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The biological potential of the raccoon dog (*Nyctereutes procyonoides*, Gray 1834) as an invasive species in Europe—new risks for disease spread?

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Abstract Invasive wildlife species have the potential to act as additional host and vector species for infectious diseases. The raccoon dog (*Nyctereutes procyonides*), a carnivore species that has its origin in Asia, was taken as an example to demonstrate biological and ecological prerequisites which enables an invasive species to occupy a new habitat permanently. Studies conducted during the last 20 years identified a total of 35 species of endoparasites, five ectoparasites, six bacterial or protozoan species, and five viruses found in the subspecies *Nyctereutes procyonoides ussuriensis* in its original and newly occupied habitat or in *Nyctereutes procyonoides koreensis* in its original habitat, respectively. With reference to raccoon dogs impact as vector species and the relevance for human and animal health, we selected *Trichinella* spp., *Echinococcus multilocularis*, *Francisella tularensis*, rabies virus, and canine distemper virus for detailed description. Results of studies from Finland and Germany furthermore showed that biological characteristics of the raccoon dog make this carnivore an ideal host and vector for a variety of pathogens. This may result in a growing importance of this invasive species concerning the epidemiology of some transmissible diseases in Europe, including the hazard that the existence of autochthonous wildlife, particularly small populations, is endangered. Potential adverse effects on human and animal health in the livestock sector must also be taken into account. Especially with regard to its potential as a reservoir for zoonotic diseases, the raccoon dog should receive more attention in disease prevention and eradication strategies.

Keywords *Nyctereutes procyonoides* · Invasive species · Disease transmission · Zoonoses

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Introduction

In recent years, awareness for wildlife diseases has increasingly been raised and their possible effects on livestock and people discussed. Profound knowledge about the biology of potential reservoir or vector species is prerequisite for developing effective monitoring and management measures for disease outbreaks and parasite cycles in wildlife. This allows to identify risk factors, for instance population density and migration behavior of vector species (Gortázar et al. 2007). In this context, not only autochthonous animals but also alien species have to be considered.

Many human activities, for example agriculture and transportation, promote both, the intentional and the accidental spread of species outside their original settlement areas (Kolar and Lodge 2001). Natural colonization barriers such as oceans, mountains, and deserts form the requirements for the formation of local biodiversity, but with human "aid", some species have overcome these barriers and have settled in new areas. These invasive species can influence autochthonous ecosystems and may damage biological diversity (Klingenstein et al. 2005). After Clout (2002), the introduction of invasive vertebrates "is a major cause of the loss of native biodiversity and predatory mammals are the worst offenders".

Moreover, invasive species may also introduce pathogens into a new region. For example, the raccoon roundworm *Baylisascaris procyonis* was brought from North America to

Europe via infested raccoons (Beltrán-Beck et al. 2012). Also, life cycles of pathogens that exist already in a region may be supported by non-native species in addition to the autochthonous vector species that were involved in the life cycle before the invasive species had arrived. From an epidemiological point of view, established populations of invasive species are of eminent significance, as their biological features enables them to settle in a wide range within a rather short period of time. The raccoon dog (*Nyctereutes procyonoides*), a widespread invasive canid species in northern, eastern, and central Europe, is an ecological generalist with a flexible habitat use (Kauhala and Auttila 2010) and an omnivorous feeding habit (Sutor et al. 2010).

After Gebhardt et al. (1996), sufficient habitat and food resources in addition with a high reproduction rate and the ability for range expansion support the establishment of an alien species in a new environment. Scarcity of coevolved natural enemies—usually parasites and pathogens—as supposed in the enemy-release hypothesis (Roy et al. 2011) seems to be of minor importance for raccoon dogs' successful establishment in its new settlement areas. Probably pathogens and parasites listed in Table 1—30 % of them occur also in the authochtonous area of the raccoon dog—act not as key factors with a crucial effect on spreading of this generalist species.

Essential features for its effective expansion among others are omnivory, high reproductive potential and dispersal behavior as it is described in detail by Kauhala and Kowalczyk (2011).This carnivore is listed among the 100 worst alien species in Europe (Drake 2009). In addition to its potential predatory influence as an omnivorous species, the raccoon dog has to be considered as a potential reservoir and vector species for a number of pathogens.

The aim of this study was to review published literature on the evidence of raccoon dog as a vector for pathogens and to describe the biological properties and ecological conditions that support a sustainable establishment of this invasive species.

In this review, we tried to take all reports on the detection of pathogens in *N. procyonoides ussuriensis* in its original and newly occupied habitat and *Nyctereutes procyonoides koreensis* in its original habitat, both mainland subspecies of the raccoon dog. We regarded scientific papers published within the last two decades, but also older publications if relevant, excluding reports on infections detected in the subspecies *N. p. viverrinus*, which lives only in Japan. On the one hand, the latter subspecies differs clearly with respect to its genetics and morphology from mainland subspecies (Kauhala and Saeki 2004), and this possibly have some influence on the susceptibility of parasites and infectious diseases. On the other hand Europe is colonized exclusively by *N. p. ussuriensis* (Nowak 1973, 1984) and therefore we took only references concerning mainland subspecies into consideration. The following description of biological characteristics of *N. p. ussuriensis*, obtained through various perennial studies in Finland and Germany, point out key factors that enable alien species to colonize new areas permanently (Kauhala and Winter 2009).

Biological characteristics of the raccoon dog

The raccoon dog is originally distributed in southeastern Asia, Russian Far East, and on Japanese islands. High mountains and deserts form natural migration barriers, and areas with long-lasting and snowy winter periods are avoided (Kauhala and Saeki 2004). In their natural range, raccoon dogs appear in six subspecies. The subspecies *N. p. ussuriensis*—permissive to low winter temperatures—lives in the most northern territory where raccoon dogs occur, the area of the rivers Amur and Ussuri (Kauhala and Saeki 2004). Therefore, this subspecies seemed especially suitable for colonization projects in different regions of the former USSR. Between 1928 and 1955 in the European part of the former Soviet Union, approximately 9,000 individuals have been released, whereas in the Ukraine, the establishment of a permanent raccoon dog population succeeded (Lavrov 1971). Starting from there, raccoon dogs populated new areas in east Europe, Fennoscandia, and central Europe (Kauhala and Helle 1995, Nowak 1993).

The raccoon dog belongs to one of 33 alien mammal species in Europe which forms self-sustaining populations and is regarded as one of the most successful alien carnivores (Kauhala and Kowalczyk 2011). The species must be considered as established in east, central, and partly in north Europe, and its further expansion west- and southwards still is in process (Kauhala and Kowalczyk 2011).

During the last decade, a further range expansion of the raccoon dog into Mediterranean areas has been shown by road-killed individuals: 2002 in the Republic of Macedonia in former Yugoslavia (Ćirović 2006) and 2008 in southern Spain (ANSE 2010). Since raccoon dogs have now been living for about 60 years in Hungary and Romania, it must be expected that the species is able to adapt to warm climate conditions. Nowadays, the Arctic Circle forms the northern limit for permanent distribution, but in view of the climate change, it seems possible that the raccoon dog will expand its distribution area northwards (Kauhala and Kowalczyk 2011). An early start of springtime and longer periods of growth help especially juvenile raccoon dogs to acquire sufficient body fat for survival during hibernation in winter (Kauhala and Helle 1995). In addition, successful invasive species usually tolerate a wide range of climatic and environmental conditions and are normally omnivorous (Caut et al. 2008).

In Germany, the presence of raccoon dogs was confirmed in the 1960s (Nowak 1973, 1984). Today, raccoon dogs may

Table 1 Pathogens detected in raccoon dogs of the mainland subspecies (*N. procyonoides ussuriensis* and *N.p.koreensis*); publications during the years 1990 and 2012. *A*=authochtonous area of the raccoon dog. *I*=area of raccoon dog introduction

Taxa	Location (selection)	A	I	References (selected)
Viruses				
Rabies virus	Europe; South Korea; Estonia	X	X	Holmala and Kauhala 2006; Kim et al. 2006; Kulonen and Boldina 1993
Canine distemper virus	China, South Korea; Germany	X	X	Zhao et al. 2010; Cha et al. 2012; Anonymous 2010
H5N1 Avian Influenza A, genotype V	China	X		Qi et al. 2009
SARS-Coronavirus	China	X		Xu et al. 2009; Graham and Baric 2010
Canine Parvovirus	China; Finland; Germany	X	X	Chen et al. 2011; Isomursu 2011; Frölich et al. 2005
Bacteria				
Rickettsia japonica	South Korea	X		Camer and Lim 2008
Rickettsia typhi	South Korea	X		Camer and Lim 2008
Francisella tularensis	Germany		X	Kühn et al. 2009
Protozoa				
Babesia microti	South Korea	X		Han et al. 2010
Neospora caninum	South Korea	X		Kim et al. 2003
Leishmania spp.	China	X		Xu et al. 1982; Ashford 1996
Trematoda				
Alaria alata	Belarus; Germany		X	Shimalov and Shimalov 2002
A. a. metacercaria	Lithuania		X	Thiess et al. 2001 Bružinskaitė-Schmidhalter et al. 2011
Isthmiophora melis	Belarus; Germany		X	Shimalov and Shimalov 2002; Thiess et al. 2001
Metorchis bilis	Belarus; Germany		X	Shimalov and Shimalov 2002; Thiess et al. 2001
Opisthorchis felineus	Belarus		X	Shimalov and Shimalov 2002
Pseudamphistomum truncatum	Belarus; Russia/Volga Delta;		X	Shimalov and Shimalov 2002; Schuster et al. 1999
Apophallus muehlingi	Russia/ Volga Delta		X	Ivanov 2008
Rossicotrema donicum	Russia/ Volga Delta		X	Ivanov 2008
Echinostomatidae	Lithuania		X	Bružinskaitė-Schmidhalter et al. 2011
Cestoda				
Dipylidium caninum	Belarus		X	Shimalov and Shimalov 2002
Mesocestoides lineatus	Belarus; Lithuania		X	Shimalov and Shimalov 2002; Bružinskaitė-Schmidhalter et al. 2011
Echinococcus multilocularis	Germany; Poland; Latvia		X	Thiess et al. 2001; Machnicka-Rowińska et al. 2002 ; Bagrade et al. 2008
Spirometra erinacei	Belarus		X	Shimalov and Shimalov 2002
Taenia crassiceps	Belarus; Lithuania		X	Shimalov and Shimalov 2002; Bružinskaitė-Schmidhalter et al. 2011
T. hydatigena	Belarus		X	Shimalov and Shimalov 2002
T. pisiformis	Belarus		X	Shimalov and Shimalov 2002
T. polyacantha	Belarus; Germany; Lithuania		X	Shimalov and Shimalov 2002; Thiess et al. 2001; Bružinskaitė-Schmidhalter et al. 2011
Nematoda				
Ancylostoma caninum	Belarus		X	Shimalov and Shimalov 2002
Arthrostoma miyazakiense	South Korea	X		Shin et al. 2007
Aonchotheca putorii Syn. Capillaria putorii	Belarus; Lithuania		X	Shimalov and Shimalov 2002; Bružinskaitė-Schmidhalter et al. 2011
Crenosoma vulpis	Belarus; Lithuania		X	Shimalov and Shimalov 2002; Bružinskaitė-Schmidhalter et al. 2011
Eucoleus aerophilus Syn. Capillaria aerophila	Belarus; Germany; Lithuania		X	Shimalov and Shimalov 2002; Thiess et al. 2001; Bružinskaitė-Schmidhalter et al. 2011
Molineus patens	Belarus; Germany		X	Shimalov and Shimalov, 2002; Thiess et al., 2001

Table 1 (continued)

Taxa	Location (selection)	A	I	References (selected)
Pearsonema plica *Syn. Capillaria plica*	Belarus; Germany;		X	Shimalov and Shimalov 2002; Thiess et al. 2001
	Lithuania			Bružinskaitė-Schmidhalter et al. 2011
Strongyloides erschovi	Belarus		X	Shimalov and Shimalov 2002
Toxascaris leonina	Belarus; Germany		X	Shimalov and Shimalov 2002; Schuster et al. 1993
Toxocara canis	Germany; Lithuania		X	Thiess et al. 2001; Bružinskaitė-Schmidhalter et al. 2011
Trichinella spp.	Belarus; Lithuania		X	Shimalov and Shimalov 2002; Bružinskaitė-Schmidhalter et al. 2011
Trichinella spiralis	Germany; Finland		X	Pannwitz et al. 2010; Oivanen et al. 2002
Trichinella pseudospiralis	Germany; Finland; Caucasus Region		X	Pannwitz et al. 2010, Oivanen et al. 2002; Pozio 2000
Trichinella nativa	Finland; Far East Russia	X	X	Oivanen et al. 2002; Pozio 2000
Trichinella britovi	Finland; Belarus		X	Oivanen et al. 2002; Pozio 2000
Trichuris vulpis	Belarus		X	Shimalov and Shimalov 2002
Uncinaria stenocephala	Belarus; Germany; Lithuania		X	Shimalov and Shimalov, 2002; Thiess et al. 2001; Bružinskaitė-Schmidhalter et al. 2011
Syphacia obvelata	Lithuania		X	Bružinskaitė-Schmidhalter et al. 2011
Heligmosomum costellatum	Lithuania		X	Bružinskaitė-Schmidhalter et al. 2011
Acanthocephala				
Macracanthorhynchus catulinus	Belarus		X	Shimalov and Shimalov 2002
Arthropods/Ectoparasites:				
Trichodectes canis	Czech Republic		X	Bádr et al. 2005
Sarcoptes scabiei	South Korea; Finland; Poland	X	X	Eo et al. 2008; Mörner 1992; Kowalczyk et al. 2009
Haemaphysalis flava	South Korea	X		Lee et al. 1997
Haemaphysalis leporispalustris	South Korea	X		Han et al. 2009
Ixodes tanuki	South Korea	X		Lee et al. 1997

be hunted all year in all German federal states except the City of Bremen. Available hunting statistics showed a substantial increase of the hunting bag over time. Two hundred four individuals were killed in the hunting year 1994/1995. In the following years, the hunting bag increased significantly and reached 30,016 raccoon dogs in the hunting season 2005/2006. Since then, the hunting bag oscillated between 27,512 and 30,053 animals. In the past two hunting seasons, a distinct decrease in the number of hunted raccoon dogs (2009/2010:17,550; 2010/2011: 14,674) has been registered (http://www.jagd-online.de/datenfakten/jahresstrecken/?meta_id=257).

As judged by the current hunting bag in Germany, a nearly country-wide establishment of the raccoon dog seems likely probably with the highest population densities in eastern federal states—particularly in Mecklenburg-Western Pomerania and Brandenburg.

Raccoon dogs live secretively and have a predominantly nocturnal activity pattern. These features may cause a delay in the detection of recent range extensions. Furthermore, they complicate reliable estimates of population densities.

The lack of top predators (e.g., big cats *Pantherinae*, wolf *Canis lupus lupus*, brown bear *Ursus arctos*) in many parts of central Europe—especially in agricultural landscapes—and a high number of offspring create optimal conditions for the dispersion of the raccoon dog. In different countries, high litter sizes had been observed: 9.0 puppies in Finland (Kauhala 1996), 8.4 puppies in Poland (Kowalczyk et al. 2008), and in Germany, the birth of 8.0 puppies between mid-April and the end of May (Boge 2006). Raccoon dogs have an all-season pair bond, both parents rear the offspring together (Kauhala et al. 1998, Drygala et al. 2008a). Raccoon dogs frequently utilize abandoned badger dens (Kowalczyk et al. 2008, Sutor and Schwarz 2011b). Because the raccoon dog obtains sexual maturity at the end of its first year, this leads to a rapid population increase.

As raccoon dogs have a distinct ability to migrate, new areas can be colonized in rather short time periods. Dispersal of juveniles may start as early as in July of their birth year. Between September and October, 20–50 % of juveniles were discovered in a distance of 40 km from the tagging places within their maternal home ranges; the animals can migrate over long distances within a few weeks (Drygala et al. 2010; Sutor 2008). Raccoon dogs observed during dispersal showed flexible migration behavior without any difference between males and females, which is expected to be a contributing factor for the successful expansion of this species (Drygala et al. 2010). Likewise, adult raccoon dogs that were not pair-bonded dispersed in a couple of days over long distances (Sutor and Schwarz 2011a).

Raccoon dogs occur in quite diverse habitats: temperate rain forests, Scandinavian boreal forests, European and Asian country sides with bogs and rivers, agricultural landscapes in Europe and the Russian Far East (Barbu 1972; Drygala et al. 2008b; Holmala and Kauhala 2009; Herfindal et al. 2012; Judin 1977). The animals are obviously able to cope with big environmental differences in their home ranges. Spacious dens in Europe—mainly abandoned badger dens—are the most important requisite, which is used for pup rearing and during winter (Kowalczyk and Zalewski 2011). Raccoon dogs have a generalistic behavior in habitat use and are able to survive in a variety of areas if they offer sheltered places (dens) and sufficient food supply.

In southern Finland in Ruissalo and Tuulos study areas consisting of managed spruce and mixed forests, meadows, and fields, the population densities of raccoon dogs were 1.9 and 2.2 adults/km^2 (Kauhala et al. 2010). In an agricultural landscape in Brandenburg (East Germany), a mean population density of 1.1 adults/km^2 during winter and of 4.9 individuals/km^2 including juveniles during summer was determined (Sutor and Schwarz 2011b). On farmland in Mecklenburg-Western Pomerania, Zoller (2010) calculated a comparable population density of 1.2 adults/km^2 and 3.4 individuals/km^2 including juveniles.

Many regions in Europe are characterized by agricultural landscapes interspersed with forest, which provide sustainable life conditions for raccoon dogs by a comprehensive supply of food, numerous hiding places, predominantly short winter periods with little snow cover and sparse natural predators. Finally these environmental factors presumably lead to high population densities. Intensive farming of energy-rich plants such as maize provide rich food sources for the omnivorous raccoon dog. Diet analysis conducted in agricultural landscapes in Germany documented maize (frequency of occurrence 18.1–32.8 %) being an important food item the year round (Sutor et al. 2010). For raccoon dog and other scavengers, road-killed animals and remains of hunted hoofed game equally offers easily accessible food. In an east German study on red fox (area 83 km^2) with an agricultural landscape, crossed by a federal highway (8 km) and some smaller roads, bordered on one side by 40 km motorway, Stiebling (2000) calculated 2,000 kg meat resulting from mammals killed by traffic per year and 2,047 kg remains from hunting of hoofed game per year. The population density of hoofed game in the study area in average was estimated with10–12 animals/km^2. In principle, its diet composition is influenced by the season and by the habitat structure, and therefore the raccoon dog as an omnivorous species is able to live in a wide range of habitats.

During wintertime, raccoon dogs minimize food intake and, similar to badgers (*Meles meles*), use their body fat, which is mainly built up in summer and autumn (Asikainen et al. 2004). This energy-saving behavior normally provides good conditions for the start into mating season, thus leading to a high reproductive capacity.

Although in Germany, a mortality rate—mainly caused by hunting and traffic—of 69.5 % has been observed (Drygala et al. 2010), in areas with favorable conditions, e.g., sufficient food supply and a small number of predators, a sufficient number of the juveniles may survive for colonizing new areas, thus potentially facilitating the distribution of pathogens carried by the animals.

Raccoon dogs as reservoirs and vectors of pathogens

Judin (1977) gave a detailed overview of the parasite fauna of the raccoon dog subspecies *N. p. ussuriensis* in its original habitat in Russian Far East and in the introduction areas of the former Soviet Union; among others, he listed a multitude of lice, flea, and mites. In this review on pathogens detected in the mainland subspecies, *N. p. ussuriensis* and *N. p. koreensis*, publications of the last two decades (1992–2012) are taken into account, plus the only earlier publication of Xu et al. (1982).

Several endoparasites, including eight trematodes, eight cestodes, 18 nematodes, and one thorny-headed worm have been described in two mainland subspecies of the raccoon dog, mentioned above (Table 1). Moreover, five ectoparasites have been observed on raccoon dogs. One of them, *Ixodes tanuki,* is actually a parasite of the two Japanese subspecies and has surprisingly been collected from a raccoon dog in South Korea (Lee et al. 1997). In the past years, Korean and European raccoon dogs have been tested by serology and PCR for several pathogens. These studies yielded evidence for infections with six bacterial or protozoon species and five viruses (Table 1). Some selected pathogens (two viruses, one bacteria, two parasites) detected in raccoon dogs are of particular interest and will therefore be presented in more detail.

As many as 55,000 humans die of rabies infection every year, and this virus is also very dangerous for wildlife and livestock. Canine distemper virus is worldwide distributed and lethal in most cases both for wildlife and livestock. Both mentioned viruses are relevant as well as with a view to conservation of indigenous wildlife. Especially species with small populations and restricted settlement areas may be particularly vulnerable if they are exposed to those pathogens, which might be increasingly distributed by an invasive species. Tularemia is a zoonotic disease, possibly spreading in Europe, which might be transferred over longer distances by migrating wildlife such as raccoon dog. Finally, we focussed on two parasites: *Echinococcus multilocularis*, inducing alveolar echinococcosis being lethal for humans if left untreated and *Trichinella* spp., causing severe health problems for humans being infected by consuming of meat infested with larvae. In the life cycles of named parasites, the raccoon dog serves as an additional host in Europe.

Rabies is caused by a virus of the genus *Lyssavirus*, family Rhabdoviridae, and has been known for thousands of years. The infection leads to a lethal encephalitis both in animals and humans. In most cases, the infection is transmitted by the bite of animals that excrete the virus in their saliva. More than 55,000 humans die of rabies every year; most human casualties are recorded in Asia and Africa (http://www.who-rabies-bulletin.org). Since 2008, Germany, is officially recognized as rabies-free as most other west and central European countries (Freuling 2009). Freedom from rabies is strictly speaking limited to terrestrial animals, while lyssavirus infections of bats are regularly reported from several European countries. In those areas, where the population density is high and where rabies still occurs, the raccoon dog comes second after the red fox among the hosts for rabies (Singer et al. 2009). In Finland, first raccoon dogs were recorded in the latter half of the 1930s (Helle and Kauhala 1991). In the mid-1950s, the colonization started, and in the1960s, the raccoon dog population density increased rapidly (Kauhala and Kowalczyk 2011). Since 1959, Finland had been rabies-free, but during an outbreak of sylvatic rabies in the country from 1988 to 1989, 73 % of verified rabies cases were recorded in raccoon dogs (Singer et al. 2009). As documented in Holmala and Kauhala (2006), raccoon dogs had been important rabies vectors also in the Baltic States like Estonia and Latvia.

In Europe, the share of raccoon dogs among registered wildlife rabies cases ranged between 6.3 % and 7.99 % in the years 2007–2011 (Freuling 2007, 2009, 2010, 2011, 2012a, b).

Depending on winter hibernation, infected raccoon dogs may contribute to the persistence of rabies and accelerate the spread of the virus (Finnegan et al. 2002). The dispersal behavior of the raccoon dog may also have critical influence on the spreading of rabies. In Finland, 17 % of juveniles dispersed more than 40 km (Kauhala and Helle 1995), and in a study conducted in Germany, even 27 % of recovered ear-marked juveniles have been 80–100 km away from their tagging places (Sutor 2008). Thus, rabid individuals may transmit this dangerous epizootic in more distant areas.

As the example of Finland has shown, raccoon dogs can play a major role in the re-emergence of rabies in a formerly rabies-free area. The colonization by the raccoon dog is still in process in some areas and population densities are increasing; therefore, the potential role of the raccoon dog with regard to the transmission of rabies in Europe might even rise in future. Any re-emergence or dissemination of this lethal disease would bear a high risk for humans and might affect relict populations of threatened mammals due to the wide host range of rabies virus.

Canine distemper virus (CDV) is a single-stranded RNA virus of the genus *Morbillivirus*, belonging to the family Paramyxoviridae. This worldwide distributed pathogen causes severe infections and frequently lethal disease, particularly in members of the order *Carnivora*. CDV can cross species barriers (Sekulin et al. 2011). The infection is highly contagious. Clinical symptoms are primarily associated with the respiratory tract and the central nervous system. Due to a developing immunosuppression that is frequently characterized by leukopenia and lymphopenia, affected animals often succumb to opportunistic infections. Primarily a disease of dogs, several new or incompletely characterized genotypes of CDV seem to spread to novel carnivore hosts (McCarthy et al. 2007; Pratelli 2011). CDV may therefore pose a high risk for threatened carnivore species worldwide and might even lead to extinction of relict populations. For example, in a free-ranging Amur tiger (*Panthera tigris altaica*) population in the Russian Far East, 15 % of the investigated animals had antibodies against CDV, and some tigers died from the disease (Goodrich et al. 2011, 2012). A high seroprevalence and a small proportion CDV vaccinated dogs, especially in rural areas, where contact between rembling pets and wild carnivores occurs easily, may enforce the problem.

At the same time, new and established carnivore species like the raccoon (*Procyon lotor*) and the raccoon dog may increase the risk of CDV spreading in wild carnivore populations in densely populated Europe. It should also be noted that the full range of European wildlife hosts for CDV is not yet known (Nikolin et al. 2012). In recent years, rising numbers of CDV cases in wild carnivores in Germany occurred in raccoon dogs (Anonymous 2010) and other members of the Canidae. Raccoons and red foxes in a particular area in Mecklenburg-Western Pomerania were found infected with distinct CDV genotypes and a new lineage of the virus has been detected in raccoons (Nikolin et al. 2012). In southern Germany, a mutation leading to an amino acid exchange in the HA protein was found in foxes and one badger, suggesting that a host switching or increased virulence could result (Sekulin et al. 2011). In areas, where raccoon dogs occur frequently, the spread of CDV might be accelerated. In South Korea, i.e., in its native range, where the raccoon dog is one of the most abundant mammals, 44 % of sampled raccoon dogs tested seropositive for CDV in a recent study, indicating that the infection is widely spread in that region (Cha et al. 2012). The generalistic mode of life of invasive and some native carnivore species, such as red fox and badger, results in high population densities of different species in the same area and increases the probability of CDV infection also in threatened carnivore species like the wolf (*C. l. lupus*), the lynx (*Lynx*

lynx), the European wildcat (*Felis silvestris*), the brown bear (*U. arctos*) and the European mink (*Mustela lutreola*) and in recovering populations.

Francisella tularensis, a gram-negative bacterium, is the cause of tularemia, a zoonotic disease that occurs in the northern hemisphere. Clinical symptoms in humans depend on the route of infection as well as on the bacterial strain and infection dose (Runge et al. 2011). Since inhalation of *F. tularensis* may cause lethal pneumonia, this bacterium is regarded as a potential biological warfare agent (Splettstoesser et al. 2007). Direct exposure, for instance by handling infected hares, oral ingestion, or inhalation of bacteria adhering to particulate material or dust, may cause infection. A multitude of vertebrates, especially rodents and hares, serve as reservoir, but also invertebrates such as blood-suckling arthropods (mosquitos, ticks) can harbor this bacterium for months (Selbitz 1992). Detection of a high number of serologically positive foxes and raccoon dogs in Brandenburg (East Germany) indicates that *F. tularensis* is permanently present in wildlife in East Germany (Kühn et al. 2009). During the last four decades, tularemia was a rare disease in humans, but since 2005, this zoonosis may be re-emerging (Runge et al. 2011). The relative importance of different routes of transmission is not fully understood and knowledge on spatial distribution of the infection in Germany and other European states is incomplete (Splettstoesser et al. 2009). It seems possible that migrating wildlife, such as raccoon dogs, could transfer the pathogen over longer distances (Splettstoesser et al. 2007).

E. multilocularis is a widely distributed endoparasite in the northern hemisphere. Its adult stage lives in the small intestine of carnivores, mainly canids (Eckert and Deplazes 2004). The main intermediate hosts of this parasite are rodents. Accidental infection of humans by ingestion of infectious parasite eggs may cause alveolar echinococcosis. This dangerous zoonosis is often lethal if left untreated. In central Europe, the red fox (*Vulpes vulpes*) is the main definitive host of *E. multilocularis* (Eckert et al. 2000, Romig et al. 2006). As the raccoon dog is highly susceptible to this parasite, the relevance of this invasive species as an additional definitive host for the parasite may increase (Thiess et al. 2001, Kapel et al. 2006, Romig et al. 2006). In a study on echinococcosis in raccoon dogs conducted in Brandenburg (East Germany), the estimated true prevalence ranged between 6 % and 12 % (Schwarz et al. 2011). As described above, the population density of the raccoon dog in this federal state is high, and growing host populations may promote the spread of *E. multilocularis* (Romig et al. 2006). As neozootic mammals may be involved in the life cycle of *E. multilocularis* (Romig 2009), we hypothesize that the raccoon dog may, in addition to the red fox as the main definitive host, increase the risk for humans to become exposed to *E. multilocularis*.

Trichinellosis, a zoonosis with worldwide distribution, is caused by different nematod species of the genus *Trichinella*. Humans are classified as highly susceptible and get infected by consumption of contaminated raw meat. Three to five days after ingesting *Trichinella* larvae, severe symptoms of disease such as deadness, insomnia, high fever, abdominal pain, vomitting, and diarrhea occur. About 4 weeks later, larvae have reached their final place for persistance in muscle tissue, which might create myocarditis, encephalitis, and secondary infections (Nöckler 2007).

The trichinellosis agent—most important *Trichinella spiralis*, further *Trichinella nativa*, *Trichinella britovi, and Trichinella pseudospiralis*—is maintained by sylvatic cycles globally or domestic cycles. Wild carnivorous and omnivorous species in Europe, for instance red fox, wolf, raccoon dog, and wild boar, participate in the sylvatic cycle and domestic pig and horse in the domestic cycle (Pozio 2000). In USA, in Spain, and in Russia, an increase of trichinellosis prevalence in wildlife by practice of hunters leaving viscera and carcasses in the field is documented. In a study conducted from 1998 to 2000 in northwest Russia, even the highest prevalence (97.5 %) ever observed in sylvatic mammals has been detected in wolf (Pozio et al. 2001). Carrion is a frequent item in the diet of the raccoon dog *N. p.ussuriensis* in its whole geographic range (Sutor et al. 2010). Therefore, the raccoon dog is a main host of *Trichinella britovi* (Pozio 2000); in a Finnish study, this canid also was the sole host for all four *Trichinella* species, and infection was the most intense in comparison to other carnivores (Oivanen et al. 2002). The simultaneous growing of the raccoon dog population is discussed to be responsible for an increase of trichinellosis prevalence in wildlife and domestic pigs in Finland (Oivanen et al. 2002). In Lithuania and Estonia, investigation data from 2000 to 2002 proved a higher prevalence of *Trichinella* in raccoon dogs compared with previous studies (Malakauskas et al. 2007). In those areas where the raccoon dog is widespread with high populations densities, this species presumably will become a key factor in the cycle of this zoonosis. An improper handling with contaminated meat both of wildlife and of domestic pig leads to a transmission between sylvatic and domestic cycle.

Discussion

Its flexible habitat use, omnivorous diet, high number of offspring, dispersal ability, and sustainable life conditions enable the raccoon dog to form steady populations in Europe. In European landscapes with heterogeneous habitat structure, high population densities are possible (Kauhala et al. 2010, Sutor and Schwarz 2011b, Zoller 2010), and further on, a common use of home ranges between red fox and raccoon dog has been recorded in telemetry studies in Finland and Germany (Holmala and Kauhala 2009, Zoller

2010). These facts could increase the intra- and interspecific contact rates and might therefore be favorable to the transmission of pathogens. The social behavior of the raccoon dog (pair bond all year) and of other vector species such as badger and raccoon, which live both in groups, favors simultaneous infections of several individuals. Likewise, individuals meet at foraging places which are for instance regularly baited with maize for hunting. Different species, autochthonous and invasive—red fox, badger, raccoon dog, raccoon—have the chance to get in contact in such places and to transmit pathogens, as their home ranges overlap (Kauhala et al. 2006). This also implies that pathogens may switch to new host species on such occasions and adapt (McCarthy et al. 2007).

In addition to direct contact, raccoon dogs, as many other animals, may contract infections by intake of contaminated food. Due to its generalistic feeding habit, the raccoon dog can use a variety of food sources and may therefore be exposed to a multitude of pathogens, as it had been described for the Amur-Ussuri distribution area by Judin (1977). For example, the animal is a definitive host for *Alaria alata*, a trematode parasite. Raccoon dogs get infected by ingesting larval stages of the parasite by eating snails (1. intermediate host) or amphibians (2. intermediate host). Small mammals represent a main component of the diet of the raccoon dog. Many of them, for example the common vole *Microtus arvalis*, are intermediate hosts for *E. multilocularis*, which explains that the raccoon dog has established as a definitive host for this parasite in some regions (Schwarz et al. 2011)

There are only few—if any—specific environmental requirements that must be fulfilled to sustain the formation of stable populations of the omnivorous raccoon dog. The species is therefore able to colonize various landscape types. The beginning colonization of raccoon dogs in southern Europe makes infections with endemic pathogens, e.g., *Leishmania infantum* possible, perhaps even likely. Canids are natural reservoirs of this parasite, and Leishmania-positive foxes have already been detected in Italy, France, and Spain (Verin et al. 2010). Because of its great flexibility, the establishment of stable raccoon dog populations can be expected in these countries in the next decades, which might lead to the development of an additional reservoir for leishmaniosis. The raccoon dog is an undemanding species, and by its good migration ability, it can cover new settlement areas, particularly lowlands, in rather short time periods. This behavior creates an ideal precondition for distribution of pathogens. The dispersal of juveniles may especially enhance this development. Its clandestine lifestyle with mainly nocturnal activity may make it difficult to detect the establishment of a population and to assess their density at the local level for extended periods. If road-killed raccoon dogs are found in an area, there is a high probability that this species is already well established.

Conclusions

High population densities and the potential for range extension of vector species pose important risk factors for the distribution of wildlife diseases (Gortázar et al. 2007). Results of recent research studies from Finland and Germany demonstrate that these criteria are fulfilled by the raccoon dog. The animal is widely distributed in Europe, it reaches high population densities in large areas not least due to successful oral vaccination campaigns against rabies, and it is a potential vector for a plethora of pathogens. The establishment of the raccoon dog as a further vector species may increase health risks for livestock, wildlife, and humans and could have a negative impact on wildlife conservation projects. Eradication of the raccoon dog in the areas the animal invaded in recent decades is impossible. Due to the fact that the raccoon dog is involved in the life cycle of a number of pathogens or can transmit them; its impact on the epidemiology of the respective infections will increase with the further expansion of the range of the raccoon dog in Europe. Therefore, the raccoon dog should prospectively be included in monitoring systems for some of the major diseases (e.g., rabies) and its specific properties, for instance variations in its seasonal activity (Holmala and Kauhala 2006), taken into account if prevention and control measurements are planned.

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