ELSEVIER

Babesiosis of wild carnivores and ungulates

Banie L. Penzhorn *

*Department of Veterinary Tropical Diseases, Faculty of Veterinary Science, University of Pretoria,
Private Bag X04, Onderstepoort 0110, South Africa*

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.
© 2006 Elsevier B.V. All rights reserved.

Keywords: Babesia leo; Wild life; Conservation; Biology; Taxonomy; Kruger National Park

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*, *Nicollia*, *Nuttalia*, *Smithia*, *Rossiella*, *Babesiella* and *Microbabesia* in favour of a single genus, *Babesia*. He even included *Gonderia*, now regarded as a synonym of

* Tel.: +27 12 529 8253; fax: +27 12 529 8312.
E-mail address: banie.penzhorn@up.ac.za.

Theileria, in this group. Levine (1971, 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 Tables 1 and 2, respectively. The

Table 1
Babesia spp. described from wild carnivores

Species	Host	Author(s) and year
Family Canidae (dogs)		
B. bauryi[a]	Fennecus dorsalis	Leger and Bédier (1922)
B. (canis) rossi	Canis adustos	Nuttall (1910)
B. ninakohlyakimovae	Canis lupus	Yakimoff and Shokor (1916)
B. procyoni	Nyctereutes procyonides	Chobotar'ov (1938)
Family Felidae (cats)		
B. catus	Felis catus	Mudaliar et al. (1950)
B. felis	Felis ocreata (= F. sylvestris)	Davis (1929)
B. herpailuri	Herpailurus yaguarundi	Dennig (1967)
B. leo	Panthera leo, P. pardus	Penzhorn et al. (2001)
B. pantherae	Panthera pardus	Dennig and Brocklesby (1972)
Family Herpestidae (mongooses)		
B. cynicti	Cynictis penicillata	Neitz (1938)
B. heischi	Helogale undulata rufula (?H. parvula)	Grewal (1957)
B. herpestidis	Herpestes ichneumon	França (1908), in Levine (1988)
B. hoarei	Helogale undulata rufula	Grewal (1957)
B. legeri	Herpestes calera (?Atilax paludinosus)	Bédier (1924); Penzhorn and Chaparro (1994)
B. mungo	Herpestes mungo (?H. edwardsi)	Carpano (1939); Levine (1984)
B. vanhoofi	Helogale varia (?H. parvula)	De Smet and Lips (1955)
Family Hyaenidae (hyaenas)		
B. alberti	Crocuta crocuta	Van den Berge (1937)
Fam Mustelidae (weasels, badgers, polecats, etc.)		
B. meles	Meles meles	Krivkova (1960)
B. mephitis	Mephitis mephitis	Holbrook and Frerichs (1970)
B. missirolii	Meles meles	Biocca and Corradetti (1952)
B. mustelae	Mustela putorius	Lebedeff and Tscharnotzky (1911)
B. roubaudi	Ictonyx striatus	Leger and Bédier (1923)
Fam Viverridae (civets, genets, etc.)		
B. civettae	Civettictis civettae	Leger and Leger (1920)
B. garnhami	Genetta genetta; Genetta tigrina	Heisch (1952)
B. genettae	Genetta genetta	Heisch (1952)
Family Procyonidae (raccoons)		
B. lotori	Procyon lotor	Anderson et al. (1981)

[a] Regarded as a synonym for *B. gibsoni* by Levine (1988); *Fenecus dorsalis* is regarded as a synonymn 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)		
B. bicornis	*Diceros bicornis*	Nijhof et al. (2003)
Order Proboscidea (elephants)		
B. loxodontis	*Loxodonta africana*	Rodhain (1936)
Order Hyracoidea (hyraxes)		
B. thomasi	*Procavia capensis*, *P. habessinica*, *Dendrohyrax brucei*	Jansen (1952); Levine (1988)
Order Artiodactyla, Family Bovidae (buffaloes, wild sheep, goats and antelopes)		
B. brachyceri	*Bos brachycerus*	De Mello et al. (1923)
B. irvinesmithi	*Hippotragus niger*	Martinaglia (1936)
B. zolotarevi	*Bison bonasus x Bison bison*	Rukhlyadev and Abramova (1956)
Order Artiodactyla, Family Cervidae (deer)		
B. capreoli	*Capreolus capreolus*	Enigk and Friedhoff (1962)
B. damae	*Cervus sika*	Ono and Kondo (1923)
B. moravica	*Capreolus capreolus*	Ullrich (1940)
B. odocoilei	*Odocoileus virginianus*	Emerson and Wright (1970)
B. pattoni	*Axis axis*, *Rusa unicolor*	Dissanaike (1963)

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*.

Some piroplasms from wild carnivores and ungulates were described under other genera, e.g. *Piroplasma*, *Nuttalia* and *Nicollia*. 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 seropreva-lence 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).

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.

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.

Table 3
Unnamed *Babesia* spp. reported from carnivores and ungulates

Host	Author(s) and year
Carnivores	
Family Felidae (cats)	
Acinonyx jubatus	Averbeck et al. (1990)
Lynx rufus	Wenyon and Hamerton (1930)
Panthera pardus	Brocklesby and Vidler (1965)
Panthera tigris	Nagar et al. (1979)
Family Hyaenidae (hyaenas)	
Proteles cristatus	Peirce et al. (2001)
Family Viverridae (mongooses)	
Galerella sanguinea	Penzhorn and Chaparro (1994)
Mungos mungo	Penzhorn and Chaparro (1994)
Ungulates	
Order Perissodactyla (odd-toed ungulates)	
Ceratotherium simum	Bigalke et al. (1970)
Order Proboscidea (elephants)	
Loxodonta africana	Brocklesby and Campbell (1963)
Order Artiodactyla: Family Giraffidae (giraffes)	
Giraffa camelopardalis	Brocklesby and Vidler (1965)
Family Bovidae (wild sheep, antelopes and buffaloes)	
Hippotragus equinus	Wilson and Hirst (1977)
Ovis canadensis	Goff et al. (1993); Thomford et al. (1993)
Tragelaphus scriptus	Bigalke et al. (1972)
Family Cervidae (deer)	
Cervus elaphus	Holman et al. (1994)
Odocoileus hemionus	Thomford et al. (1993); Kjemtrup et al. (2000)
Rangifer tarandus	Holman et al. (2002)

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

Table 4
Babesia spp. recovered from both domestic animals and wildlife

Domestic host	*Babesia* species	Wildlife host	Author(s) and year
Horse	*B. caballi*	*Equus burchelli*	Neitz (1965)
		Equus zebra	Zweygarth et al. (2002)
Donkey	*B. equi*[a]	*Equus burchelli*	Neitz (1931)
		Equus grevyi	Dennig (1966)
		Equus zebra	Young et al. (1973)
Cattle	*B. bigemina*	*Syncerus caffer*	Karbe et al. (1979)
		Bison bison	Zaugg and Kuttler (1987)
		Mazama americana	Clark and Zetek (1925)
		Odocoileus virginianus	Clark and Zetek (1925)
		Gazella soemmeringi	Enigk and Friedhoff (1963a,b)
		Hippotragus niger (?)	Hove et al. (1998)
	B. bovis	*Capreolus capreolus*	Levine (1988)
		Cervus elaphus	Levine (1988)
		Odocoileus virginianus	Brumpt (1920)
		Bison bison	Salabarria et al. (1981)
	B. divergens	*Ovis musimon*	Levine (1988)
		Cervus elaphus	Levine (1988)
		Dama dama	Levine (1988)
		Capreolus capreolus	Levine (1988)
		Rangifer tarandus	Nilsson et al. (1965)
	B. major	*Bison bison*	Findlay and Begg (1977)
Sheep	*B. ovis*	*Capra pyrenaica*	Ferrer et al. (1998a); Marco et al. (2000)
		Ovis musimon	Ferrer et al. (1998a,b)
Dog	*B. canis*	*Canis latrans*	Ewing et al. (1964)
		Canis mesomelas	Neitz and Steyn (1947)
		Cyon dukhunensis	Leger and Bédier (1922)
		Nyctereutes procyonides	Levine (1988)
		Lycaon pictus	Neitz (1965)
		Vulpes vulpes	Schoop and Dedié (1938)
	B. gibsoni	*Canis aureus*	Patton (1910)
		Canis latrans	Evers et al. (2003)
		Fennecus zerda	Maronpot and Guindy (1970)
		Vulpes vulpes	Maronpot and Guindy (1970)
Cat	*B. felis*	*Felis concolor*	Carpano (1934)
Pig	*B. trautmanni*	*Potamochoerus porcus*	Shone and Philip (1960)
		Phacochoerus aethiopicus	Stewart et al. (1992)
	B. perroncitoi	*Sus cristatus*	Levine (1988)

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

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; 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, 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; Van Heerden, 1980). This parasite was originally described from a side-striped jackal (*Canis adustos*) (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 Kertzelli (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; Mugera and Wandera, 1967) and Tanzania (McCullogh 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 piroplasmosis (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, 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 though 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 diproprionate, 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 piroplasmosis, 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.

References

Adam, K.M.G., Blewett, D.A., Brocklesby, D.W., Sharman, G.A.M., 1976. The isolation and characterization of a *Babesia* from red deer (*Cervus elaphus*). Parasitology 73, 1–11.

Adamson, J., 1962. Living free. Collins & Harvill, London.

Anderson, J.F., Magnarelli, L.A., Sulzer, A.J., 1981. Racoon babesiosis in Connecticut, USA: *Babesia lotori* sp. n. J. Parasitol. 67, 415–417.

Averbeck, G.A., Bjork, K.E., Packer, C., Herbst, L., 1990. Prevalence of haematozoans in lions (*Panthera leo*) and cheetah (*Acinonyx jubatus*) in Serengeti National Park and Ngorongoro Crater, Tanzania J. Wildl. Dis. 26, 392.

Barnett, S.F., Brocklesby, D.W., 1968. Some piroplasms of wild animals. Symp. Zool. Soc. Lond. 24, 159–176.

Bédier, E., 1924. Piroplasme de la mangouste d'Afrique *Herpestes calera* Erxleben. C. R. Hebd. Séanc. Mém. Soc. Biol. 90, 415–417.

Bigalke, R.D., Keep, M.D., Keep, P.J., Schoeman, J.H., 1970. A large *Babesia* sp. and a *Theileria*-like piroplasm of the square-lipped rhinoceros. J. S. Afr. Vet. Med. Assoc. 41, 292–294.

Bigalke, R.D., Keep, M.D., Schoeman, J.H., 1972. Some protozoan parasites of tragelaphine antelopes in South Africa with special reference to a *Babesia* sp. in a bushbuck and a *Trypanosoma theileri*-like parasite in a nyala. Onderstepoort J. Vet. Res. 39, 225–228.

Biocca, E., Corradetti, A., 1952. *Babesia missirolli*, n. sp., parassita del tasso (*Meles meles*). Riv. Parassitol. 13, 17.

Blancou, J., 1983. Serologic testing of wild roe deer (*Capreolus capreolus* L.) from the Trois Fontaines forest region of eastern France J. Wildl. Dis. 19, 271–2731.

Blewett, D.A., Adam, K.M.G., 1978. *Babesia capreoli* (Enigk and Friedhoff, 1963), in red deer in Scotland. In: Wilde, J.K.H. (Ed.), Tick-borne Diseases and their Vectors. Edinburgh Univ. Press, pp. 377–378.

Brocklesby, D.W., 1967. A *Babesia* species of the black rhinoceros. Vet. Rec. 80, 484.

Brocklesby, D.W., Campbell, H., 1963. A *Babesia* of the African elephant. E. Afr. Wildl. J. 1, 19.

Brocklesby, D.W., Vidler, B.O., 1965. Some parasites of East African wild animals. E. Afr. Wildl. J. 3, 120–122.

Brumpt, E., 1920. Les piroplasmes des bovidés et leurs hôtes vecteurs. Bull. Soc. Pathol. Exot. 13, 416–460.

Büscher, G., 1988. The infection of various tick species with *Babesia bigemina*, its transmission and identification. Parasitol. Res. 74, 324–330.

Carmichael, I.H., Hobday, E., 1975. Blood parasites of some wild Bovidae in Botswana. Onderstepoort J. Vet. Res. 42 (2), 55–62.

Carpano, M., 1934. Sur les piroplasmoses carnassiers et sur un nouveau piroplasme des félins (*Babesiella felis* chez le puma: *Felis concolor*). Bull. Tech. Sci. Serv., Min. Agric., Egypt. 137, 1–26.

Carpano, M., 1939. Sui piroplasmidi del cheiloni e su una nuova specie rinvenute nelle tartughe., *Nuttalia guglielmi*. Riv. Parasitol. 3, 267–276.

Chambers, F., 1921. Piroplasmosis of the reindeer. Vet. J. 77, 415–419.

Chobotar'ov, R.S., 1938. Description of *Piroplasma* of raccoon dogs—*Piroplasma procyoni* n. sp. Nauk. Zap. Kiev. Vet. Inst. 1, 158.

Clark, H.C., Zetek, J., 1925. Tick biting experiments in bovine and cervine piroplasmosis. Am. J. Trop. Med. 5, 17–26.

Colly, L.P., Nesbit, J.W., 1992. Fatal acute babesiosis in a juvenile wild dog (*Lycaon pictus*). J. S. Afr. Vet. Ass. 63, 36–38.

Davis, L.J., 1929. On a piroplasm of the Sudanese wild cat (*Felis ocreata*). Trans. R. Soc. Trop. Med. Hyg. 22, 523–534.

De Mello, F., Rubello, F., Paes, S., d'Almeida, C., 1923. Sur un piroplasmide parasite du *Bos brachycerus* d'Angola, C. R. 1er. Cong. Med. Trop. Afr. Occid., Luanda, p. 527.

Dennig, H.K., 1966. The isolation of *Babesia* species from wild animals. In: Proceedings of the First International Congress Parasitology. pp. 262–263.

Dennig, H.K., 1967. Eine unbekannte Babesienart beim Jaguarundi (*Herpailurus yaguaroundi*). Kleintierpraxis 12, 146–152.

Dennig, H.K., Brocklesby, D.W., 1972. *Babesia pantherae* new species, a piroplasm of the leopard *Panthera pardus*. Parasitology 64, 525–532.

De Smet, R.M., Lips, M., 1955. Un nouveau *Babesia* du Katanga, Congo Belge. Ann. Soc. Belg. Med. Trop. 35, 5–10.

Dissanaike, A.S., 1963. On some blood parasites of wild animals in Ceylon. Ceylon Vet. J. 11, 73.

Emerson, H.R., Wright, W.T., 1968. The isolation of a *Babesia* in white-tailed deer. Bull. Wildl. Dis. Assoc. 4, 142–143.

Emerson, H.R., Wright, W.T., 1970. Correction. J. Wildl. Dis. 5, 519.

Enigk, K., Friedhoff, K., 1962. *Babesia capreoli* n. sp. beim Reh (*Capreolus capreolus* L.). Z. Tropenmed. Parasit. 13, 9–20.

Enigk, K., Friedhoff, K., 1963a. Zur Wirtspezifität von *Babesia bigemina* (Piroplasmidea). Z. Tropenmed. Parasit. 14, 502–506.

Enigk, K., Friedhoff, K., 1963b. Zur Empfänglichkeit von Rot- und Damhirsch für *Babesia capreoli* (Piroplasmidea). Z. Tropenmed. Parasit. 14, 57–62.

Evers, H.V., Kocan, A.A., Reichard, M.V., Meinkoth, J.H., 2003. Experimental *Babesia gibsoni* infection in coyotes (*Canis latrans*). J. Wildl. Dis. 39, 904–908.

Ewing, S.A., Buckner, R.G., Stringer, B.G., 1964. The coyote, a potential host for *Babesia canis* and *Ehrlichia* sp. J. Parasitol. 50, 704.

Ferrer, D., Castella, J., Gutierrez, J.F., Lavin, S., Marco, I., 1998a. Seroprevalence of *Babesia ovis* in Spanish ibex (*Capra pyrenaica*) in Catalonia, northeastern Spain Vet. Parasit. 75, 93–98.

Ferrer, D., Castella, J., Gutierrez, J.F., Lavin, S., Marco, I., 1998b. Seroprevalence of *Babesia ovis* in mouflon sheep in Spain. J. Wildl. Dis. 34, 637–639.

Findlay, C.R., Begg, T.B., 1977. Redwater in American bison caused by *Babesia major*. Vet. Rec. 100, 406.

França, A., 1908. Cited, but not listed, by Levine (1988).

Frerichs, W.M., Holbrook, A.A., 1970. *Babesia* spp. and *Haemobartonella* spp. in wild mammals trapped at the Agricultural Research Center, Beltsville, Maryland. J. Parasitol. 56, 130.

Goff, W.L., Jessup, D.A., Waldrup, K.A., Thomford, J.W., Conrad, R.A., Boyce, W.M., Gorham, J.R., Wagner, G.G., 1993. The isolation and partial characterization of a *Babesia* sp. from desert bighorn sheep (*Ovis canadensis nelsoni*). J. Eukar. Microbiol. 40, 237–243.

Grewal, M.S., 1957. Two new piroplasms, *Babesia* (*Babesiella*) *heischi* and *Babesia* (*Babesia*) *hoarei* from Peter's pigmy mongoose, *Helogale undulata rufula* (demonstrated by Professor Garnham) Trans. R. Soc. Trop. Med. Hyg. 51, 290–291.

Heisch, R.B., 1952. New piroplasms of a genet cat and a ground-squirrel from Kenya. Ann. Trop. Med. Parasit. 46, 150–154.

Hinaidy, H.K., 1987. Blutparasiten der wildlebenden Wiederkäuer Österreichs. J. Vet. Med. B 34, 81–87.

Holbrook, A.A., Frerichs, W.M., 1970. *Babesia mephitis* sp. nov. (Protozoa: Piroplasmida): a hematozoan parasite of the striped skunk, *Mephitis mephitis* J. Parasitol. 56, 930–931.

Holman, P.J., Craig, T.M., Crider, D.L.D., Petrini, K.R., Rhyan, J., Wagner, G.G., 1994. Culture isolation and partial characterization of a *Babesia* sp. from a North American elk (*Cervus elaphus*). J. Wildl. Dis. 30, 460–465.

Holman, P.J., Madeley, J., Craig, T.M., Allsopp, B.A., Allsopp, M.T.E.P., Petrini, K.R., Waghela, S.D., Wagner, G.G., 2000. Antigenic, phenotypic and molecular characterization confirms *Babesia odocoilei* isolated from three cervids. J. Wildl. Dis. 36, 518–530.

Holman, P.J., Swift, P.K., Frey, R.E., Bennett, J., Cruz, D., Wagner, G.G., 2002. Genotypically unique *Babesia* spp. isolated from reindeer (*Rangifer tarandus tarandus*) in the United States Parasitol. Res. 88, 405–411.

Holman, P.J., Waldrup, K.A., Droleskey, R.E., Corrier, D.E., Wagner, G.G., 1993. In vitro growth of *Babesia bovis* in white-tailed deer (*Odocoileus virginianus*) erythrocytes J. Parasitol. 79, 233–237.

Hove, T., Sithole, N., Munodzana, D., Masaka, S., 1998. Isolation and characterization of a *Babesia* species from *Rhipicephalus evertsi evertsi* ticks picked off a sable antelope (*Hippotragus niger*) which died of acute babesiosis Onderstepoort J. Vet. Res. 65, 75–80.

Ivanics, E., 1982. A fatal case of babesiosis in a deer. Magyar Allotorvosok Lapja 37, 625–626.

Jansen, B.C., 1952. *Babesia thomasi* sp. nov., an intra-erythrocytic parasite of the Cape dassie [*Procavia capensis* (Pallas)]. Onderstepoort J. Vet. Res. 25, 3–6.

Karbe, E., Grootenhuis, J.G., Kelley, S., Karstad, L., 1979. Experiments on the *Babesia bigemina* carrier state in East African buffalo *Syncerus caffer* and eland *Taurotragus oryx*. Tropenmed. Parasitol. 30, 313–317.

Kjemtrup, A.M., Thomford, J.W., Gardner, I.A., Conrad, P.A., Jessup, D.A., Boyce, W.M., 1995. Seroprevalence of two *Babesia* spp. isolates in selected bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) populations in California J. Wildl. Dis. 31, 467–471.

Kjemtrup, A.M., Thomford, J., Robinson, T., Conrad, P.A., 2000. Phylogenetic relationships of human and wildlife piroplasm isolates in the western United States inferred from the 18S nuclear small subunit RNA gene. Parasitology 120, 487–493.

Krivkova, A.M., 1960. Novyi vid piroplazmy—*Piroplasma meles* sp. nov. iz krovi barsuka. Tr. Inst. Zool. Akad. Nauk Kaz. SSR 14, 42.

Langton, C., Gray, J.S., Waters, P.F., Holman, P.J., 2003. Naturally acquired babesiosis in a reindeer (*Rangifer tarandus tarandus*) herd in Great Britain Parasitol. Res. 89, 194–198.

Laveran, A., 1901. Contributions à l'étude du *Piroplasma equi*. C.R. Séanc. Soc. Biol. 53, 385–388.

Lebedeff, W., Tscharnotzky, A., 1911. Ein neuer Parasit im Blute des Iltis, *Microsoma mustelae*. Zbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. 58, 625–631.

Leger, A., Leger, M., 1920. Piroplasme de la civette au Sénégal. Bull. Soc. Pathol. Exot. 13, 649–652.

Leger, M., Bédier, E., 1922. Piroplasme du renard d'Afrique, *Fennecus dorsalis* Gray. C. R. Hebd. Séanc. Mem. Soc. Biol. 87, 934–935.

Leger, M., Bédier, E., 1923. *Plasmodium* d'un mustélidé, *Ictonyx zorilla*, du Sénégal. C. R. Hebd. Séanc. Mem. Soc. Biol. 88, 422–424.

Levine, N.D., 1971. Taxonomy of the piroplasms. Trans. Am. Microsc. Soc. 90, 2–33.

Levine, N.D., 1984. Nomenclatural corrections and new taxa in the apicomplexan protozoa. Trans. Am. Microsc. Soc. 103, 195–206.

Levine, N.D., 1988. The Protozoan Phylum Apicomplexa, vol. II. CRC Press, Boca Raton, FL, USA, 154 pp.

Lopez-Rebollar, L.M., Penzhorn, B.L., de Waal, D.T., Lewis, B.D., 1999. A possible new piroplasm in lions from the Republic of South Africa. J. Wildl. Dis. 35, 82–85.

Marco, I., Velarde, R., Castellà, J., Ferrer, D., Lavín, S., 2000. Presumptive *Babesia ovis* infection in a Spanish ibex (*Capra pyrenaica*). Vet. Parasitol. 87, 217–221.

Maronpot, R.R., Guindy, E., 1970. Preliminary study of *Babesia gibsoni* Patton in wild carnivores and domesticated dogs in Egypt. Am. J. Vet. Res. 31, 797–799.

Martinaglia, G., 1930. Red-water (babesiosis) in a sable antelope J. S. Afr. Vet. Med. Assoc. 1 (4), 41–42.

Martinaglia, G., 1936. Some considerations regarding the health of wild animals in captivity. Rep. Dir. Abattoir, Livestock & Vet. Serv. Ice & Cold Storage 1935/36 no. 26, pp. 30–33.

McCullogh, B., Achard, P.L., 1960. Mortalities associated with capture, translocation, trade and exhibition of black rhinoceroses. Int. Zoo Yb. 9, 184–195.

McInnes, E.F., Stewart, C.G., Penzhorn, B.L., Meltzer, D.G.A., 1992. An outbreak of babesiosis in imported sable antelope (*Hippotraguis niger*). J. S. Afr. Vet. Assoc. 62, 30–32.

Mehlhorn, H., Schein, E., 1998. Redescription of *Babesia equi* Laveran, 1902 as *Theileria equi* Mehlhorn, Schein. Parasit. Res. 84, 467–475.

Mudaliar, S.V., Acahry, G.R., Alwar, V.S., 1950. On a species of *Babesia* in an Indian wild cat. Ind. Vet. J. 26, 391–395.

Mugera, G.M., Wandera, J.G., 1967. Degenerative myopathies in East African domestic and wild animals. Vet. Rec. 80, 410–413.

Nagar, S.K., Saxena, V.K., Kumar, K., 1979. Studies on small mammals of Delhi Zoological Park as possible source of babesiosis infection among white tigers in the zoo. J. Commun. Dis. 10, 175–178.

Neitz, W.O., 1931. Blood parasites of game in Zuluand. Rep. Dir. Vet. Serv. An. Ind., S. Afr. 17, 45–60.

Neitz, W.O., 1938. The occurrence of *Nuttalia cynicti* sp. nov. in the yellow mungoose (sic.) *Cynictus* (sic.) *penicillata* in South Africa Onderstepoort J. Vet. Sci. An. Ind. 10, 37–40.

Neitz, W.O., 1965. A checklist and hostlist of the zoonoses occurring in mammals and birds in South Africa. Onderstepoort J. Vet. Res. 32, 189–374.

Neitz, W.O., Steyn, H.P., 1947. The transmission of *Babesia canis* (Piana and Galli-Valerio, 1895) to the black-backed jackal [*Thos mesomelas* (Schreber)], with a discussion on the classification of the piroplasms of the Canidae J. S. Afr. Vet. Med. Assoc. 18, 1–12.

Nijhof, A., Penzhorn, B.L., Lynen, G., Mollel, J.O., Bekker, C., Jongejan, F., 2003. *Babesia bicornis* sp. n. and *Theileria bicornis* sp.n.: tick-borne parasites associated with mortality in the black

rhinoceros (*Diceros bicornis*). J. Clin. Microbiol. 41, 2249–2254.

Nikolskii, S.M., Pozov, S.A., 1972. *Ixodes ricinus* ticks as carriers of *Babesia capreoli* in the roe deer (in Russian). Veterinariya (Moscow). 4, 62.

Nilsson, O., Nordkvist, M., Ryden, L., 1965. Experimental *Babesia divergens* infection in reindeer (*Rangifer tarandus*). Acta Vet. Scand. 6 (4), 353–359.

Nuttall, G.F.H., 1910. On haematozoa occurring in wild animals in Africa. 1. *Piroplasma rossi* N. Sp. and *Haemogregarina canis adusti* N. Sp. found in the jackal. Parasitology 3, 108–116.

Ono, S., Kondo, S., 1923. Studies on rinderpest in deer (*Cervus sika*) and changes in the blood of infected animals J. Jpn. Soc. Vet. Sci. 2, 135–161.

Patton, W.S., 1910. Preliminary report on a new piroplasm ("Piroplasma Gibsoni" sp. nov.) found in the blood of hounds of the Madras Hunt and subsequently discovered in the blood of the jackal "Canis aureus" Bull. Soc. Pathol. Exot. 3, 271–281.

Peirce, M.A., Anderson, M.D., Penzhorn, B.L., 2001. Piroplasmosis in the aardwolf (*Proteles cristatus*). Vet. Rec. 149, 561–562.

Penzhorn, B.L., Chaparro, F., 1994. Prevalence of *Babesia cynicti* infection in three populations of yellow mongooses (*Cynictis penicillata*) in the Transvaal, South Africa J. Wildl. Dis. 30, 557–559.

Penzhorn, B.L., Kjemtrup, A.E., López-Rebollar, L.M., Conrad, P.A., 2001. *Babesia leo* n. sp. from lions in the Kruger National Park, South Africa, and its relation to other small piroplasms. J. Parasitol. 87, 681–685.

Perry, B.D., Nichols, D.K., Cullom, E.S., 1985. *Babesia odocoilei* Emerson and Wright, 1970 in white-tailed deer, *Odocoileus virginianus* (Zimmermann), in Virginia J. Wildl. Dis. 21, 149–152.

Petrini, K.R., Holman, P.J., Rhyan, J.C., Jenkins, S.J., Wagner, G.G., 1995. Fatal babesiosis in an American woodland caribou (*Rangifer tarandus caribou*). J. Zoo Wildl. Med. 26, 298–305.

Rodhain, J., 1936. Cited by Levine (1988), but paper not listed.

Rukhlyadev, D.P., Abramova, O.M., 1956. Gemosporidii u zubrov. Tr. Inst. Zhivotnovod. Dagest. Fil. Akad. Nauk SSSR 3, 42.

Salabarria, F.F., Godshaev, A., Jimenez, T., 1981. Proceso hemolitico agudo en bisontes (*Bison bison*) causada por *Babesia argentina* Rev. Cub. Cienc. Vet. 12, 165–170.

Schoop, G., Dedié, K., 1938. Uebertragung von *Babesia canis* auf Füchse. Deut. Tierärztl. Wochschr. 46, 88–90.

Shone, D.K., Philip, J.R., 1960. The susceptibility of the African bushpig, *Potamochoerus porcus maschona*, Lönnberg, to infection with *Babesia trautmanni*. J. S. Afr. Vet. Med. Assoc. 31, 451–453.

Spindler, L.A., Allen, R.W., Diamond, L.S., Lotze, J.C., 1958. *Babesia* in a white-tailed deer. J. Protozool. 5, 8.

Stewart, C.G., Keffen, R.H., McCrindle, C., Duncan, A.N., De Waal, D.T., 1992. *Babesia trautmanni* infection in a warthog (*Phacochoerus aethiopicus*). J. S. Afr. Vet. Assoc. 63, 98.

Thomas, S.E., Wilson, D.E., Mason, T.E., 1982. *Babesia*, *Theileria* and *Anaplasma* spp. infecting sable antelope, *Hippotragus niger* (Harris, 1838) in Southern Africa Onderstepoort J. Vet. Res. 49, 163–166.

Thomford, J.W., Conrad, P.A., Boyce, W.M., Holman, P.J., Jessup, D.A., 1993. Isolation and in vitro cultivation of *Babesia* parasites from free-ranging desert bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus*) in California J. Parasitol. 79, 77–84.

Ullrich, K., 1940. Ein Fall von Piroplasmose beim Rehwild. Tierärztl. Rdsch. 46, 331–334.

Van den Berge, L., 1937. Une piroplasmide nouveau, *Nuttalia alberti* n. sp. chez une hyène du parc national Albert (Congo Belge). Bull. Soc. Pathol. Exot. 30, 271–272.

Van Heerden, J., 1980. The transmission of *Babesia canis* to the wild dog *Lycaon pictus* (Temminck) and black-backed jackal (*Canis mesomelas*) Schreber J. S. Afr. Vet. Assoc. 51, 119–120.

Waldrup, K.A., Kocan, A.A., Barker, R.W., Wagner, G.G., 1990. Transmission of *Babesia odocoilei* in white-tailed deer (*Odocoileus virginianus*) by *Ixodes scapularis* (Acari: Ixodidae) J. Wildl. Dis. 21, 149–152.

Waldrup, K.A., Kocan, A.A., Qureshi, T., Davis, D.S., Baggett, D., Wagner, G.G., 1989. Serological prevalence and isolation of *Babesia odocoilei* among white-tailed deer (*Odocoileus virginianus*) in Texas and Oklahoma J. Wildl. Dis. 25, 194–210.

Waldrup, K.A., Moritz, J., Baggett, D., Magyar, S., Wagner, G.G., 1992. Monthly indicence of *Theileria cervi* and seroconversion to *Babesia odocoilei* in white-tailed deer (*Odocoileus virginianus*) in Texas J. Wildl. Dis. 28, 457–459.

Wenyon, C.M., 1926. Protozoology, vol. 2. Bailiere/Tindall & Cox, London.

Wenyon, C.M., Hamerton, A.E., 1930. Piroplasms of the west African civet cat (*Viverra civetta*) and the bay lynx (*Felis rufus*) of North America Trans. R. Soc. Trop. Med. Hyg. 24, 7–8.

Wilson, D.E., Hirst, S.M., 1977. Ecology and factors limiting roan and sable antelope populations in South Africa. Wildl. Monogr. 54, 1–111.

Yakimoff, W.L., Kolmakoff, W.D., 1929. Zur Frage über die Piroplasmose des Renntieres. Arch. Protistenk. 66, 322–328.

Yakimoff, W.L., Shokor, N.I., 1916. Un cas de piroplasmose des loups au Turkestan. Arkh. Vet. Nauk. St. -Peterb. 46, 343.

Young, E., Zumpt, F., Boomker, J., Penzhorn, B.L., Erasmus, B., 1973. Parasites and diseases of Cape mountain zebra, black wildebeest, mountain reedbuck and blesbok in the Mountain Zebra National Park, South Africa. Koedoe 16, 77–81.

Zaugg, J.L., Kuttler, K.L., 1987. Experimental infections of *Babesia bigemina* in American bison. J. Wildl. Dis. 23, 99–102.

Zweygarth, E., Lopez-Rebollar, L.M., Meyer, P., 2002. In vitro isolation of equine piroplasms derived from Cape Mountain zebra (*Equus zebra zebra*) in South Africa Onderstepoort J. Vet. Res. 69, 197–200.