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A comparison of collecting methods in relation to the diversity of Collembola in scree habitats

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Abstract

We compared the species composition, relative abundances and life form structure of subterranean Collembola (Hexapoda) captured by two different methods along a depth gradient of five forested scree sites in the Western Carpathians, Slovakia: (1) high-gradient extraction of soil samples, and (2) collection using subterranean traps. Our results showed that the soil samples were more efficient in covering species richness at the majority of the sites. The body size of the captured animals depended remarkably on the sampling method. Extraction was more effective in collecting smaller, less active hemi- and euedaphic forms of Collembola, while collection by subterranean traps favoured both motile ground-dwelling as well as relatively large, active euedaphobionts. Additionally, different trends in the vertical stratification of Collembola life forms and their relative abundances were detected by the two methods. Atmobionts and epigeonts, forming the greater part of the communities in traps compared to soil samples, were distributed along the entire scree profiles, but their relative abundance and species numbers had a strongly decreasing trend with depth. Moreover, motile, large hemi- and euedaphic forms had high relative abundances in traps in the middle and deeper scree levels at three sites. In contrast, in soil samples the hemi- and euedaphobionts with small body size were abundant on the surface of the MSS sites. Thus, soil sampling applied before installation of subterranean traps may serve as an appropriate complementary technique to obtain a more complete pattern of Collembola diversity in forested scree habitats.

Keywords

Body size, high-gradient extraction, life forms, MSS habitats, relative abundance, species richness, subterranean traps, vertical distribution

Introduction

In recent years, increased attention has been paid to arthropods inhabiting a peculiar underground environment, the so-called mesovoid shallow substratum (MSS) (e.g., Jiménez-Valverde et al. 2015; Rendoš et al. 2016, 2020; Nitzu et al. 2018; Ledesma et al. 2020). This aphotic habitat with relatively stable microclimate conditions is considered to be an intermediate zone between the soil surface and deep subterranean realm (e.g., caves, pits), in which both epigean and hypogean animals are represented (Gers 1998; Juberthie 2000; Mammola et al. 2016; Jureková et al. 2021).

Generally, MSS fauna can be collected by active and passive methods (Mammola et al. 2016). Active sampling consists in direct excavation of the MSS substrate followed by hand collecting arthropods using tweezers or aspirators. Conversely, passive techniques, e.g., high-gradient extraction of soil samples, pitfall traps and their modifications, are based on digging a horizontal or vertical hole to a suitable depth and subsequent sample collection or burying the trap inside the hole (e.g., Nitzu et al. 2014, 2018). Many of the latter techniques provide high quantities of Collembola, with pitfall traps being the method most widely employed in studies of this group (e.g., Rendoš et al. 2012, 2016, 2020; Jureková et al. 2019). Hitherto, the majority of ecological and faunistic studies carried out in MSS habitats have used only a single method for community evaluation, preferably pitfall trapping (e.g., Laška et al. 2011; Jimenéz-Valverde et al. 2015; Růžička and Dolanský 2016), and studies targeting a comparison of collection methods for arthropods inhabiting MSS biotopes are very rare (Gers and Cugny 1983). Studies on soil arthropods, carried out in various habitats, have clearly demonstrated that a combination of pitfall traps and extraction of soil samples is the most efficient sampling strategy for evaluating their species composition and diversity (Bitzer et al. 2005; Querner and Bruckner 2010; Tuf 2015; Nsengimana et al. 2017).

However, each of these techniques has its own limitations, which may considerably influence catch efficiency for arthropods due to their specificity for certain target soil taxa or life forms (Yi et al. 2012). Subterranean traps for invertebrates occupying shallow MSS layers were designed by Schlick-Steiner and Steiner (2000). The pitfall trapping technique seems to be useful for the capture of more motile, epigeic arthropods (e.g., Jimenéz-Valverde and Lobo 2005; Lensing et al. 2005; Pacheco and Vasconselos 2012; Siewers et al. 2014; Hohbein and Conway 2018). Basic characteristics and sampling schemes of pitfall trapping, which commonly vary among studies, include trap size, preservative solution, distance between adjacent traps and time of trap exposure (e.g., Adis 1979; Woodcock 2005; Schmidt et al. 2006; Knapp and Růžička 2012; Mammola et al. 2016; Jureková et al. 2019). Moreover, trap efficiency, in terms of species diversity and abundance, is affected by the type of geological bedrock, the season and microclimatic and edaphic parameters (López and Oromí 2010; Mock et al. 2015; Nitzu et al. 2018). The high-gradient extraction of soil samples is efficient for capturing less active and small hemi- and euedaphic species (Querner and Bruckner 2010) and its effectivity does not depend on the invertebrates activity to such an extent, as in the case of traps (Yi et al. 2012; Tuf 2015). Thus, soil sampling is often used as an alternative or complementary method to pitfall traps (e.g., Querner and Bruckner 2010; Querner et al. 2013).

Collembola are among the abundant and diverse groups of soil and subterranean mesofauna inhabiting scree habitats in all climatic zones (e.g., Palacios-Vargas and Wilson 1990; Coulson et al. 1995; Rusek 1998; Trajano and Bichuette 2010; Baquero et al. 2017, 2021; Jordana et al. 2020). We selected Collembola in this study as a model group for comparison of the invertebrate community structure in relation to the sampling method used in an MSS habitat. The extraction of soil samples was applied as a collecting method complementary to subterranean traps and was carried out before the installation of the subterranean pitfall traps.

The combination of both methods aimed at capturing the representative species richness and community structure of Collembola along the vertical gradient at five scree sites. We expected that species richness and abundance of Collembola would differ considerably between these two sampling techniques along the vertical profile at individual screes. We also hypothesized that soil sampling would tend to be more efficient for the collection of less active, soil-specialist species (hemi- and euedaphic), whereas subterranean pitfall trapping would show a reverse trend in favour of the surface-active (atmobiotic and epigeic) forms. The main aim of this study was to compare diversity, relative abundance and life form structure of Collembola between two sampling methods (collection by subterranean traps and high-gradient extraction of the soil samples) along the vertical profile of five scree sites.

Material and methods

Sites description

The current study was conducted at five scree sites on limestone bedrock situated in different geomorphological units of the Western Carpathians, Slovakia (Fig. 1A, B). For more detailed characteristics of the study sites, see also the previous studies (Jureková et al. 2019, 2021):

- **A** – a forested scree slope (48°31.27'N, 20°25.23'E) with cornel-oak wood (association *Corneto-Quercetum acerosum*), mosses and sparse herbal cover near the entrance of Ardovská jaskyňa Cave, Slovenský kras Karst, 317 m a.s.l., SW exposure, slope 20–25°, soil type rendzina. The scree profile: leaf litter and humus (0–15 cm), organo-mineral layer with admixtures of tiny rocks and spaces partially filled with soil and tree roots (15–75 cm), a deeper scree layer formed by larger rocks partially filled with soil and tree roots (75–100 cm).
- **S** – a forested scree slope (48°32.98'N, 20°30.22'E) with horn-beam wood (assoc. *Waldsteinio-Carpinetum*) and dense vegetation cover (*Urtica dioica* Linné, 1753, *Lunaria* sp., and *Galium* sp. dominated) located in the sinkhole near the entrance of Silická ľadnica Ice Cave, Slovenský kras Karst, 455 m a.s.l., W exposure, slope 20°,

soil type rendzina. The scree profile: leaf litter and humus (0–10 cm), organo-mineral layer with a well-developed rhizosphere and spaces mostly filled with soil (10–35 cm), a layer of rock fragments interspersed with tree roots (35–110 cm).

- **B** – a forested scree slope (48°16.23'N, 17°7.37'E) with beech wood (assoc. *Fagetum typicum*), mosses and lacking a vegetation cover in Strmina, Borinský kras Karst (Malé Karpaty Mountains), 410 m a.s.l., SW exposure, slope 14°, soil type rendzina. The scree profile: leaf litter and humus (0–5 cm), organo-mineral layer (5–20 cm), a layer with an aggregation of mineralized soil and rocks (20–75 cm), a scree with spaces partially filled with the soil and tree roots (75–110 cm).
- **ZA** – the lower part of a forested scree slope (gully) at the gorge bottom near the bank of Blatnica Creek (~10 meters) (48°37.76'N, 20°49.81'E), with maple-lime wood (assoc. *Aceri-Tilietum*), mosses and sparse herbal cover in Zádielska tiesňava Valley, Slovenský kras Karst, 400 m a.s.l., E exposure, slope 35°, soil type rendzina. The scree profile: leaf litter and humus (0–15 cm), organo-mineral layer formed by fist-size rocks and dark soft soil with a less-developed rhizosphere (15–45 cm), a scree formed by larger rocks (30–40 cm in diameter) with spaces partially filled with the soil and tree roots (45–100 cm).
- **ZB** – the upper part of a forested scree slope (gully) below a rock cliff (48°37.75'N, 20°49.70'E) with maple-ash wood (assoc. *Aceri-Fraxinetum*) and dense herbal cover in Zádielska tiesňava Valley, Slovenský kras Karst, 470 m a.s.l., E exposure, slope 35°, soil type rendzina. The scree profile: leaf litter and humus (0–5 cm), organo-mineral layer with well-developed rhizosphere and spaces between small stones (10–15 cm in diameter) largely filled with soil (5–40 cm), a layer with aggregations of small stones with spaces between them partially filled with soil and tree roots (40–100 cm).

Design of Collembola sampling

This study included two sampling methods: soil extraction – (SS) and the subterranean pitfall trapping – (ST) (Fig. 1C).

Soil extraction

A total of three replicates of the soil samples were taken from four depth layers of 5, 35, 65 and 95 cm at each site using a soil corer (10 cm in diameter, 5–8 cm in depth, including the leaf litter layer). The three replicate samples were taken from each layer at *ca*. 50 cm distance, the same as the distance between subterranean traps (see below). Altogether, 60 samples were taken by soil sampling (5 scree sites × 4 depth layers × 3 replicates), on a day identical with pitfall traps installation. At sites A and S, the soil samples were collected on 10 and 11 Jun. 2014, at site B on 18 Jun. 2014 and at sites ZA, ZB on 6–7 Jun. 2017. All samples were extracted in a modified high-gradient apparatus (Crossley and Blair 1991) for 7 days. Collembola and other invertebrates were fixed into 75% benzine-alcohol for storage and subsequent identification.

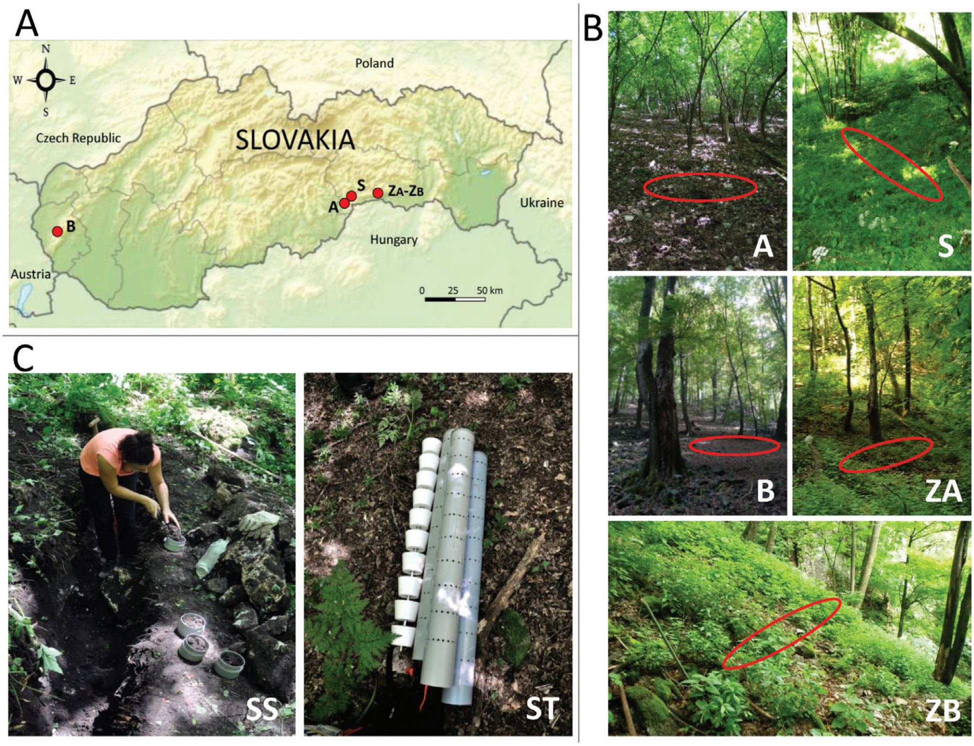

Figure 1. A Location of the study sites **B** red ellipse – site with subterranean traps at a scree slope, Abbreviations: A – site near Ardovská jaskyňa Cave (Photo: N. Raschmanová), S – site near Silická ľadnica Ice Cave (Photo: N. Raschmanová), B – site at Borinský kras Karst (Photo: A. Mock), ZA – site at the base of the scree gully in Zádielska tiesňava Valley (Photo: P. Ľuptáčik), ZB – site at the upper part of the scree gully in Zádielska tiesňava Valley (Photo: P. Ľuptáčik) **C** sampling methods, Abbreviations: SS – soil sampling (Photo: Ľ. Kováč), ST – sampling using subterranean traps (Photo: P. Ľuptáčik).

Subterranean pitfall traps

Three subterranean traps were placed in the scree at each sampling site at a distance of 50 cm from each other. The traps were constructed according to Schlick-Steiner and Steiner (2000) and consisted of PVC pipes (length 110 cm, diameter 10.5 cm) with openings (diameter 0.8 cm) allowing the entry of animals at 10 horizontal levels (5, 15, 25, 35, 45, 55, 65, 75, 85 and 95 cm), and 10 plastic jars (volume 500 ml) connected to each other by 10-cm metal rods, which were inserted into the pipe. At sites A, S and B, two different types of fixative solutions were used: for two traps – a 4% water solution of formaldehyde (FO) and for one trap – a 50% water solution of ethylene glycol (ET). At sites ZA and ZB, propylene glycol was used as the fixation fluid in each trap to allow subsequent DNA analyses of selected arthropod taxa from these sites. Data from the same depths of 5, 35, 65 and 95 cm were evaluated. Altogether, 60 samples were analysed from the subterranean pitfall traps (5 scree sites × 4 depth layers × 3 trap pipes), at sites A, S and B in the sampling period from Apr.–Oct. 2015 and at sites ZA and ZB from May–Oct. 2018. Thus, there was a 10-month interval between installation and the sampling period in order to stabilize the scree profile disrupted by digging the traps. The collected material was poured into plastic bottles, transported to the laboratory and taxonomically analysed.

Identification of Collembola to species level

Collembola specimens from soil samples and subterranean traps were mounted on permanent slides according to Rusek (1975) and identified to the species level using a Leica DM1000 phase-contrast microscope (Leica Microsystems GmbH, Wetzlar, Germany) and multiple taxonomic keys, e.g., Fjellberg (1998, 2007); Pomorski (1998); Bretfeld (1999); Potapov (2001); Thibaud et al. (2004). Juveniles belonging to the families Entomobryidae and Tomoceridae could not be determined at the species level and therefore were not included in the total species number. All Collembola specimens are deposited in the collection of the Department of Zoology, P. J. Šafárik University, Košice, Slovakia.

Community data analysis

Species richness, mean number of specimens (average of the three samples per given depth), and relative abundances (%) were presented as community characteristics to compare Collembola collected by the two different methods.

Spearman correlation analysis was used to test relations between the Collembola species richness of the two sampling techniques, and differences between them were analysed using the Wilcoxon Matched Pairs Test (Statistica for Windows, version 12, TIBCO Software Inc 2013).

Two graphs were used to express the number of species and their relative abundance separately covered by the soil samples, subterranean traps, and both methods.

Theoretical species richness was estimated for each site by diversity estimators from sample-based abundance data. By default, the biased corrected form of Chao1 along with log-linear 95% confidence intervals (CI) is used. For those datasets with a coefficient of variation of the abundance distribution greater than 0.5, the larger from the Chao1 classic and ACE richness estimators is recommended (Chao 1987; Chao et al. 2005; Colwell et al. 2012). Furthermore, the data were analysed using rarefaction procedures that are specifically designed to avoid the potential bias generated by uneven sampling. The estimation of species richness, rarefaction and extrapolation curves were calculated using the EstimateS software (Colwell 2013).

The similarities of Collembola communities with respect to two sampling techniques used were analysed using Non-metric multidimensional scaling (NMS) ordination based on species relative abundance/dominance (D > 10%). Autopilot with slow and thorough mode and Sörensen (Bray-Curtis) distance (recommend for community data) were selected. After randomization runs, a 3-dimensional solution was accepted as optimal. NMS analysis was performed by the PC-ORD 7 package (McCune and Grace 2002; McCune and Mefford 2016).

Vertical distribution of species richness and relative abundances of Collembola life forms across the scree profile were analysed using both collecting methods.

The relation between a species' relative abundance and body length was evaluated in dominant species (D > 10%) (Tischler 1955). For determination of the species body length the maximum body size provided in the various literature sources was considered (e.g., Fjellberg 1998, 2007; Potapov 2001).

Life forms

Based on the experience of the authors and data in the literature (Rusek 2007; Potapov et al. 2016), Collembola species were distinguished into four main life forms (see the individual characteristics in Rusek 2007) according to morphological and ecological adaptations to the soil environment:

- **Atmobionts** – species mostly inhabiting grasses, trunks and branches of trees. These species are large (from 1 to several mm long), pigmented and have very long appendages (furca, antennae and legs). Ocelli are generally present in the full number of 8+8. Four subgroups are recognized based on the microhabitats they occupy: macro- and microphytobionts, xylobionts and neustons.
- **Epigeonts** – species predominantly occurring on the soil surface and in the upper litter layer. These species are of medium and large size (0.2 mm and more), uniformly dark pigmented, in most cases with 5+5 to 8+8 eyes. Limbs, antennae and furca are less developed than in atmobionts species.
- **Hemiedaphobionts** – species occurring in the uppermost soil horizons (leaf litter and upper layers of the humus horizon). These forms are 1–2 mm long with dark pigmentation, sometimes with small pigment grains. Antennae and legs are not very long, and the furca is well developed or reduced (sometimes completely missing). Eyes are present, but their number is usually reduced. Two subgroups are recognized: upper and lower hemiedaphobionts.
- **Euedaphobionts** – species inhabiting diverse soil or subsoil horizons, from the soil surface to deep mineral layers and caves. They have well developed morphological adaptations to life in the soil. These species tend to have an elongated, soft body of small (0.25–0.7 mm), medium (0.7–1.2 mm) and large size, without pigmentation. The furca in some cases is strongly developed, otherwise reduced or completely absent; ocelli are usually present in a reduced number or completely absent. Six subgroups are recognized based on size and furca development: large, medium or small size, either with a furca present or a furca reduced or completely missing.

Results

Diversity and relative abundance

The mean number of Collembola specimens collected by both methods at five scree sites was 3,818 (987 from soil samples and 2831 from subterranean traps), comprising totally 100 species, 79 collected from soil samples and 68 from subterranean traps (Table 1, Appendices 1–5).

Species richness and relative abundances of Collembola at the sites varied with respect to the sampling technique (Table 1, Appendices 1–5). With the exception of site ZA, a higher number of species was detected by soil samples compared to subterranean traps. In contrast, at all scree sites considerably higher relative abundances of species were recorded by subterranean traps than by soil samples.

Collembola species richness at the sites showed a non-significant Spearman correlation between the two sampling techniques ($r = 0.36$, $P > 0.05$, $N = 20$). Similarly, a high but non significant correlation, was observed for species richness at separate depths ($n = 5$): 5 cm ($r = 0.72$, $P > 0.05$), 35 cm ($r = -0.30$, $P > 0.05$), 65 cm ($r = 0.20$, $P > 0.05$) and 95 cm ($r = -0.20$, $P > 0.05$), although at a depth of 5 cm the correlation was strongly positive. The Wilcoxon Matched Pairs Test revealed non-significant differences in species richness detected by the two different sampling techniques ($Z = 1.40$, $P > 0.05$, $N = 20$).

Overall, about half of the species was shared by both sampling techniques, while 32% were found exclusively in soil samples and 21% in subterranean traps (Fig. 2). Graph illustrate the percentage share of species richness in the soil samples, subterranean traps, and the combination of both methods at the sites (Fig. 2A). Contrary to sites A and S, a higher proportion of species richness was observed shared by both methods compared to soil extraction and traps separately at sites B, ZA and ZB. Overall, a much larger number of species was captured by the extraction method, with the exception of sites S and ZA. Figure 2B demonstrates the significantly higher proportion of abundance shared by both methods at each study site compared to traps and soil samples, separately. With the exception of site B, significantly higher relative abundance was captured by the subterranean trap method compared with the soil samples.

The rarefaction curves plotting the number of individuals against the number of species for individual sites did not approach a horizontal asymptote (Fig. 3), indicat-

Table 1. Number of species – S and relative abundance – D (%) of Collembola at scree slopes using two different sampling methods.

Site	SS		ST		Total	
	S	D	S	D	S	D
A	36	5.5	28	8.1	50	13.6
S	36	6.3	35	10.7	53	17.0
B	25	6.2	21	6.5	33	12.7
ZA	32	3.4	36	36.4	43	39.8
ZB	31	4.5	25	12.3	38	16.8
Total	**79**	**25.9**	**68**	**74.1**	**100**	**100**

SS – soil samples, ST – subterranean traps (for site abbreviations see the "Material and method" section).

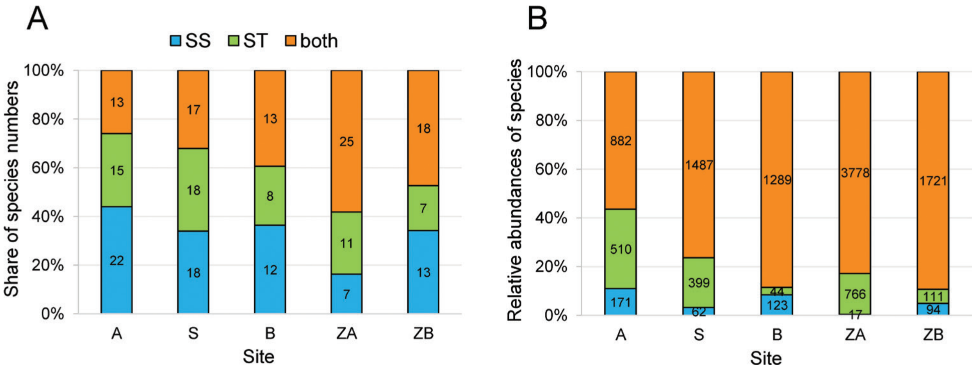

Figure 2. Percentage share of Collembola species numbers and dominance recorded by two techniques at five study sites **A** species numbers (in columns) associated with the sampling method **B** relative abundance of species (numbers in columns indicate number of specimens), Abbreviations: SS – exclusively in soil samples, ST – exclusively in subterranean traps, both–shared by both methods (for site abbreviations, see the "Material and methods" section).

ing that during the study total species richness was underestimated in all cases. To get a more precise picture, species richness estimators (ACE for site ZA for soil samples, Chao1 for the rest) were generated for each site (Table 2). The greatest difference between the observed and estimated richness was at site A in the subterranean traps: 28 (CI: 18.7–37.3) and 83 (CI: 45.5–200.2) species, respectively; thus, only 33.8% of the estimated species richness was recorded in this case. Similarly, only about 45% of species were recorded at site ZB in soil samples. Surprisingly, a slight difference was observed between both parameters at sites B and ZA, both for subterranean traps, with 98% and 97% of the estimated species richness, respectively.

Collembola life form structure, vertical distribution and body size

An NMS ordination diagram (Fig. 4) shows Collembola life forms at the sites and the collection method used. A three-dimensional solution was recommended by Autopilot and confirmed by the Monte Carlo permutation test, with a significance of $P = 0.004$ and a mean stress of 5.31 for real data and 250 runs for both real and randomised data. The best three-dimensional solution had a final stress of 4.08, $P < 0.00001$, after 78 iterations. Only species with a total dominance (relative abundance) greater than 10% are indicated in the diagram regarding three principal life forms. The diagram separated species into two well-defined clusters with the respect to the sampling method. The first cluster represented species collected by the pitfall traps. Epigeic *Lepidocyrtus serbicus* and euedaphic *Deuteraphorura insubraria* were associated with site A, hemiedaphic *Pseudosinella thibaudi* with site B, while euedaphic species *Heteromurus nitidus* dominated at both sites A and B. Euedaphic species *Folsomia kerni*, *Kalaphorura carpenteri* and *Oncopodura crassicornis* were associated with site S. Hemiedaphic *Ceratophysella granulata* and euedaphic *Pygmarrhopalites pygmaeus* were characteristic species at site ZA, while hemiedaphic *Pygmarrhopalites principalis* at ZB. Epigeic *Lepidocyrtus lignorum*, *Plutomurus carpaticus* and

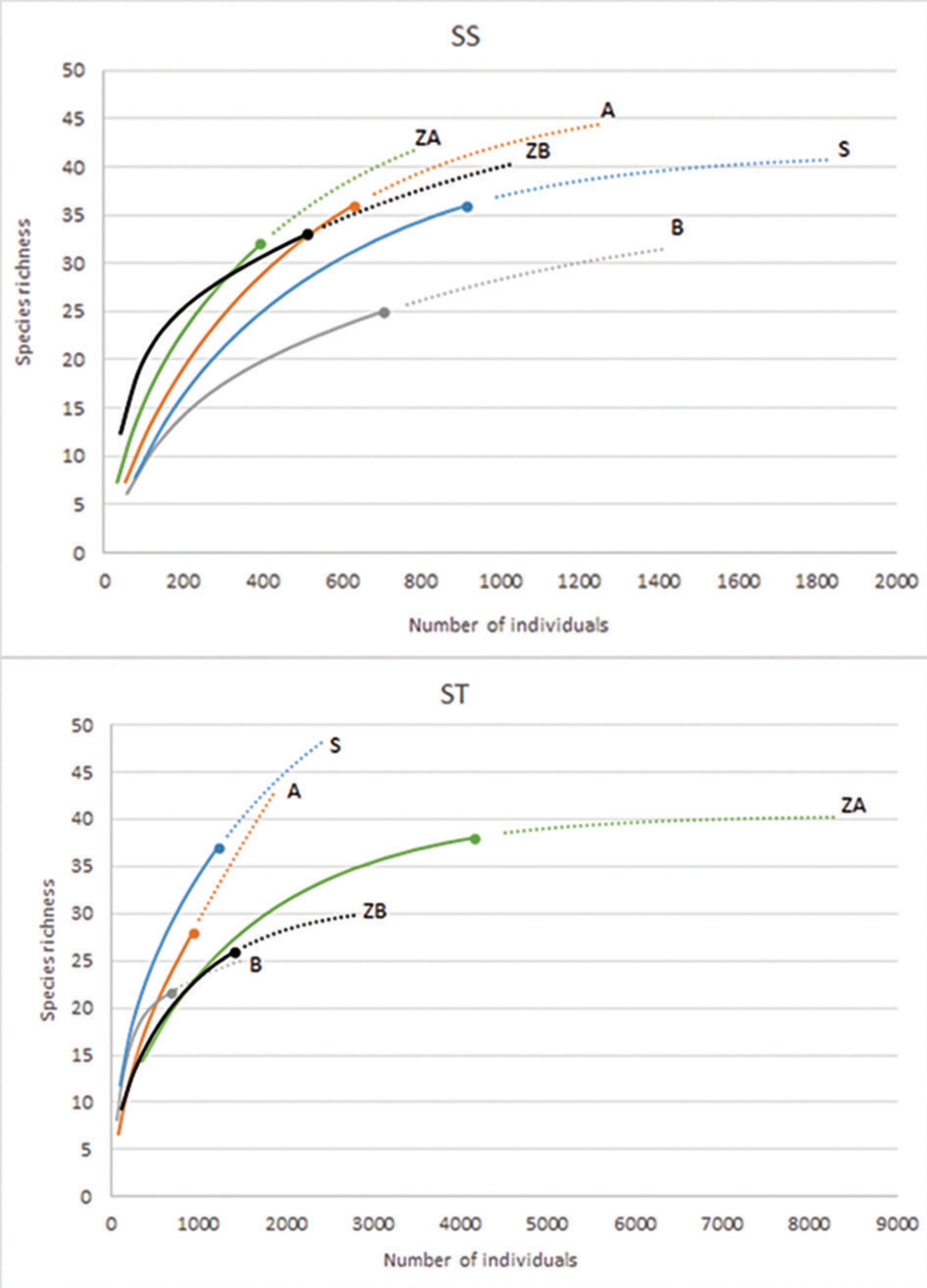

Figure 3. Rarefaction (solid line) and extrapolation (dotted line) of soil collembolan species richness from soil samples (SS) and sampling using subterranean traps (ST). Reference samples are indicated by solid circles, (for site abbreviations, see the "Material and methods" section).

Table 2. Species richness and richness estimator of Collembolla at five study sites and two sampling methods.

Site	A		B		S		ZA		ZB	
Sampling method	SS	ST	SS	ST	SS	ST	SS	ST	SS	ST
Species richness S	36	28	25	22	36	37	32	38	33	26
CI for S (Lower Bound)	30.2	18.7	19.5	17.4	31.7	29.6	25.5	35.0	26.7	22.0
CI for S (Upper Bound)	41.8	37.3	30.5	26.6	40.3	44.4	38.6	41.0	39.3	30.0
Chao1 / *ACE	40	83	33	22	40	42	44*	39	73	29
CI for Chao1 (Lower Bound)	36.9	45.5	26.6	22.0	36.8	38.1	-	38.1	39.3	26.4
CI for Chao1(Upper Bound)	54.0	200.2	67.4	28.0	58.3	60.4	-	48.7	293.6	43.0
% of total S	89.8	33.8	75.4	98.5	89.6	87.8	-	97.4	44.9	91.2

SS – soil samples, ST – subterranean traps, S – species richness, Chao1–richness estimator for individual-based abundance data, *ACE – abundance coverage-based estrimator of species richness, CI–95% confidence intervals with lower and upper bounds, (for site abbreviations see the "Material and method" section).

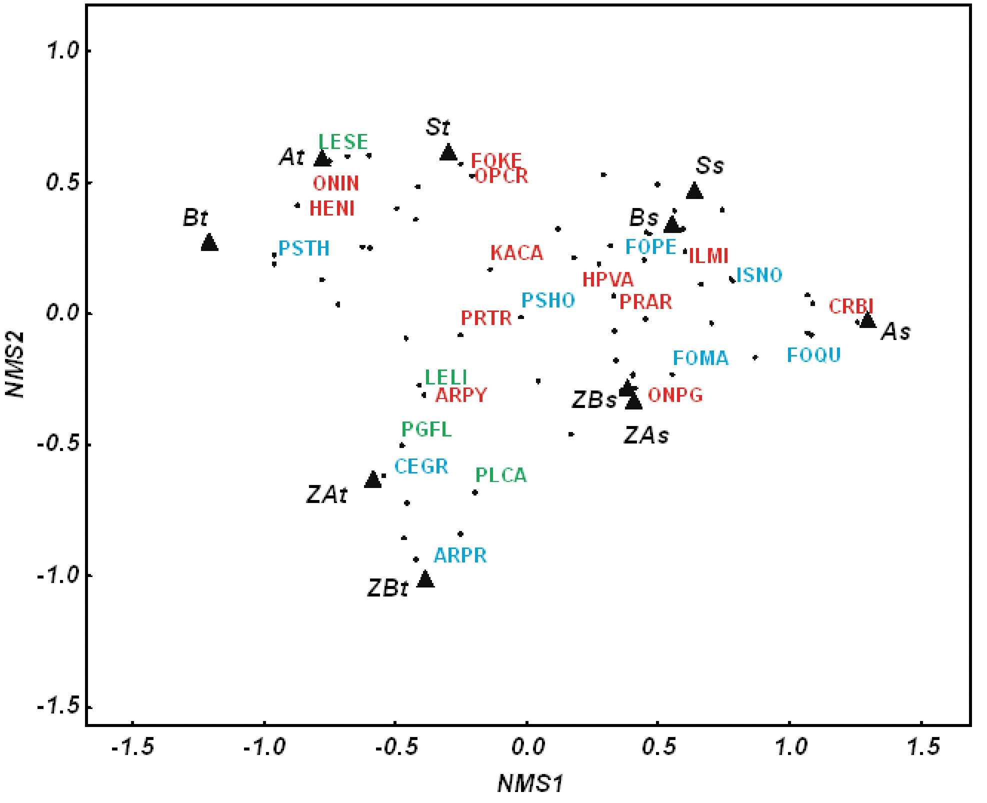

Figure 4. NMS ordination diagram of collembolan communities at five scree sites collected by two sampling methods; the variance explained by the *x* and *y* axes is 55% and 20%, respectively, Abbreviations: s – soil samples, t – subterranean traps, life forms: green – epigeonts, blue – hemiedaphobionts, red – euedaphobionts, (for site abbreviations, see the "Material and methods" section, for species abbreviations see the Appendices 1–5).

Pogonognathellus flavescens were characteristic species for the both sites ZA and ZB. The second cluster represented species extracted from the soil samples. Hemiedaphic *Pseudosinella horaki* was closely associated with site S, while hemiedaphic *Folsomia penicula* and euedaphic *Isotomiella minor* and *Protaphorura armata* were abundant at sites S and B. Hemiedaphic *Folsomia quadrioculata* and *Parisotoma notabilis* and euedaphic *Proisotomodes bipunctatus* were associated with site A. Hemiedaphic *Folsomia manolachei* and euedaphic *Onychiuroides pseudogranulosus* were characteristic for nearby sites ZA and ZB.

Vertical distribution of Collembola life forms along the scree slope profiles differed remarkably between the two methods (Fig. 5). In subterranean traps considerably higher species richness and relative abundances of atmobiotic and epigeic forms were captured at all sites compared to those extracted from the soil samples. Although some atmobiotic and epigeic species were also captured in subterranean traps deeper in the scree profile, their relative abundances were very low. These forms showed decreasing patterns of both community parameters with increasing depth. Moreover, a considerably high share of the relatively large hemi- and euedaphic species, such as *Ceratophysella granulata*, *Heteromurus nitidus*, *Pygmarrhopalites principalis* and *P. pygmaeus*, were recorded by traps in the middle and especially deeper scree layers at sites A, S and ZA. In soil samples, a higher abundance of hemi- and euedaphic forms was recorded compared to traps, showing a decreasing trend in abundance towards the scree depth. High species richness and relative abundance of small, less active hemi- and euedaphic forms, such as *Folsomia manolachei*, *Isotomiella minor* and *Parisotoma notabilis*, were recorded in the surface scree layer (soil) commonly at each site.

The relationship between species relative abundance and body length in the dominant collembolan species showed different trends regarding the two sampling methods (Fig. 6). In soil samples the abundance of Collembola had a decreasing trend with increasing body length. Small species, such as *Proisotomodes bipunctatus*, *Folsomia manolachei*, *F. quadrioculata*, *Isotomiella minor* and *Parisotoma notabilis*, were predominantly collected by this technique, with the exception of the large *Protaphrura armata*. In contrast, the abundance of species collected with subterranean traps had an increasing trend with larger body size. Medium and large species, e.g., *Heteromurus nitidus*, *Lepidocyrtus lignorum*, *L. serbicus*, *Plutomurus carpaticus*, *Pogonognathellus flavescens* and *Pygmarrhopalites pygmaeus*, were collected more frequently by traps; the only exception was the small species *Oncopodura crassicornis*.

Discussion

Comparison of species diversity and relative abundance between sampling methods

In a given habitat, a combination of several collecting methods is required to obtain a reliable picture of such a diverse arthropod group as Collembola (e.g., Prasifka et al. 2007; Querner and Bruckner 2010). This study is the first attempt to assess the

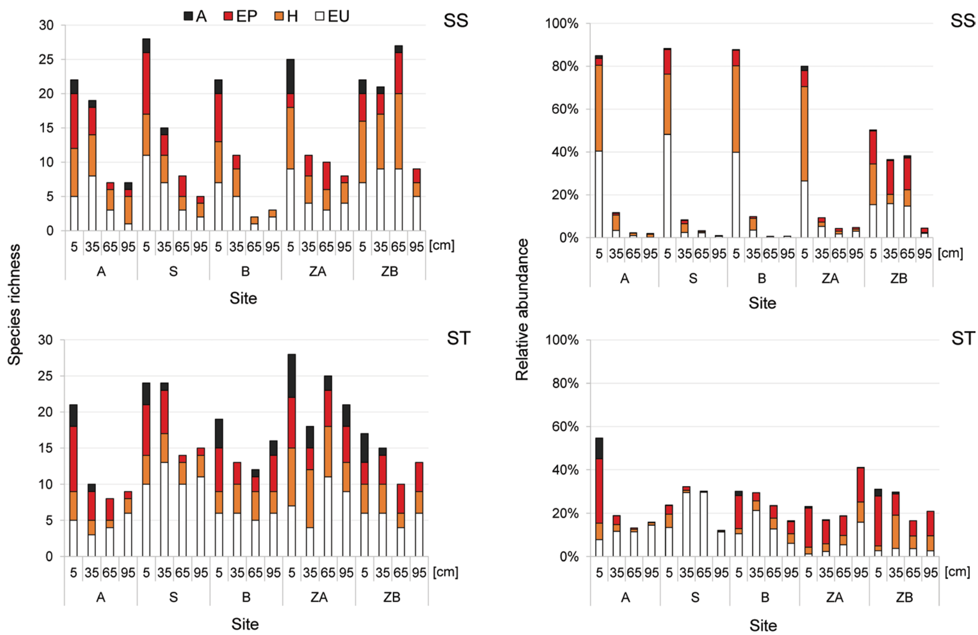

Figure 5. Vertical distribution of species richness and relative abundances of Collembola life forms along scree profiles recorded by two different methods, Abbreviations: SS – soil samples, ST – subterranean traps, 5, 35, 65, 95 – soil/scree depth [cm], A – atmobionts, EP – epigeonts, H – hemiedaphobionts, EU – euedaphobionts, (for site abbreviations, see the "Material and methods" section).

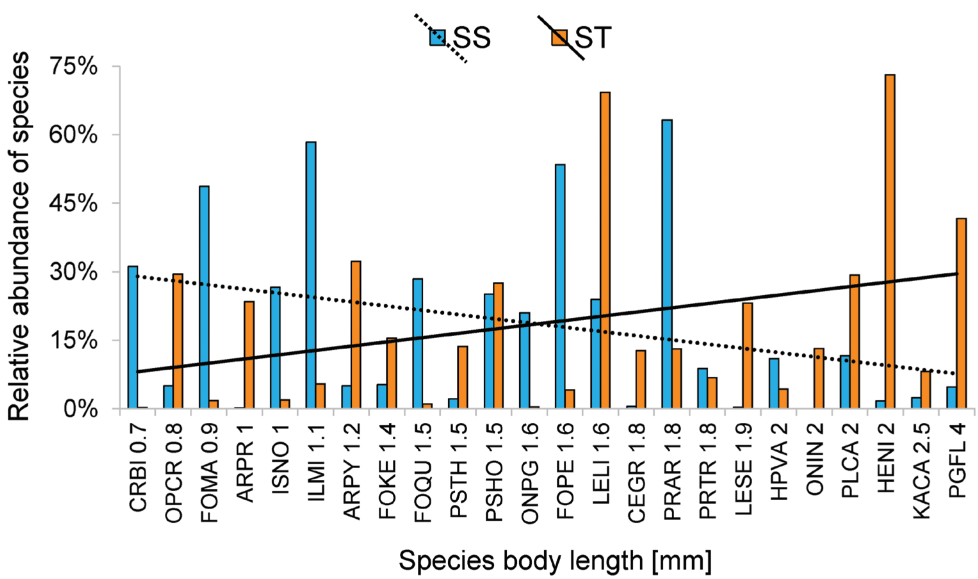

Figure 6. Relationship between the relative abundance and the body length of dominant species for each collecting method (axis 1–species rank follows increasing body size), Abbreviations: SS – soil samples with dotted trend line, ST – subterranean traps with solid trend line (for species abbreviations, see the Appendices 1–5).

efficiency of recently popularized subterranean traps for invertebrate fauna occupying colluvial MSS biotopes with respect to the species richness of different life forms. Our results demonstrated that soil samples were more efficient for covering species richness at most MSS sites, whereas subterranean traps working during 6–7 months captured a substantial portion of the quantity, which is clearly the result of the long exposure time of these traps in this study. The soil extraction method thus appears to be a suitable complementary sampling method in addition to subterranean pitfall trapping, as already stated by other authors surveying soil Collembola in different habitats (Querner and Bruckner 2010; Querner et al. 2013; Nsengimana et al. 2017).

Species richness estimators and rarefaction curves are both traditionally used for comparing and assessing species diversity from sample units per site (e.g., Buddle et al. 2004; Querner and Bruckner 2010; Raschmanová et al. 2018). The rarefaction curves calculated from our data did not reach an asymptote at all sites and both methods, indicating that the species inventory was incomplete. Moreover, there was no obvious pattern in the obtained and estimated species diversity between sites and methods, which is probably associated with the low number of samples involved in these analyses. This result suggests that complementary sampling methods should be used and/or a greater number of traps should be installed to obtain a more complete picture of the community inhabiting MSS habitats.

Life form structure, vertical distribution and body size

Our study showed that the collecting method determines the captured species composition of the community. For example, small-sized euedaphic *Proisotomodes bipunctatus*, occupying a thermophilous talus habitat covered by mosses and tree vegetation near the Ardovská jaskyňa Cave, had only a random occurrence in subterranean traps. However, it was recorded as the most abundant species in the soil samples, preferably occupying upper scree layers that are consistent with its habitat requirements (Potapov 2001). Similarly, the medium-sized hemi- and euedaphic species *Folsomia quadrioculata*, *Isotomiella minor* and *Parisotoma notabilis* were abundant in the soil of the uppermost horizon at nearby sites A and S in the Slovenský kras Karst. These eurytopic species dwell in various types of habitats, such as pastures, meadows, thermophilous and also mountain forests (Potapov 2001; Fjellberg 2007; Raschmanová et al. 2016, 2018).

As already noted by some authors (e.g., Ivanov and Keiper 2009; Carneiro et al. 2016; Sommaggio et al. 2018), pitfall trapping usually overestimates large and motile species, and thus it does not provide an objective community pattern of ground-dwelling invertebrates. Our data pointed out that subterranean traps were effective in collecting not only surface-active (atmobiotic and epigeic) species, e.g., *Lepidocyrtus lignorum*, *L. serbicus*, *Plutomurus carpaticus* and *Pogonognathellus flavescens*, commonly documented as abundant species in traps from other MSS biotopes of the Carpathians Mts (e.g., Nitzu et al. 2014, 2018; Jureková et al. 2019), but this technique also covered larger and motile hemi- and euedaphic life forms. For instance, the large euedaphic *Heteromurus nitidus* with complete furca showed markedly high activity exclusively in pitfall traps along the entire scree profile at nearby sites A and S in the Slovenský kras Karst, and similarly considerably numerous in traps at site B in the Borinský kras Karst. However, this species was only incidental in the soil samples. In Central Europe, *H. nitidus* inhabits the soils of thermophilous forests and relatively warm caves rich in organic materials (Kováč et al. 2016). Likewise, the active euedaphobiont *Deuteraphorura insubraria*, that was exclusively collected by subterranean traps at thermophilous forest scree site A, is also known from beech forests with limestone outcrops at high elevations (Salmon et al. 2010).

It is obvious that the number of collembolan species inhabiting the interiors of forested screes and their activity decline with increasing depth and decreasing organic carbon content (e.g., Gers 1998; Pipan et al. 2010; Rendoš et al. 2016). In the present study, different trends in vertical stratification of Collembola life forms and their relative abundances were documented between both methods. Atmobiotic and epigeic species, forming greater part of the communities in pitfall traps compared to soil samples, were distributed along the entire scree profiles, but their abundance and species numbers had a rather strongly decreasing trend with depth.

High-gradient extraction of soil samples evidently supported species with small body size, whereas pitfall trapping advanced species with greater body size. Similarly, Querner and Bruckner (2010) compared the combination of soil sampling and pitfall trapping to collect collembolan assemblages in agricultural fields, with large surface-active forms as well as motile and large euedaphic species, e.g., *Heteromurus nitidus*, mostly caught by traps. Although *Protaphorura armata* is large and occupies deeper soil layers, it was abundant using soil sample extraction, which is in accordance with Querner et al. (2013). Thus, these two collection methods differ substantially in efficiency with respect to the body size and life forms of Collembola.

It was found that some obligate cave collembolans may occupy the deeper MSS layers, such as the small *Neelus koseli* (Rendoš et al. 2016, 2020), which in our study was captured exclusively by pitfall traps from the moist deeper layers of the upper site of the scree gully (ZB) in Zádielska tiesňava Valley, Slovenský kras Karst. In general, obligate cave invertebrates are captured by soil samples only very rarely (Raschmanová et al. 2018).

Finally, we must keep in mind that the 6–7-months timespan of pitfall trapping on one hand, and the simple collection of a soil sample at a given date on the other are difficult to compare in terms of vertical distribution of soil-scree Collembola. Moreover, there was almost a one year lag between soil samples collection and start of Collembola collection by subterranean traps.

Factors affecting catch efficiency of sampling methods

The efficiency of soil sample extraction does not depend primarily on the fauna activity; therefore, this collecting method provides a relatively objective pattern of the actual spatial distribution of invertebrates in the soil profile at a given time (Yi et al. 2012; Tuf 2015). In contrast, comparing species inventories carried out by pitfall traps in different habitats is difficult, because capture efficiency is biased in many ways, i.e., sampling interval, degree of activity of individual taxa and their behavioural reaction to the conservation fluid (e.g., Woodcock 2005; Querner and Bruckner 2010; Knapp and Ružička 2012; Carneiro et al. 2016; Hohbein and Conway 2018). Furthermore, the vertical stratification of Collembola assemblages in the soil/scree may be markedly influenced by the microclimate across its depth profile (e.g., Hopkin 1997; Cassagne et al. 2003; Nitzu et al. 2014; Jureková et al. 2021). Regarding colluvial MSS, soil Collembola usually migrate to deeper scree levels with higher and more stable moisture during warm and dry periods (e.g., Nitzu et al. 2014; Mammola et al. 2017; Mammola 2019), which may elucidate great quantities of hemi- and euedaphic forms in pitfall traps at some sites.

Conclusion

In conclusion, the species richness, relative abundance, life form structure and body size of Collembola differed between the two sampling techniques used in this study. As we expected, extraction of soil samples was more effective in collecting smaller, less active hemi- and euedaphic forms of Collembola, while subterranean traps captured both epigeic as well as relatively large, active euedaphic species in considerable numbers. High-gradient extraction of soil samples preferentially caught species with a small body size, whereas pitfall trapping was more effective for species with a greater body size. The present study showed that the extraction of soil samples collected before the installation of pitfall traps during faunal surveys of MSS may serve as an appropriate complementary sampling method to obtain a more realistic pattern of Collembola diversity and community structure in these superficial subterranean habitats.

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Appendix 1

Table A1. List of Collembola species with mean number of specimens and their life forms recorded by two sampling methods at the depths 5, 35, 65 and 95 cm at scree site A near the Ardovská jaskyňa Cave (Slovenský kras Karst).

Code	Species	Lf	Soil samples					Subterranean traps				
			5	35	65	95	$N_{(SS)}$	5	35	65	95	$N_{(ST)}$
ARCA	*Arrhopalites caecus* (Tullberg, 1871)	EU L	-	-	0.3	-	0.3	-	-	-	-	-
CAMA	*Caprainea marginata* (Schött, 1893)	EP	-	-	-	0.3	0.3	-	-	-	-	-
CEBE	*Ceratophysella bengtssoni* (Agren, 1904)	H u	0.7	1.3	-	-	2	-	0.3	-	-	0.3
CEDE	*Ceratophysella denticulata* (Bagnall, 1941)	EP	0.7	0.3	-	-	1	-	-	-	-	-
CELU	*Ceratophysella luteospina* Stach, 1920	EP	-	-	-	-	-	0.3	-	-	-	0.3
CESL	*Ceratophysella silvatica* (Rusek, 1964)	EP	1.7	-	-	-	1.7	-	-	-	-	-
DR	*Desoria* sp. juv.	EP	-	0.7	-	-	0.7	-	-	-	-	-
DRTI	*Desoria tigrina* Nicolet, 1842	EP	-	-	-	-	-	0.3	-	-	-	0.3
ONIN	*Deuteraphorura insubraria* (Gisin, 1952)	EU M	-	-	-	-	-	12.3	1.3	12.3	15	41
DOXE	*Doutnacia xerophila* Rusek, 1974	EU S	1	-	-	-	1	-	-	-	-	-
ENMA	*Entomobrya marginata* (Tullberg, 1871)	A mi	0.3	-	-	-	0.3	3	0.3	-	-	3.3
EN	Entomobryidae juv.	H u	-	0.7	0.7	0.3	1.7	-	-	-	-	-
FOCA	*Folsomia candida* Willem, 1902	EU L f	-	-	-	-	-	-	-	1	-	1
FOFI	*Folsomia fimetaria* (Linnaeus, 1758)	EU L f	-	-	-	-	-	0.3	0.7	-	15.7	16.7
FOKE	*Folsomia kerni* Gisin, 1948	EU L f	-	-	-	-	-	-	-	19.3	6.7	26
FOMA	*Folsomia manolachei* Bagnall, 1939	H l	7.7	10.3	1.3	1.3	20.7	-	-	-	-	-
FOQU	*Folsomia quadrioculata* (Tullberg, 1871)	H l	48.7	-	-	-	48.7	1.3	-	-	-	1.3
HENI	*Heteromurus nitidus* (Templeton, 1835)	EU L f	-	-	-	-	-	9	33.3	2	6	50.3
ILMI	*Isotomiella minor* (Schäffer, 1896)	EU M f	20	0.7	-	-	20.7	-	-	-	-	-
LE	*Lepidocyrtus* cf. *cyaneus* Tullberg, 1871	EP	-	-	-	-	-	2.7	-	-	-	2.7
LECY	*Lepidocyrtus cyaneus* Tullberg, 1871	EP	-	-	-	-	-	-	-	0.3	-	0.3
LELI	*Lepidocyrtus lignorum* (Fabricius, 1775)	EP	0.3	-	-	-	0.3	3.0	3	0.7	0.7	7.3
LESE	*Lepidocyrtus serbicus* Denis, 1936	EP	0.7	-	-	-	0.7	63	8.3	0.7	-	72
LEVI	*Lepidocyrtus violaceus* (Lubbock, 1873)	EP	-	-	-	-	-	0.3	-	-	-	0.3
LILU	*Lipothrix lubbocki* (Tullberg, 1872)	EP	-	0.3	-	-	0.3	-	-	-	-	-

Code	Species	Lf	Soil samples					Subterranean traps				
			5	35	65	95	$N_{(SS)}$	5	35	65	95	$N_{(ST)}$
MGMI	*Megalothorax minimus* Willem, 1900	EU S f	0.3	-	-	-	0.3	-	-	-	-	-
MSFL	*Mesaphorura florae* Simón, Ruiz, Martin & Luciañéz, 1994	EU S	-	0.7	-	-	0.7	-	-	-	-	-
MSJI	*Mesaphorura jirii* Rusek, 1982	EU S	-	0.3	-	0.3	0.7	-	-	-	-	-
MISE	*Micranurida sensillata* (Gisin, 1953)	H l	0.3	-	-	-	0.3	-	-	-	-	-
MRDU	*Microgastrura duodecimoculata* Stach, 1922	H u	-	0.3	-	0.3	0.7	-	-	-	-	-
NP	*Neonaphorura* cf. *adulta* Bagnall, 1935	EU S	-	0.7	0.7	-	1.3	-	-	-	-	-
ONPG	*Onychiuroides pseudogranulosus* (Gisin, 1951)	EU L	0.3	0.3	-	-	0.7	-	-	-	-	-
ORBI	*Orchesella bifasciata* (Bourlet, 1839)	A mi	2.3	-	-	-	2.3	16.3	-	-	-	16.3
ORFL	*Orchesella flavescens* (Bourlet, 1839)	A mi	-	-	-	-	-	9.7	-	-	-	9.7
ISNO	*Parisotoma notabilis* (Schäffer, 1896)	H u	22	1.3	0.3	1	24.7	0.3	-	-	-	0.3
PGFL	*Pogonogathellus flavescens* (Tullberg, 1871)	EP	-	-	-	-	-	18.7	0.7	-	-	19.3
PO	*Proisotoma* sp. juv.	H u	-	-	-	-	-	-	-	-	0.3	0.3
CRBI	*Proisotomodes bipunctatus* (Axelson, 1903)	EU S f	62.3	0.3	1	-	63.7	0.3	-	-	-	0.3
PRAR	*Protaphorura armata* (Tullberg, 1869)	EU L	-	0.7	-	-	0.7	1.7	-	-	-	1.7
PRAU	*Protaphorura aurantiaca* (Ridley, 1880)	EU L	-	3.3	-	-	3.3	-	-	-	0.3	0.3
PRSG	*Protaphorura subuliginata* (Gisin, 1956)	EU L	-	-	-	-	-	-	-	-	0.3	0.3
PCPA	*Pseudachorutes parvulus* Börner, 1901	EP	1.3	-	-	-	1.3	-	-	-	-	-
PSHO	*Pseudosinella horaki* Rusek, 1985	H u	4	1	-	-	5	20	9	3.7	3.0	35.7
PSTH	*Pseudosinella thibaudi* Stomp, 1977	H l	-	-	-	-	-	1.3	-	-	-	1.3
PULO	*Pumilinura loksai* (Dunger, 1973)	A x	-	0.7	-	-	0.7	-	-	-	-	-
SNBI	*Sminthurinus bimaculatus* Axelson, 1902	EP	0.7	-	-	-	0.7	0.3	-	-	-	0.3
SN	*Sminthurinus* sp. juv.	EP	-	-	0.3	-	0.3	-	-	-	-	-
SPPU	*Sphaeridia pumilis* (Krausbauer, 1898)	EP	1	-	-	-	1	-	-	-	-	-
OD	*Superodontella* cf. *pseudolamellifera* (Stach, 1949)	H u	0.3	-	-	-	0.3	-	-	-	-	-
TOVU	*Tomocerus vulgaris* (Tullberg, 1871)	EP	0.3	0.3	-	-	0.7	1.3	0.3	-	-	1.7
WIBU	*Willowsia buski* (Lubbock, 1870)	A mi	-	-	-	0.3	0.3	-	-	-	-	-
	N_{tot}		**177**	**24.3**	**4.7**	**4**	**210**	**165.7**	**57.3**	**40**	**48**	**311**
	S_{tot}		**22**	**19**	**7**	**7**	**36**	**21**	**10**	**8**	**9**	**28**

N_{tot} – total number of specimens, S_{tot} – total species richness, $N_{(SS)}$ – mean number of specimens collected by soil samples, $N_{(ST)}$ – mean number of specimens collected by subterranean pitfall traps, Lf – life form, A – atmobiotic, mi – microphytobiont, x – xylobiont, EP – epedaphic, H – hemiedaphic, u – upper, l – lower, EU – euedaphic, L – large, M – medium, S – small, f – presence of furca, 5, 35, 65, 95 – soil/scree depth [cm], “sp. juv.” – uncertain relationship to the soil/subterranean environment.

Appendix 2

Table A2. List of Collembola species with mean number of specimens and their life forms recorded by two sampling methods at the depths 5, 35, 65 and 95 cm at scr ee site S near the Silická ľadnica Ice Cave (Slovenský kras Karst).

Code	Species	Lf	Soil samples					Subterranean traps				
			5	35	65	95	$N_{(SS)}$	5	35	65	95	$N_{(ST)}$
AP	*Anurophorus* sp.	A mi	-	0.7	-	-	0.7	-	-	-	-	-
CAMA	*Caprainea marginata* (Schött, 1893)	EP	2	-	-	-	2	-	-	-	-	-
CESI	*Ceratophysella sigillata* (Uzel, 1891)	EP	-	2.7	-	-	2.7	-	-	-	-	-
DRTI	*Desoria tigrina* Nicolet, 1842	EP	-	-	-	-	-	6.3	-	-	-	6.3
DEST	*Deutonura stachi* (Gisin, 1952)	A x	0.3	-	-	-	0.3	-	-	-	-	-
DIMI	*Dicyrtomina minuta* (Fabricius, 1783)	A mi	-	-	-	-	-	-	0.3	-	-	0.3
EN	Entomobryidae juv.	H u	10.7	5	1	-	16.7	0.3	0.3	0.3	0.3	1.3
FOCA	*Folsomia candida* Willem, 1902	EU L f	-	-	-	-	-	-	-	-	0.3	0.3
FOFI	*Folsomia fimetaria* (Linnaeus, 1758)	EU L f	-	-	-	-	-	2.3	1.3	5	4.3	13
FOKE	*Folsomia kerni* Gisin, 1948	EU L f	12.7	-	-	-	12.7	13	11.7	4.3	-	29

Code	Species	Lf	Soil samples					Subterranean traps				
			5	**35**	**65**	**95**	**$N_{(SS)}$**	**5**	**35**	**65**	**95**	**$N_{(ST)}$**
FOMA	*Folsomia manolachei* Bagnall, 1939	H l	0.3	-	-	0.3	0.7	-	-	-	-	-
FOPE	*Folsomia penicula* Bagnall, 1939	H l	21.3	1.3	-	-	22.7	9.7	0.7	0.7	-	11
FRAL	*Friesea albida* Stach, 1949	H u	0.3	-	-	-	0.3	-	-	-	-	-
HP	*Heteraphorura* sp.	EU L	0.3	-	-	-	0.3	-	-	-	-	-
HPVA	*Heteraphorura variotuberculata* (Stach, 1934)	EU L	10.3	1.3	-	-	11.7	12	1.3	2.3	0.7	16.3
HENI	*Heteromurus nitidus* (Templeton, 1835)	EU L f	-	-	-	-	-	5.3	39.3	11	13.3	69
IS	*Isotoma* sp. juv.	EP	-	-	-	-	-	0.7	-	-	-	0.7
ILMI	*Isotomiella minor* (Schäffer, 1896)	EU M f	63.3	0.3	-	-	63.7	3.7	2	5	8.3	19
KACA	*Kalaphorura carpenteri* (Stach, 1919)	EU L	-	0.7	1	0.3	2	2.3	11	9.3	2.7	25.3
LECY	*Lepidocyrtus cyaneus* Tullberg, 1871	EP	5.3	0.3	-	-	5.7	-	1	-	-	1
LELA	*Lepidocyrtus lanuginosus* (Gmelin, 1788)	EP	2.3	-	-	-	2.3	-	-	-	-	-
LELI	*Lepidocyrtus lignorum* (Fabricius, 1775)	EP	8.7	0.3	0.3	-	9.3	7	3.3	0.3	1	11.7
MGIN	*Megalothorax incertus* Börner, 1903	EU S f	0.3	-	-	-	0.3	-	-	-	-	-
MGMI	*Megalothorax minimus* Willem, 1900	EU S f	4.3	0.3	-	-	4.7	-	-	-	-	-
MGWL	*Megalothorax willemi* Schneider & d'Haese, 2013	EU S f	-	-	-	-	-	-	-	0.7	-	0.7
OPCR	*Oncopodura crassicornis* Shoebotham, 1911	EU M f	4	1	-	-	5	6.7	14	80.7	13.7	115
OPRE	*Oncopodura reyersdorfensis* Stach, 1936	EU M f	-	-	-	-	-	-	-	-	0.7	0.7
ONPG	*Onychiuroides pseudogranulosus* (Gisin, 1951)	EU L	-	-	1	-	1	-	-	-	-	-
ORFL	*Orchesella flavescens* (Bourlet, 1839)	A mi	-	-	-	-	-	0.3	-	-	-	0.3
ISNO	*Parisotoma notabilis* (Schäffer, 1896)	H u	16.3	0.3	0.3	-	17	2.7	0.3	-	-	3
PLCA	*Plutomurus carpaticus* Rusek & Weiner, 1978	EP	4	-	-	-	4	0.7	0.3	-	-	1
PGFL	*Pogonognathellus flavescens* (Tullberg, 1871)	EP	1	-	-	0.3	1.3	0.7	0.3	-	-	1
POMM	*Proisotoma minima* (Absolon, 1901)	H u	-	-	-	-	-	-	-	-	0.7	0.7
PRAR	*Protaphorura armata* (Tullberg, 1869)	EU L	16.3	1.7	3.3	1	22.3	9.3	6.7	4.7	2.3	23
PRAU	*Protaphorura aurantiaca* (Ridley, 1880)	EU L	1.7	-	-	-	1.7	0.3	-	-	-	0.3
PRCM	*Protaphorura campata* (Gisin, 1952)	EU L	-	0.3	-	-	0.3	-	0.3	-	-	0.3
PRFI	*Protaphorura fimata* (Gisin, 1952)	EU L	0.3	-	-	-	0.3	-	-	-	-	-
PRPA	*Protaphorura pannonica* (Haybach, 1960)	EU L	1	-	-	-	1	1	0.3	-	-	1.3
PRSA	*Protaphorura subarmata* (Gisin, 1957)	EU L	-	-	-	-	-	-	0.7	-	-	0.7
PRTR	*Protaphorura tricampata* (Gisin, 1956)	EU L	-	-	-	-	-	-	-	-	0.7	0.7
PCDU	*Pseudachorutes dubius* Krausbauer, 1898	EP	-	-	0.3	-	0.3	-	-	-	-	-
PSHO	*Pseudosinella horaki* Rusek, 1985	H u	18	3.3	-	-	21.3	13	3	0.3	-	16.3
PSTH	*Pseudosinella thibaudi* Stomp, 1977	H l	-	-	-	-	-	-	-	-	1	1
ARBI	*Pygmarrhopalites bifidus* Stach, 1945	EU L	-	-	-	-	-	-	1.3	-	0.3	1.7
ARPY	*Pygmarrhopalites pygmaeus* (Wankel, 1860)	EU L	-	-	-	-	-	-	33.3	1	-	34.3
SCUN	*Schoetella ununguiculata* (Tullberg, 1869)	H u	-	-	-	0.3	0.3	-	-	-	-	-
SNAU	*Sminthurinus aureus* (Lubbock, 1862)	EP	-	-	-	-	-	0.7	1	-	-	1.7
SNEL	*Sminthurinus elegans* (Fitch, 1863)	EP	0.3	-	-	-	0.3	-	-	-	-	-
SM	*Sminthurus* sp. juv.	EP	-	-	0.3	-	0.3	-	-	-	-	-
SPPU	*Sphaeridia pumilis* (Krausbauer, 1898)	EP	-	-	-	-	-	-	0.3	-	-	0.3
TO	Tomoceridae sp. juv.	EP	-	-	-	-	-	0.3	-	-	-	0.3
TOMI	*Tomocerina minuta* (Tullberg, 1877)	EP	1	-	-	-	1	-	-	-	-	-
TOVU	*Tomocerus vulgaris* (Tullberg, 1871)	EP	2.7	-	-	-	2.7	-	-	-	-	-
VE	*Vertagopus* sp. juv.	A mi	-	-	-	-	-	0.3	-	-	-	0.3
WINI	*Willowsia nigromaculata* (Lubbock, 1873)	A mi	1	-	-	-	1	0.3	-	-	-	0.3
	N_{tot}		**210.3**	**19.7**	**7.7**	**2.3**	**240**	**99**	**134.3**	**125.7**	**50.3**	**409.3**
	S_{tot}		**28**	**15**	**8**	**5**	**36**	**24**	**24**	**14**	**15**	**35**

N_{tot} – total number of specimens, S_{tot} – total species richness, $N_{(SS)}$ – mean number of specimens collected by soil samples, $N_{(ST)}$ – mean number of specimens collected by subterranean pitfall traps, Lf – life form, A – atmobiotic, mi – microphytobiont, x – xylobiont, EP – epedaphic, H – hemiedaphic, u – upper, l – lower, EU – euedaphic, L – large, M – medium, S – small, f – presence of furca, 5, 35, 65, 95 – soil/scree depth [cm], "sp. juv." – uncertain relationship to the soil/subterranean environment.

Appendix 3

Table A3. List of Collembola species with mean number of specimens and their life forms recorded by two sampling methods at the depths 5, 35, 65 and 95 cm at scree site B at the Strmina Natural Reserve (Borinský kras Karst).

Code	Species	Lf	Soil samples					Subterranean traps				
			5	35	65	95	$N_{(SS)}$	5	35	65	95	$N_{(ST)}$
CEDE	*Ceratophysella denticulata* (Bagnall, 1941)	EP	3	-	-	-	3	3.7	1.7	3.3	1	9.7
ONDE	*Deharvengiurus denisi* (Stach, 1934)	EU M	5	3.7	-	-	8.7	1	0.3	1.3	0.3	3
DRHI	*Desoria hiemalis* (Schött, 1839)	EP	0.3	-	-	-	0.3	-	-	-	-	-
DRTI	*Desoria tigrina* Nicolet, 1842	EP	1.3	1.7	-	-	3	3.7	0.7	-	1.3	5.7
DECO	*Deutonura conjucta* (Stach, 1926)	A x	0.3	-	-	-	0.3	-	-	-	-	-
ENCO	*Entomobrya corticalis* (Nicolet, 1841)	A mi	-	-	-	-	-	0.3	-	-	0.3	0.7
ENMA	*Entomobrya marginata* (Tullberg, 1871)	A mi	-	-	-	-	-	0.3	-	-	-	0.3
ENNI	*Entomobrya nivalis* (Linnaeus, 1758)	A mi	0.3	-	-	-	0.3	2	-	0.3	0.7	3
EN	Entomobryidae juv.	H u	-	-	-	-	-	-	0.3	0.3	0.3	1
FOMA	*Folsomia manolachei* Bagnall, 1939	H l	2.3	4	-	0.3	6.7	-	-	-	-	-
FOPE	*Folsomia penicula* Bagnall, 1939	H l	82.0	7.3	-	-	89.3	1	1.3	0.7	-	3
FOQU	*Folsomia quadrioculata* (Tullberg, 1871)	H l	-	-	0.3	-	0.3	-	-	-	-	-
HPVA	*Heteraphorura variotuberculata* (Stach, 1934)	EU L	-	-	-	0.3	0.3	-	-	-	-	-
HENI	*Heteromurus nitidus* (Templeton, 1835)	EU L f	1.3	0.3	-	-	1.7	20.7	50.3	20.7	8.3	100
ILMI	*Isotomiella minor* (Schäffer, 1896)	EU M f	25.3	1	-	-	26.3	-	-	-	-	-
LELI	*Lepidocyrtus lignorum* (Fabricius, 1775)	EP	10.3	0.3	-	-	10.7	18	7.3	11	9.3	45.7
LILU	*Lipothrix lubbocki* (Tullberg, 1872)	EP	1	-	-	-	1	-	-	-	-	-
MGMI	*Megalothorax minimus* Willem, 1900	EU S f	2	-	-	-	2	-	-	-	-	-
NEPS	*Neanura pseudoparva* Rusek, 1963	H u	-	0.3	-	-	0.3	-	-	-	-	-
ND	*Neelides* sp.	EU S f	-	-	-	-	-	0.3	-	-	-	0.3
OPCR	*Oncopodura crassicornis* Shoebotham, 1911	EU M f	0.7	1	-	-	1.7	1.7	0.7	-	0.3	2.7
ORFL	*Orchesella flavescens* (Bourlet, 1839)	A mi	-	-	-	-	-	2.3	-	-	-	2.3
ISNO	*Parisotoma notabilis* (Schäffer, 1896)	H u	8.3	1.3	-	-	9.7	1	-	-	-	1
PGFL	*Pogonogathellus flavescens* (Tullberg, 1871)	EP	0.7	-	-	-	0.7	10	-	-	2	12
PRAR	*Protaphorura armata* (Tullberg, 1869)	EU L	59.3	2.3	1	1	63.7	-	0.7	1.3	0.7	2.7
PRTR	*Protaphorura tricampata* (Gisin, 1956)	EU L	1.3	-	-	-	1.3	1.7	0.7	7.3	5	14.7
PCSU	*Pseudachorutes subcrassus* Tullberg, 1871	EP	0.7	-	-	-	0.7	-	-	-	-	-
PSHO	*Pseudosinella horaki* Rusek, 1985	H u	2.3	-	-	-	2.3	-	-	-	-	-
PSTH	*Pseudosinella thibaudi* Stomp, 1977	H l	0.7	-	-	-	0.7	4	8	10	10.3	32.3
PSZY	*Pseudosinella zygophora* (Schille, 1912)	H u	0.3	-	-	-	0.3	-	-	-	-	-
ARPR	*Pygmarrhopalites principalis* Stach, 1945	H l	-	-	-	-	-	-	1.3	1.3	0.3	3
ARPY	*Pygmarrhopalites pygmaeus* (Wankel, 1860)	EU L	-	-	-	-	-	1	0.7	1.3	0.7	3.7
SNAU	*Sminthurinus aureus* (Lubbock, 1862)	EP	-	-	-	-	-	0.7	-	-	-	0.7
TOMR	*Tomocerus minor* (Lubbock, 1862)	EP	-	-	-	-	-	2.3	-	-	0.3	2.7
	N_{tot}		**209**	**23.3**	**1.3**	**1.7**	**235.3**	**75.7**	**74**	**59**	**41.3**	**250**
	S_{tot}		**23**	**12**	**3**	**4**	**25**	**20**	**14**	**13**	**17**	**21**

N_{tot} – total number of specimens, S_{tot} – total species richness, $N_{(SS)}$ – mean number of specimens collected by soil samples, $N_{(ST)}$ – mean number of specimens collected by subterranean pitfall traps, Lf – life form, A – atmobiotic, mi – microphytobiont, x – xylobiont, EP – epedaphic, H – hemiedaphic, u – upper, l – lower, EU – euedaphic, L – large, M – medium, S – small, f – presence of furca, 5, 35, 65, 95 – soil/scree depth [cm], "sp. juv." – uncertain relationship to the soil/subterranean environment.

Appendix 4

Table A4. List of Collembola species with mean number of specimens and their life forms recorded by two sampling methods at the depths 5, 35, 65 and 95 cm at scree site ZA at the base of the slope in Zádielska tiesňava Valley (Slovenský kras Karst).

Code	Species	Lf	Soil samples					Subterranean traps				
			5	35	65	95	$N_{(SS)}$	5	35	65	95	$N_{(ST)}$
ALFU	*Allacma fusca* (Linnaeus, 1758)	A mi	-	-	-	-	-	0.7	-	-	-	0.7
CEDE	*Ceratophysella denticulata* (Bagnall, 1941)	EP	-	-	-	-	-	-	-	-	1.3	1.3
CEGR	*Ceratophysella granulata* (Stach, 1949)	H u	0.3	-	0.3	-	0.7	6.3	30.3	38.3	101.3	176.3
CESI	*Ceratophysella sigillata* (Uzel, 1891)	EP	-	-	0.3	-	0.3	-	-	-	-	-
CESL	*Ceratophysella silvatica* (Rusek, 1964)	EP	-	0.7	-	-	0.7	-	-	1	-	1
DRHI	*Desoria hiemalis* (Schött, 1893)	EP	-	0.3	0.7	-	1	0.3	-	-	-	0.3
DEST	*Deutonura stachi* (Gisin, 1952)	A x	0.3	-	-	-	0.3	-	-	-	-	-
DCFU	*Dicyrtoma fusca* (Lubbock, 1873)	A mi	0.7	-	-	-	0.7	0.3	1.3	1.7	0.3	3.7
DIMI	*Dicyrtomina minuta* (Fabricius, 1783)	A mi	-	-	-	-	-	1.3	2.7	1	-	5
ENMA	*Entomobrya marginata* (Tullberg, 1871)	A mi	0.3	-	-	-	0.3	-	-	-	-	-
ENNI	*Entomobrya nivalis* (Linnaeus, 1758)	A mi	0.3	-	-	-	0.3	0.7	-	-	1	1.7
EN	Entomobryidae juv.	H u	-	-	-	-	-	0.3	-	-	-	0.3
FOMA	*Folsomia manolachei* Bagnall, 1939	H l	32	0.3	-	0.3	32.7	8.7	2	0.7	2.7	14
FOPE	*Folsomia penicula* Bagnall,1939	H l	4	-	0.7	0.7	5.3	-	0.7	1.3	-	2
FOQU	*Folsomia quadrioculata* (Tullberg, 1871)	H l	4.3	-	-	-	4.3	8	1	-	-	9
FRAL	*Friesea albida* Stach, 1949	H u	2.3	1	-	-	3.3	-	-	-	-	-
HPVA	*Heteraphorura variotuberculata* (Stach, 1934)	EU L	2.3	-	-	0.3	2.7	0.3	-	3.3	0.3	4
HENI	*Heteromurus nitidus* (Templeton, 1835)	EU L f	0.7	-	0.7	-	1.3	-	-	0.7	-	0.7
ILMI	*Isotomiella minor* (Schäffer, 1896)	EU M f	0.7	0.7	-	-	1.3	1.3	-	1.3	-	2.7
LELI	*Lepidocyrtus lignorum* (Fabricius, 1775)	EP	9.7	1.7	0.3	1	12.7	188	114.7	84.3	122.7	509.7
MGIN	*Megalothorax incertus* Börner, 1903	EU S f	-	-	-	-	-	-	-	-	0.3	0.3
MGMI	*Megalothorax minimus* Willem, 1900	EU S f	-	-	-	-	-	-	2.7	1.7	2.7	7
MGWL	*Megalothorax willemi* Schneider & d'Haese, 2013	EU S f	-	-	-	-	-	-	0.7	0.7	1.7	3
NEPS	*Neanura pseudoparva* Rusek, 1963	H u	1.7	0.7	-	-	2.3	0.7	3.3	-	-	4
OPCR	*Oncopodura crassicornis* Shoebotham, 1911	EU M f	-	0.3	-	-	0.3	1	-	-	-	1
ONPG	*Onychiuroides pseudogranulosus* (Gisin, 1951)	EU L	11	-	0.3	0.3	11.7	2.7	-	0.3	-	3
ORFL	*Orchesella flavescens* (Bourlet, 1839)	A mi	-	-	-	-	-	4.7	-	-	1.7	6.3
ISNO	*Parisotoma notabilis* (Schäffer, 1896)	H u	1	-	0.7	-	1.7	5.3	0.7	1.3	-	7.3
PLCA	*Plutomurus carpaticus* Rusek & Weiner, 1978	EP	-	-	-	-	-	16.7	19.3	25.3	57.3	118.7
PGFL	*Pogonognathellus flavescens* (Tullberg, 1871)	EP	-	-	-	-	-	43.7	15.7	13	35.3	107.7
CRBI	*Proisotomodes bipunctatus* (Axelson, 1903)	EU S f	0.3	-	-	-	0.3	-	-	-	-	-
PRAR	*Protaphorura armata* (Tullberg, 1869)	EU L	13	4.7	1.3	2.7	21.7	5.7	4	25.7	25.3	60.7
PRAU	*Protaphorura aurantiaca* (Ridley, 1880)	EU L	1.7	-	-	-	1.7	-	-	1	2	3
PRPA	*Protaphorura pannonica* (Haybach, 1960)	EU L	0.3	-	-	-	0.3	-	-	1	0.7	1.7
PRTR	*Protaphorura tricampata* (Gisin, 1956)	EU L	5.3	1.3	-	-	6.7	0.7	-	1	3	4.7
PCDU	*Pseudachorutes dubius* Krausbauer, 1898	EP	0.3	-	-	-	0.3	1	-	-	-	1
PSHO	*Pseudosinella horaki* Rusek, 1985	H u	12.7	-	-	0.3	13	13.7	11	15.7	24.7	65
PSTH	*Pseudosinella thibaudi* Stomp, 1977	H l	-	0.7	-	-	0.7	-	-	-	-	-
ARPR	*Pygmarrhopalites principalis* Stach, 1945	H l	-	-	-	-	-	-	-	0.7	1	1.7
ARPY	*Pygmarrhopalites pygmaeus* (Wankel, 1860)	EU L	-	-	-	0.7	0.7	5	25.3	39.7	184.3	254.3
SNAU	*Sminthurinus aureus* (Lubbock, 1862)	EP	-	-	-	-	-	1	-	-	-	1
TPBI	*Tetrodontophora bielanensis* (Waga, 1842)	H u	0.3	-	-	-	0.3	0.7	0.3	0.3	-	1.3
TO	Tomoceridae sp. juv.	EP	-	-	-	-	-	0.3	-	0.7	1.3	2.3
TOVU	*Tomocerus vulgaris* (Tullberg, 1871)	EP	-	-	0.3	-	0.3	-	-	-	-	-
WINI	*Willowsia nigromaculata* (Lubbock, 1873)	A mi	1	-	-	-	1	1.7	0.3	-	-	2
	$\mathbf{N_{tot}}$		**106.7**	**12.3**	**5.7**	**6.3**	**131**	**320.7**	**236**	**261.7**	**571**	**1389.3**
	$\mathbf{S_{tot}}$		**25**	**11**	**10**	**8**	**32**	**28**	**18**	**25**	**21**	**36**

N_{tot} – total number of specimens, S_{tot} – total species richness, $N_{(SS)}$ – mean number of specimens collected by soil samples, $N_{(ST)}$ – mean number of specimens collected by subterranean pitfall traps, Lf – life form, A – atmobiotic, mi – microphytobiont, x – xylobiont, EP – epedaphic, H – hemiedaphic, u – upper, l – lower, EU – euedaphic, L – large, M – medium, S – small, f – presence of furca, 5, 35, 65, 95 – soil/scree depth [cm], "sp. juv." – uncertain relationship to the soil/subterranean environment.

Appendix 5

Table A5. List of Collembola species with mean number of specimens and their life forms recorded by two sampling methods at the depths 5, 35, 65 and 95 cm at scree site ZB in the upper part of the slope in Zádielska tiesňava Valley (Slovenský kras Karst).

Code	Species	Lf	Soil samples					Subterranean traps				
			5	35	65	95	$N_{(SS)}$	5	35	65	95	$N_{(ST)}$
ALFU	*Allacma fusca* (Linnaeus, 1758)	A mi	-	-	-	-	-	0.3	-	-	-	0.3
ECO	*Deutonura conjucta* (Stach, 1926)	A x	0.3	-	-	-	0.3	-	-	-	-	-
DEST	*Deutonura stachi* (Gisin, 1952)	A x	0.3	0.7	1.7	-	2.7	-	-	-	-	-
DCFU	*Dicyrtoma fusca* (Lubbock, 1873)	A mi	-	-	-	-	-	4.3	4.3	-	-	8.7
DIMI	*Dicyrtomina minuta* (Fabricius, 1783)	A mi	-	-	-	-	-	2.3	-	-	-	2.3
EN	Entomobryidae juv.	H u	-	-	0.3	-	0.3	-	0.3	-	-	0.3
FOMA	*Folsomia manolachei* Bagnall, 1939	H l	12.7	2	3.3	0.3	18.3	3.7	-	-	-	3.7
FOPE	*Folsomia penicula* Bagnall,1939	H l	1.7	-	1.7	-	3.3	-	-	-	0.3	0.3
FOQU	*Folsomia quadrioculata* (Tullberg, 1871)	H l	2	-	1	-	3	-	-	-	-	-
FRAL	*Friesea albida* Stach, 1949	H u	-	0.7	0.3	-	1	-	-	-	-	-
HPVA	*Heteraphorura variotuberculata* (Stach, 1934)	EU L	0.3	0.7	5.3	0.3	6.7	-	-	-	-	-
ILMI	*Isotomiella minor* (Schäffer, 1896)	EU M f	8.7	4.7	3.3	-	16.7	1.7	1	-	-	2.7
KACA	*Kalaphorura carpenteri* (Stach, 1919)	EU L	0.3	1.3	1	-	2.7	7	0.7	1	0.7	9.3
LELI	*Lepidocyrtus lignorum* (Fabricius, 1775)	EP	3.3	1.3	2.7	2.3	9.7	23.7	8.3	8.0	2.7	42.7
LILU	*Lipothrix lubbocki* (Tullberg, 1872)	EP	-	-	0.3	-	0.3	-	-	-	-	-
MGMI	*Megalothorax minimus* Willem, 1900	EU S f	-	-	0.3	-	0.3	-	-	-	0.3	0.3
MIGR	*Micranurida granulata* (Agrell, 1943)	H l	-	-	0.3	-	0.3	-	-	-	-	-
NEMU	*Neanura muscorum* (Templeton, 1835)	H u	1.3	-	-	-	1.3	-	-	-	-	-
NEPS	*Neanura pseudoparva* Rusek, 1963	H u	7.3	2.3	2	-	11.7	-	-	-	-	-
NLKO	*Neelus koseli* Kováč & Papáč, 2010	EU S f	-	-	-	-	-	-	4.7	8	4.3	17
OPCR	*Oncopodura crassicornis* Shoebotham, 1911	EU M f	-	2	-	1.3	3.3	-	-	1	-	1
ONPG	*Onychiuroides pseudogranulosus* (Gisin, 1951)	EU L	12.0	3.3	4	-	19.3	1	-	-	-	1
ORFL	*Orchesella flavescens* (Bourlet, 1839)	A mi	-	-	-	-	-	7.7	-	-	-	7.7
ISNO	*Parisotoma notabilis* (Schäffer, 1896)	H u	1	0.7	2	0.3	4	-	0.7	-	-	0.7
PLCA	*Plutomurus carpaticus* Rusek & Weiner, 1978	EP	10	4.3	2.3	0.3	17	14	16.3	18.7	47.3	96.3
PGFL	*Pogonognathellus flavescens* (Tullberg, 1871)	EP	2.3	2	2.3	-	6.7	75.7	21.7	6	3.3	106.7
CRBI	*Proisotomodes bipunctatus* (Axelson, 1903)	EU S f	-	0.7	0.3	-	1	0.7	-	-	-	0.7
PRAR	*Protaphorura armata* (Tullberg, 1869)	EU L	3.3	5.7	7	1	17	1.3	4.7	-	1	7
PRTR	*Protaphorura tricampata* (Gisin, 1956)	EU L	0.3	4.3	0.3	0.3	5.3	-	1	-	1	2
PCDU	*Pseudachorutes dubius* Krausbauer, 1898	EP	-	-	0.3	-	0.3	-	-	-	-	-
PCPA	*Pseudachorutes parvulus* Börner, 1901	EP	-	-	0.3	-	0.3	-	-	-	-	-
PSHO	*Pseudosinella horaki* Rusek, 1985	H u	4	0.7	0.3	-	5	3.7	10	7.3	13.7	34.7
PSTH	*Pseudosinella thibaudi* Stomp, 1977	H l	1	0.3	1	-	2.3	-	-	-	-	-
ARPR	*Pygmarrhopalites principalis* Stach, 1945	H l	-	0.3	-	-	0.3	2	62.3	20.7	19.3	104.3
ARPY	*Pygmarrhopalites pygmaeus* (Wankel, 1860)	EU L	0.7	3.7	3	0.3	7.7	1.3	5.7	7.3	5	19.3
SNAU	*Sminthurinus aureus* (Lubbock, 1862)	EP	-	-	-	-	-	-	0.3	-	-	0.3
TPBI	*Tetrodontophora bielanensis* (Waga, 1842)	H u	0.7	0.3	0.3	-	1.3	1.3	-	-	-	1.3
TO	Tomoceridae sp. juv.	EP	-	-	0.7	-	0.7	-	-	-	-	-
TOMR	*Tomocerus minor* (Lubbock, 1862)	EP	0.3	-	-	-	0.3	-	-	-	-	-
TOVU	*Tomocerus vulgaris* (Tullberg, 1871)	EP	-	-	-	-	-	-	-	-	0.7	0.7
	N_{tot}		**74**	**42**	**48**	**7**	**171**	**152**	**142**	**78**	**100**	**471**
	S_{tot}		**22**	**21**	**28**	**9**	**31**	**17**	**15**	**9**	**13**	**25**

N_{tot} – total number of specimens, S_{tot} – total species richness, $N_{(SS)}$ – mean number of specimens collected by soil samples, $N_{(ST)}$ – mean number of specimens collected by subterranean pitfall traps, Lf – life form, A – atmobiotic, mi – microphytobiont, x – xylobiont, EP – epedaphic, H – hemiedaphic, u – upper, l – lower, EU – euedaphic, L – large, M – medium, S – small, f – presence of furca, 5, 35, 65, 95 – soil/scree depth [cm], "sp. juv." – uncertain relationship to the soil/subterranean environment.