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# An introductory study of subterranean communities of invertebrates in forested talus habitats in southern Slovakia

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**Abstract**. This study of subterranean communities of invertebrates was carried out at two talus sites located in protected areas in southern Slovakia that differ in the nature of the bedrocks: the Belinské skaly, Cerová vrchovina Mts with basalt bedrock and Drienok Valley, Revúcka vrchovina Mts, with limestone bedrock. In May 2012, three perforated PVC tubes (11 cm in diameter) were buried vertically in deposits on slopes at both of these sites. In each tube there were 10 removable pitfall traps located at from 5 to 95 cm below the soil surface and filled with either formaldehyde or ethylene glycol as a preservative. Invertebrates were collected from the traps in June and October 2012. In this paper, we present the first results of this comparative study. In total 4,520 invertebrates were caught of which 99.8% were arthropods and the rest were mainly gastropods and annelids. Springtails (1,742 inds., 50 spp.) and beetles (154 inds., 40 spp.) were the most diverse in terms of species and were caught in all the traps. Springtails were the most abundant making up 38.5% of the total catch compared to beetles that made up only 3.4%. No obligate cavernicolous species was recorded in the first set of samples. However, some arthropods associated with subterranean habitats were recorded in the October samples. The millipede *Archiboreoiulus pallidus* (Brade-Birks, 1920) was recorded in the volcanic talus deposit, the woodlouse *Mesoniscus graniger* (Frivaldszky, 1865) and carabid beetle *Duvalius bokori* (Csiki, 1910) in the limestone talus. The staphylinid beetle *Atheta pervagata* Benick, 1975 and three taxonomically uncertain species of Collembola belonging to the genus *Pseudosinella* with troglomorphic traits, were recorded at both the volcanic and limestone sites. The millipede *A. pallidus* and springtail *Pygmarrhopalites elegans* Cassagnau et Delamare Deboutteville, 1953 are reported for the first time occurring in Slovakia. Compared to formaldehyde, ethylene glycol is a more suitable preservative for the majority of arthropods in terms of the numbers of species and total number of individuals caught. The use of two different preservative solutions revealed a rich fauna. Based on the spectrum of species caught the capture efficiency of formaldehyde and ethylene glycol differed substantially. The other dominant arthropod groups were Acari (18.3%) and Diptera (14.6%), which were not investigated to species level. In general, there was a more diversified arthropod community at the limestone talus site, with the exception of mites, spiders and ants, which were better represented at the site with basalt bedrock.

**Key words**. Invertebrates, forested talus, vertical distribution, Cerová vrchovina Mts, Revúcka vrchovina Mts, subterranean traps, basalt, limestone.

## INTRODUCTION

Deep layers of soil in talus deposits are a specific type of subterranean habitats. They possess several unique features that distinguish them from better known cave habitats: close contact with the surface of the ground (distance less than 10 m), minimal seasonal fluctuations in microclimate and better availability of organic matter (Culver & Pipan 2009, Pipan & Culver 2012). On the other hand, both scree deposits and superficial layers of soil are closely interconnected with deep underground spaces (network of mesocaverns in the parent rock and caves) and together constitute a monolithic framework (Giachino & Vailati 2010). Subterranean habitats located near the surface of the ground play an important role as gateways for species penetrating underground during the course of history. They served as suitable shelters for part of Tertiary fauna during the harsh climatic conditions in the Quaternary. Thus, talus deposits in temperate zones acted as refuges for the ancestors of contemporary troglobionts (Růžička 1993, 2000). In some cases, the consistently low temperatures inside some screes throughout the year enable the persistence there of a unique community of glacial relicts (Růžička 1988, 1990, Růžička et al. 1995, Růžička & Klimeš 2005). Fauna and ecology of such habitats is relatively poorly known due to methodological problems, especially those related to the efficient collection of this fauna. The construction of traps that can be placed at various depths in the substratum using plastic tubes has provided new possibilities for studying the underground life in terrestrial subterranean habitats other than caves (López & Oromí 2010, Schlick-Steiner & Steiner 2000).

At the areas studied in southern Slovakia, the Cerová vrchovina Mts and the Revúcka vrchovina Mts, there are subterranean habitats, such as caves and crevices, open stony debris or forested taluses (Gaál 2000, Gaál et al. 2010). There are several interesting records of the arthropod fauna in the pseudokarst caves in the Cerová vrchovina Mts, namely the blind woodlouse *Mesoniscus graniger* (Mlejnek & Ducháč 2001, 2003, Papáč et al. 2009), the endogenous harvestman *Holoscotolemon jaqueti* (Corti, 1905) (Franc & Mlejnek 1999, Mihál et al. 2009), relic spiders *Kratochviliella bicapitata* Miller, 1938 (Franc & Hanzelová 1995) and *Porrhomma profundum* M. Dahl, 1939, cavernicolous oribatid mites *Belba clavigera* Willmann, 1954 and *Pantelozetes cavaticus* (Kunst, 1962) (Papáč et al. 2009) and the psychrophilous relict beetle *Choleva lederiana* Reitter, 1901 (Růžička 2000, Růžička & Vávra 2003). There is a lot of information on arachnids living in surface habitats, stony debris, crevices in the bedrock and pseudokrastic caves in the area (Mašán & Mihál 2009). There is a full-scale study of the cave dwelling invertebrates in the Cerová vrchovina Mts, which summarises previous data of Papáč et al. (2009) and Lantos et al. (2010) provide a general survey of invertebrate fauna in this area.

The Drienčanský kras, a small area of karst in the Revúcka vrchovina Mts, is known as the location for some troglophilous beetles of the genus *Duvalius*. The first sampling of the local cave fauna was carried out in1922 and resulted the report of the presence of the endemic *D. goemoeriensis* (Bokor, 1922). First synopsis of regional cave dwelling fauna was published by Pomichal (1982). Later on, Franc & Mlejnek (2000) found another rare rove beetle *Bryaxis monstrosetibialis* (Stolz, 1923) in two caves in this area. Subsequently, Mlejnek & Ducháč (2001, 2003) documented the distribution of the terrestrial isopod *M. graniger* in several local caves. A detailed study of terrestrial invertebrates in the Podbanište Cave (the longest in the region with a length of 1,570 m) by Papáč (2008a) revealed several rare subterranean taxa, e.g. the orbatid mites *Pantelozetes cavaticus* and *Kunstidameus lengersdorfi* (Willmann, 1932), and the troglomorphic springtails *Pygmarrhopalites aggtelekiensis* (Stach, 1929) and *Deuteraphorura* cf. *kratochvili* (Nosek, 1963). The same author also studied the distribution of springtails in other caves in the area (Papáč 2008b, 2011). So far, the colonization of forested scree habitats by invertebrates has not been studied in this area. The present study is a preliminary part of an ongoing comprehensive investigation of the fauna of superficial subterranean habitats in the Western Carpathians.

We hypothesized that the air-filled interstices in both limestone and basalt bedrock are permanently inhabited by invertebrates (arthropods) and at limestone localities there is a more diverse underground fauna than at non-karst localities. In addition to caves, cavernicolous fauna also inhabits other types of underground habitats, primarily in limestone bedrock. Invertebrate communities at localities with dissimilar bedrocks should be significantly different and the number of specific cave and relict forms are expected to be higher at a limestone site.

The objectives of this study were: (1) to characterize the composition and distribution of invertebrate fauna at different depths in the ground at two talus sites, (2) to compare the structure of subterranean invertebrate communities at localities with different bedrocks, and (3) to test the capture efficiency of traps filled with different preservative solutions and determine the time it takes for the vertical zonation of invertebrate assemblages to stabilize after the traps are buried.

## METHODS

Two different localities near the town Rimavská Sobota in southern Slovakia, were selected:

(1) The Belinské skaly National Nature Monument, the Cerová vrchovina Protected Landscape Area; 48° 13' N, 19° 52' E, 460 m a. s. l., quadrate of the Fauna Databank of Slovakia (DFS) 7785c. This site is a sloping deposit with south-west orientation under a cliff of basalt rock, which is overgrown with oak-hornbeam forest with xerophilous vegetation (Fig. 1). The substratum consisted of a mixture of small rock fragments (ca. 2 cm in diameter) and soil. Three well defined layers were recognizable within the slope profile: 0–30 cm deep (stony soil with humus and roots = rhizosphere), 30–70 cm deep (relatively homogenous mixture of soil and small stones) and 70–110 cm deep (almost exclusively mineral stratum of non-compact bedrock).

(2) the Drienok Valley, beginning of the valley near the village of Španie Pole, Drienčanský kras area of European Importance, in the Revúcka vrchovina Mts; 48° 32' N, 20° 07' E, 315 m a. s. l., DFS: 7486d. Steep north facing scree slope on

Fig. 1. Photograph of the study site in the volcanic Cerová vrchovina Mts taken on 12 October 2012 (foot of the Belinské skaly rocks) (photo by A. Mock).

Fig. 2. Photograph of the study site on a forested slope in the Drienok Valley, Drienčanský kras, showing the digging of the hole for the traps, 15 May 2012 (photo by A. Mock).

limestone rocks with small caves, the surroundings of which are covered with beech-hornbeam forest (Fig. 2). Three layers were defined in the profile of the slope: humus layer with roots and stones (0–25 cm deep), layer formed of a mixture of bigger stones and soil (25–70 cm deep) and accumulation of small stones (70–110 cm deep).

At both sites, three subterranean traps were set (Schlick-Steiner & Steiner 2000), which were made from PVC tubes (11 cm in diameter, 110 cm in length) with ten small holes (0.7 cm) drilled at intervals along the tube at depths of from 5 to 95 cm, which allowed animals to enter the tubes when buried (Fig. 1). A set of ten removable pitfall traps (plastic cups) fixed on a central metal axis were placed inside each tube. The position of the pitfall traps filled with preservative solutions (formaldehyde or ethylene glycol) corresponded to the holes drilled in the tube. The tubes with traps were placed in the same hole, which was then filled with the excavated soil strata in the original order (for details see Rendoš et al. 2012, 2014).

This study started in 15 May 2012, samples were collected on 26 June and 12 October 2012. The material from the traps was transported to the laboratory and identified to a high taxanomic level and stored in 75% ethanol. Selected arthropod taxa were determined to species level: Araneae (by V. Růžička), Chilopoda (K. Tajovský), Oniscidea and Diplopoda (A. Mock), Collembola (N. Raschmanová) and Coleoptera (T. Jászay). Species richness and evenness were determined. The following formulas for calculating Simpson´s index of diversity were used: $H'=1-D$ and $D=\Sigma n(n-1)/N(N-1)$, where "n" is the total number of specimens of a particular species and "N" is the total number of specimens of all species. This was done for the two groups with the highest species richness.

## RESULTS

In total 4,520 invertebrates consisting of enchytreid worms, gastropods and 19 higher taxa of arthropods were trapped. Collembola (38.5%) and Acari (18.3%) were the most abundant groups in the soil mesofauna. The macrofauna consisted mainly of insects such as Diptera (14.6%), Formicidae (3.8%) and Coleoptera (3.4%). Both adults and larvae of holometabolous insects of several orders were present with adults moderately more numerous than larvae (56.4 vs. 43.6% of

Table 1. Number of invertebrates caught by the subterranean traps at different depths in vertical profile at both sites studied. CV – Cerová vrchovina, DK – Drienčanský kras, ETH – ethylene glycol/water solution, FOR – formaldehyde, I – sampling period 15 May –26 June 2012, II – sampling period 26 June –12 October 2012

| | depth (cm) depth (cm) | | | | | | | | | | orographic unit | | fixation solution | | sampling period | | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| taxon | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | CV | DK | ETH | FOR | I | II | I+II |
| Gastropoda | 3 | – | – | – | – | – | – | – | – | – | – | 3 | 2 | 1 | 1 | 2 | 3 |
| Enchytraeidae | 5 | – | – | – | – | – | – | – | – | – | 2 | 3 | 4 | 1 | 2 | 3 | 5 |
| Acari | 358 | 119 | 80 | 49 | 39 | 46 | 42 | 39 | 32 | 22 | 630 | 196 | 336 | 490 | 181 | 645 | 826 |
| Araneae | 8 | 4 | – | – | – | – | – | – | – | – | 10 | 2 | 3 | 9 | 5 | 7 | 12 |
| Pseudoscorpiones | 4 | – | 1 | – | – | – | 1 | – | 1 | – | 5 | 2 | 2 | 5 | 2 | 5 | 7 |
| Opiliones | – | 1 | – | – | – | – | – | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| Oniscidea | 1 | – | – | 1 | – | 1 | 1 | 3 | 4 | 1 | – | 12 | 3 | 9 | 1 | 11 | 12 |
| Diplopoda | 5 | 2 | 5 | 1 | – | 2 | 2 | 3 | 4 | 5 | 14 | 15 | 24 | 5 | 6 | 23 | 29 |
| Chilopoda | 5 | 3 | 1 | – | – | 1 | 3 | 1 | 1 | 1 | 7 | 9 | 9 | 7 | 2 | 14 | 16 |
| Symphyla | 3 | – | 1 | – | 1 | – | 1 | 1 | – | – | 2 | 5 | 1 | 6 | 2 | 5 | 7 |
| Collembola | 279 | 306 | 204 | 271 | 180 | 60 | 97 | 86 | 157 | 51 | 711 | 1031 | 1111 | 631 | 117 | 1625 | 1742 |
| Diplura | – | – | 2 | – | 1 | – | – | 3 | – | – | 6 | – | 4 | 2 | 4 | 2 | 6 |
| Aphidinea | – | – | – | 1 | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 |
| Auchenorrhyncha | 1 | – | – | – | 1 | – | – | – | – | – | – | 2 | 1 | 1 | 1 | 1 | 2 |
| Heteroptera | – | 1 | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | – | 1 |
| Diptera | 59 | 43 | 33 | 13 | 7 | 14 | 24 | 63 | 236 | 169 | 172 | 489 | 152 | 509 | 345 | 316 | 661 |
| Hymenoptera | 2 | 3 | 2 | 2 | 1 | 3 | 3 | – | – | – | 11 | 5 | 9 | 7 | 4 | 12 | 16 |
| Formicidae | 28 | 5 | 4 | 2 | 9 | 59 | 8 | 16 | 20 | 20 | 166 | 5 | 46 | 125 | 103 | 68 | 171 |
| Coleoptera | 26 | 17 | 17 | 12 | 12 | 13 | 8 | 19 | 20 | 11 | 53 | 101 | 85 | 69 | 61 | 93 | 154 |
| Thysanoptera | 5 | 3 | 3 | 3 | 5 | – | 2 | 9 | 5 | 5 | 1 | 39 | 16 | 24 | 33 | 7 | 40 |
| Siphonaptera | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | – | 1 | 1 |
| Holometabola larvae | 77 | 78 | 189 | 90 | 112 | 50 | 88 | 37 | 43 | 44 | 17 | 791 | 241 | 567 | 396 | 412 | 808 |
| total number of taxa | 17 | 13 | 13 | 11 | 11 | 10 | 13 | 12 | 11 | 11 | 16 | 20 | 19 | 21 | 20 | 20 | 22 |
| total number of inds. | 869 | 585 | 542 | 445 | 368 | 249 | 280 | 280 | 523 | 330 | 1808 | 2713 | 2032 | 2471 | 1268 | 3253 | 4521 |

total Holometabola) (Table 1). More abundant invertebrate groups were caught at all the depths sampled, with slightly higher numbers of individuals caught by the traps situated close to the soil surface. Higher numbers of individuals were caught by the deepest traps than by those located in the middle of the tubes. Diptera were the most numerous in catches of the two deepest traps (–85 and –95 cm). A higher subterranean activity of invertebrates was recorded at the limestone locality. In contrast, mites, spiders and ants were more abundant at the basalt bedrock site. In general, traps with ethylene glycol caught more arthropods, other than spiders, terrestrial isopods and beetles (both measured in terms of numbers of individuals and/or species), than the traps with formaldehyde (Tables 1, 2).

Six tiny species of eurytopic spiders (Araneae) were caught in the uppermost strata (–5 to –15 cm) mainly at the volcanic locality and mostly by the traps filled with formaldehyde. There was no significant difference in the numbers of spiders in the first and second set of samples.

The local assemblages of terrestrial isopods (Oniscidea) were rather poor in terms of numbers of species. Isopods were recorded only at the limestone site and there were significantly more in the second sample collected in October. Slightly more Isopoda were caught by the traps containing formaldehyde. Two common surface species, *Hyloniscus riparius* and *Protracheoniscus politus* were rarely recorded in the traps. At deeper levels (from –35 to –95 cm), the blind isopod *Mesoniscus graniger* occurred. It was recorded only in the second sampling period and the highest numbers of individuals (about 60%) were recorded at the deepest levels, –75 to –85 cm, sampled.

Millipedes (Diplopoda) were recorded at all the depths sampled. Six species were identified of which some were mainly caught by the traps closest to the surface of the ground. The juveniles of polydesmids and julids tended to be caught mainly by the deeper traps (up to –85 cm). The blind species *Archiboreoiulus pallidus* was only recorded in subterranean habitats in the basalt bedrock. The females and juveniles of this species were caught at depths below 15 cm and most often in the deepest strata (from –75 to –95 cm). *A. pallidus* was caught mainly in traps containing ethylene glycol, like most of the other species of millipedes, and exclusively in the second sampling period. The other species of millipedes recorded are generally edaphic forms.

Six species of centipedes (Chilopoda) belonging to two ecomorphological groups, the orders Geophilomorpha and Lithobiomorpha, were caught by the traps (Table 2). Like the millipedes they were caught in similar numbers by all the traps, mainly at the limestone locality and by the traps containing ethylene glycol and in the second sample.

Springtails (Collembola) were the most abundant arthropod group. They were slightly more abundant at the limestone locality and caught 3.5 times more frequently by the traps containing ethylene glycol than formaldehyde. Their assemblages were characterized by a high number of species (34 spp. at the basalt bedrock and 38 at the limestone localities, 50 spp. in total). The species composition differed at the limestone and basalt localities. Only 22 species were trapped at both localities. No exclusively subterranean species were recorded in the first sample; however, several of the species are associated with underground habitats: *Arrhopalites caecus*, *Hypogastrura purpurescens*, *Oncopodura reyersdorfensis, Plutomurus carpaticus*, *Protaphorura armata*, *Pseudosinella thibaudi*, *Pygmarrhopalites elegans*, *P. principalis*, and *P. pygmaeus*. In the second sample there was both a greater number individuals and species of springtails. In addition, three well adapted blind species of the genus *Pseudosinella* were recorded. Activity and number of species of springtails (including subterranean forms) was slightly higher at the limestone locality, but diversity indexes were very high and similar for both sites. Simpson´s index of diversity for springtails at the limestone locality was 0.993 and the volcanic locality 0.990. Two eutroglophilous species *Arrhopalites pygmaeus* and *Pseudosinella thibaudi*, and the troglophilous *Folsomia kerni* were the most abundant at the limestone locality. The eurytopic species *Lepidocyrtus lignorum* and *Pseudosinella horaki*, and the eutroglophilous species *Pseudosinella thibaudi* were the most

Table 2. List of species of selected arthropod groups and their distribution in subterranean traps at both sites studied. CV – Cerová vrchovina, DK – Drienčanský kras, ETH – ethylene glycol/water solution, FOR – formaldehyde, I – sampling period 15 May – 26 June 2012, II – sampling period 26 June – 12 October 2012, * troglobiont

| | depth (cm) | | | | | | | | | | orographic unit | | fixation solution | | sampling period | | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| taxon | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | CV | DK | ETH | FOR | I | II | I+II |
| Araneae | | | | | | | | | | | | | | | | | |
| *Apostenus fuscus* Westring, 1851 | 2 | 2 | – | – | – | – | – | – | – | – | 4 | – | 2 | 2 | 2 | 2 | 4 |
| *Hahnia helveola* Simon, 1875 | 1 | – | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 |
| *Palliduphantes alutacius* (Simon, 1884) | 2 | 1 | – | – | – | – | – | – | – | – | 3 | – | – | 3 | 1 | 2 | 3 |
| *Phrurolithus* sp. | 1 | – | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 |
| *Saloca diceros* (Cambridge, 1871) | 1 | 1 | – | – | – | – | – | – | – | – | – | 2 | 1 | 1 | 2 | – | 2 |
| *Zodarion germanicum* (Koch, 1837) | 1 | – | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 |
| species richness | 6 | 3 | – | – | – | – | – | – | – | – | 5 | 1 | 2 | 6 | 3 | 5 | 6 |
| Oniscidea | | | | | | | | | | | | | | | | | |
| *Hyloniscus riparius* (Koch, 1838) | 1 | – | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 |
| *Mesoniscus graniger* (Frivaldszky, 1865) | – | – | – | 1 | – | 1 | 1 | 3 | 3 | 1 | – | 10 | 2 | 8 | – | 10 | 10 |
| *Protracheoniscus politus* (Koch, 1841) | – | – | – | – | – | – | – | – | 1 | – | – | 1 | 1 | – | 1 | – | 1 |
| species richness | 1 | – | – | 1 | – | 1 | 1 | 1 | 2 | 1 | – | 3 | 2 | 2 | 1 | 2 | 3 |
| Diplopoda | | | | | | | | | | | | | | | | | |
| *Archiboreoiulus pallidus* (Brade-Birks, 1920) | – | – | 1 | – | – | – | – | 2 | 3 | 4 | 10 | – | 9 | 1 | 1 | 9 | 10 |
| Julidae gen sp. juv. | – | – | 1 | – | – | 2 | 1 | – | – | – | – | 4 | 1 | 3 | 1 | 3 | 4 |
| *Polydesmus complanatus* (Linnaeus, 1761) | 4 | 1 | 2 | – | – | – | 1 | 1 | 1 | – | 1 | 9 | 9 | 1 | – | 10 | 10 |
| *Polyxenus lagurus* (Linnaeus, 1758) | – | – | 1 | 1 | – | – | – | – | – | 1 | 3 | – | 3 | – | 2 | 1 | 3 |
| *Strongylosoma stigmatosum* (Eichwald, 1830) | – | 1 | – | – | – | – | – | – | – | – | – | 1 | 1 | – | 1 | – | 1 |
| *Unciger foetidus* (C.L.Koch, 1838) | 1 | – | – | – | – | – | – | – | – | – | – | 1 | 1 | – | 1 | – | 1 |
| species richness | 2 | 2 | 4 | 1 | – | 1 | 2 | 2 | 2 | 2 | 3 | 4 | 6 | 3 | 5 | 4 | 6 |
| Chilopoda | | | | | | | | | | | | | | | | | |
| *Geophilus flavus* (De Geer, 1778) | – | – | – | – | – | 1 | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 |
| *Lithobius austriacus* (Verhoeff, 1937) | – | – | – | – | – | – | 1 | – | – | – | – | 1 | 1 | – | – | 1 | 1 |
| *Lithobius burzenlandicus* Verhoeff, 1931 | – | – | – | – | – | – | – | – | 1 | – | – | 1 | 1 | – | – | 1 | 1 |
| *Lithobius forficatus* (Linnaeus, 1758) | 2 | 2 | – | – | – | – | – | – | – | – | 2 | 2 | 1 | 3 | – | 4 | 4 |
| *Lithobius muticus* Koch, 1847 | 3 | – | – | – | – | – | 1 | 1 | – | – | 5 | – | 3 | 2 | 2 | 3 | 5 |
| *Lithobius* sp. | – | 1 | – | – | – | – | – | – | – | – | – | 2 | 1 | 1 | – | 2 | 2 |
| *Strigamia crassipes* (Koch, 1835) | – | – | 1 | – | – | – | – | – | – | 1 | – | 2 | 2 | – | – | 2 | 2 |
| species richness | 2 | 1 | 1 | – | – | 1 | 2 | 1 | 1 | 1 | 2 | 5 | 5 | 3 | 1 | 6 | 6 |
| Collembola | | | | | | | | | | | | | | | | | |
| *Allacma fusca* (Linné, 1758) | 1 | – | – | 1 | 2 | – | 1 | 2 | 2 | 1 | 3 | 7 | 3 | 7 | 9 | 1 | 10 |

Table 2. (continued)

| taxon | depth (cm) 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | orographic unit CV | DK | fixation solution ETH | FOR | sampling period I | II | total I+II |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Anurophorus* sp. | – | – | – | – | – | 2 | 2 | – | – | – | 4 | – | 4 | – | 4 | – | 4 |
| *Arrhopalites caecus* (Tullberg, 1871) | – | 2 | 3 | 7 | 5 | – | 1 | – | 13 | 7 | 1 | 37 | 31 | 7 | 3 | 35 | 38 |
| *Caprainea marginata* (Schöt, 1893) | 1 | 2 | 3 | – | – | – | – | 1 | 1 | – | 1 | 7 | 2 | 6 | 6 | 2 | 8 |
| *Ceratophysella armata* (Nicolet, 1841) | 3 | – | 3 | – | 1 | – | – | – | – | – | 7 | – | 6 | 1 | 4 | 3 | 7 |
| *Ceratophysella engadinensis* (Gisin, 1949) | 2 | – | – | – | – | 1 | – | – | – | – | 3 | – | – | 3 | – | 3 | 3 |
| *Ceratophysella granulata* Stach, 1949 | 14 | – | – | – | – | – | – | – | – | – | 14 | – | 3 | 11 | – | 14 | 14 |
| *Deuteraphorura cebennaria* (Gisin, 1956) | – | – | 3 | – | 1 | – | 1 | – | – | – | 1 | 4 | 4 | 1 | – | 5 | 5 |
| *Deuteraphorura silesiaca* (Dunger, 1977) | 3 | 13 | 18 | 6 | 14 | 2 | 5 | – | 1 | – | – | 62 | 60 | 2 | 2 | 60 | 62 |
| *Dicyrtoma fusca* (Lubbock, 1873) | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 | – | 1 |
| *Dicyrtomina violacea* (Krausbauer, 1898) | – | – | – | – | – | – | – | – | 1 | 1 | – | 2 | 2 | – | 2 | – | 2 |
| Entomobryidae juv. | – | 3 | – | – | 1 | 1 | – | 1 | 1 | – | 5 | 2 | 5 | 2 | 2 | 5 | 7 |
| *Folsomia fimetaria* (Linnaeus, 1758) | – | – | 4 | – | 8 | – | – | – | – | 2 | – | 14 | 14 | – | – | 14 | 14 |
| *Folsomia kerni* Gisin, 1948 | – | 11 | 10 | 101 | 104 | 4 | 34 | 13 | 13 | 1 | | 291 | 278 | 13 | 1 | 290 | 291 |
| *Folsomia manolachei* Bagnall, 1939 | 6 | 10 | 7 | 4 | 3 | 2 | 9 | – | – | – | 22 | 19 | 31 | 10 | 7 | 34 | 41 |
| *Folsomia penicula* Bagnall, 1939 | – | – | 1 | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 |
| *Heteraphorura variotuberculata* (Stach, 1934) | – | 1 | – | – | – | 1 | – | – | – | – | – | 2 | 1 | 1 | – | 2 | 2 |
| *Hypogastrura purpurescens* (Lubbock, 1867) | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 | – | 1 |
| *Isotomiella minor* (Schäffer, 1896) | – | 1 | 1 | 3 | 1 | – | – | – | 2 | 1 | 5 | 4 | 6 | 3 | – | 9 | 9 |
| *Kalaphorura paradoxa* (Schäffer, 1900) | – | – | – | – | – | – | – | 1 | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Lepidocyrtus cyaneus* Tullberg, 1871 | 4 | 1 | – | 1 | – | – | – | – | – | – | 5 | 1 | 5 | 1 | – | 6 | 6 |
| *Lepidocyrtus lignorum* (Fabricius, 1775) | 62 | 77 | 45 | 22 | 12 | 6 | 19 | 24 | 14 | 3 | 220 | 64 | 80 | 204 | 35 | 249 | 284 |
| *Lipothrix lubbocki* (Tullberg, 1872) | – | 1 | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | – | 1 |
| *Megalothorax minimus* Willem, 1900 | – | 2 | 1 | 5 | 1 | – | – | – | – | 1 | 1 | 9 | 2 | 8 | – | 10 | 10 |
| *Oncopodura crassicornis* Shoebotham, 1911 | 2 | 1 | 11 | 13 | 5 | 11 | 10 | 5 | 6 | 1 | 12 | 53 | 43 | 22 | – | 65 | 65 |
| *Oncopodura reyersdorfensis* Stach, 1936 | – | – | – | – | 2 | 1 | – | – | – | – | 1 | 2 | 3 | – | – | 3 | 3 |
| *Orchesella bifasciata* Nicolet, 1842 | 39 | – | – | – | – | – | – | – | – | – | 38 | 1 | 26 | 13 | – | 39 | 39 |
| *Orchesella flavescens* (Bourlet, 1839) | 4 | 1 | – | 1 | – | – | – | – | – | 1 | 3 | 4 | – | 7 | 1 | 6 | 7 |
| *Orchesella multifasciata* Stscherbakow, 1898 | 36 | – | – | – | – | – | – | – | – | – | 36 | – | 12 | 24 | – | 36 | 36 |
| *Parisotoma notabilis* (Schäffer, 1896) | 1 | – | – | 1 | 1 | – | – | – | – | – | 1 | 2 | 2 | 1 | – | 3 | 3 |
| *Plutomurus carpaticus* Rusek et Weiner, 1978 | – | 1 | – | – | – | – | 1 | 1 | – | – | – | 3 | 3 | – | 2 | 1 | 3 |
| *Pogonognathellus flavescens* (Tullberg, 1871) | 6 | 2 | 1 | – | – | – | – | – | 4 | 1 | 3 | 11 | 12 | 2 | 2 | 12 | 14 |
| *Proisotoma* juv. | 1 | – | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | 1 |
| *Protaphorura armata* (Tullberg, 1869) | 1 | 2 | 4 | 3 | – | 2 | – | 4 | 1 | 2 | 13 | 6 | 17 | 2 | 2 | 17 | 19 |
| *Protaphorura aurantiaca* (Ridley, 1880) | – | – | – | – | – | – | – | 1 | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Pseudosinella* cf. *paclti** | – | – | 2 | – | – | – | 2 | – | – | – | – | 4 | 4 | – | – | 4 | 4 |
| *Pseudosinella* sp. 1* | – | – | – | – | – | – | – | – | – | 1 | 11 | 40 | 44 | 7 | 1 | 50 | 51 |

Table 2. (continued)

| taxon | depth (cm) 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | orographic unit CV | DK | fixation solution ETH | FOR | sampling period I | II | total I+II |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pseudosinella* sp. 2* | – | – | – | – | – | – | – | – | – | 1 | – | 1 | 1 | – | – | 1 | 1 |
| *Pseudosinella horaki* Rusek, 1985 | 56 | 34 | 20 | 5 | – | – | 1 | – | – | – | 68 | 48 | 56 | 60 | 4 | 112 | 116 |
| *Pseudosinella thibaudi* Stomp, 1977 | 29 | 75 | 31 | 41 | 17 | 13 | 7 | 7 | 3 | 1 | 104 | 120 | 133 | 91 | 6 | 218 | 224 |
| *Pygmarrhopalites elegans* (Cassagnau et Delamare, 1953) | 7 | 18 | 16 | – | – | 6 | 1 | – | – | | 48 | – | 38 | 10 | – | 48 | 48 |
| *Pygmarrhopalites principalis* (Stach, 1945) | 33 | 9 | 12 | 1 | 2 | 7 | 2 | | 16 | 4 | 61 | 26 | 52 | 35 | 3 | 84 | 87 |
| *Pygmarrhopalites pygmaeus* (Wankel, 1860) | 3 | 38 | 8 | 17 | – | 1 | – | 24 | 70 | 21 | 8 | 174 | 119 | 63 | 9 | 173 | 182 |
| *Sminthurinus elegans* (Fitch, 1863) | 1 | – | – | 1 | – | – | – | – | 1 | – | – | 3 | 2 | 1 | 1 | 2 | 3 |
| *Superodontella* sp. | – | 1 | – | 1 | – | – | – | – | 3 | 1 | 6 | – | 4 | 2 | 1 | 5 | 6 |
| Tomoceridae gen. sp. juv. | – | – | – | – | 1 | – | – | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Vertagopus cinereus* (Nicolet, 1841) | – | – | – | 1 | – | – | – | – | 1 | – | – | 2 | – | 2 | 2 | – | 2 |
| *Vertagopus* sp. | – | – | – | – | – | – | – | – | 2 | – | 2 | – | 2 | | 1 | 1 | 2 |
| *Willowsia nigromacullata* (Lubbock, 1873) | – | – | – | – | – | – | – | 1 | – | – | 1 | – | – | 1 | | 1 | 1 |
| *Xenylla brevisimilis* Stach, 1949 | 1 | – | – | – | – | – | – | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| species richness | 24 | 23 | 21 | 20 | 18 | 15 | 15 | 13 | 21 | 18 | 34 | 38 | 38 | 41 | 31 | 40 | 50 |
| Coleoptera | | | | | | | | | | | | | | | | | |
| *Anotylus mutator* Lohse, 1963 | – | 1 | – | – | – | 1 | – | – | – | – | – | 2 | 1 | 1 | 2 | – | 2 |
| *Anotylus rugosus* (Fabricius, 1775) | 1 | – | – | – | – | – | – | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Anotylus clypeonitens* (Pandellé, 1867) | 4 | 2 | 4 | 5 | 7 | 8 | 3 | 6 | – | – | 1 | 37 | 18 | 20 | 13 | 25 | 38 |
| *Anotylus tetracarinatus* (Block, 1799) | – | – | – | – | 2 | – | – | 1 | – | – | – | 3 | – | 3 | 2 | 1 | 3 |
| *Atheta amicula* (Stephens, 1832) | – | – | 1 | – | – | – | – | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Atheta oblita* (Erichson, 1839) | – | 1 | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 |
| *Atheta pervagata* Benick, 1975 | 1 | 4 | 3 | 1 | – | – | – | – | – | – | 2 | 7 | – | 9 | 2 | 7 | 9 |
| *Atheta sodalis* (Erichson, 1837) | – | – | – | – | – | – | – | 1 | 1 | – | – | 2 | 1 | 1 | 1 | 1 | 2 |
| *Bryaxis nigripennis* (Aubé, 1844) | 2 | – | – | – | – | – | – | – | – | – | – | 2 | 2 | – | – | 2 | 2 |
| *Bryaxis ullrichii* (Motschulsky, 1851) | 5 | – | – | 1 | – | – | – | – | – | – | 6 | – | – | 2 | – | 6 | 6 |
| *Coprophilus striatulus* (Fabricius, 1793) | – | 1 | 2 | – | – | – | – | – | 1 | – | – | 3 | 2 | 1 | 2 | 1 | 3 |
| *Gabrius astutus* (Erichson, 1840) | – | 2 | – | 1 | – | 1 | – | 6 | 4 | – | 1 | 13 | – | 1 | – | 14 | 14 |
| *Liogluta granigera* (Kiesenwetter, 1850) | – | 2 | – | 1 | 1 | – | 1 | 1 | – | 2 | 5 | 4 | 2 | 7 | 9 | – | 9 |
| *Liogluta microptera* Thomson, 1867 | 2 | – | – | – | – | – | – | – | – | – | – | 2 | 2 | – | – | 2 | 2 |
| *Omalium rivulare* (Paykull, 1789) | – | 2 | 1 | – | – | – | – | – | – | – | – | 3 | 3 | – | 3 | – | 3 |
| *Omalium rugatum* Mulsant et Rey, 1880 | – | – | – | – | – | – | 1 | – | 1 | – | – | 2 | 2 | – | 2 | – | 2 |
| *Oxypoda longipes* Mulsant et Rey, 1861 | – | – | – | – | – | – | – | 1 | – | – | 1 | – | – | 1 | 1 | – | 1 |
| *Philonthus decorus* (Gravenhorst, 1802) | 1 | – | – | 1 | – | – | – | – | – | – | – | 2 | – | 2 | 1 | 1 | 2 |
| *Trimium brevicorne* (Reichenbach, 1816) | 1 | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | – | 1 |
| *Abax parallelus* (Duftschmid, 1812) | 1 | – | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 |

Table 2. (continued)

| taxon | depth (cm) 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | orographic unit CV | DK | fixation solution ETH | FOR | sampling period I | II | total I+II |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Duvalius bokori* (Csiki, 1910) | – | – | 1 | – | – | 1 | – | – | – | – | – | – | 1 | 1 | – | 2 | 2 |
| *Barypeithes araneiformis* (Schrank, 1781) | – | – | – | – | 1 | – | – | – | – | – | 1 | – | – | 1 | 1 | – | 1 |
| *Brachysomus echinatus* (Bonsdorff, 1785) | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 | – | 1 |
| *Dienerella elongata* (Curtis, 1830) | 5 | – | 1 | 1 | 1 | – | – | – | 1 | – | 8 | 1 | 7 | 2 | 2 | 7 | 9 |
| *Dienerella filum* (Aubé, 1850) | – | – | – | – | – | – | – | – | 1 | 1 | 1 | 1 | 1 | 1 | 2 | – | 2 |
| *Enicmus brevicornis* (Mannerheim, 1844) | – | – | – | – | – | – | – | 1 | – | – | – | 1 | 1 | – | 1 | – | 1 |
| *Cryptophagus dentatus* (Herbst, 1793) | – | – | – | – | – | 1 | – | – | – | – | 1 | – | 1 | – | 1 | – | 1 |
| *Cryptophagus nitidulus* Miller, 1858 | 2 | – | – | – | – | 1 | 1 | – | 5 | 3 | 12 | – | 10 | 2 | 1 | 11 | 12 |
| *Cryptophagus schmidti* Sturm, 1845 | – | – | – | – | – | – | – | 1 | – | – | 1 | – | 1 | – | – | 1 | 1 |
| *Cryptophagus sporadum* Bruce, 1934 | – | – | – | – | – | – | – | 1 | – | – | 1 | – | – | 1 | 1 | – | 1 |
| *Cryptophagus* spp. | – | – | 2 | – | – | – | – | – | 3 | 1 | 6 | – | 5 | 1 | – | 6 | 6 |
| *Malthinus* sp. | – | – | – | – | – | – | – | – | – | 1 | 1 | – | 1 | – | 1 | – | 1 |
| *Mniophila muscorum wroblewskii* Wankowicz, 1880 | – | – | 1 | – | – | – | – | – | – | – | – | 1 | 1 | – | 1 | – | 1 |
| *Phyllotreta* cf. *undulata* Kutschera, 1860 | – | – | – | – | – | – | – | – | – | 1 | – | 1 | – | 1 | 1 | – | 1 |
| *Phyllotreta* sp. | – | 1 | – | – | – | – | – | – | 1 | 1 | – | 3 | – | 3 | 3 | – | 3 |
| *Meligethes aeneus* (Fabricius, 1775) | – | – | – | – | – | – | 1 | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Agathidium varians varians* (Beck, 1817) | 1 | – | – | – | – | – | – | – | – | – | – | 1 | – | 1 | 1 | – | 1 |
| *Ptinus fur* (Linnaeus, 1758) | – | – | – | – | – | – | – | – | 2 | – | 2 | – | 2 | – | – | 2 | 2 |
| *Acrotrichis danica* Sundt, 1958 | – | – | 1 | – | – | – | – | – | – | – | – | 1 | 1 | – | 1 | – | 1 |
| *Ptenidium intermedium* Wankowicz, 1869 | – | – | – | – | – | – | 1 | – | – | – | – | 1 | – | 1 | – | 1 | 1 |
| *Cercyon analis* (Paykull, 1798) | – | – | – | 1 | – | – | – | – | – | – | – | 1 | 1 | – | 1 | – | 1 |
| *Rhizophagus perforatus* Erichson, 1845 | – | 1 | – | – | – | – | – | – | – | – | – | 1 | 1 | – | – | 1 | 1 |
| species richness | 12 | 10 | 10 | 8 | 5 | 6 | 6 | 9 | 9 | 7 | 16 | 30 | 23 | 27 | 29 | 19 | 40 |

abundant at the volcanic bedrock locality. Two troglobionts of the genus *Pseudosinella*: *Pseudosinella* cf. *paclti* and *Pseudosinella* sp. 2 were recorded at the limestone locality, and another troglobiont *Pseudosinella* sp.1 at both talus sites where it occurred at depths from 25 to 95 cm and was most abundant at the karst talus. *Pseudosinella* cf. *paclti* occurred exclusively at depths of 25 to 65 cm, while *Pseudosinella* sp. 2 was recorded even deeper in the debris (95 cm). Among the springtails, four cold adapted, montane forms were identified with most caught at the limestone locality: *Heteraphorura variotuberculata*, *Kalaphorura paradoxa*, *Plutomurus carpaticus*; *Ceratophysella granulata* was recorded only at the basalt talus (Table 2).

Beetles (Coleoptera) was another abundant group of arthropods. High total richness of species (40 spp.) and families (12) was recorded. The family Staphylinidae predominated (19 spp. and 102 inds., making up 48 and 66% of the beetles caught, respectively). Beetles were recorded at all the depths sampled. The species richness and evenness values recorded for the limestone locality were twice those recorded for the volcanic locality. Simpson's index of diversity recorded for the limestone and volcanic localities were 0.936 and 0.813, respectively. The local assemblages differed greatly, with only six species (15%) common to both the limestone and basalt localities. There was a higher number of specimens but lower number of species in the second sample. None of the beetles caught in the first sample showed a specific vertical distribution. However, the results for the second sample revealed that some species were more frequently caught in either deep or shallow underground habitats. Deep layers in basalt talus were inhabited mainly by members of the family Cryptophagidae, whereas at the limestone talus it was Staphylinidae and the carabid *Duvalius bokori*.

## DISCUSSION

Subterranean habitats in stony debris are poorly studied in Slovakia, with only one pilot study at a limestone locality (Rendoš et al. 2012, 2014). Using similar methods we confirmed there are rich communities in these habitats in two geographic regions with different bedrocks.

In the first sample collected well-adapted subterranean species were rare or absent and the assemblages of invertebrates had a mixed character, with many epigeic or hemiedaphic forms occurring at various depths. Evidently this mixture of invertebrate assemblages was a result of the initial digging of the holes for the tubes with the traps. In order to determine the vertical stratification of underground fauna it is necessary to collect an initial control sample and then another sample at a later date. In the second sample collected roughly three months later some well-adapted (even troglomorphic) springtails and relict millipedes were recorded at deep horizons at both localities. The above method is recommended for similar, especially single-sample studies. Detailed investigations of the seasonal dynamics of underground invertebrates (Rendoš et al. 2012) has revealed that in Central Europe the most successful period for short-term studies is late spring (May–June), but some rare forms may occur in traps at other times of the year. The results using two preservative solutions were complementary, thus this approach is strongly recommended.

In general within the vertical profile, there are two main zones: (a) upper zone (–5 to –25 or –35 cm), where forms adapted to life on the surface of soil predominate and obligate subterranean dwellers occur rarely and individually, and (b) deep zone (from –55 or deeper to –85 or –95 cm) where a high frequency of subterranean forms were recorded. It is possible to distinguish also a transient zone (–35 to –45 or –55 cm), which is characterized by a significant decline or absence of species and individuals of both surface and subterranean dwellers (see millipedes, centipedes and terrestrial isopods in Table 2).

No subterranean or relic species of spiders were recorded, which contrasts with the spider fauna recorded in pseudokarstic caves in the Cerová vrchovina Mts (Papáč et al. 2009, Svatoň et al.

2009). Probably such species prefer more aerated spaces in open debris, which were not included in this study (Růžička 1999, Růžička & Klimeš 2005). No exclusively subterranean representative of centipedes was recorded. Some interesting arthropods with affinities for subterranean habitats were recorded, e.g. the blaniulid millipede *Archiboreoiulus pallidus* at the volcanic locality, the terrestrial isopod *Mesoniscus graniger* and the carabid beetle *Duvalius bokori* at the limestone locality and the staphylinid beetle *Atheta pervagata* at both localities. The blind endogenous millipede *A. pallidus* is common in soil habitats in Western Europe (Blower 1985), but rare in Central Europe, where it usually inhabits caves. It is the first record of this species in Slovakia. As only females were found it is highly probable that it is parthenogenetic in this area. The numerous records of the rove beetle, *A. pervagata,* is remarkable as this species is rare in Slovakia and was recorded for the first time in this area by Jászay & Kodada (1997).

There are high numbers of forms springtails well adapted to subterranean habitats. In total five eutroglophilous, seven troglophilous and three troglobiotic species of Collembola were recorded at both localities. These results substantially increase our knowledge of the subterranean springtail fauna not just locally (Papáč 2011) but also in the whole Western Carpathian region. Among them three eutroglophilous forms (*Pygmarrhopalites pygmaeus*, *Oncopodura reyersdorfensis*, *Pseudosinella thibaudi*), four troglophilous forms (*Arrhopalites caecus*, *Pygmarrhopalites principalis*, *Deuteraphorura cebennaria*, *Protaphorura armata*) and one troglobiont, *Pseudosinella* sp. 1, were identified at both localities, with all most abundant at the limestone locality. Most of these species were recorded throughout the whole vertical profile studied, except for *Ceratophysella granulata* (occurred exclusively at the non-karst locality) and *Plutomurus carpaticus* (exclusively at the karst locality) recorded in upper part of the profile, *Oncopodura reyersdorfensis* recorded in the middle of the profile and *Hypogastrura purpurescens* and *Pseudosinella* sp. 2 occurring in the deepest part of the profile. Both of the last mentioned species were recorded exclusively at the limestone locality. Another two species *Folsomia kerni* and *Kalaphorura paradoxa* are rather rare and recorded only at the karst locality. Similarly, the Carpathian endemic *Plutomurus carpaticus* was also only recorded at the karst locality. *Pygmarrhopalites elegans* was recorded for the first time in Slovakia and exclusively at the basalt locality, where it was abundant at depths of between –15 and –25 cm in the vertical profile. These results support reports that karst/limestone microhabitats at talus sites harbour a high diversity of springtails, including numerous “rare” or endemic species (Nitzu et al. 2011). The conditions at the two talus sites with different bedrocks are favourable for subterranean communities of springtails, but most of the eutroglophilous, troglophilous forms and troglobionts were recorded at the limestone locality.

The present findings of a rather rich and distinct subterranean communities of arthropods at the localities studied provide significant basic knowledge of overlooked subterranean habitats and their fauna and provide important support for the need to protect these localities.


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