009), including cats, since the infection rate of rodents is correlated with the infection rate in domestic cats and therefore determines the risk of infection for the final host (Hill and Dubey, 2002). There are only a few reports on *T. gondii* in wild rodents in Austria. Frank (1977) reported this parasite in a common vole in eastern Austria. In western Austria (Vorarlberg) the prevalence of *T. gondii* was examined in the brains of common voles (0.7%) and water voles (4.7%) using gene amplification techniques (Fuehrer et al., 2010).

Recently a serological and molecular survey of rodents in Lower Austria (North-Eastern Austria) reported no findings of *T. gondii* (Schmidt et al., 2014), so the current epidemiological situation of *T. gondii* in Austria remains elusive.

Rodents are also frequent carriers of the most important tick-borne pathogens in Austria, borreliae and the TBE virus (Stanek and Hofmann, 1994). They carry all stages of ticks, which often feed together on individual hosts. This enables transmission via co-feeding, supporting the transmission cycle in addition to the systemic infection of the rodent host (Pérez et al., 2011). In an Austrian rodent population a TBE virus prevalence of 29–48% has been documented (Labuda et al., 1993).

The European subtype of TBE flavivirus can be found in several transmission foci in Austria (Heinz et al., 2013). It is transmitted by *I. ricinus* (Labuda and Randolph, 1999), the dominant tick species in Austria (Duscher et al., 2012, 2013a). The prevalence in ticks is rather low and ranges between 0 and 3% (Dobler et al., 2008; Durmiši et al., 2011; Süss, 2011). The occurrence of the TBE virus in the landscape is mostly clustered together in a small area and these areas are distributed in a patchy pattern all over the country (Stefanoff et al., 2013; Estrada-Peña and de la Fuente, 2014). Whereas canine TBE is occasionally diagnosed, cats are not reported to develop clinical symptoms (Leschnik et al., 2002). In dogs but not in humans, *Dermacentor reticulatus* may also play a role in the transmission of

TBE (Wójcik-Fatla et al., 2011). *D. reticulatus* frequently infests dogs in Eastern Austria (Duscher et al., 2013a) and nymphs are commonly found on *Microtus* species, maintaining this pathogen in the zoonotic cycle and linking woodland and field habitats (Paziewska et al., 2010).

Identifying all of these TBE transmission foci is mostly hampered by the impossibility of sampling ticks and rodents in sufficiently high numbers. Therefore, the risk of being infected is generally assumed for Austria and vaccination is recommended (Heinz et al., 2013). Despite a high rate of vaccinated individuals in the Austrian population of about 85% (GfK Healthcare, 2014), the disease rates are still around 100 cases a year in Austria (Heinz et al., 2013). Nevertheless it is estimated that as a consequence of the vaccination about 4000 people were prevented from developing acute TBE in the period 2000–2011 (Heinz et al., 2013).

Lyme borreliosis is the most common tick-borne infection in humans (Stanek et al., 2012). Cats do not seem to be susceptible (Krupka and Straubinger, 2010), and naturally acquired disease in European dogs remains unproven (Leschnik et al., 2010). Rodents are considered important reservoir hosts for borreliae and in two local studies 14.8% to 24% of rodents harboured *Borrelia*-specific DNA, in the common vole up to 53.3% in Eastern Austria (Khanakah et al., 2006; Schmidt et al., 2014). Prevalence in ticks ranged from 4 to 33% (Blaschitz et al., 2008), but the source of ticks (collected from animals versus questing ticks) seems to influence the percentage of tick infection (Leschnik et al., 2012b).

Besides their well-known role as reservoir hosts, they might also play a role with other tick-borne pathogens like *Candidatus* Neoehrlichia mikurensis (Silaghi et al., 2012b; Földvári et al., 2014). A current paper describes distinct genetic differences of *Anaplasma phagocytophilum* within the murine reservoir compared to the ungulate reservoir, leading to the conclusion that rodents in Europe are not as important as reservoir hosts compared to the United States (Víchová et al., 2014).

2.3. *Insectivores – Hedgehogs (*Erinaceus europaeus *and* Erinaceus roumanicus*)*

Hedgehogs are common in Austria, and there is evidence for the occurrence of both species *E. europaeus* and *E. roumanicus* (Bolfíková and Hulva, 2012; Skuballa et al., 2012). They are protected species and sampling for scientific purposes is restricted. Data on species and pathogens therefore mainly originate from rescue stations in the course of treatment observations. Most of the pathogens and parasites are of negligible interest concerning human or pet health. Nevertheless, hedgehogs are massive carriers of ticks and fleas, playing a role in maintaining and spreading of these vectors.

However, in Hungary hedgehogs (*E. roumanicus*) were found as carriers of the newly emerging *Candidatus* Neoehrlichia mikurensis, as well as *A. phagocytophilum* and borreliae (Silaghi et al., 2012a; Skuballa et al., 2012; Földvári et al., 2014). Földvari and coworkers (2014) found high prevalences of these pathogens in hedgehogs on the Danube Island in Budapest, which serves as a local recreational area for people and their dogs. Hedgehogs mainly inhabit sheltered areas within dense vegetation in the area, and it was concluded that the actual exposure is low compared to the potential risk due to the high prevalence of pathogens in these small mammals. A similar situation can be assumed for Austria, although no data on infected hedgehogs are available.

2.4. *Wild ungulates*

Austria harbours a great variety of wild ungulates, some of them endemic such as roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), wild boar (*Sus scrofa*), and rarely moose (*Alces alces*), and in the alpine region chamois (*Rupicapra rupicapra*) (Reimoser and Reimoser, 2010). Additionally some species are introduced such as fallow deer (*Dama dama*) or sika deer (*Cervus nippon*) or reintroduced such as ibex (*Capra ibex*) (Reimoser and Reimoser, 2010).

Wild ungulates, especially roe deer, represent reservoirs for both pathogens and vectors. Concerning helminths, the filaroid *Onchocerca jakutensis* has to be mentioned due to its zoonotic potential (Koehsler et al., 2007). However, human cases seem to be very scarce, reflected by the low number of cases.

The role of wild boar as reservoirs of *Trichinella* and *A. alata* was already described in connection with foxes. In about 6% of the wild boars originating from eastern Austria mesocercariae of *A. alata* were found (Paulsen et al., 2012).

Red deer from Austria are known to harbour *Theileria* (Fuehrer et al., 2013), which is considered to be of low to mild pathogenicity for ungulates with no known influence in dogs, cats or humans.

By contrast, *A. phagocytophilum*, which is known to infect a wide range of wild and domestic animals, including cats and dogs, as well as humans, might have an ungulate reservoir. In Central Europe this pathogen is transmitted mainly by *I. ricinus* with an infection prevalence of 3.5% to 6.6% (Polin et al., 2004; Leschnik et al., 2012b). A high percentage of roe deer, red deer and wild boar harbour these intracellular bacteria (Víchová et al., 2014). However, wild ungulates seem to harbour genotypes different from those affecting dogs, horses or humans. By investigation of a single nucleotide polymorphism in the groEL gene, human cases were defined as G variant, harbouring the base guanine at the 500 bp position. The same G variant is found in dogs, horses and a wolf (Polin et al., 2004; Leschnik et al., 2012a; Duscher, unpublished data). Deer, by contrast, mainly harbour an A variant, having an adenine as substitution at this position (Polin et al., 2004).

For TBE wild ungulates are probably not directly involved in the transmission cycle as viraemia is supposed to be too low to influence the spread of the disease (Nosek et al., 1967; Labuda et al., 2002). Large ungulates are believed to be mainly carriers of adult ticks (Estrada-Peña and de la Fuente, 2014), thus supporting tick development and multiplication, but they also were found to reduce the prevalence of tick infection by *B. burgdorferi* s. l. (Kjelland et al., 2011; Pacilly et al., 2014). Interestingly, roe deer are found to harbour all three blood-sucking stages of ticks. Additionally, the different stages feed in close vicinity, therefore enabling co-feeding, especially between larvae and nymphs and nymphs and adults, which might favour transmission of TBE (Skarphédinsson et al., 2005; Kiffner et al., 2011). Roe deer feed adult ticks and are the driving force for spreading these vectors (Labuda and Randolph, 1999; Medlock et al., 2013) because of their large home range compared to small mammals, thus disseminating the vectors for several tick-borne pathogens.

3. Conclusion

In Austria several wildlife reservoirs for different pathogens exist, representing a permanent threat for humans and pets. Moreover, many wild reservoir hosts are increasing in number and geographic range, thus increasing intra- and interspecies contact rates. Foxes, golden jackals, racoons and racoon dogs are noticed more frequently, presumably due to larger and expanding populations. As a consequence, the infection pressure of pathogens such as *E. multilocularis, T. canis, A. alata, B. procyonis, Trichinella* spp. and *Dirofilaria* spp. are assumed to increase. Due to the reported increasing wild boar population in the recent past, some pathogens like *T. britovi* or *A. alata* may find their way into the food chain and lead to human infections (Duscher et al., 2005).

Additionally, reports from central European countries show a shift of tick abundance (*I. ricinus*) to higher latitudes and altitudes (Daniel et al., 2003; Jaenson et al., 2012; Medlock et al., 2013). One reason for this may be increasing temperature, commonly described as global warming. It is assumed that an increase of the mean temperature from April to September of 2–3 °C will provide a suitable climate for the Mediterranean tick species *R. sanguineus* to establish a constant outdoor population in more northern areas like Austria (Gray et al., 2009). Another possibility for spreading ticks is the movement of host species. Roe deer are believed to be one of the driving forces in maintaining *I. ricinus* populations and spreading them to new habitats (Medlock et al., 2013). A higher density of roe deer hosts can be related to higher tick abundances (Medlock et al., 2013), and consequently to higher infection rates (Rizzoli et al., 2009).

In addition, leisure outdoor activities of humans together with their pets enjoy great popularity, promoting a broader interaction with wildlife pathogens. Travelling with pets opens new doors for foreign pathogens to be introduced, possibly leading to the establishment of new endemic foci if suitable parameters prevail.

In summary, parasites and vector-borne diseases transmissible to domestic animals and humans are abundant in Austria, and the spread of wildlife species as well as the introduction of neozoa may foster the spread and abundance of these agents. A close monitoring is necessary to plan and carry out control measures to prevent excessive transmission from wildlife reservoirs to humans and their pets. There is a significant lack of knowledge on many pathogens, vectors as well as reservoir hosts, which has to be filled by using new molecular methods and population modelling tools in the near future.

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Conflict of interest

The authors declared that there is no conflict of interest.

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