



Soil mite (Acari: Oribatida) communities in the limestone quarry of Sashkhor (Georgia)

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Abstract

The present publication provides a review of the soil mite (Acari; Oribatida) community's structure and the connection between changes in environmental factors and oribatid mite diversity in the limestone quarry of Sashkhor and its adjacent areas. Overall, 52 species were recorded during the study. The most abundant oribatid mite species were *Steganacarus carinatus*, *Aleurodamaeus setosus*, *Xenillus tegeocranus*, *Ceratoppia bipilis*, *Oribatula tibialis*, and *Punctoribates punctum*. Interestingly, 23 species of oribatid mites were recorded for the first time from the limestone quarry of Sashkhor, and one species (*Liacarus oribatelloides*) was a new record for the Caucasus fauna. The following indices were analyzed: abundance (N), species diversity (S), Shannon's diversity index (H), and Pielou's evenness index (J'). Regarding the obtained results, the highest density of oribatid mites was recorded in the habitat with Shibliak shrubbery (332 inds/m²), while the forest habitat was characterized with the highest value for Shannon's diversity index (2.64). In the publication, we also provide a detailed morphological description of the newly recorded species *L. oribatelloides*, with the respective illustration, as no figures are given in its original description.

Key words

Caucasus; Kartly Region, Liacaridae; *Liacarus oribatelloides*

Introduction

Soil is an important reservoir of biodiversity and plays an essential role in the ecosystem (Menta 2012). Species diversity is a key component of ecosystem functioning; the variety of living organisms influences ecological processes, and different environmental factors determine the composition of soil-dwelling invertebrates (Loreau et al. 2003).

Species diversity and ecosystem stability have a special relationship with each other. Biodiversity acts as insurance for ecosystem functioning against temporal environmental changes; the functional compensations provide enhanced and more productive ecosystem properties (Loreau et al. 2003; Schmidt 2005).

Anthropogenic degradation of soil habitats leads to dramatic changes in the biotic structure of ecological communities because of either the loss of native taxa or the introduction

of new species (Hooper et al. 2005). These changes could be strong enough to exceed the resilience capacity of the ecosystems, resulting in the collapse of their functions (Downing et al. 2012; Oliver et al. 2015).

The faunal diversity of soil microarthropods is an important feature of soil ecosystems and can be used to evaluate ecosystem quality and health (Moghimian et al. 2013). Thus, it can act as a warning system for ecosystem conditions (Muscolo et al. 2015). Among the soil microarthropods, oribatid mites (Acari, Oribatida) are one of the most dominant animal groups; the densities of the individuals can reach several hundred thousand per square meter (Norton and Behan Pellerier 2009). Oribatid mites are strongly responsive to external influences in their habitats, and hence it is possible to monitor changes in soil processes (Nielsen et al. 2010).

In 2018, oribatid mite communities were investigated on the territory of the limestone quarry in the surroundings of

Saskhori village (Georgia) before quarry mining activities started (Murvanidze et al. 2018). The authors have investigated soil mites in different habitats of the limestone quarry of Saskhori and recorded 51 species of oribatid mites (Murvanidze et al. 2018). After four years of the above-mentioned study, we also investigated the oribatid mite community in the same area to observe the possible changes due to extensive anthropogenic disturbance. In particular, we aimed to investigate: (i) the oribatid mite species composition of the main habitat types of the limestone quarry at Saskhori village and the surrounding areas; (ii) the interaction between the oribatid mite species diversity and habitat change and thus compare new results to the published ones (Murvanidze et al. 2018); and (iii) the quantitative and qualitative parameters of oribatid communities inhabiting the study area.

Materials and methods

Study area

The limestone quarry of Saskhori is located to the southeast of Kaspi town in Kartly Region. The area of the limestone quarry belongs to the 'Heidelberg Cement Company', and mining of the quarry started in 2018. The territory of the Saskhori quarry is surrounded by dry grasslands and shrubbery. The territory was experiencing continuous anthropogenic disturbance, such as intensive cattle grazing.

Sampling and identification

Soil samples were collected in the limestone quarry of Saskhori three times, in February, April, and July of 2022. The investigation of oribatid mites was conducted at seven different locations (Fig. 1). Sampling sites, habitat descriptions, and geographical coordinates are provided in the table (Table 1).

Three soil samples (10 cm³) were randomly selected and collected using a steel corer from each site. The samples from the active mining territory of the limestone quarry were taken from an area where the soil structure is not highly degraded. The samples with the understory vegetation and litter layer were placed in plastic bags and transported into the laboratory. In total, 63 soil samples were extracted using a Berlese-Tullgren apparatus for 7 days. The extracted material was preserved in 96% alcohol. Specimens were mounted on temporary slides using lactic acid for morphological identification. Mites were identified under the microscope (ACUU-SCOPE EXC-350) using the keys of Ghilarov and Krivolutsky (1975), Balogh and Mahunka (1983), and Weigmann (2006). All body measurements are presented in micrometers. Formulas for leg setation are given in parentheses (trochanter-femur-genu-tibia-tarsus); formulas for leg solenidia are given in square brackets (genu-tibia-tarsus). A list of oribatid mites was produced in systematic order. The superfamily and family names follow the nomenclature of Schatz et al. (2011); genus and species names are



Figure 1. Sampling sites of oribatid mite in the limestone quarry of Saskhori.

Table 1. Sample sites on the limestone quarry in Saskhori and its adjacent areas. For the habitat classification we followed EUNIS (European Nature Information System) habitat classification scheme (Davies et al. 2004).

Site N	Latitude	Longitude	Habitat	Landscape feature
Sa1	41.841	44.520	Degraded landscape with the floral elements of Bothriochloeto-Stipeto-Artemisieto steppes (similar to the Mediterranean tallgrass and wormwood (<i>Artemisia</i> sp.) steppes recognized by EUNIS habitat classification [habitat code: E1.3])	The landscape of the abandoned site of the limestone quarry with significantly modified vegetation of the steppe dominated by rural and invasive plants.
Sa2	41.846	44.519	Shibliak or Mediterranean-type deciduous drought-resistant shrubbery (similar to 'Pseudomaquis' recognized by EUNIS habitat classification [habitat code: F5.3])	Shrubland in the adjacent area to the limestone quarry
Sa3	41.845	44.517	Extremely degraded habitat poor in vegetation	Landscape distributed with a bare surface of the limestone quarry (bedrock)
Sa4	41.845	44.517	Xero-thermophilous oak forest (similar to the Meso- and eutrophic <i>Quercus</i> , <i>Carpinus</i> , <i>Fraxinus</i> , <i>Acer</i> , <i>Tilia</i> , <i>Ulmus</i> , and related woodland recognized by EUNIS habitat classification (habitat code: G 1. A))	Landscape with a degraded forest in the adjacent area to the limestone quarry
Sa5	41.843	44.524	Shibliak or Mediterranean-type deciduous drought-resistant shrubbery (similar to 'Pseudomaquis' recognized by EUNIS habitat classification [habitat code: F5.3])	Shrubland in the adjacent area to the limestone quarry
Sa6	41.847	44.516	Rural and urban vegetation (similar to 'Arable land with unmixed crops grown by low-intensity agricultural methods' recognized by EUNIS habitat classification [habitat code: I 1.3])	A landscape dominated by cropland - Almond garden
Sa7	41.847	44.509	Mixed vegetation of the Oak-hornbeam woodland and Shibliak or Mediterranean-type deciduous drought-resistant shrubbery (similar to 'Pseudomaquis' recognized by EUNIS habitat classification [habitat code: F5.3])	Degraded forest in the small and dry ravine in the adjacent area to the limestone quarry

in accordance with Subías (2023) and Weigmann (2006). The drawings were made in CorelDRAW 2020 from the specimens taken in the investigation area. The material is deposited in the collection of the Institute of Zoology, Iliia State University, Tbilisi, Georgia.

Data analysis

The sampling completeness of oribatid mites for the study area was evaluated using the rarefaction method. Hundred bootstrap replicates were used to calculate the confidence limits for the rarefaction curve. Analyses were performed using R Statistical Software (v.4.3) and the iNEXT R package (Chao et al. 2014; Hsieh et al. 2022; R Core Team 2023).

To compare species diversity and abundance between sites and habitat types, we calculated total species richness for each type of habitat as well as average species richness and individual density for sampling sites. The metrics that were calculated for a comparison of the oribatid mite communities for the study sites are as follows: Shannon-Weiner diversity index (H), Pielou's evenness (J), and Sorensen index of similarity (S₀) (Magurran 2013). Diversity metrics and neighbor-joining tree clustering based on the Euclidean distance were performed using PAST software, version 4.03 (Hammer et al. 2001).

Results

In total, 983 specimens of 52 species of oribated mites belonging to 41 genera and 28 families were collected and identified; among them, 23 species were registered for the

first time in the Saskhori limestone quarry (Table 2). The site Sa2 was the most diverse with mites (27 species); the second highest number of species were registered in Sa1, Sa4, and Sa7, with 22 species in each site. In terms of individual density, the most abundant species were *Xenillus tegeocranus* (Hermann, 1804) (120 specimens collected from six sites), followed by *Aleurodamaeus setosus* (106 specimens collected from six sites), *Punctoribates punctum* (85 specimens collected from six sites), and *Ceratoppia bipilis* (66 specimens collected from six sites). Thus, all four species were common in six sites out of seven, while seventeen species occurred in only one location (Table 2).

Among the studied habitats, Shibliak, or Mediterranean-type deciduous drought-resistant shrubbery (EUNIS habitat code F5.3), was the richest, represented by 37 mite species. *Xenillus tegeocranus*, *Zetorchestes micronychus*, and *Oribatula tibialis* were the most abundant of oribatid mites in this type of habitat (Table 2). Xero-thermophilous oak forest and mixed vegetation of the oak-hornbeam woodland (EUNIS habitat code: G 1. A) were also quite rich with 32 oribatid mite species, dominated by typical forest and ubiquitous species such as *Steganacarus carinatus*, *Ceratoppia bipilis*, *Punctoribates punctum*, and *Schellobates laevigatus*. Rural and urban vegetation (EUNIS habitat code: I 1.3) was the poorest in mite species diversity; fauna was represented by 10 species, with the highest abundance for *Lasiobelba pori* Vasiliu, 1995, and *Oribatula (Zygoribatula) cognata* (Oudemans, 1902). Results show that agricultural land without vegetation was the worst for the development of oribatid mite communities (Table 2). According to the individual density, the highest number (191 specimens) was recorded in the Shibliak or Mediterranean-type de-

Table 2. Species occurrence data in the study area of Saskhori limestone quarry. Species lists are grouped into a taxonomy. For each sampled site (Sa1-7), pooled species abundance data after three replicates is given. The new recorded species of Saskhori quarry are marked by asterisks.

Species	Sa1	Sa2	Sa3	Sa4	Sa5	Sa6	Sa7
Hyperorder EUPTYCTIMA Grandjean, 1967							
Euphthiracaridae Jacot, 1930							
<i>Acrotritia ardua</i>	0	0	0	0	0	3	0
Phthiracaridae Perty, 1841							
<i>Phthiracarus lentulus*</i>	0	0	0	0	0	0	2
<i>Steganacarus carinatus</i>	8	11	17	10	1	0	11
<i>Steganacarus magnus*</i>	0	0	0	0	0	0	1
<i>Steganacarus ochraceus</i>	0	0	0	0	4	0	0
Infraorder HOLOSOMATA Grandjean, 1969							
Nothridae Berlese, 1896							
<i>Nothrus parvus*</i>	4	0	0	0	0	0	0
Crotoniidae Thorell, 1876							
<i>Camisia horrida</i>	0	0	0	1	1	0	0
<i>Camisia lapponica</i>	0	5	1	0	0	0	0
Infraorder BRACHYPYLINA Hull, 1918							
Hermanniellidae Grandjean, 1934							
<i>Hermanniella punctulata</i>	0	0	1	4	4	0	0
Neolioididae Sellnick, 1928							
<i>Neoliodes theleproctus*</i>	0	1	0	3	4	0	0
<i>Poroliodes farinosus</i>	0	4	0	0	0	0	0
Plateremaeidae Trägårdh, 1926							
<i>Lopheremaeus mirabilis*</i>	0	0	0	6	0	0	0
Gymnodamaeidae Grandjean, 1954							
<i>Arthrodamaeus femoratus</i>	5	1	1	2	0	0	0
<i>Aleurodamaeus setosus</i>	63	7	15	6	4	0	11
Damaeidae Berlese, 1896							
<i>Metabelba flagelliset*</i>	0	3	0	0	0	0	0
<i>Metabelba monilipeda</i>	0	0	0	0	0	0	11
Ceratoppiidae Grandjean, 1954							
<i>Ceratoppia bipilis*</i>	7	8	2	1	5	0	43
Zetorchestidae Michael, 1898							
<i>Microzetorchestes emeryi*</i>	3	0	0	0	0	1	0
Gustaviidae Oudemans, 1900							
<i>Gustavia microcephala</i>	0	6	6	2	0	0	3
Liacaridae Sellnick, 1928							
<i>Liacarus brevilamellatus</i>	0	0	1	4	14	0	4
<i>Liacarus oribatelloides*</i>	7	0	0	0	0	0	0
<i>Liacarus (Dorycranosus) ovatus*</i>	0	0	5	3	0	0	0
<i>Liacarus (Dorycranosus) splendens</i>	0	10	4	0	10	0	5
Xenillidae Woolley et Higgins, 1966							
<i>Xenillus tegeocranus</i>	0	50	24	13	26	0	7
Zetorchestidae Michael, 1898							
<i>Zetorchestes micronychus</i>	5	6	26	2	0	0	4
Amerobelbidae Grandjean, 1954							
<i>Amerobelba decedens*</i>	0	0	0	0	1	0	0
Oppiidae Sellnick, 1937							
<i>Ramusella clavipectinata</i>	3	0	0	0	0	0	1
<i>Oppiella (Rhinoppia) hygrophila*</i>	2	7	0	0	0	0	0
<i>Lasiobelba pori*</i>	0	0	0	0	0	9	1
Carabodidae Koch, 1843							
<i>Austrocarabodes foliaceisetus georgiensis</i>	11	1	2	0	0	0	0
Tectocephidae Grandjean, 1954							
<i>Tectocephus velatus</i>	0	12	6	1	0	0	0
Scutoverticidae Grandjean, 1954							
<i>Scutovertex minutus*</i>	6	0	0	1	20	0	0
Phenopelopidae Petrunkevitch, 1955							
<i>Eupelops acromios</i>	0	1	5	7	0	0	0
<i>Eupelops occultus*</i>	0	2	0	0	0	0	0
<i>Eupelops torulosus*</i>	0	0	7	0	0	0	4
<i>Peloptulus phaenotus</i>	0	8	2	1	0	0	0
Tegoribatidae Grandjean, 1954							
<i>Tectoribates ornatus*</i>	1	0	0	0	0	0	0
Oribatellidae Jacot, 1925							
<i>Oribatella berlesei*</i>	0	0	0	0	0	0	2
<i>Oribatella foliata*</i>	7	0	0	0	3	0	0

<i>Oribatella reticulata</i> *	3	0	0	0	0	0	0
Ceratozetidae Jacot, 1925							
<i>Trichoribates naltschicki</i>	0	6	0	0	0	0	0
Punctoribatidae Thor, 1937							
<i>Minunthozetes pseudofusiger</i>	12	2	0	0	0	1	2
<i>Punctoribates punctum</i>	0	22	4	23	8	4	24
Oribatulidae Thor, 1929							
<i>Lucoppia burrowsi</i> *	5	0	0	0	0	0	5
<i>Oribatula tibialis</i>	20	1	31	2	0	1	1
<i>Oribatula (Zygoribatula) cognate</i>	1	1	0	2	1	5	2
<i>Oribatula (Zygoribatula) exilis</i> *	3	9	0	0	0	0	0
Schelorbitidae Grandjean, 1933							
<i>Schelorbitates laevigatus</i>	8	5	3	9	15	0	11
Protoribatidae Balogh et P. Balogh, 1984							
<i>Protoribates capucinus</i>	1	0	0	0	0	1	0
Haplozetidae Grandjean, 1936							
<i>Haplozetes tenuifusus</i> *	0	0	0	0	9	1	0
Galumnidae Jacot, 1925							
<i>Galumna alata</i>	0	1	12	1	11	2	4
<i>Pergalumna nervosa</i>	0	1	0	0	0	0	0
Total number of species	22	27	21	22	18	10	22
Total number of individuals	185	191	175	104	141	28	159

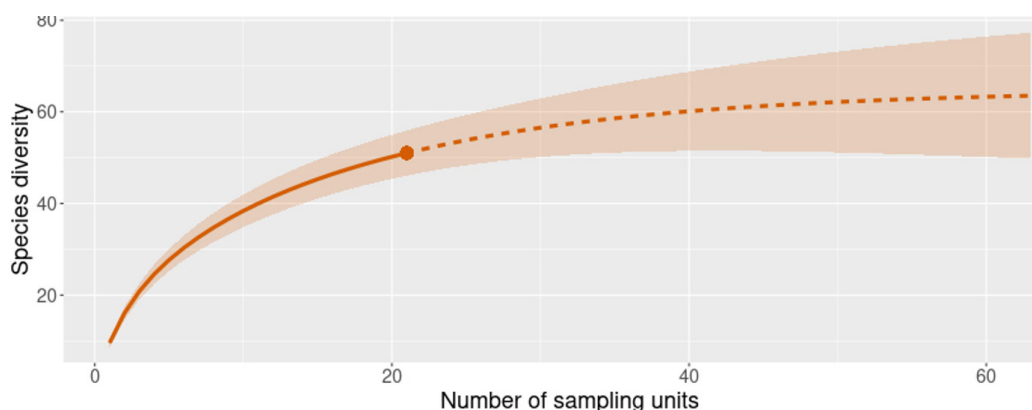


Figure 2. Rarefaction/extrapolation curves as a function of the number of survey sites from the Saskhori limestone quarry. The dotted part of the curve indicates the expected species diversity, along with an increasing sample size. The confidence intervals of the curve, after 100 bootstrap replicates, are indicated by the shaded area along the curve.

ciduous drought-resistant shrubbery site (Sa2), which was followed by oak forests (Sa4 and Sa7) and meadows with rural and invasive plants (Sa1) (Table 3).

The highest diversity (Shannon’s diversity, H) was revealed for Sa2 (H = 2.72), and the lowest value was in Sa6 (rural and urban habitat) (H = 1.9). Regarding Pielou’s evenness index, the highest value belonged to Sa5 (0.87), while the lowest belonged to Sa1 (0.77) (Table 3).

The extrapolation curve was modeled for 21 survey samples from 7 sites. The asymptotic pattern indicates that more sampling should increase the number of detected species (Fig. 2) to a maximum expected number of species equal to 67 (88 species as an upper confidence limit).

The cluster analysis, based on the Sorensen index (S_{θ}), grouped oribatid mite communities from Sa1 and Sa2 sites as well as Sa3 and Sa4 sites together (Fig. 3). The comparison of the mite communities at each site showed the greatest similarity between Shibliak shrubbery and steppe habitats. Cluster analyses confirmed that the oribatid mite community found in arable land (Sa6) is most distinct from the communities of natural and semi-natural habitats (Fig. 3).

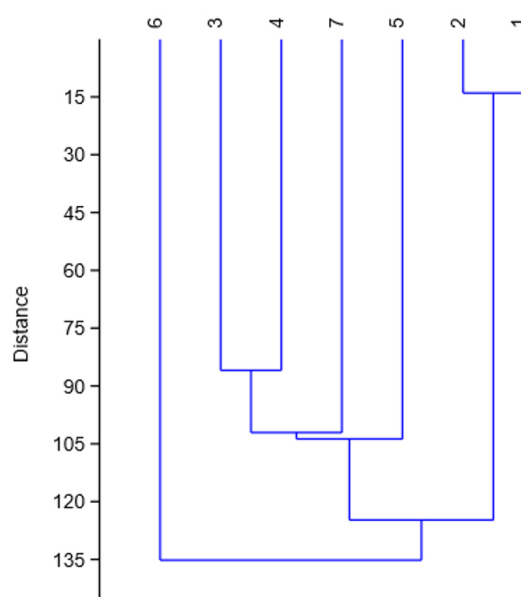


Figure 3. Cluster analysis of community similarity based on Sorensen index (S_{θ}) among the six study locations: 1-Sa1, 2-Sa2, 3-Sa3, 4-Sa4, 5-Sa5 and 6-Sa6.

Table 3. Sample sites on the limestone quarry in Saskhori and its adjacent areas. For the habitat classification, we followed the EUNIS (European Nature Information System) habitat classification scheme (Davies et al. 2004).

	Sa1	Sa2	Sa3	Sa4	Sa5	Sa6	Sa7
N	184	191	175	104	141	28	159
S	22	27	21	22	18	10	22
H	2.4	2.72	2.56	2.64	2.52	1.97	2.53
J	0.77	0.83	0.84	0.86	0.87	0.87	0.82

Liacarus oribatelloides Winkler, 1956 new record of Caucasus fauna

During the investigation of the limestone quarry of Saskhori, one species from the genus *Liacarus* (*L. oribatelloides* Winkler, 1956) was registered for the first time for the Caucasus and Georgian fauna.

Family Liacaridae comprises 6 genera, 4 subgenera, 126 species, and 6 subspecies (Subías 2023). The following genera and subgenera belonging to the family *Liacarus* (*Liacarus*) Michael, 1898; *Liacarus (Dorycranosus)* Woolley, 1969; *Adoristes (Adoristes)* Hull, 1916; *Adoristes (Gordeevilla)* and *Birsteiniius* Krivolutsky, 1965 are known from the Caucasus region (Shtanchaeva et al. 2009). Genus *Liacarus* contains 112 species, of which 10 are represented in Georgia (Murvanidze et al. 2016). During our research in the limestone quarry of Saskhori, two species of the genus *L. oribatelloides* and *L. brevilamellatus* were registered (Figs. 4A,B). The former was a new record for Georgian and Caucasus fauna.

The genus *Liacarus* is one of the best-known and easily recognized genera of oribatid mites. Although numerous species have been described and then synonymized according to their morphological characters by many authors, no attempts have been made at interspecific differentiation using genetic methods. Here we provide detailed characteristics for the newly recorded *L. oribatelloides* to facilitate its further research.

Morphology and taxonomy. *L. oribatelloides* was described by Winkler (1956) from the Czech Republic as a new species due to the bladellike lamellae with well-developed inner and outer cusps taken in combination with other morphological details. Later, the author (Winkler 1957) explains that individuals from different locations show a certain morphological and ecological variability, which is expressed differently in closely related species. In the latest classification, *L. oribatelloides* is considered a senior synonym of *L. coracinus* (Subías 2023). This mite is redescribed and figured here.

Redescription of new recorded species

Liacarus (L.) oribatelloides Winkler, 1956

Fig. 4A

Diagnosis. Large-sized species (1084–1198 × 657–728). Rostrum truncate, with two incisions and small projections laterally, lamellar cusps well developed, distally concaved with strong inner and outer teeth. Translamella with medial tooth; rostral, lamellar and interlamellar setae strong,

setiform and slightly barbed. Bothridial setae spindle-form, apex noticeably longer than head, slightly barbed. Notogaster setae are short, thin, and smooth. Epimeral and anogenital setae are setiform and thin. Leg IV trochanters and femora with teeth from the lateral view.

Measurements. Body length: 1084–1198 (four individuals); body width: 657–728 (four paratypes).

Integument. Body color brown to dark brown. Notogaster and anogenital surfaces are punctuated with small foveolae. External margin of lamellae, tatoria with striations. Lateral parts of the body granulate with small foveolae.

Prodorsum. The rostrum is truncate dorso-anteriorly, with two incisions and small lateral teeth. Lamellae longer than half of prodorsum with well-developed translamella and tooth medially. Lamellar cusps are well developed, broad, and extend nearly to the end of the rostrum; the inner cusps are longer (33–36) than the outer ones (15–18). Rostral (68–71), lamellar (94–123), and interlamellar (193–205) setae are setiform and slightly barbed. Sensilli (128–132) spindle-form slightly barbed; the apical part is longer (57–68) than the length of the head (34–41). Notogaster slightly narrows anteriorly and posteriorly, with very small humeral projections. Notogaster with eleven pairs of minutes, glabrous setae (15–18) except seta p1, which is longer (34–38), and easily separated from the other ones. Ventral side. Epimeres I–III well separated with parallel lines, laterally integument granulated; epimeral formula 3:1:3:3. Epimeral setae setiform, slightly barbed, 1a, 2a and 3a short, 1b, and 3b longer than other setae.

Anogenital region. Six pairs of genitals, one pair of aggenital, two pairs of anal and three pairs of adanal setae setiform. Genital plate wider than long (87–91 and 57–63, respectively). Anal plate nearly as long as wide (132–136 and 119–125, respectively). Length of anal setae 22–27.

Legs. Legs three-clawed. Formulae of leg setation and solenidia: I (1–5–3–4–20) [1–2–2], II (1–4–2–4–16) [1–1–2], III (2–3–1–3–15) [1–1–0], IV (1–2–2–3–12) [0–1–0]; All setae setiform, slightly barbed on the dorsal sides of the legs. Leg IV trochanter and femora have a long, slender appendage from the lateral view.

Differential diagnosis. According to the morphological diagnostic features of the available specimens of *Liacarus oribatelloides* collected from the limestone quarry of Saskhori and *L. coracinus* collected from Machakhela National Park (Gratiashvili et al. 2022), the various characteristics are different between these closely related species.

Compared to *L. coracinus*, which has a more oval-shaped body and a yellow-brown color, *L. oribatelloides* has an elongated body with a dark-brown or black color.

The species is distinguished most readily by the lamellar cuspid. *L. oribatelloides* has strongly elongated tips of the lamellar cuspid on both the inner and outer sides (Fig. 4A), whereas *L. coracinus* has strong inner and indistinct outer teeth of the lamellar cusps. The distance between the outer teeth of the lamellar cusps is also noticeably different between the species; they are wider for *L. oribatelloides* than for *L. coracinus*, and represent 36–38 and 25, respectively.

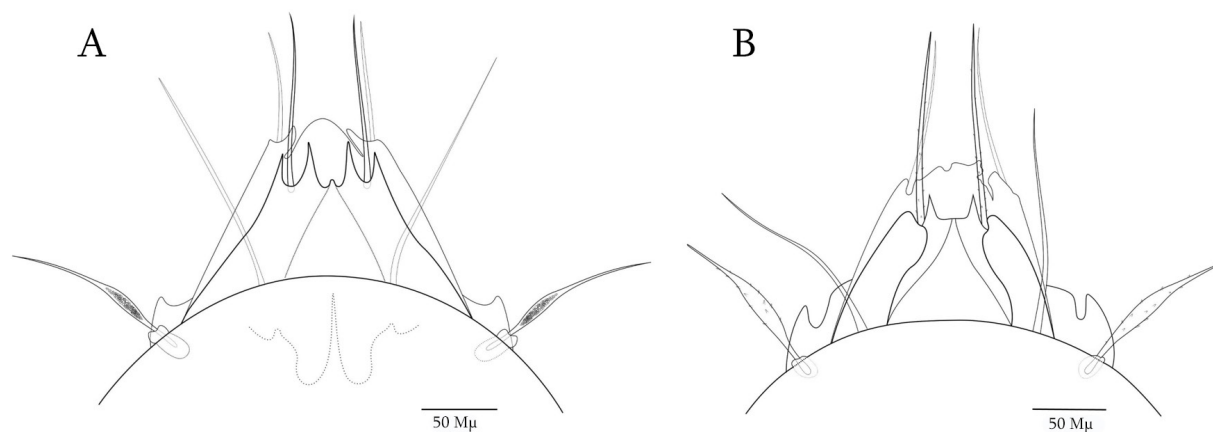


Figure 4. **A:** Lamellae with inner and outer cusps of *Liacarus oribatelloides* Winkler, 1956; **B:** Lamellae with inner and outer cusps of *Liacarus (L) brevilamellatus* Mihelčič, 1955.

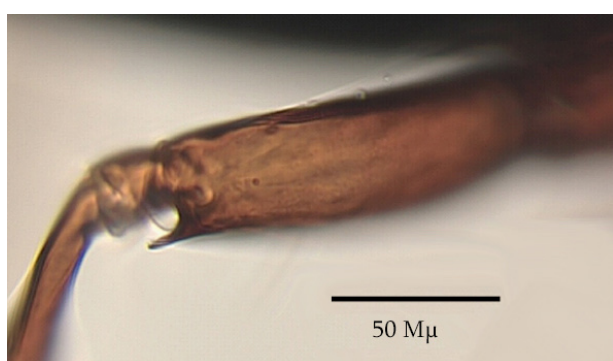


Figure 5. *Liacarus oribatelloides* Winkler, 1956. Femur of leg IV with inner tooth

Liacarus oribatelloides and *L. coracinus* also differ from each other by the length of leg IV, which is 225 and 165, respectively. In addition, the femur of leg IV of *L. oribatelloides* has clearly distinguishable inner teeth (Fig. 5). In having the combination of a shape of lamellae with well-developed lamellar cusps, a shape of sensilli, and the presence of an inner tooth in the femur of leg IV, *L. oribatelloides* differs from *L. coracinus*.

Remarks. The taxonomic status of *Liacarus oribatelloides* is unclear. Weigmann (2006) registered *L. oribatelloides* in southern Germany and gave the differential diagnosis with the drawings for *L. coracinus* and *L. oribatelloides*.

During a long period of time, *Liacarus oribatelloides* was registered as a valid species, but in the latest world catalog of oribatid mites (Subías 2023) and some other publications (Schatz 2018), the species is synonymized with *L. coracinus*. According to the literature data, *L. oribatelloides* is distributed in the Czech Republic, Southern Germany, Austria, Italy, Slovakia, Poland, the Central Alps, and the Tatra Mountains (Fischer & Schatz 2013; Schatz 2016; Miko 2016; Wierzbicka et al. 2020; Miko 2021; Jászayová et al. 2023). Before our finding, the species distribution was known only from Central Europe, and the species had never been found in the Caucasus region.

The taxonomy of *Liacarus oribatelloides* and similar taxa needs to be studied further. In particular, using the molecular genetic framework is necessary in order to better understand species status and delineate interspecific boundaries.

Discussion

Oribatid mite community structure in the limestone quarry of Saskhori was studied from the habitats that will be subject to the mining processes and the neighboring semi-natural and natural areas. The oribatid mite fauna studied shows high proportions of rare species. According to the results of the previous study by Murvanidze et al. (2018), 51 species were recorded, with 22 singleton and 18 doubleton taxa. In the current study, we recorded 52 species, of which 19 were singletons and 11 were doubletons.

Perhaps more interesting is that only 39% of taxa (29 species) were common between Murvanidze et al. (2018) and the current study. Such a great difference in oribatid mite composition is most probably a result of incomplete sampling in the past and current research rather than due to faunal turnover in a short time period. Indeed, the rarefaction curve shows that the maximum expected species number is around 75, which nicely matches the total number of taxa found in both studies. However, changes in species composition, especially species relative density, are also apparent. For instance, *Steganacarus carinatus*, *Camisia horrida*, *C. lapponica*, *Hermanniella punctulata*, *Arthrodamaeus femoratus*, *Eupelops acromios*, and *Punctoribates punctum* were collected in only one location by Murvanidze et al. (2018), while in the current study, each of these species was found in more than one sampling site. Further, Murvanidze et al. (2018) noted that two oribatid species, *Xenillus tegeocranus* and *Scheloribates laevigatus*, were most common and recorded in all four types of habitats. In the current study, two additional species, *Aleurodamaeus setosus* and *P. punctum*, were the most common with wide distribution in the limestone quarry of Saskhori. According to Murvanidze et al. (2018), *P. punctum*, *Tectocephus velatus*, and *S. laevigatus* were the most abundant in degraded habitats; however, our data showed unexpected findings of high numbers of *Lasiobelba pori* in rural habitats, which is hard to explain with the current level of knowledge.

Overall, oribatid mite density and diversity were much lower in the heavily grazed sites where the soil structure was destroyed, while in sites with more or less natural vegetation, the mite diversity was higher. Based on the compar-

son of the results of the current study with literature data, it is evident that community change has taken place, which most probably is because of the ongoing limestone mining process. However, the extent and design of our study do not allow for further prediction of possible faunal changes; rather, they provide baseline information for future monitoring purposes.

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References

- Balogh J, Mahunka S (1983) The soil mites of the World – Vol. 1. Primitive Oribatids of the Palaearctic Region. Akadémiai Kiadó, 372 pp.
- Chao A, Gotelli NJ, Hsieh TC, Sande EL, Ma KH, Colwell RK, Ellison AM (2014) Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. *Ecological Monographs* 84: 45–67. <https://doi.org/10.1890/13-0133.1>
- Davies CE, Moss D, Hill MO (2004) EUNIS Habitat Classification Revised 2004. Report to the European Topic Centre on Nature Protection and Biodiversity. European Environment Agency.
- Downing AS, van Nes EH, Mooij WM, Scheffer M (2012) The Resilience and Resistance of an Ecosystem to a Collapse of Diversity. *PLoS ONE* 7(9): e46135. <https://doi.org/10.1371/journal.pone.0046135>
- Fischer BM, Schatz H (2013) Biodiversity of oribatid mites (Acari: Oribatida) along an altitudinal gradient in the Central Alps. *Zootaxa* 3626 (4): 429–454. <https://doi.org/10.11646/zootaxa.3626.4.2>
- Ghilarov MS, Krivolutsky DA (1975) Identification keys of soil inhabiting mites, Sarcopitiformes. Nauka, Moscow, pp. 491. (in Russian)
- Gratiashvili N, Arabuli T, Kuchava M (2022) Biodiversity of oribatid mites and nematodes of Machakhela National Park. *Bulletin of the Georgian National Academy of Sciences* 16(2): 122–128.
- Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. *Palaentologia Electronica* 4(1): 1–9.
- Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J, Wardle DA (2005) Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* 75: 3–35. <https://doi.org/10.1890/04-0922>
- Hsieh TC, Ma KH, Chao A (2022) iNEXT: Interpolation and Extrapolation for Species Diversity. R package version 3.0.0.
- Jászayová A, Luptáčík P, Čsanády A, Chovancová G, Hurníková Z (2023) Biodiversity of oribatid mites (Acari: Oribatida) in the Tatra Mountains, Central Europe. *International Journal of Acarology*. <https://doi.org/10.1080/01647954.2022.2161630>
- Loreau M, Mouquet N, Gonzalez A (2003) Biodiversity as spatial insurance in heterogeneous landscapes. *Proc. Natl. Acad. Sci. U.S.A.* 100: 12765–12770. <https://doi.org/10.1073/pnas.2235465100>
- Magurran AE (2013) *Measuring biological diversity*. John Wiley & Sons, Hoboken, New Jersey, 264 pp.
- Menta C (2012) Soil Fauna Diversity - Function, Soil Degradation, Biological Indices, Soil Restoration. In: Lameed GA (Ed.) *Biodiversity Conservation and Utilization in a Diverse World*. IntechOpen, Rijeka, 59–94. <https://doi.org/10.5772/51091>
- Miko L (2016) Oribatid mites (Acarina: Oribatida) of the Czech Republic Revised check-list with a proposal for Czech oribatid nomenclature. *Klapalekiana* 52(Suppl.): 1–302.
- Miko L (2021) Faunistic records of Slovak oribatids III. Oribatid mites (Acarina) of Levoča Mountains, East Slovakia. *SPIŠ* 10: 275–289.
- Moghimian N, Habashi H, kheiri M (2013) Comparison of Soil Macro Fauna Biodiversity in Broad Leaf and Needle Leaf Afforested Stands. *Molecular Soil Biology* 4(3): 16–26. <https://doi.org/10.5376/msb.2013.04.0003>
- Murvanidze M, Mumladze L (2016) Annotated checklist of Georgian oribatid mites. *Zootaxa* 4089(1): 1–81. <https://doi.org/10.11646/zootaxa.4089.1.1>
- Murvanidze M, Todria N, Mumladze L, Kalatozishvili L (2018) Diversity of soil mite communities in different habitats of Sashkhor quarries, Georgia. *Persian Journal of Acarology* 7(3): 297–305. <https://doi.org/10.22073/pja.v7i3.37647>
- Muscolo A, Settineri G, Attinà E (2015) Early warning indicators of changes in soil ecosystem functioning. *Ecological Indicators* 48: 542–549. <https://doi.org/10.1016/j.ecolind.2014.09.017>
- Nielsen UN, Osler GHR, Campbell CD, Burslem FRP, Van der Wal R (2010) The influence of vegetation type, soil properties and precipitation on the composition of soil mite and microbial communities at the landscape scale. *Journal of Biogeography* 37: 1317–1328. <https://doi.org/10.1111/j.1365-2699.2010.02281.x>
- Norton R, Behan-Pelletier V (2009) Oribatida. In: Krantz GW, Walter DE (Eds) *A manual of acarology* (3rd Edition). Texas Tech University Press, Lubbock, Texas, 430–564.
- Oliver T, Isaac N, August T, Woodcock B, Roy D, Bullock J (2015) Declining resilience of ecosystem functions under biodiversity loss. *Nature Communications* 6: 10122. <https://doi.org/10.1038/ncomms10122>
- R Core Team (2023) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. <https://www.R-project.org>
- Schatz H (2016) Oribatid mites (Acari, Oribatida) from the biodiversity days in South Tyrol (Prov. Bolzano, Italy). *Gredleriana* 016: 113–132.
- Schatz H (2018) Catalogue of oribatid mites (Acari: Oribatida) from South Tyrol (Prov. Bolzano, Italy). *Zootaxa* 4435(1): 001–089. <https://doi.org/10.11646/zootaxa.4435.1.1>
- Schatz H, Behan-Pelletier VM, Oconnor BM, Norton RA (2011) Suborder Oribatida van der Hammen, 1968. In: Zhang ZQ (Ed.) *Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness*. *Zootaxa* 3148: 141–148. <https://doi.org/10.11646/zootaxa.3148.1.26>
- Schmidt W (2005) Herb layer species as indicators of biodiversity of managed and unmanaged beech forests. *Forest Snow and Landscape Research* 79(1/2): 111–125
- Shtanchaeva UY, Subías LS, Arillo A (2009) New taxa of oribatid mites of the family Liacaridae (Acariformes: Oribatida) from the Caucasus. *Entomologica Fennica* 20: 245–248.
- Subías LS (2023) Listado sistemático, sinonímico y biogeográfico de los ácaros oribátidos (Acariformes: Oribatida) del mundo (excepto fósiles). *Monografías Electrónicas* 12: 1–538. <http://bba.bioucm.es> [accessed February 2023]
- Wierzbička A, Rączka G, Urbanowski KC, Cembala M, Pańka J, Kamczyc J (2020) Soil mites communities (Acari: Oribatida, Mesostigmata) in

- Kokorycz Natural Reserve (South Western Poland) – a case study. *Forestry Letters* 113: 12–18.
- Weigmann G (2006) Hornmilben (Oribatida). *Die Tierwelt Deutschlands*. Teil 76. Goecke & Evers, Keltern, 520 pp. [(in German)]
- Winkler JR (1956) Nove druhy rodu *Liacarus* (Acari: Oribatoidea) z okolí Cabove (okr. Bruntal). *Zpravy KVM Olomouc* 62: 81–82.
- Winkler JR (1957) Über zwei *Liacarus*-Arten aus der Tschechoslowakei (Acari: Oribatoidea). *Acta faunistica entomologica Musei nationalis* 2: 131–133.