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Natural infections of small mammals with blood parasites on the borderland of boreal and temperate forest zones

Grzegorz KARBOWIAK, Leszek RYCHLIK,
Wojciech NOWAKOWSKI and Irena WITA

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Blood parasites of small mammals living in Białowieża Forest (eastern Poland) were investigated between 1996 and 2002. The following haemoparasite species were found: *Trypanosoma* (*Herpetosoma*) *evotomys* in bank vole *Clethrionomys glareolus*; *T.* (*H.*) *microti* in root vole *Microtus oeconomus*; *Babesia microti* in root vole; *Hepatozoon erhardovae* in bank vole and *Hepatozoon* sp. in root vole. Some non-identified *Bartonella* species were found in bank vole, root vole, field vole *Microtus agrestis*, yellow-necked mouse *Apodemus flavicollis*, common shrew *Sorex araneus*, Eurasian water shrew *Neomys fodiens*, and Mediterranean water shrew *N. anomalus*. The prevalence and diversity of blood parasites were lower in shrews than small rodents. Totally, 52.0% of bank voles, 50.0% of root voles, 32.5% of common shrews, and 41.2% of Eurasian water shrews were infected with any of the blood parasites. Mixed infections were seldom observed in bank vole (17.3% of investigated individuals) and root vole (14.7%). No animals were infected with three or four parasites simultaneously. Infection of Białowieża small mammals with haemoparasites seemed to be similar to those described in other temperate forest regions rather than boreal ones. Infection rates of rodent species seem to be higher in their typical habitats: for bank vole it was the highest in mixed forest, whereas for root vole in sedge swamp. The results suggest that Arvicolidae play a greater role than Muridae or Soricidae in maintenance of *Babesia* and *Hepatozoon* foci in natural environments of central Europe.

W. Stefański Institute of Parasitology, Polish Academy of Sciences, Twarda 51/55, 00-818 Warsaw, Poland, e-mail: grzgrz@twarda.pan.pl (GK, IW); Mammal Research Institute, Polish Academy of Sciences, 17-230 Białowieża, Poland, e-mail: lrychlik@bison.zbs.bialowieza.pl (LR); Department of Biology, University of Podlasie, Prusa 12, 08-110 Siedlce, e-mail: koszatek@poczta.onet.pl (WN)

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Introduction

Wild rodents are known to carry various pathogens which can be transmitted to man. However, little data exists about the role of small mammals in disseminating vector-transmitted blood parasites. In Poland, the occurrence of many parasites in rodents and shrews has been studied as part of ecological surveys on small mammals. Parasitological investigations of small mammals living in Białowieża Forest have been conducted since the second part of 20th century.

They covered mainly the ectoparasites (Lachmajer and Wegner 1956, Lachmajer 1959, Wegner 1959) and helmints (Kisielewska 1963, 1964, 1970). The first study of blood parasites were made in late 1990s only (Karbowiak *et al*. 1999, 2002). Blood parasites of shrews have not been reported from Poland before, however, there are reports from elsewhere (eg Laakkonen 2000).

Białowieża Forest is one of the last primeval forest complexes in western and middle Europe. Moreover, it is an especially interesting place for biological investigations due to the geographical location on the borderland of the boreal and temperate forest zones. This fact results in the mix of fauna and flora from both zones (Faliński 1968, 1986, Gutowski and Jaroszewicz 2001, 2004). For example, among small mammals, masked shrew *Sorex caecutiens* – a boreal species – reaches its south-western limit in this area, whereas for Mediterranean water shrew *Neomys anomalus* and bi-coloured white-toothed shrew *Crocidura leucodon*, Białowieża Forest is the north-eastern boundary (Pucek 1981, Mitchell-Jones *et al.* 1999). The same can be expected for ecto- and endoparasites of small mammals. A typical taiga tick, *Ixodes persulcatus*, has its western limit in Belarussia and Lithuania, however, single findings were noted in Białowieża (Siuda 1993). Therefore, we expected the differences in the structure or biological features of blood parasite fauna in comparison with other parts of Europe.

The aims of this study were: (1) To describe the protozoan parasites living in the blood of small rodents and shrews. A mixture of parasitological faunas typical for boreal and temperate forest zones was expected. (2) To compare prevalence and diversity of blood parasites in shrews and rodents. Higher prevalence and diversity were predicted in rodents because they are more social than shrews (Eisenberg 1966, Crook *et al.* 1976, Rychlik 1998), so more frequent parasite exchange should occur in rodents. (3) To investigate parasite infection levels in different habitats. A higher prevalence was expected in habitats optimal for given species, due to higher densities of conspecifics and thus a higher risk of parasite transmission.

Material and methods

One-week trapping sessions of small rodents and shrews were conducted in four areas: area 1 – Czerlonka (mixed forest, compartment 491 of the Białowieża Forest; in June 1996 and June 1997), area 2 – Knihiniówka (ash-alder forest and sedge swamp, compartment 426; June, July and August 1996), area 3 – Podolany (bank of an old river arm, between Białowieża and Podolany villages; August 2002), and area 4 – Reski (sedge swamp, compartment 398; August 2002). The mammals were caught in live-traps placed at permanent trap stations arranged in a rectangular grid or line. Traps were placed and set (without pre-baiting) in the afternoon, checked four times per day, and blocked after a final check around midnight.

Captured mammals were individually identified and released after collection of blood samples. Animals previously caught in the same session were immediately released. Blood samples were taken from the tip of tail and thin smears prepared. Smears were air-dried, fixed in methyl alcohol and stained for 1 hour with Giemsa, diluted (1:5) in phosphate buffer, pH 7.2. Slides were rinsed in buffer, dried and examined under a light microscope.

For measurements of parasites, "Analysis" software, in combination with a video camera and Olympus BX50F4 microscope, was used. This method affords possibilities for obtaining the measurements with accuracy to 0.01 μm. Stained blood smears were analysed at a magnification of 800× and 1500×. For each slide, about 50 fields were examined. Measurements were done on 100 parasite specimens. Terminology adapted by other researchers (Hoare 1972, Matthews *et al.* 1977, Kingston *et al.* 1992) was employed to characterise morphological features of protozoa found in the present study.

Results

A total of 158 small mammals (including 52 individuals of bank vole *Clethrionomys glareolus*, 34 root voles *Microtus oeconomus*, 2 field voles *M. agrestis*, 6 yellow-necked mice *Apodemus flavicollis*, 2 northern birch mice *Sicista betulina*, 40 common shrews *Sorex araneus*, 4 pygmy shrews *S. minutus*, 17 Eurasian water shrews *Neomys fodiens*, and 1 Mediterranean water shrew *N. anomalus*) were examined (Table 1). The following haemoparasite species were found: *Try-*

Table 1. Infection rates with blood parasites of small mammals captured between June 1996 and August 2002 at four study areas within Białowieża Forest (E Poland). The number (*n* inf) and percentage (%) of infected animals are shown. *n* – number of individuals examined, * the species names of the genera *Trypanosoma* and *Hepatozoon*, found in particular species of small mammals, are detailed in the text.

Mammal species	*n*	*Trypanosoma* spp.*		*Babesia microti*		*Hepatozoon* spp.*		*Bartonella* spp.	
		n inf	%	*n* inf	%	*n* inf	%	*n* inf	%
Area 1 (mixed forest)									
C. glareolus	12	3	25.0	–	–	5	41.6	5	41.7
M. oeconomus	6	2	33.3	2	33.3	–	–	–	–
A. flavicollis	6	–	–	–	–	–	–	4	66.6
Area 2 (ash-alder forest and sedge swamp)									
C. glareolus	37	1	2.7	–	–	7	18.9	10	27.7
M. oeconomus	14	3	21.4	1	7.1	1	7.1	1	7.1
S. araneus	37	–	–	–	–	–	–	12	32.4
S. minutus	4	–	–	–	–	–	–	–	–
N. fodiens	17	–	–	–	–	–	–	7	46.6
N. anomalus	1	–	–	–	–	–	–	1	–
Area 3 (old river arm)									
C. glareolus	3	–	–	–	–	1	33.3	1	33.3
M. oeconomus	6	2	33.3	–	–	–	–	–	–
M. agrestis	2	–	–	–	–	–	–	1	–
S. betulina	2	–	–	–	–	–	–	–	–
S. araneus	2	–	–	–	–	–	–	1	–
Area 4 (sedge swamp)									
M. oeconomus	8	4	50.0	4	50.0	–	–	3	37.5
S. araneus	1	–	–	–	–	–	–	–	–

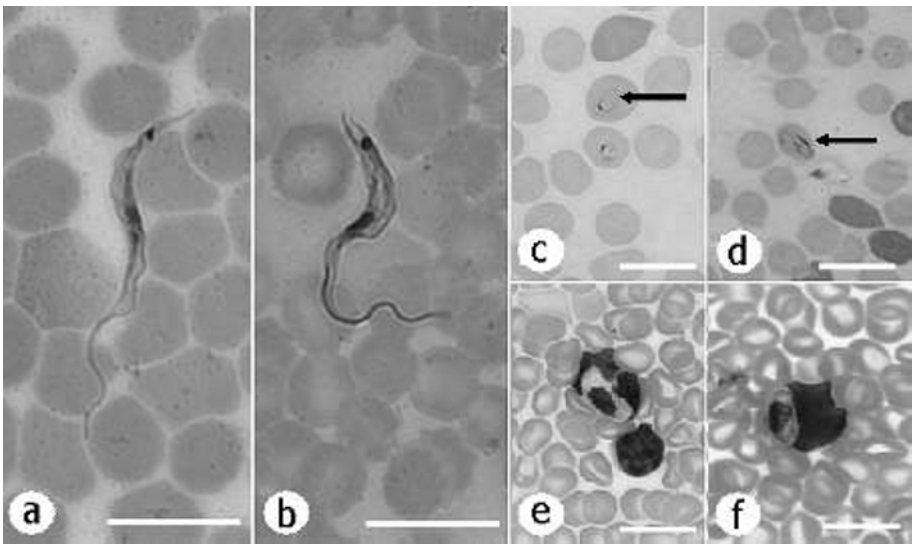

Fig. 1. Blood parasites of voles from Białowieża Forest (E Poland): (a) *Trypanosoma evotomys* from bank vole, (b) *Trypanosoma microti* from root vole, (c) ring-like and (d) pear-shaped forms of *Babesia microti* piroplasms detected in root vole, (e) *Hepatozoon erhardovae* from bank vole, (f) *Hepatozoon* sp. from root vole. Scale bars = 10 μm.

panosoma (*Herpetosoma*) *evotomys* Hadwen, 1912 in bank vole; *Trypanosoma* (*Herpetosoma*) *microti* Laveran and Pettit, 1909 in root vole; piroplasma *Babesia microti* in root vole; *Hepatozoon erhardovae* in bank vole, *Hepatozoon* sp. in root vole (Fig. 1). A number of non-identified bacteria, belonging to *Bartonella* genus were found in bank, root and field voles, yellow-necked mouse, common shrew, Eurasian and Mediterranean water shrews (Fig. 2, Table 1). Totally, 52.0% of bank voles, 50.0% of root voles, 32.5% of common shrews, and 41.2% of Eurasian water shrews were infected with any of the blood parasites.

Trypanosomes were found in rodents only. The prevalence of infection of bank vole with *T.* (*H.*) *evotomys* ranged from 2.7% (area 2) to 25% (area 1). The prevalence of infection of root vole with *T.* (*H.*) *microti* ranged from 21.4% (area 2) to 50% (area 4). The trypanosomes appeared in peripheral blood streams in the trypomastigota form (Fig. 1a, b). The detailed measurement parameters of trypanosomes are shown in Table 2.

Infection with *Babesia microti* was detected only in root vole. The prevalence of infection varied from 7.1% (area 2) to 50% (area 4). The mean intensity of the erythrocyte infection was 2.5%. The parasites were mostly of the ring-like and pear-shaped form (the morphological terminology after Mehlhorn and Schein 1984) and were 1.5–3.0 μm in diameter (Fig. 1c, d). Dividing stages, which occurred rarely, were 2.5–3.5 μm in diameter. Usually one parasite was seen in an infected erythrocyte. The regular form of four cells – "maltese cross", charac-

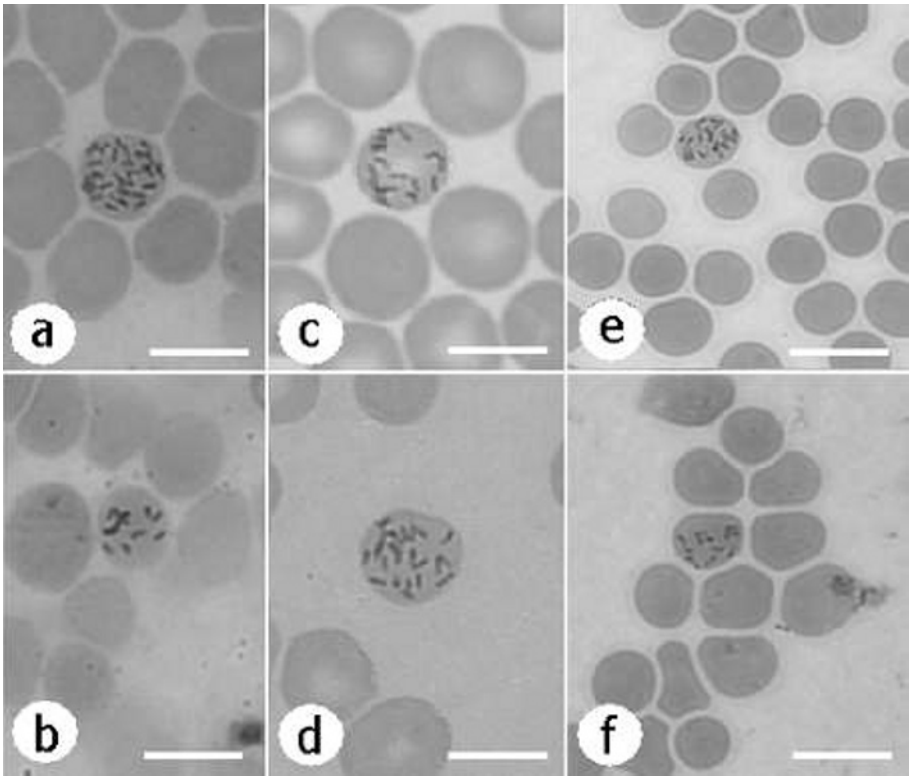

Fig. 2. *Bartonella* sp. detected in erythrocytes of small rodents and shrews from Białowieża Forest (E Poland): (a, b) bank vole, (c) root vole, (d) yellow-necked mouse, (e) common shrew, (f) Eurasian water shrew. Scale bars = 5 μm.

teristic for "small" *Babesia* species, was seldom noticed. The infected animals did not show any noticeable pathological symptoms. However, during *post mortem* examination of some voles, accidentally died in the traps, a high degree of splenomegaly was observed (the size of the spleen was 25 × 15 mm in infected and 14–16 × 3–5 mm in non-infected root voles).

The gametocytes of *Hepatozoon erhardovae* were found inside leucocytes of bank voles (Table 1). The prevalence was relatively high (up to 41.6% in area 1). Root voles were infected with *Hepatozoon* sp. only in area 2 with low prevalence (7.1%). Only single parasite was seen in infected lymphocytes (Fig. 1e, f). The measurements of *Hepatozoon* sp. are presented in Table 3.

The *Bartonella* bacterias were found in nearly all mammal species investigated (Table 1). The prevalence of infection in rodents was high, especially in their optimal habitats (66.6% in yellow-necked mouse and 41.7% in bank vole from area 1, 37.5% in root vole from area 4). In contrast, root voles from areas 1 and 3 were

Table 2. Measurements (in μm) and size indices of *Trypanosoma evotomys* from stained films of the blood of bank vole *Clethrionomys glareolus* and *T. microti* from root vole *Microtus oeconomus* caught in Białowieża Forest (E Poland). Measurements: PK – posterior end to kinetoplast, KN – kinetoplast to nucleus centre, PN – posterior end to nucleus centre, NA – nucleus centre to anterior end, BL – body length, FF – free flagellum length, L – total length, N – nucleus length, W – width of body on the nucleus level excluding the undulating membrane. Indices: nuclear index NI = PN/NA, kinetoplastic index KI = PN/KN, flagellar index FF:BL.

Trypanosoma species		Parameter					
		PK	KN	PN	NA	BL	FF
T. evotomys	mean	3.26±0.29	7.66±0.51	10.92±0.52	10.50±1.46	21.43±1.47	6.23±1.42
n = 100	range	2.87–3.73	6.98–8.70	10.05–11.74	8.20–12.18	19.37–23.28	3.99–8.71
T. microti	mean	4.31±0.53	6.44±0.71	10.74±0.79	10.92±1.15	21.66±1.48	8.50±0.99
n = 100	range	2.68–6.06	3.58–8.14	7.93–12.65	8.03–14.07	17.36–25.76	6.14–11.31
		L	N	W	NI	KI	FF:BL
T. evotomys	mean	27.56±1.47	3.03±0.26	1.12±0.18	1.06±0.17	1.43±0.05	3.63±0.92
n = 100	range	24.15–29.10	2.65–3.61	0.83–1.53	0.88–1.36	1.35–1.51	2.22–5.05
T. microti	mean	30.16±1.36	2.77±0.44	1.57±0.48	0.99±0.12	1.67±0.15	2.59±0.41
n = 100	range	25.09–33.00	1.09–3.94	0.87–3.38	0.75–1.40	1.26–2.22	1.76–3.79

not infected. The infection with *Bartonella* seemed to be also high in common shrew and Eurasian water shrew. It was detected in Mediterranean water shrew and field vole, whereas not in pygmy shrew and birch mouse, but these results are based on too small samples. The bacteria found in Eurasian water shrew (mean 1.5 × 0.4 μm, range 0.6–1.7 × 0.2–0.7 μm) were bigger than in bank vole, field vole, yellow-necked mouse, and common shrew (0.9 × 0.4 μm, range 0.5–1.6 × 0.1–0.8 μm; Fig. 2). The mean number of bacteria per single infected erythrocyte was lower in bank vole, field vole and Eurasian water shrew (16–17) than in yellow-necked mouse and common shrew (19–20).

Table 3. Measurements (in μm) of *Hepatozoon erhardovae* and *Hepatozoon* sp. from stained films of the blood of bank vole *Clethrionomys glareolus* and root vole *Microtus oeconomus* caught in Białowieża Forest (E Poland).

Parasite		Length	Width	Nucleus length × width
H. erhardovae from	mean	9.4±0.8	3.4±0.4	4.8±0.7 × 2.5±0.4
C. glareolus	range	8.4–11.0	2.8–4.3	2.4–6.0 × 1.8–3.8
H. sp. from	mean	9.4±0.5	3.3±0.4	4.8±0.4 × 2.4±0.3
M. oeconomus	range	8.0–10.4	2.4–3.9	4.0–5.7 × 1.7–2.9

Mixed infections, with two parasite species, were observed in bank vole and root vole. There were the following combinations of parasitism: *Trypanosoma* sp. + *Bartonella* sp., *Trypanosoma* sp. + *Babesia* sp., *Babesia* sp. + *Bartonella* sp., *Hepatozoon* sp. + *Bartonella* sp. All combinations were found in 14.7% of investigated root voles, and *Trypanosoma* sp. + *Bartonella* sp. and *Hepatozoon* sp. + *Bartonella* sp. in 17.3% of investigated bank voles. There were 36.5% of bank voles and 35.3% of root voles infected with one parasite species, whereas 46.2% of bank voles and 50.0% of root voles were not infected. No animals were infected with three and four parasites simultaneously.

Discussion

The prevalence of bank vole infection with *Trypanosoma evotomys* (up to 25.0% on area 1) was relatively high in Białowieża Forest. Our results are in accordance to data from former Czechoslovakia, Austria and Great Britain (Šebek 1975, Šebek *et al.* 1980, Frank 1978, Healing 1981, Turner 1986), but higher than from Norway (0–16.7% in summer – Wiger 1979). However, the infection with *Herpetosoma* trypanosomes depends on season (Turner 1986, Karbowiak and Wita 2001). *T. evotomys* was relatively rare in bank vole in spring (0.9% – Šebek 1975, Šebek *et al.* 1980) and frequent in late summer (Baker *et al.* 1963, Karbowiak and Wita 2001). The prevalence of *T. microti* was higher in root vole from Białowieża Forest (21.4–50.0%) than those noted for field vole (0.9–12.8% – Baker *et al.* 1963, Šebek 1975, Healing 1981) and common vole *Microtus arvalis* (9.0% – Pawelczyk *et al*. 2004). However, some authors showed the between-year variability in prevalence of this parasite (Wiger 1979, Pawelczyk *et al*. 2004).

In Białowieża, the *Babesia microti* infection was found in root vole only, but with a high frequency (up to 50.0%). The prevalence of *B. microti* in field vole ranged from 13.5 to 30.5% in temperate forest zone (Baker *et al.* 1963, Cox 1970, Krampitz and Bäumler 1978, Šebek *et al.* 1980, Healing 1981), was 14.6% in boreal zone of Europe (Wiger 1979), and amounted only 9.0% in common vole from Mazurian Lakeland, northern Poland (Pawelczyk *et al*. 2004). Simultaneously, these authors, as well as Bajer *et al.* (2001) noted the low prevalence or lack of *B. microti* infection in other co-existing small mammals. This supports the great role of *Microtus* voles in maintenance of zoonotic babesiosis foci in natural environments in central Europe (Karbowiak *et al.* 1999, Pawelczyk *et al*. 2004).

A high degree of splenomegaly observed in root vole corresponds with the previous observations that splenomegaly is a characteristic symptom of mammals infected with *B. microti* (Fay and Rausch 1969, Krampitz and Bäumler 1978, Watkins *et al.* 1991). Some authors correlate splenomegaly to infections with all blood parasites (eg Wiger 1978); however, we have not observed this phenomenon in animals infected with *Trypanosoma* or *Hepatozoon*. Apart splenomegaly symptoms, voles infected with *Babesia* displayed no other visible signs, so it is

evident that piroplasms cause chronic avirulent infections in its natural hosts (Fay and Rausch 1969, Krampitz and Bäumler 1978, Turner 1986).

Hepatozoon spp. were detected in bank vole and root vole but not in yellow-necked mouse and insectivores. The prevalence of infection of bank vole in Białowieża (18.9–41.6%) was similar or lower than described in other temperate regions (28.2–56.0%; Šebek 1975, Healing 1981, Turner and Cox 1985), and similar or higher than in boreal ones (2.5–36.6% – Wiger 1979, 18–55% – Laakkonen *et al*. 2001). Our measurements of *H. erhardovae* in bank vole are in accordance with description given by Krampitz (1964). The prevalence of *Hepatozoon* sp. in root vole tended to be higher in Białowieża (7.1%) than in root vole (2% – Laakkonen *et al*. 2002) and field vole (4.2% – Wiger 1979) from northern regions. Based on morphology (Table 3), it is impossible to include the *Hepatozoon* found in our root voles to *H. microti* Coles, 1914 or *H. lavieri* (Brumpt, 1946), two species described in field and common voles, respectively (Krampitz 1964). Similarly to our findings, in other studies *Hepatozoon* was not detected in wood mouse *Apodemus sylvativus* (Wiger 1979) and insectivores (Laakkonen *et al.* 2002). Thus, it can be concluded that Microtidae play a greater role in maintenance of *Hepatozoon* than Muridae or Soricidae.

The prevalence of *Bartonella* infection in rodents can be as high as > 60% (Breitschwerdt and Kordick 2000). In Białowieża, this infection seemed to be higher in yellow-necked mouse (66.6%) and field vole (50%) than in bank vole (27.7–41.7%) and root vole (7.1–37.5%). Similar results (above 25% in seasonal peak of infections) have been obtained in Great Britain (Baker 1974, Healing 1981), Austria (Šebek *et al.* 1980), and northern Poland (Bajer *et al*. 2001, Pawelczyk *et al*. 2004). In contrast, lower infection was observed in summer months in Norway: ca 10% of wood mice, 32% of field voles and 24% of bank voles (Wiger 1979).

The high prevalence of *Bartonella* infection was also detected in insectivores from Białowieża: 32.4–50.0% of common shrews and 46.6% of Eurasian water shrews were infected. So far, the *Bartonella* infection of *Sorex* shrews has been found in central (Šebek *et al.* 1980) and northern Europe (Laakkonen 2000) as well as North America (Breitschwerdt and Kordick 2000, Laakkonen *et al.* 2002), but the values were lower (2–20%). There are few probable reasons of the differences among localisations and mammal taxa: (1) the different composition of ectoparasites (especially dominant species of mites or fleas) in particular regions and on rodents and insectivores (Haitlinger 1983, 1984); (2) specific local conditions influencing the host-parasite interactions; and (3) blood parasites sampled from live (this study) versus dead animals (most other studies). Thus, these issues requires further investigations.

Bartonella species are very similar morphologically (Breitschwerdt and Kordick 2000). Except for the bigger bacteria from Eurasian water shrew, the mean sizes of bartonellas from Białowieża Forest did not differ. Moreover, we observed a quite high variability in number of bacteria per infected cell. These facts suggest

that our mammals were infected with different *Bartonella* species. However, we did not identify the bacteria found because these parasites are not host-specific and cases of co-infection of one host with some *Bartonella* species have been reported (Birtles *et al.* 1994, Breitschwerdt and Kordick 2000).

The above literature survey showed many similarities in haemoparisite infection of small mammals between Białowieża and other regions of temperate forests, as well as some differences in comparison to the boreal zone. Usually, the infection rates of both rodents and shrews with particular parasites were lower in boreal zone than in Białowieża. Also, the total infection of rodents with all types of the blood parasites seemed to be lower in northern regions (eg about 30% for bank vole – Wiger 1979) than in Białowieża (about 50%). Laakkonen *et al*. (2002) observed a similar phenomenon and suggested that it is caused by an absence of vectors in arctic areas. On the other hand, in Białowieża we have not found haemoparisites of typical boreal inhabitants, as for example *Trypanosoma lemmi* living on lemmings (Wiger 1978). Thus, although data on blood parasites of small mammals from the boreal zone are scarce, we can conclude that the haemoparasitic infections in Białowieża were similar to those described in other regions of temperate forests rather than boreal ones.

Some small mammals investigated have been mix-infected with two parasite species. However, the number of mixed infections is relatively low in comparison to the whole number of infected rodents. The most common co-infection was *Hepatozoon* + *Bartonella* in bank vole. Other combinations, as well as co--infections in other host species, were seldom. Consistently with our prediction, the prevalence and diversity of blood parasites were higher in rodents (social) than shrews (asocial). Similar results were found by other authors (Cox 1970, Baker 1974, Turner 1986). This corresponds to higher infection rates and diversities of ectoparasites in rodents than shrews (Haitlinger 1983, 1984, Stanko 1989, Stanko *at al*. 2002).

Deciduous and mixed forests are the optimal habitats for bank vole, whereas sedge swamps and wet meadows are optimal for root vole (Pucek 1981, Rychlik 2001). The densities of these species were the highest in the mentioned habitats, respectively (eg Aulak 1970). Consistently with our prediction, parasite infections found in the present study were also higher in optimal then sub-optimal habitats: for bank vole they were higher in mixed forest (area 1) than in the three wet habitats (areas 2–4), whereas for root vole an opposite situation was observed, with the highest infection rates in sedge swamp (area 4). The differences in infection rates observed between the three wet habitats could result, for example, from local environmental conditions that may influence the dominance structure, prevalence of infestation and seasonal dynamics of ectoparasites (Haitlinger 1981) and, in turn, the blood parasites.

We would like to point out that, considering the factors described above, it is very difficult to describe the full picture of blood parasite infection of small mammals under natural conditions. Unfortunately, there are only few data about

ecological factors (flora components, humidity, etc) in parasitological studies (Bajer *et al*. 2001, Karbowiak and Wita 2001, Pawelczyk *et al*. 2004). The infection with blood parasites depends also on the age of animals (Krampitz and Bäumler 1978, Healing 1981, Turner 1986, Bajer *et al*. 2001, Pawelczyk *et al*. 2004). By these reasons, single observations are often insufficient and can give false results. It is therefore necessary to conduct annual thorough investigations of selected mammal populations in order to obtain detailed data about infection with blood parasites, as well as their carriers.

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