

Babesiosis of wild carnivores and ungulates

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Abstract

Although large and small piroplasms have been reported from various wild carnivore and ungulate species, relatively few have been named. In the past, mere presence of a piroplasm in a specific host frequently prompted naming of a new species. Descriptions were often inadequate or lacking altogether. Currently, demarcation of species relies heavily on molecular characterisation. Even serological evidence is deemed insufficient. Experimental transmission of *Babesia* spp. from domestic to wild animals is usually only successful in closely related species, or after splenectomy. There are indications that endemic stability, similar to the situation in livestock, is the general pattern in *Babesia* sp. infections in wildlife. All lions in Kruger National Park were found to be infected with *B. leo*, which did not lead to clinical disease manifestation in artificially infected lions. Under stressful conditions, infections could flare up and be fatal, as purportedly happened to the famous lioness “Elsa”. Similarly black rhinos, which can harbour *Babesia bicornis* without ill effects, may develop clinical babesiosis during confinement after capture. Zoo-bred animals, which were not exposed to *Babesia* spp. at a young age, may be fully susceptible when released into a natural environment where other members of their species occur. This could have major implications for ex situ conservation programmes aimed at bolstering natural wildlife populations.

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1. Introduction

Large and small piroplasms have been reported from various wild carnivore and ungulate species. The reports frequently are mere documentations of organisms seen on blood smears randomly made of clinically normal animals. In a minority of cases, these organisms are incriminated as causing diseases in their hosts. In most cases, the organisms are not named.

There has also been a plethora of names under which these organisms are reported. Some small piroplasms may also have been recorded as *Theileria* species, based on morphology. Wenyon (1926) discarded the genus names *Piroplasma*, *Nicolliia*, *Nuttalia*, *Smithia*, *Rossiella*, *Babesiella* and *Microbabesia* in favour of a single genus, *Babesia*. He even included *Gonderia*, now regarded as a synonym of *Theileria*, in this group. Levine, 1971 and Levine, 1988 basically followed the same approach. It is becoming apparent that this classification is an oversimplification. Splitting is probably imminent, and some of the discarded genus names may have to be resurrected.

In contrast to the rather informal descriptions of the past, demarcation and definition of species has become much more rigorous and relies heavily on molecular characterisation. Even serological evidence is deemed insufficient (Lopez-Rebollar et al., 1999). Few new *Babesia* species have been described in recent years.

2. *Babesia* species described from wild carnivores and ungulates

In the past, mere presence of a piroplasm in a specific host frequently prompted naming of a new species. Descriptions were often inadequate by today's standards, or lacking altogether. In the absence of reference type material, it is often virtually impossible today to determine the identity of many of these organisms with any degree of certainty.

The *Babesia* species named from carnivores and ungulates are given in Table 1 and Table 2, respectively. The current taxonomic status of several of these entities is uncertain. In a survey of haemoparasites of free-ranging ruminants in Austria, Hinaidy (1987) questioned the validity of several species, including *Babesia moravica*, *Babesia capreoli* and *Babesia odocoilei*.

Table 1.

Babesia spp. described from wild carnivores

Species	Host	Author(s) and year
Family Canidae (dogs)		
<i>B. bauryi</i> ^a	<i>Fennecus dorsalis</i>	Leger and Bédier (1922)
<i>B. (canis) rossi</i>	<i>Canis adustus</i>	Nuttall (1910)
<i>B.</i>	<i>Canis lupus</i>	Yakimoff and Shokor (1916)

Species	Host	Author(s) and year
<i>ninakohlyakimo vae</i>		
<i>B. procyoni</i>	<i>Nyctereutes procyonides</i>	Chobotar'ov (1938)
Family Felidae (cats)		
<i>B. catus</i>	<i>Felis catus</i>	Mudaliar et al. (1950)
<i>B. felis</i>	<i>Felis ocreata</i> (= <i>F. sylvestris</i>)	Davis (1929)
<i>B. herpailuri</i>	<i>Herpailurus yaguarundi</i>	Dennig (1967)
<i>B. leo</i>	<i>Panthera leo</i> , <i>P. pardus</i>	Penzhorn et al. (2001)
<i>B. pantherae</i>	<i>Panthera pardus</i>	Dennig and Brocklesby (1972)
Family Herpestidae (mongooses)		
<i>B. cynicti</i>	<i>Cynictis penicillata</i>	Neitz (1938)
<i>B. heischi</i>	<i>Helogale undulata rufula</i> (? <i>H. parvula</i>)	Grewal (1957)
<i>B. herpestidis</i>	<i>Herpestes ichneumon</i>	França (1908), in Levine (1988)
<i>B. hoarei</i>	<i>Helogale undulata rufula</i>	Grewal (1957)
<i>B. legeri</i>	<i>Herpestes calera</i> (? <i>Atilax paludinosus</i>)	Bédier (1924); Penzhorn and Chaparro (1994)
<i>B. mungo</i>	<i>Herpestes mungo</i> (? <i>H. edwardsi</i>)	Carpano (1939); Levine (1984)
<i>B. vanhoofi</i>	<i>Helogale varia</i> (? <i>H. parvula</i>)	De Smet and Lips (1955)
Family Hyaenidae (hyaenas)		
<i>B. alberti</i>	<i>Crocuta crocuta</i>	Van den Berge (1937)
Fam Mustelidae (weasels, badgers, polecats, etc.)		

Species	Host	Author(s) and year
<i>B. meles</i>	<i>Meles meles</i>	Krivkova (1960)
<i>B. mephitis</i>	<i>Mephitis mephitis</i>	Holbrook and Frerichs (1970)
<i>B. missirolii</i>	<i>Meles meles</i>	Biocca and Corradetti (1952)
<i>B. mustelae</i>	<i>Mustela putorius</i>	Lebedeff and Tscharnotzky (1911)
<i>B. roubaudi</i>	<i>Ictonyx striatus</i>	Leger and Bédier (1923)
Fam Viverridae (civets, genets, etc.)		
<i>B. civettae</i>	<i>Civettictis civettae</i>	Leger and Leger (1920)
<i>B. garnhami</i>	<i>Genetta genetta</i> ; <i>Genetta tigrina</i>	Heisch (1952)
<i>B. genettae</i>	<i>Genetta genetta</i>	Heisch (1952)
Family Procyonidae (raccoons)		
<i>B. lotori</i>	<i>Procyon lotor</i>	Anderson et al. (1981)

^a Regarded as a synonym for *B. gibsoni* by Levine (1988); *Fenecus dorsalis* is regarded as a synonym for *Canis aureus dorsalis* (Maronpot and Guindy, 1970).

Table 2.

Babesia spp. described from wild ungulates

Species	Host(s)	Author(s) and year
Order Perissodactyla, Family Rhinocerotidae (rhinoceroses)		
<i>B. bicornis</i>	<i>Diceros bicornis</i>	Nijhof et al. (2003)
Order Proboscidea (elephants)		
<i>B. loxodontis</i>	<i>Loxodonta africana</i>	Rodhain (1936)

Species	Host(s)	Author(s) and year
Order Hyracoidea (hyraxes)		
<i>B. thomasi</i>	<i>Procavia capensis</i> , <i>P. habessinica</i> , <i>Dendrohyrax brucei</i>	Jansen (1952); Levine (1988)
Order Artiodactyla, Family Bovidae (buffaloes, wild sheep, goats and antelopes)		
<i>B. brachyceri</i>	<i>Bos brachycerus</i>	De Mello et al. (1923)
<i>B. irvinesmithi</i>	<i>Hippotragus niger</i>	Martinaglia (1936)
<i>B. zolotarevi</i>	<i>Bison bonasus x Bison bison</i>	Rukhlyadev and Abramova (1956)
Order Artiodactyla, Family Cervidae (deer)		
<i>B. capreoli</i>	<i>Capreolus capreolus</i>	Enigk and Friedhoff (1962)
<i>B. damae</i>	<i>Cervus sika</i>	Ono and Kondo (1923)
<i>B. moravica</i>	<i>Capreolus capreolus</i>	Ullrich (1940)
<i>B. odocoilei</i>	<i>Odocoileus virginianus</i>	Emerson and Wright (1970)
<i>B. pattoni</i>	<i>Axis axis</i> , <i>Rusa unicorn</i>	Dissanaike (1963)

Some piroplasms from wild carnivores and ungulates were described under other genera, e.g. *Piroplasma*, *Nuttalia* and *Nicolliia*. Molecular characterisation is sorting out some of the uncertainty, but a lot remains. For instance, the species currently regarded as *Theileria equi* (Mehlhorn and Schein, 1998) and initially described as *Piroplasma equi* (Laveran, 1901), was long regarded as a *Babesia* species. It has been classified under at least seven other genera. Current indications are that the small *Babesia* spp., primarily those isolated from rodents and felids, may be ancestral to the whole *Babesia/Theileria* complex (Penzhorn et al., 2001). The use of the genus name *Babesia* for this cluster of species should therefore be reconsidered.

Unidentified piroplasms have been recorded from various other wild carnivores and ungulates (Table 3). An unnamed *Babesia* from the North American elk (*Cervus elaphus*) has been isolated in culture and partially characterized (Holman et al., 1994). Two *Babesia* spp. isolated from mule deer (*Odocoileus hemionus*) and bighorn sheep (*Ovis canadensis*) in California, USA, have been

cultured and seroprevalence determined, but the species have not been named (Kjemtrup et al., 1995). Prevalence reached 60% in some areas. One of these isolates has been partially characterized (Goff et al., 1993).

Table 3.

Unnamed *Babesia* spp. reported from carnivores and ungulates

Host	Author(s) and year
Carnivores	
Family Felidae (cats)	
<i>Acinonyx jubatus</i>	Averbeck et al. (1990)
<i>Lynx rufus</i>	Wenyon and Hamerton (1930)
<i>Panthera pardus</i>	Brocklesby and Vidler (1965)
<i>Panthera tigris</i>	Nagar et al. (1979)
Family Hyaenidae (hyaenas)	
<i>Proteles cristatus</i>	Peirce et al. (2001)
Family Viverridae (mongooses)	
<i>Galerella sanguinea</i>	Penzhorn and Chaparro (1994)
<i>Mungos mungo</i>	Penzhorn and Chaparro (1994)
Ungulates	
Order Perissodactyla (odd-toed ungulates)	
<i>Ceratotherium simum</i>	Bigalke et al. (1970)
Order Proboscidea (elephants)	
<i>Loxodonta africana</i>	Brocklesby and Campbell (1963)

Host	Author(s) and year
Order Artiodactyla: Family Giraffidae (giraffes)	
<i>Giraffa camelopardalis</i>	Brocklesby and Vidler (1965)
Family Bovidae (wild sheep, antelopes and buffaloes)	
<i>Hippotragus equinus</i>	Wilson and Hirst (1977)
<i>Ovis canadensis</i>	Goff et al. (1993); Thomford et al. (1993)
<i>Tragelaphus scriptus</i>	Bigalke et al. (1972)
Family Cervidae (deer)	
<i>Cervus elaphus</i>	Holman et al. (1994)
<i>Odocoileus hemionus</i>	Thomford et al. (1993); Kjemtrup et al. (2000)
<i>Rangifer tarandus</i>	Holman et al. (2002)

3. *Babesia* species of domestic animals occurring in wildlife

The *Babesia* species of domestic carnivores and ungulates reported from wildlife are listed in Table 4. Not surprisingly, these shared *Babesia* spp. occur in hosts that are closely related to each other. Examples of these are *Babesia trautmanni* from the domestic pig and the wild boar, but also from African bushpig *Potamochoerus porcus* and warthog *Phacochoerus aethiopicus*, and *Babesia caballi* and *Babesia equi* from various zebra species.

Table 4.

Babesia spp. recovered from both domestic animals and wildlife

Domestic host	<i>Babesia</i> species	Wildlife host	Author(s) and year
<u>Horse</u>	<u><i>B. caballi</i></u>	<u><i>Equus burchelli</i></u>	<u>Neitz (1965)</u>
		<u><i>Equus zebra</i></u>	<u>Zweygarth et al. (2002)</u>

Domestic host	<i>Babesia</i> species	Wildlife host	Author(s) and year
<u>Donkey</u>	<u><i>B. equi</i>^a</u>	<u><i>Equus burchelli</i></u>	<u>Neitz (1931)</u>
		<u><i>Equus grevyi</i></u>	<u>Dennig (1966)</u>
		<u><i>Equus zebra</i></u>	<u>Young et al. (1973)</u>
<hr/>			
<u>Cattle</u>	<u><i>B. bigemina</i></u>	<u><i>Syncerus caffer</i></u>	<u>Karbe et al. (1979)</u>
		<u><i>Bison bison</i></u>	<u>Zaugg and Kuttler (1987)</u>
		<u><i>Mazama americana</i></u>	<u>Clark and Zetek (1925)</u>
		<u><i>Odocoileus virginianus</i></u>	<u>Clark and Zetek (1925)</u>
		<u><i>Gazella soemmeringi</i></u>	<u>Enigk and Friedhoff, 1963a and Enigk and Friedhoff, 1963b</u>
		<u><i>Hippotragus niger</i> (?)</u>	<u>Hove et al. (1998)</u>
<hr/>			
	<u><i>B. bovis</i></u>	<u><i>Capreolus capreolus</i></u>	<u>Levine (1988)</u>
		<u><i>Cervus elaphus</i></u>	<u>Levine (1988)</u>
		<u><i>Odocoileus virginianus</i></u>	<u>Brumpt (1920)</u>
		<u><i>Bison bison</i></u>	<u>Salabarría et al. (1981)</u>
<hr/>			
	<u><i>B. divergens</i></u>	<u><i>Ovis musimon</i></u>	<u>Levine (1988)</u>
		<u><i>Cervus elaphus</i></u>	<u>Levine (1988)</u>
		<u><i>Dama dama</i></u>	<u>Levine (1988)</u>
		<u><i>Capreolus capreolus</i></u>	<u>Levine (1988)</u>
		<u><i>Rangifer tarandus</i></u>	<u>Nilsson et al. (1965)</u>
<hr/>			
	<u><i>B. major</i></u>	<u><i>Bison bison</i></u>	<u>Findlay and Begg (1977)</u>
<hr/>			
<u>Sheep</u>	<u><i>B. ovis</i></u>	<u><i>Capra pyrenaica</i></u>	<u>Ferrer et al. (1998a); Marco et al.</u>

Domestic host	<i>Babesia</i> species	Wildlife host	Author(s) and year
			<u>(2000)</u>
		<u><i>Ovis musimon</i></u>	<u>Ferrer et al., 1998a and Ferrer et al., 1998b</u>
<hr/>			
<u>Dog</u>	<u><i>B. canis</i></u>	<u><i>Canis latrans</i></u>	<u>Ewing et al. (1964)</u>
		<u><i>Canis mesomelas</i></u>	<u>Neitz and Steyn (1947)</u>
		<u><i>Cyon dukhunensis</i></u>	<u>Leger and Bédier (1922)</u>
		<u><i>Nyctereutes procyonides</i></u>	<u>Levine (1988)</u>
		<u><i>Lycaon pictus</i></u>	<u>Neitz (1965)</u>
		<u><i>Vulpes vulpes</i></u>	<u>Schoop and Dedié (1938)</u>
<hr/>			
	<u><i>B. gibsoni</i></u>	<u><i>Canis aureus</i></u>	<u>Patton (1910)</u>
		<u><i>Canis latrans</i></u>	<u>Evers et al. (2003)</u>
		<u><i>Fennecus zerda</i></u>	<u>Maronpot and Guindy (1970)</u>
		<u><i>Vulpes vulpes</i></u>	<u>Maronpot and Guindy (1970)</u>
<hr/>			
<u>Cat</u>	<u><i>B. felis</i></u>	<u><i>Felis concolor</i></u>	<u>Carpano (1934)</u>
<hr/>			
<u>Pig</u>	<u><i>B. trautmanni</i></u>	<u><i>Potamochoerus porcus</i></u>	<u>Shone and Philip (1960)</u>
		<u><i>Phacochoerus aethiopicus</i></u>	<u>Stewart et al. (1992)</u>
	<u><i>B. perroncitoi</i></u>	<u><i>Sus cristatus</i></u>	<u>Levine (1988)</u>

^a Regarded by some authors as *Theileria equi* (Mehlhorn and Schein, 1998).

It is not clear from the literature whether the identity of the *Babesia* sp. involved was confirmed in all cases, or whether the wildlife host's close relatedness to a domestic counterpart led to the

assumption that the same *Babesia* sp. was involved. Caution should always be exhibited when making inferences about *Babesia* spp. from historical literature. In a recent publication (Hove et al., 1998) an unspoken inference is made that *B. bigemina* may have caused fatal babesiosis in a sable antelope. *Rhipicephalus evertsi* nymphs collected from the carcass of the sable antelope transmitted *B. bigemina* when allowed to feed on a bovine as adults. *B. bigemina* was not recovered from the carcass of the sable antelope. The authors do not indicate the locality involved, nor do they mention whether there were cattle in the vicinity. This is crucial information to bear in mind when interpreting the results of the study. The possibility exists that the *R. evertsi* ticks may have been the progeny of females engorging on cattle that carried *B. bigemina*. Transovarial transmission is known to occur (Büscher, 1988). The larvae attaching to the sable antelope could conceivably have been infected with *B. bigemina*. It should be noted that Thomas et al. (1982) attempted artificial infection of sable antelope with both *B. bigemina* and *B. bovis*, but were not successful.

Experimental infection of captive wild animals with *Babesia* spp. of domestic animals does not necessarily imply that their free-ranging counterparts would be susceptible. For instance, three captive African buffalo (*Syncerus caffer*) were injected with 5×10^9 bovine erythrocytes with *B. bigemina*, pathogenic for cattle (Karbe et al., 1979). None of the buffalo showed signs of disease, but *Babesia* were found in blood smears for 4 days indicating their multiplication. The carrier state of *B. bigemina* was established in two buffaloes for 28 and 147 days, respectively, by sub-inoculation into splenectomized calves, while no parasites were demonstrated 28 days after injection in the third buffalo. Two buffalo shot in Kenya did not appear to be carriers of *B. bigemina*, as shown by sub-inoculation of blood into splenectomized calves. Carmichael and Hobday (1975) found no *Babesia* spp. on blood smears of 190 African buffaloes in Northern Botswana. Karbe et al. (1979) speculated that African buffalo may play a role in the epidemiology of babesiosis in cattle, but any such role would probably be insignificant.

Two captive eland (*Taurotragus oryx*) were also inoculated with *B. bigemina* and their blood investigated as with the experimental buffalo (Karbe et al., 1979). Neither eland appeared to harbour *B. bigemina* 28 days after injection, even though one was splenectomized. *B. bigemina* could be established in a Soemmering's gazelle (*Gazella soemmeringi*) only after the recipient had been splenectomized (Enigk and Friedhoff, 1963a).

On the other hand, one spleen-intact and two splenectomized American bison (*Bison bison*) inoculated with *B. bigemina* stabilate exhibited clinical and hematological signs of babesiosis within 10 days of exposure (Zaugg and Kuttler, 1987). Redwater caused by *B. major* in a naturally infected captive American bison herd in the UK was confirmed serologically (Findlay and Begg, 1977), while a hemolytic process in bison was ascribed to *B. bovis* (Salabarria et al., 1981).

Wild animals may demonstrate clinical manifestation of babesiosis similar to that in domestic animals when placed in captivity in non-native areas. Reindeer (*Rangifer tarandus*) artificially infected with *B. divergens* (Nilsson et al., 1965) became anorectic and polypnoeic, and developed pale mucous membranes and hemoglobinuria. The authors noted that no disease suggestive of babesiosis was known to have occurred in reindeer in Sweden. The natural distribution of reindeer in that country does not coincide with the areas where bovine babesiosis is endemic. Furthermore, *Ixodes ricinus*, the vector of *B. divergens*, has never been recorded from Swedish

reindeer. Fatal naturally acquired babesiosis, attributed to *B. divergens* infection, also occurred in a captive reindeer herd in the UK (Langton et al., 2003). Fatal babesiosis has been recorded in a captive American woodland caribou (*Rangifer tarandus caribou*) (Petrini et al., 1995). Serum from this animal cross-reacted strongly with *B. bovis* and *B. divergens*, and weakly with *B. bigemina* and *B. odocoilei* (see below).

B. bovis has been transmitted to white-tailed deer (*Odocoileus virginianus*), and has also been grown in vitro in white-tailed deer erythrocytes (Brumpt, 1920 and Holman et al., 1993).

Seroprevalences of antibodies against *B. ovis* of 12% and 32.6%, respectively, were found in mouflon (*Ovis musimon*) and ibex (*Capra pyrenaica*) in Spain (Ferrer et al., 1998a and Ferrer et al., 1998b).

Coyotes (*Canis latrans*) artificially infected with *B. gibsoni* (Evers et al., 2003) developed a maximum parasitaemia of 8–11% at weeks 3–4 after infection. Parasites were still detectable 20 weeks post-infection. *B. canis rossi* has been transmitted naturally and artificially to African wild dogs (*Lycaon pictus*) and black-backed jackals (*Canis mesomelas*) (Neitz, 1965, Neitz and Steyn, 1947 and Van Heerden, 1980). This parasite was originally described from a side-striped jackal (*Canis adustus*) (Nuttall, 1910). Fatal acute babesiosis has been recorded in a captive juvenile African wild dog (Colly and Nesbit, 1992).

4. Effect of *Babesia* infections in wild animals

The first report of clinical babesiosis in a wild animal may well be that of a fatal case in a wild-caught sable antelope (*Hippotragus niger*) in the Johannesburg zoo (South Africa), 6 weeks after arrival in mid-winter (Martinaglia, 1930). The condition was ascribed to reduced resistance following a change of environment and close confinement. The organism was later named *B. irvinesmithi* (Martinaglia, 1936).

An earlier report of piroplasmosis in reindeer by Kertzei (1909; English translation in Chambers, 1921), who coined the name “*Piroplasma tarandi rhangferis*” for the causative organism concerned a *Theileria* sp. (Levine, 1971). The organisms are described as small, with cruciform division (Yakimoff and Kolmakoff, 1929).

Generally, piroplasms of wild carnivores appear to be incidental findings unrelated to disease. *B. lotori* has been described from raccoons (*Procyon lotor*) in the eastern USA (Anderson et al., 1981). The names *B. procyoni* and *B. procyonis* used previously for this organism by Frerichs and Holbrook (1970) are invalid, as “*Piroplasma procyoni*” (now regarded as *B. procyoni*) was used for an organism found in raccoon dogs (*Nyctereutes procyonides*) in Asia (Chobotar’ov, 1938).

Prevalence of *B. cynicti* infection in three yellow mongoose (*Cynictis penicillata*) populations in the north-eastern part of South Africa, as determined by blood smear examination, ranged from 72% to 96% (Penzhorn and Chaparro, 1994). The tendency of yellow mongooses to live in small clans frequenting permanent burrow systems could facilitate the transmission of *B. cynicti* by ticks and could account for the high prevalence of infection. Deleterious effects of the parasites on the mongooses are unknown, but Neitz (1938) found signs of anemia, with anisocytosis,

polychromasia and erythrophagocytosis of the parasitized cells, on one of the smears that he examined.

All the lions examined in Kruger National Park (KNP), South Africa, harboured small piroplasms in their erythrocytes (Lopez-Rebollar et al., 1999). A similar situation was reported in Serengeti National Park in Tanzania (Averbeck et al., 1990). Although the KNP piroplasms resembled *B. felis*, they were serologically distinct (Lopez-Rebollar et al., 1999) and were subsequently characterized and described as a new species, *B. leo* (Penzhorn et al., 2001). There are, as yet, no reports of clinical babesiosis in free-ranging lions in South Africa or elsewhere. That does not necessarily rule it out altogether, as fresh lion carcasses are hardly ever found. Blood smears of a cat experimentally infected with *B. leo* remained negative for 42 days after infection, at which time the cat was splenectomized. Parasites appeared in the blood smears 8 days later. Parasitemia peaked at 45%, 30 days after splenectomy. The only clinical sign observed in the cat was slight anemia. The parasitemia responded well to standard treatment for feline babesiosis. Piroplasms were seen on blood smears of a leopard 2 months after experimental infection. The leopard also seroconverted, but did not show any clinical signs of disease.

Babesia-related mortalities have been reported in various black rhinoceros (*Diceros bicornis*) populations in Kenya (Brocklesby, 1967 and Mugeru and Wandera, 1967) and Tanzania (McCulloch and Achard, 1960), which limited successful translocation efforts. Mortality due to babesiosis may be triggered by stress factors, since in most cases animals died soon after capture. *B. bicornis*, recently described from black rhinoceroses in East and South Africa, has been incriminated in causing mortality (Nijhof et al., 2003). However, 5/11 healthy black rhinoceroses sampled in South Africa harboured the parasite without any obvious untoward effects.

Endemic stability to babesiosis has been well studied in cattle. For the first few months, calves are protected by passive immunity acquired from the dam's colostrum. If the calves are infected between the ages of about 3 and 9 months, they develop a solid immunity without showing any clinical signs. Immunity will wane if the animal is immunocompromised. This stable situation requires a high prevalence of infection in cattle, as well as a large enough tick population to ensure that calves become infected during the critical period.

Although this has not been studied in wildlife populations, there are indications that, in general, a similar endemically stable situation may exist. This could have major implications in the translocation of animals. Animals bred in captivity, which often occurs with so-called endangered species, may not be exposed to their natural parasites and will therefore not build up immunity. If these animals are then introduced into the wild to augment dwindling natural populations or to establish new ones, they could succumb to these parasites, nullifying the effort. Artificial infection of these animals with the specific parasite and follow-up treatment with anti-*Babesia* compounds would be a practical solution.

B. capreoli, described from the roe deer (*Capreolus capreolus*) (Enigk and Friedhoff, 1962) occurs widespread (Blancou, 1983) and causes fatalities in this species (Ivanics, 1982). *Ixodes ricinus* is the vector (Nikolskii and Pozov, 1972). The susceptibility of red deer (*C. elaphus*) and fallow deer (*Dama dama*) to *B. capreoli* has been investigated (Enigk and Friedhoff, 1963b). It should be noted that *B. moravica* was described from a roe deer with clinical piroplasmiasis (Ullrich, 1940). This may be a synonym for *B. capreoli*. A *Babesia* from red deer (*C. elaphus*),

isolated and characterized but not named (Adam et al., 1976), is now regarded as *B. capreoli* (Blewett and Adam, 1978).

After early reports of a *Babesia* in white-tailed deer (*Odocoileus virginianus*) (Spindler et al., 1958), *B. odocoilei* was isolated and described as a new species (Emerson and Wright, 1968 and Emerson and Wright, 1970). Artificial infection of a splenectomized white-tailed deer led to hemolytic anemia (Perry et al., 1985). Stage-to-stage transmission (nymph to adult) of *B. odocoilei* by *Ixodes scapularis* has been demonstrated (Waldrup et al., 1990). Serological prevalence in white-tailed deer was found to be 34% in Texas and 73% in Oklahoma, while deer less than 12 months old had significantly lower prevalence than other age classes (Waldrup et al., 1989). In Texas, seroconversion occurred during October–December, possibly continuing to January and February, strengthening the case for *I. scapularis* being a major vector (Waldrup et al., 1992). *B. odocoilei* has also been isolated from elk (*C. elaphus*) and caribou (Holman et al., 2000), while a genotypically distinct *Babesia* species has been isolated from caribou in the USA (Holman et al., 2002).

5. Potential impact of *Babesia* infections on conservation actions

Many wild animals, especially ungulates, are captured for translocation to establish new populations or augment existing ones. In ex situ conservation attempts, captive-bred animals are released into the wild. Well-meaning individuals also sometimes return hand-reared wild animals to the wild. All of these actions can create conditions favourable for the development of clinical babesiosis in the animals concerned, either through stress-mediated recrudescence of latent infections or through infection of naive animals.

The following is a case scenario: nine adult sable antelope were exported from a zoo in Germany to a game ranch in South Africa (McInnes et al., 1992). After arrival, the imported antelope were kept in pens on the ranch. During this time a wild-caught sable antelope that originated from an area where *B. irvinesmithi* is known to occur in the sable antelope population was held in an adjacent enclosure. This animal previously had been held in one of the pens used for the imported animals. No tick-control measures were implemented. Two imported antelopes died of acute babesiosis about 2 months after arrival on the ranch. The remaining animals were prophylactically treated with imidocarb dipropionate, and no further deaths occurred. The source of infection for the imported sable antelope is a matter of speculation. The most likely source of infection was the local animal that had been kept in the same pens later occupied by the imported animals. It is not unreasonable to speculate that ticks engorging on this animal had become infected, dropped off, moulted to the next instar and/or oviposited. The next instar/generation of ticks then fed on the imported sable and transmitted the infection to them. If *B. irvinesmithi* could be isolated from sable antelope, a stabilate could be prepared and used as a crude vaccine for imported animals. This will be the classical “infection and treatment” method.

“Return to the wild” of hand-reared animals should also be approached with caution. Although clinical babesiosis has not been recorded in lions, the famous lioness “Elsa” was reported to have died of babesiosis (Barnett and Brocklesby, 1968). Elsa was born in the wild, but had been hand-reared. Eventually, Elsa and her cubs were introduced to an area with a resident lion population that resented the intrusion. Elsa had been severely mauled by other lions on two occasions during the 4 months before she died (Adamson, 1962). In retrospect, it is clear that Elsa must have been

severely stressed, which would have impacted on her immunocompetence. This could be the reason why she succumbed to an infection that a healthy lion would have tolerated.

The stress of capture and captivity can also cause latent infections to flare up. Dennig (1966) reported fatal equine piroplasmiasis, caused by *B. equi*, in newly captured Grevy's zebras (*Equus grevyi*) in Kenya. He stated that the owner of the zebras and another trapper from Uganda estimated that they lost 20–25% of all their zebra catch from this disease, usually in the first 2–3 weeks after capture. The mortalities ascribed to babesiosis in black rhinos, discussed previously, also appeared to be linked directly to stressful situations. It may therefore be wise to attempt prophylactic treatment of the animals to prevent precipitation of disease. As dosages of prophylactic compounds have not been determined for wildlife, the only alternative would be extrapolating information from related domestic animals, and to proceed with caution.

6. Conclusions

Although some, generally well-studied, *Babesia* spp. commonly found in domestic animals have been reported from wild ungulates and carnivores closely related to their domestic counterparts, this would appear to be the exception to the rule. Exceptions may occur where wild animals are held in captivity. Under these conditions, infection of wild animals with *Babesia* spp. from domestic animals may well prove fatal. Indications are that wild animals have their own *Babesia* spp., with varying degrees of host specificity, and that endemic stability generally prevails. Various stressors, for instance capture and temporary captivity, may precipitate clinical babesiosis, caused by usually benign parasites, in wild animals. Prophylactic treatment of such animals may therefore be indicated.

Molecular biology is an invaluable tool for studying *Babesia* spp. in wild animals. As far as possible, new species should not be described solely on molecular evidence, but morphology, host-parasite interaction and biological factors, such as vectors involved, should also be taken into account. In wild animals the latter information may not always be readily available and may prove virtually impossible to acquire.

By default, extant phylogenetic trees are largely based on *Babesia* spp. from domestic animals, with some species from wild animals included. There can be no doubt that these *Babesia* species represent the proverbial tip of the iceberg, and that phylogenetic relationships become clearer as more and more *Babesia* spp. from wildlife are added. This process should continue apace. In a number of papers isolation and/or partial molecular characterisation of *Babesia* spp. from wild animals are reported. If this process is taken to its logical conclusion, i.e. formal description of species, overall understanding of the phylogeny of these piroplasms will be enhanced.

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