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Oribatid mites (Acari, Oribatida) in selected caves of the Kraków-Wieluń Upland (southern Poland)

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Abstract: This paper describes and compares the species composition and community structure of the oribatid mite fauna of 5 caves in the Kraków-Wieluń Upland (Wyżyna Krakowsko-Wieluńska). We also compare oribatid communities in 3 chosen caves with oribatid communities in the soil and litter (leaves, dead wood, bat guano) in the vicinity of the cave entrances. Three hypotheses were tested: (1) oribatid communities from the soil and litter near the caves differ from the communities inhabiting caves; (2) the composition of oribatid communities depends on cave size; (3) the cave communities strongly depend on microhabitat quality and diversity. We collected 1112 adult oribatids from caves and 838 from the soil and litter near the caves. Oribatid communities in the caves were different from the soil communities. Litter, guano and dead wood were the microhabitats that affected oribatid communities significantly. In the other cave microhabitats (soil and mud), oribatids were infrequent. Cave size affected the oribatid community structure.

Keywords: cave, oribatid mites, microhabitats

INTRODUCTION

Caves are particularly interesting environments for researchers because they are useful places to study a multitude of problems in ecology and evolution (Poulson & White 1969; Howarth 1983). Although the arthropods make up a majority of the cave fauna, relatively little attention is paid to the communities of mites in these subterranean habitats. There have been only few studies of mite communities in caves in Europe (Leruth 1939; Hippa et al. 1988; Bruckner 1995; Leberton 1998; Ducarme et al. 2003, 2004, 2005; Ducarme & Lebrun 2004). About 100 taxa of oribatid mites (Oribatida, also known as moss mites or beetle mites) have been reported from European caves (Ducarme et al. 2000). One study concerned a similar but human-made environment: underground workings in a mine (Skubała & Kłys 2002).

The shortage of information about oribatid communities in subterranean environments inspired us to start the research on moss mites in Polish caves. Our main prediction was that soil and cave mite communities are distinct, inhabited by different species. Another hypothesis was that oribatid communities from the larger and more isolated caves are similar to each other and different from the communities inhabiting smaller caves. We also supposed that there is a positive relationship between oribatid species richness and abundance and increasing diversity of microhabitats and that some species are exclusive to different types of microhabitats.

MATERIALS AND METHODS

The research was conducted in the Kraków-Wieluń Upland (Wyżyna Krakowsko-Wieluńska) in southern Poland. Five caves of various size were chosen: Nietoperzowa, Wierna, Studnisko, Błotna, and Pod Porzeczką (Table 1). All the caves were situated in beech-dominated forests (Szelerewicz & Górny 1986; Wiśniewski 1991). In total, 117 samples (400 cm^3 each) were taken from the caves. The following microhabitats in the caves were studied: cave mud, soil patches, dead wood, leaves, and guano. Thirty soil and litter samples of the same size (400 cm^3 each) were additionally collected around the entrances of Błotna Cave, Studnisko Cave, and Pod Porzeczką Cave. All the samples were collected in November 2006. Mites were extracted in a week's time using a Tullgren funnel. Adult specimens were identified to species level using Weigmann (2006).

Table 1. Characteristics of sampling sites

Sampling site	Length [m]	Depth [m]	No. of samples	Remarks
Błotna	140	42	25	wet substrate
Nietoperzowa	326	23	17	–
Pod Porzeczką	67	15	20	open cave
Studnisko	212	78	35	large bat breeding colony
Wierna	1027	35	20	–
Entrance to Błotna	–	–	10	–
Entrance to Pod Porzeczką	–	–	10	–
Entrance to Studnisko	–	–	10	–

Differences in the abundance of adult oribatids between microhabitats were tested by the rank analysis of variance (Kruskal-Wallis ANOVA) and Bonferroni-Dunn post-hoc test. Spearman rank correlation coefficient was used to assess the strength of the link between the total number of species found in the cave and the number of investigated microhabitats. These analyses were conducted using STATISTICA 8 software. CANOCO 4.5 was used to carry out Principal Component Analysis (PCA) and *2* redundancy analyses (RDA). Principal Component Analysis assessed the similarities and relations between species and communities in different caves and in microhabitats. It was carried out using species abundance data. The dependent variables in both RDA analyses were the abundances of species in cave communities. As the explanatory variables, the type of microhabitats or maximum length and depth of the caves were used. Marginal and conditional effects in both RDA analyses were also calculated to identify which environmental variables explained the greatest proportion of variation in the communities. The abundance of oribatid mites was transformed (log[x+1]) for the ordination analyses.

RESULTS

Overall, 1 112 specimens and 65 species of adult Oribatida were collected from caves (Table 2) and 838 from the soil and litter samples near the cave entrances. Oribatid density in samples from caves was highly variable, ranging from 0 to 380 mites/ dm^3. Kruskal-Wallis ANOVA revealed significant differences in oribatid abundance

Table 2. List of oribatid species and numbers of adult individuals collected in caves

	Nietoperzowa	Wierna	Studnisko	Pod Porzeczką	Błotna
Adoristes ovatus (Koch, 1839)	0	0	4	1	0
Anachipteria deficiens Grandjean, 1932	0	0	3	1	0
Atropacarus striculus (Koch, 1835)	1	0	0	3	1
Autogneta longilamellata (Michael, 1885)	1	0	0	0	1
Berniniella bicarinata (Paoli, 1908)	0	0	0	4	0
Carabodes femoralis (Nicolet, 1855)	0	0	0	30	0
Carabodes ornatus Štorkán, 1925	0	0	0	2	0
Cepheus dentatus (Michael, 1888)	0	0	0	1	0
Ceratozetes gracilis gracilis (Michael, 1884)	1	0	3	0	0
Ceratozetes mediocris Berlese, 1908	0	0	0	2	2
Chamobates cuspidatus (Michael, 1884)	1	0	0	0	0
Chamobates pusillus (Berlese, 1895)	0	0	0	0	0
Chamobates subglobulus (Oudemans, 1900)	0	0	0	0	0
Chamobates (Xiphobates) voigtsi (Oudemans, 1902)	0	0	1	2	0
Cultroribula bicultrata (Berlese, 1905)	0	0	0	8	0
Damaeus sp.	17	0	6	7	0
Dissorhina ornata (Oudemans, 1900)	1	0	0	29	2
Eupelops acromios (Hermann, 1804)	0	0	0	1	0
Eupelops plicatus (Koch, 1835)	0	0	0	1	0
Euphthiracarus cribrarius (Berlese, 1904)	0	0	0	2	0
Fosseremus laciniatus (Berlese, 1905)	1	0	1	0	0

Globozetes birulai (Kulczynski, 1902)	0	0	0	63	0
Hemileius initialis (Berlese, 1908)	0	0	1	0	0
Hypochthonius luteus Oudemans, 1917	1	1	2	0	0
Kunstidamaeus tecticola (Michael, 1888)	0	0	0	1	0
Lauroppia beskidyensis (Niemi et Skubala, 1993)	0	0	0	5	0
Lauroppia falcata marginedentata (Strenzke, 1951)	0	0	0	1	0
Lauroppia maritima (Willmann, 1928)	16	6	31	0	0
Licneremaeus licnophorus (Michael, 1882)	0	0	0	0	1
Liebstadia longior (Berlese, 1908)	0	0	0	1	0
Liochthonius hystricinus (Forsslund, 1942)	0	0	0	7	0
Melonozetes sp.	1	0	0	0	0
Metabelba pulverulenta (Koch, 1839)	0	0	0	18	0
Metabelba (Parametabelba) italica (Sellnick, 1931)	0	0	0	1	0
Minunthozetes pseudofusiger (Schweizer, 1922)	0	0	1	1	0
Moritzoppia keilbachi (Moritz, 1969)	20	4	201	0	1
Moritzoppia unicarinata (Paoli, 1908)	19	3	42	0	2
Multioppia glabra (Mihelčič, 1955)	0	0	1	5	3
Oppia sp.	5	0	3	0	0
Oppiella nova (Oudemans, 1902)	4	0	15	22	16
Oribatella calcarata (Koch, 1835)	18	2	5	36	0
Oribellopsis cavaticus (Kunst, 1962)	27	26	59	1	3
Pantelozetes paolii (Oudemans, 1913)	0	2	8	0	0
Phthiracarus (Archiphthiracarus) bryobius Jacot, 1930	0	0	1	2	0
Pilogalumna crassiclava (Berlese, 1914)	0	0	0	13	0
Pilogalumna tenuiclava (Berlese, 1908)	0	0	0	3	0
Punctoribates-punctum (Koch, 1839)	0	0	0	0	0
Quadroppia quadricarinata (Michael, 1885)	5	2	3	2	0
Ramusella (Insculptoppia) furcata (Willmann, 1928)	1	1	1	0	0
Rhinoppia hygrophila (Mahunka, 1987)	0	0	0	1	0
Rhinoppia nasuta (Moritz, 1965)	0	0	0	9	0
Rhinoppia obsoleta (Paoli, 1908)	0	0	0	1	0
Rhinoppia subpectinata (Oudemans, 1900)	30	25	58	15	2
Scheloribates laevigatus (Koch, 1835)	0	0	0	2	0
Sphaerozetes piriformis (Nicolet, 1855)	0	0	0	11	0
Subiasella (Lalmoppia) quadrimaculata (Evans, 1952)	1	2	4	2	5

Suctobelba altvateri Moritz, 1970	5	3	5	0	0
Suctobelba lapidaria Moritz, 1970	0	0	1	1	0
Suctobelba trigona (Michael, 1888)	0	0	1	3	0
Suctobelbella (Flagrosuctobelba) alloenasuta Moritz, 1971	0	0	0	1	0
Suctobelbella similis (Forsslund, 1941)	0	0	1	4	1
Tectocepheus alatus Berlese, 1913	0	2	4	3	1
Tectocepheus velatus (Michael, 1880)	1	0	0	1	0
Unduloribates undulatus (Berlese, 1914)	0	0	0	3	1
Zetorchestes micronychus micronychus (Berlese, 1883)	0	0	0	9	0

between caves ($H = 36.01$; $p < 0.01$). The density of moss mites in Błotna Cave was significantly lower than in the other caves (Table 3). The lowest number of species was also recorded in Błotna Cave. The richest in species was Pod Porzeczką Cave (Table 3). Principal Component Analysis (PCA) revealed differences in oribatid species composition between caves (Fig. 1). Eigenvalues of axes 1 and 2 were 0.183 and 0.118, respectively. Over 30.2% of the variance was explained by the first 2 axes. Studnisko, Wierna and Nietoperzowa Caves form one cluster. Communities inhabiting Studnisko and Wierna Caves are very similar to each other. Communities of Błotna and Pod Porzeczką Caves create a second cluster, which is very close to the cluster of soil and litter communities outside the caves. Species characteristic for larger caves included *Oribellopsis cavaticus* (Kunst, 1962), *Rhinoppia subpectinata* (Oudemans, 1900), *Lauroppia maritima* (Willmann, 1928), *Moritzoppia keil-*

Table 3. Mean abundance of adult oribatids and number of species collected in individual caves

	Lambda 1 (marginal effect)	Lambda A (conditional effect)	*F*	*p*
Microhabitat				
leaves	0.67	0.67	4.86	0.002
guano	0.51	0.47	3.47	0.002
wood	0.49	0.32	2.42	0.004
soil (in cave)	0.28	0.11	0.85	0.468
cave mud	0.12	0.07	0.37	0.753
Cave size				
length	0.05	0.05	5.33	0.002
depth	0.03	0.03	3.30	0.004

Mean values followed by the same letter do not differ at $p < 0.05$

bachi (Moritz, 1969), and *M. unicarinata* (Paoli, 1908). In Błotna cave, *Oppiella nova* (Oudemans, 1902) was the most abundant species. The Pod Porzeczką Cave community is the most similar to soil communities outside the caves. The most frequent species in the latter habitats were *Oribatella calcarata* (Koch, 1835), *Chamobates (Xiphobates) voigtsi* (Oudemans, 1902), *Dissorhina ornata* (Oudemans, 1900)*, O. nova* and *Metabelba pulverulenta* (Koch, 1839) (Fig. 1).

Redundancy analysis showed that the species composition of the cave communities was significantly affected by microhabitat types (Monte Carlo permutation test:

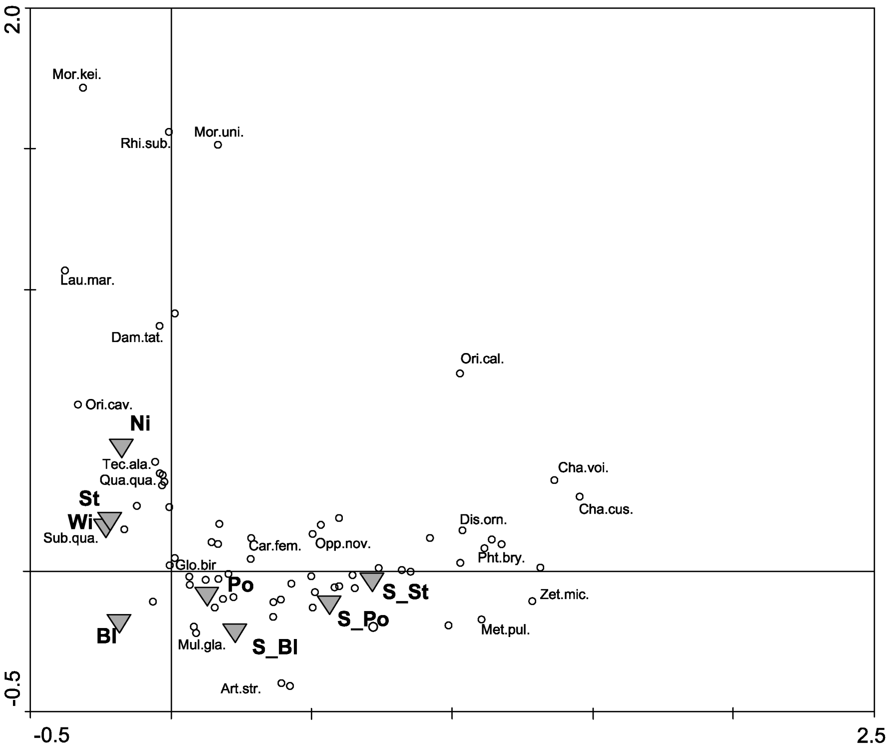

Fig. 1. A biplot of the first 2 axes of Principal Component Analysis (PCA) of sampling sites and species from the caves and from the soil and litter near cave entrances. Site codes: Ni = Nietoperzowa Cave; St = Studnisko Cave; Wi = Wierna Cave; Bl = Błotna Cave; Po = Pod Porzeczką Cave; S_St = soil near Studnisko Cave; S_Bl = soil near Błotna Cave; S_Po = soil near Pod Porzeczką Cave. Species codes: Art.str. = *Atropacarus striculus*; Car.fem. = *Carabodes femorali*s; Cha.cus. = *Chamobates cuspidatus*; Cha.voi. = *Chamobates* (*Xiphobates*) *voigtsi*; Dis.orn. = *Dissorhina ornata*; Glo.bir. = *Globozetes birulai*; Lau.mar. = *Lauroppia maritima*; Met.pul. = *Metabelba pulverulenta*; Mor.kei. = *Moritzoppia keilbachi*; Mor.uni. = *Moritzoppia unicarinata*; Mul.gla. = *Multioppia glabra*; Opp.nov. = *Oppiella nova*; Ori.cal. = *Oribatella calcarata*; Ori.cav. = *Oribellopsis cavaticus*; Pht.bry. = *Phthiracarus (Archiphthiracarus) bryobius*; Qua.qua. = *Quadroppia quadricarinata*; Rhi.sub. = *Rhinoppia subpectinata*; Sub.qua. = *Subiasella (Lalmoppia) quadrimaculata*; Tec.ala. = *Tectocepheus alatus*; Zet.mic. = *Zetorchestes micronychus micronychus*

$F = 2.97$ and $p < 0.01$). The cumulative percentage of the explained variance of the first and second axis was 80.5%. In the ordination graph of the species composition (Fig. 2), 4 groups of species can be distinguished. In leaves found on the cave floor,

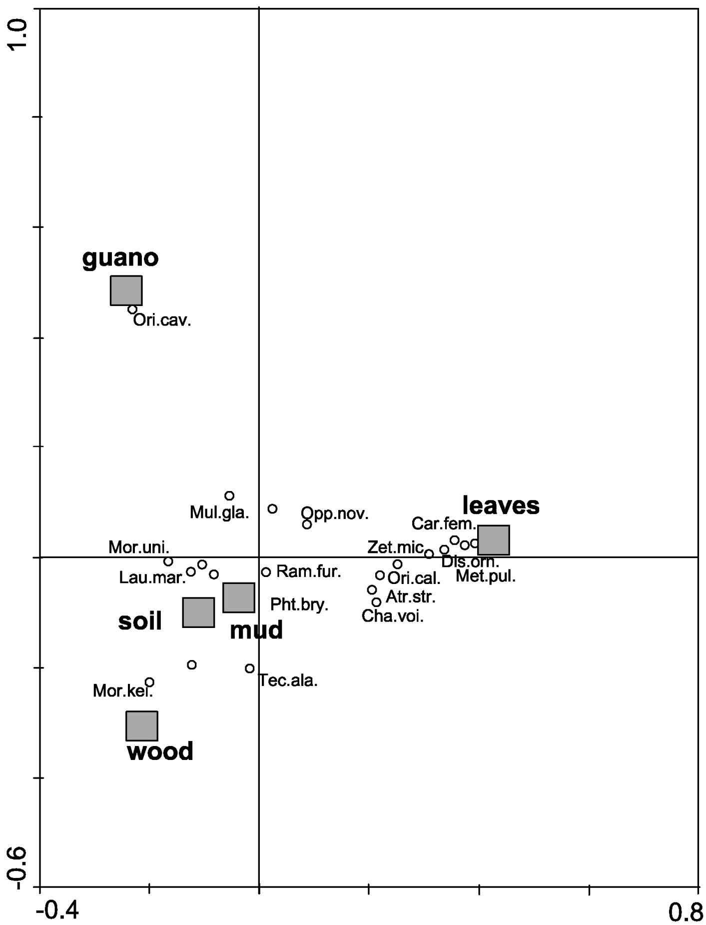

Fig. 2. A biplot of the first 2 axes of Redundancy Analysis (RDA) of sampling sites and species in caves and microhabitat types. Site codes: Ni = Nietoperzowa Cave; St = Studnisko Cave; Wi = Wierna Cave; Bl = Błotna Cave; Po = Pod Porzeczką Cave; S_St = soil near Studnisko Cave; S_Bl = soil near Błotna Cave; S_Po = soil near Pod Porzeczką Cave. Species codes: Art.str. = *Atropacarus striculus*; Car.fem. = *Carabodes femoralis*; Cha.cus. = *Chamobates cuspidatus*; Cha.voi. = *Chamobates (Xiphobates) voigtsi* ; Dis.orn. = *Dissorhina ornata*; Glo.bir. = *Globozetes birulai*; Lau.mar. = *Lauroppia maritima*; Met.pul. = *Metabelba pulverulenta*; Mor.kei. = *Moritzoppia keilbachi*; Mor.uni. = *Moritzoppia unicarinata*; Mul.gla. = *Multioppia glabra*; Opp.nov. = *Oppiella nova*; Ori.cal. = *Oribatella calcarata*; Ori.cav. = *Oribellopsis cavaticus*; Pht.bry. = Phthiracarus *(Archiphthiracarus) bryobius*; Qua.qua. = *Quadroppia quadricarinata*; Rhi.sub. = *Rhinoppia subpectinata*; Sub.qua. = *Subiasella (Lalmoppia) quadrimaculata*; Tec.ala. = *Tectocepheus alatus*; Zet.mic. = *Zetorchestes micronychus micronychus*

Carabodes femoralis (Nicolet, 1855), *M. pulverulenta* and *Sphaerozetes piriformis* (Nicolet, 1855) were the most frequent. *M. keilbachi* and *Tectocepheus alatus* (Berlese, 1913) are characteristic for dead wood. Bat guano was inhabited by *O. cavaticus*. The species that occurred in cave mud and patches of the soil in the caves are situated in the middle of the ordination graph. These are the microhabitats with the most common species composition.

Leaves, guano, and dead wood were the cave microhabitats that significantly affected the oribatid community species composition (see lambda factors and probability values in Table 4. Maximum length as well as maximum depth of the caves also had an impact on the oribatid community structure (Table 4).

Table 4. Marginal and conditional effects of various microhabitats and cave size on species composition of oribatid cave communities

Cave	Mean abundance ± S.D. [adult mites/dm^3]	No. of species
Błotna	3.0 ± 9.8 [a]	15
Nietoperzowa	31.6±35.8 [b]	22
Pod Porzeczką	43.6±47.9 [b]	47
Studnisko	33.3±65.9 [b]	28
Wierna	19.8±12.2 [b]	20

There was no relationship between the number of microhabitats and number of species found in caves (Spearman rank correlation: R = -0.70 and p = 0.18).

DISSCUSSION

The fauna of the investigated caves was poor in species and only one typical cave species was found. Despite that, cave communities were clearly different from the typical soil fauna. Community species composition of the largest caves differed from that of the smaller caves. In Pod Porzeczką and Błotna Caves, oribatid communities were grouped in a separate cluster. Oribatid species composition in these caves was more similar to that of soil communities than to the fauna of the lager caves. Błotna Cave is often flooded with water and, consequently, it is very wet. According to Ducarme et al. (2003), oribatids are scarce in flooded Belgium caves. Those caves are dominated by the Prostigmata, Endeostigmata or Astigmata. *Oppiella nova* is the dominant species in Błotna Cave. It is a very common, eurytopic, and mobile species (Ojala & Huhta 2001) and it could easily colonize the cave at the time when the cave substrate was drier. Pod Porzeczką Cave is a partly open slot-cave, with a lot of leaves, litter, and plant roots lying on the cave floor. It is very easily accessible for the soil mites and rich in organic matter.

Oribellopsis cavaticus was the only species exclusive to the cave communities. Other species that were highly abundant in caves also occurred in soil and litter samples from the outside of the caves. The differences in species composition between soil communities were not as large as the differences in species composition between cave communities. Also in general, species composition is more variable in cave communities than in soil communities (Ducarme et al. 2003). In Nietoperzowa, Wierna and Studnisko Caves, the abundance of *O. cavaticus* – the typical cave species – was much higher than at the other sites. This species is associated with bat guano (Kunst 1962). Thanks to the favourable structure and character of those caves, they are inhabited by bats (Szelerewicz & Górny 1986).

An increasing number of microhabitats is usually related with an increased species richness. This is thought to be a result of an increased number of inhabited niches (Anderson 1978; Hansen & Coleman 1998). By contrast, in our research such a relation did not occur. It seems that species composition is affected here by microhabitat quality, and species richness is not influenced by microhabitat diversity in this study. The microhabitats that affected significantly species composition of cave communities, were: leaves, guano, and pieces of wood. These are the main sources of mite food in caves and the most preferred habitats (Howarth 1983). It can be concluded that various species compete to occupy those habitats. Indeed, those substrates were dominated by some exclusive species, which probably are very well adapted to them. The patches of soil in caves and the cave mud were inhabited accidentally. Species composition in those microhabitats was very random and mainly consisted of recedent and subrecedent taxa. Those species were abundant in soil and litter communities from the outside of the caves.

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