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THE INFLUENCE OF GEOLOGICAL SUBSTRATE ON THE FAUNAL STRUCTURE OF THE SUPERFICIAL SUBTERRANEAN HABITATS

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Abstract: The majority of the previous studies on the faunal structure and dynamic were carried out on calcareous scree slopes, and a few descriptive studies were conducted on fauna inhabiting the MSS on other geological substrates. Here, we analyzed the invertebrate communities from the MSS developed in calcareous substrate and in crystalline schists. We investigated how the environmental conditions in two different geological substrates influence the spatial distribution of invertebrate communities over time. We sampled invertebrate species, monthly, in both geological substrates, at different altitudes, depths and types of scree slopes (covered and nude screes). We identified a total of 99 invertebrate species. Canonical correspondence analysis indicated a strong correlation of the calcareous geological substratum with an invertebrate species assemblage. Calcareous substratum, altitude, exterior temperature, relative humidity and the type of gravel were identified as the main factors influencing community structure. The crystalline schists are inhabited by a heterogeneous community of species (cryphilous species or opportunistic species) and are mainly influenced by altitude and exterior relative humidity. The complex environmental conditions of Leaota Mountains emphasized that the calcareous geological substratum is an important abiotic factor that influence the structure of the invertebrate community of MSS.

Keyword: mesovoid shallow substratum, invertebrates, abiotic factors, geological substrates, Leaota

1. INTRODUCTION

The study of the mesovoid shallow substratum (MSS) (a habitat developed inside different screes), has recently caught the attention of ecologists, especially due to the particular micro-climatic conditions. MSS was defined since the early 1980s in biology to categorize an array of different hypogean habitats (Culver & Pipan, 2014). A particularity of the MSS is that the amplitude of the thermic variations is much lower than temperature amplitudes from the outside. The thermic variability from the surface moderately affects the micro-climate in the MSS, resulting in seasonal internal variations, with lower amplitude than those of the external environment. Due to its microclimatic particularities, the mesovoid shallow substratum (abbreviated as MSS or SUC– superficial underground compartment) represents a significantly ecological refuge to numerous edaphic species (soil species) during drought or cold periods. Besides the mentioned soil species, in the MSS were recorded species preferential to this type of habitat (Růžička et al., 2012; Mock et al., 2015), some of them being glacial relicts and even endemic species (Gilgado et al., 2015). An exhaustive paper on the history of the MSS research (including the concepts under which this habitat was described), the diversity of the MSS, its features as well as on its significance, has been recently published by Mammola et al., (2016). Recent papers have described the influence of some environmental factors on the microclimatic conditions in the MSS such as the altitude, the presence or absence of vegetation, the nature of the rocks where it develops, the exposure of the slopes, the pluviometric regime and the external temperature (Badino, 2010). For some of these abiotic factors, there is a correlation with the dynamics and structure of the fauna from the mesovoid shallow substratum (MSS) developed on limestone rocks, as proved by Nitzu et al., (2014). In a first attempt of mathematic modeling, Mammola et al., (2016) show the potential of the geological substratum to explain the energy flow in the MSS.

The statistical ecology studies published until now aimed the correlations between the fauna and some abiotic factors (temperature, relative humidity, altitude) of different types of MSS developed within a certain geological substratum (especially limestone rocks) (Gers, 1998; Pipan et al., 2011; Jimenez-Valverde et al., 2015; Nitzu et al., 2014; Nitzu, 2016). There are no comparative ecological studies on MSS types developed on different geological substrata, to test the correlation between the structure of fauna and substratum. In this paper, we aimed to evaluate the role of the geological substratum on the structure and the diversity of the invertebrate fauna in the MSS, through a complex analysis of statistical ecology. To this extent, we have studied: (1) the diversity and the structure of the invertebrate fauna in the MSS developed in two types of rocks: limestone and mezometamorphic crystalline schists; (2) spatial data (from different sites and altitudes) and temporal data (monthly data) for each of the two types of rocks; (3) the influence of the environmental variables (geological substratum type, relative humidity, temperature, the type of habitat – MSS developed in mobile or fixed scree) on the structure of the arthropods communities. We identified in the Leaota Mountains a favorable study area, which has not been influenced by anthropic activities. There, the MSS is developed both within limestone and crystalline schists situated at different altitudes and belonging, in the case of both geological substratum types, to different MSS categories: fixed MSS (covered by soil and forest vegetation) (Gfix) and mobile MSS (nude scree) (Gmob).

2. MATERIALS AND METHODS

2.1. Study area

Two sampling areas, in two different types of geological substratum: one in limestone MSS (Ghimbav) and the other one in crystalline schists MSS (Valea Popii) were selected in the Leaota Massif. The Ghimbav sampling area was situated on limestone scree outcropping on a surface of approximately 80 meters length and approximately 25–30 meters wide, on the southern slope of the Ghimbav Mountain. In the upper part of the scree, there is a soil genesis process, generated by the chemical alteration of limestone and by the development of residual clays. Soil particles are gravitationally transported from the forest bordering the scree on the upper northern side, accelerating the soil genesis process. At the Southern border of the forested area, the scree is stabilized through the development of vegetation dominated by *Teucrium montanum* Linnaeus, 1753, *Teucrium chamaedrys* Linnaeus, 1753, *Thymus comosus* Heuff. ex Griseb. & Schenk, 1852. This confirms the affiliation of these phytocenoses to the NATURA 2000 habitat (code 8120)| "Limestone and crystalline shists scree from the mountain to the alpine floor (Thalispietea rotundifolii)" (Gafta & Mountford, 2008). The Valea Popii sampling area was situated in a geographic area of the Leaota Massif with outcrops of mezo-metamorphic crystalline schists, belonging to the Leaota Series (Fig. 1).

The sampling area, on a slope of 40°, with southern exposure, is covered by a mixed forest of beech and spruce from the NATURA 2000 habitat (code 91V0) "Dacian beech (Symphyto-Fagion) forests" (Gafta & Mountford, 2008).

In the Ghimbav sampling area, we used three sampling units (pitfall traps in drillings).

Drilling 1, of 1 meter depth, placed in a mobile MSS (nude scree), at 879 meters altitude (GPS coordinates: N 45°22´43.0″ E 25°13´49.4″).

Drilling 2, of 0.75 meters depth, placed in a mobile MSS (nude scree) (GPS coordinates N 45° 22´43.1″ E 25°13´49.2″), at an altitude of 883 meters. Drilling 3, of 0.5 meters depth, placed in a fixed MSS (GPS coordinates N 45°22´42.7″ E 25° 13´49.3″), at an altitude of 860 meters.

In the Valea Popii sampling area, 4 sampling units (drillings) were placed. Drillings 1 and 2 were installed in a colluvial mobile MSS (schists crystalline scree, recently formed and completely nude). The scree was gravitationally accumulated at the base of the western slope of the Cumpărata Mare Mountain, on the right bank of Valea Popii stream. The absence or the incipient phase of the chemical alteration of the rocks, points the recent origin of the scree.

The first drilling had a depth of one meter and the second one a depth of 0.5 meters.The distance between them was 1.5 meters (GPS coordinates N 45°21´41.6″ E 25°16´38.8″, 1076 meters altitude).

The drillings 3 and 4 were placed at 0.5 meters depth in crystalline schists, in fixed MSS, on the left bank of Valea Popii stream (GPS coordinates N 45° 21´42.4″ E 25°16´36.9″,1081 meters altitude – drilling 3; N 45°21´45.5″ E 25°16´36.1″, 1070 meters altitude – drilling 4). The residual clay infilling of the crystalline schists prevented the digging of drillings at depths over 0.5 – 0.6 meters, excepting the area allowing the installation of the first drilling. For the mineralogical analysis in thin sections of the schists rock samples, we used a petrographic microscope with polarized light Carl Zeiss Jena Amplival Pol ● U.

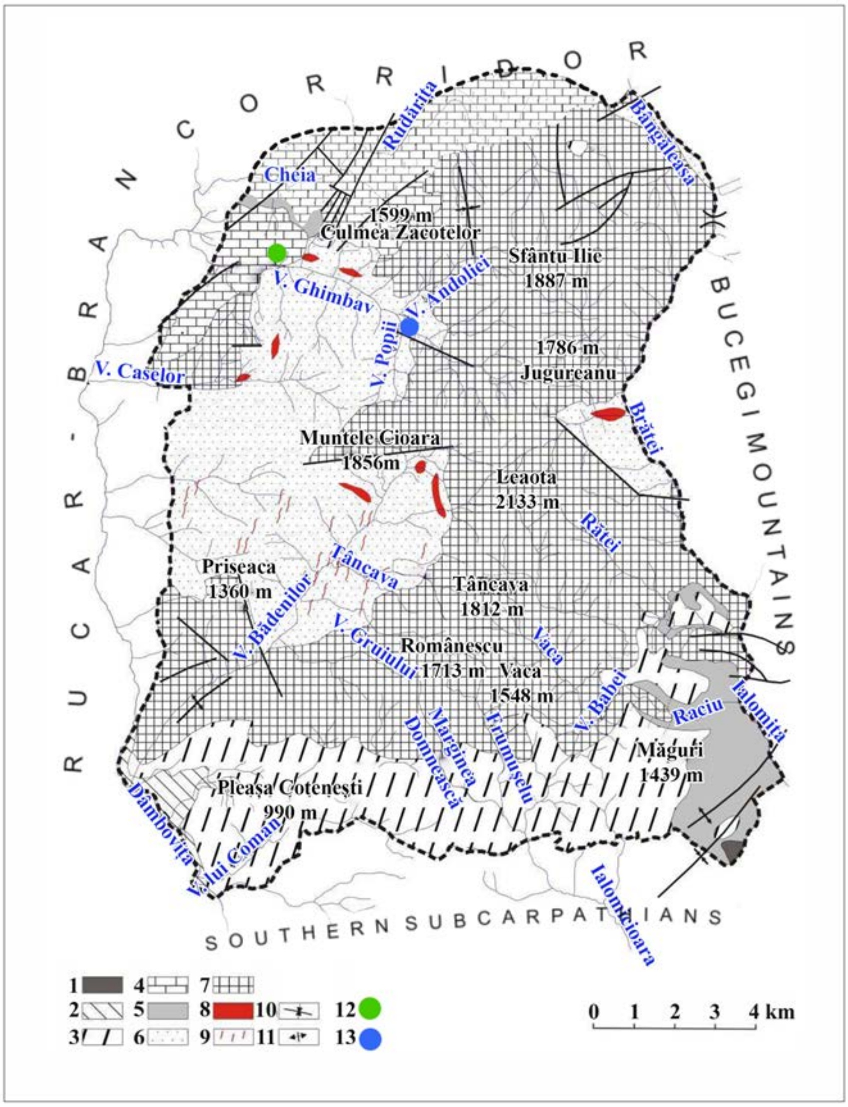

Figure 1. Leaota Mountain – Geological Map (after Murătoreanu, 2009, modified)
Legend: 1. graves, sands, gritty clay; 2. shale, silica, massive sandstone, conglomerates; 3. coarse sandstone, clay sandstone, Bucegi conglomerates, limestone breccias; 4 limestones, dolomite limestones and dolomites, radiolarites; 5 shales, sandstones, conglomerates; 6 The Leaota Series – phyllites, chlorite-sericite schists; 7. Cumpăna Series – metablastic migmatites; 8. Granites; 9. Metablastic magmatites; 10. syncline axis; 11: Anticline axis; 12 = Rudărița ecological stationary; 13 = Valea Popii ecological stationary.

2.2. Arthropod abundance sampling

During 2014 and 2015, the faunal samples were monthly collected, from April until December (9 monthly samples/3 depths), making a total of 51 assemblages, as follows:

- in Ghimbav sampling area, a total of 27 sampling assemblages (9 samples x 1 depth of 0.5m + 9 samples x 1 depth of 0.75m + 9 samples x 1 depth of 1m = 27).

- in Valea Popii sampling area, a total of 24 sampling assemblages (6 samples × 1 depth of 1 m + 18 samples × 1 depth of 0.5 m = 24 samples).

Fauna was sampled with pitfall traps filled with ethylene glycol as preservative solution. Each pitfall trap was placed at the mentioned depth in a vertically dug hole and protected by a perforated PVC pipe to prevent gravel from falling in the trap and to provide access for the specimens, using the same technique described by us in Piatra Craiului (Nitzu et al., 2014).

All taxa were identified at species and subspecies levels using Discovery 8 stereoscope and Olympus CH2 microscope.

2.3. Measurement of environment variables

The continuous monitoring of the relative temperature (T) and the relative humidity (Rh) was made using the DT 171 data-loggers, set to record the data every 2 hours. The values of the relative temperature and humidity were measured both for the outside, at the soil level (Text, Rhext) and in the drillings, at the mentioned depths and altitudes (Tint, Rhint, Alt.).

2.4. Data analysis

The studies were based on the species abundances. To estimate the species richness, we used the Jacknife 1 and 2 indexes (McAleece, 1997) – Biodiversity Professional, V.2 software.

To establish the correlation between the dependent variable (the species richness) and the tested environmental variables, we have used the linear ordering method RDA (redundancy analysis). Despite our data suggest high beta diversity, and consequently, use of a unimodal ordination method, because there are two samples with zero species, according to Lepš & Šmilauer (2003), use of a linear ordination method was mandatory. For RDA, we selected the standardization by error variance to observe, separately for each species, how much of its variance was not explained by the environment variables, according to the protocol recommended by the previously quoted authors.

The database for environmental variables contains three quantitative environment variables (T, Rh, Alt), a semi-quantitative variable (depth), divided by 3 categories (0.5, 0.75 and 1) and two nominal dummy variables (type of geological substrate – limestone/crystalline schists, and type of MSS – mobile/fixed).

Because we have two factors coded as dummy variables and used as explanatory (environmental) variables, we followed the protocol described by Lepš and Šmilauer (2003) in the "Variation among ranges" section to estimate the contribution of each factor at once. For this, in RDA we first used the type of geological substrate as the predictor, ignoring the other variables. To test the differences among areas on different geological substrate, we used the Monte Carlo permutation test. Subsequently, when estimating the variation explained by type of habitat (MSS mobile or fixed) we used the type of MSS as the predictor and the type of geological substrate as covariable in the partial RDA, with restricted (split-plot type) permutations with blocks (Monte Carlo test) defined by geological substrate covariables.

For the species data set we used only species with abundances ≥ 5 (36 species). The square-root transformation was applied on the species abundances (in this case varying from 5 to 697 individuals per species) to maintain normal distribution and to avoid the "arch effect" in the ordination method of analysis (Ludwig & Reynolds, 1988; Krebs, 1989).

To test the significance level of correlations between environmental variables and associations of arthropod communities, we used the Monte Carlo test with 199 permutations. Only the environmental variables significant at $P < 0.05$ were included in final constrained ordination model. For RDA we used the program CANOCO (4.02).

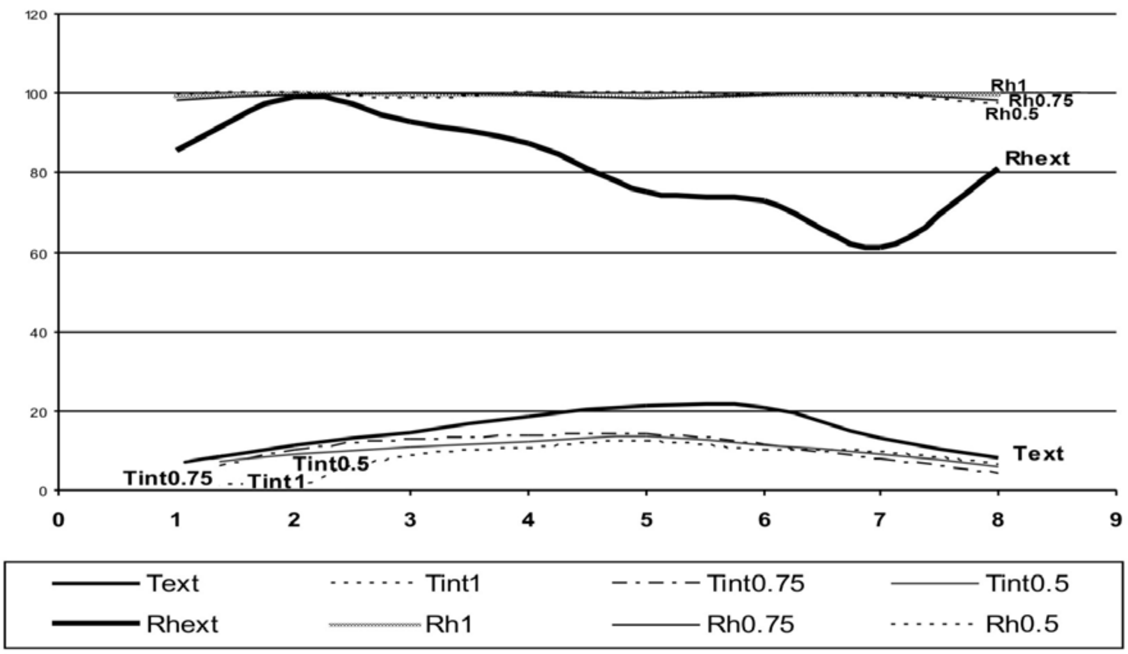

Figure 2A. Monthly variations of the external (Text) and internal (Tint) temperatures, external (Rhext) and internal relative humidity (Rhint) at 0.5 m, 0.75 m and 1 m depth for limestone substrate at Ghimbav.

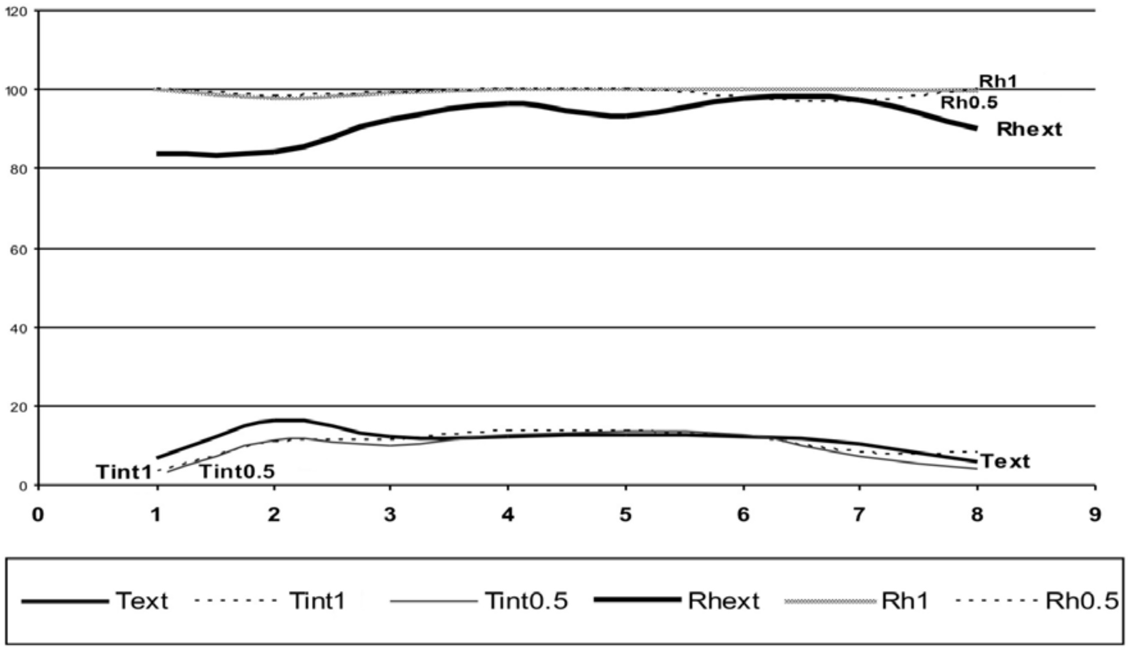

Figure 2B. Monthly variations of the external (Text) and internal (Tint) temperatures, external (Rhext) and internal relative humidity (Rhint) at 0.5m and 1m depth for crystalline schists at Valea Popii from April (1) to November (8).

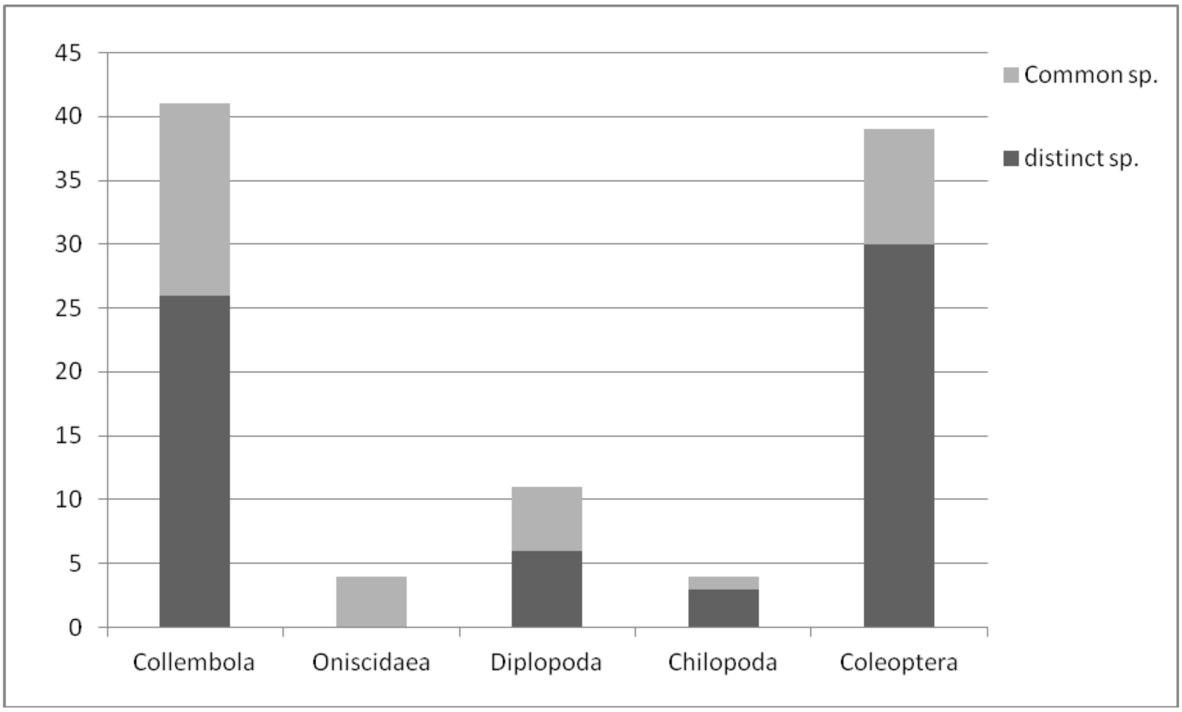

Figure 3. Contribution of species common in both sites to the total number of species distributed on macrotaxa in the MSS habitats from Valea Popii and Ghimbav.

3. RESULTS

3.1. Mineral analysis

The mineral composition of crystalline schists was as follows: quartz 40–44%; plagioclase feldspars 20–24%; biotite and chlorite 29–33%; muscovite 3–5%, traces of epidote, potassium feldspars, granats, limonite, calcite and ilmenite.

Limestone rocks are composed of almost 99% calcium carbonate (calcite). Limestone has a biogenic origin with bioclastic. The MSS on limestone is characterized by low clay content (1%) correlated with a high interclastic porosity. Although, the solubility of the calcium carbonate is much higher than the solubility of the silicates (Anastasiu et al., 2007), the absence of clay minerals from these limestones, leads through chemical alteration (after levigation of the soluble part) to a low quantity of soil forming residual clays.

3.2. Ecological analysis

The monthly variations of temperature and relative humidity recorded at different depths are depicted in Figures 2A and 2B. A total of 99 species have been identified, 30 of them recorded in both investigated sites (Fig 3). 70 species were identified in the Ghimbav station (limestone rocks) and 59 species in the Valea Popii (mezometamorphic crystalline schists). These represent a percentage of 55–68% of the estimated species (105–127 species) for the Ghimbav and respectively between 59–70% for the Valea Popii sampling areas (84–100 estimated species) for the studied systematic groups (at a confidence interval of 95%) (Fig. 4). A number of 36 species with ≥ 5 abundance (3093 individuals) have been selected to test of the correlations between the Arthropod communities structure and the environmental variables using the linear ordering method RDA (Table 1).

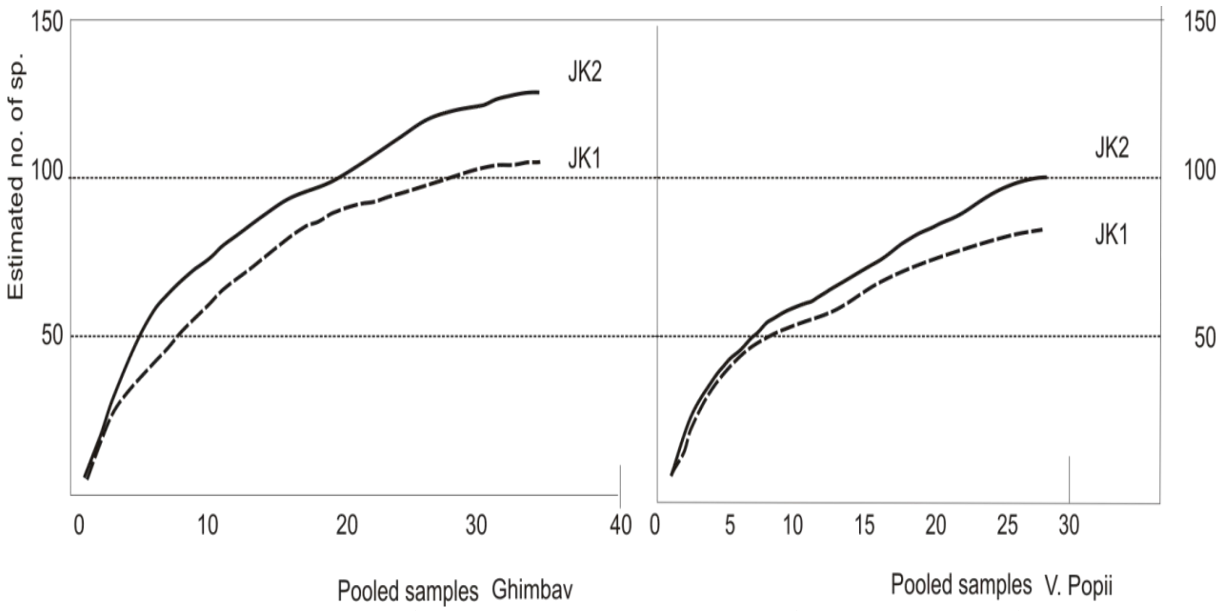

Figure 4. Estimated species richness for sampling sites using the Jackknife1 (JK1) and Jacknife2 (JK2) indexes.

Table 1. The list of the ≥ 5 species used for the RDA

No.	Species	Acronym	Abundance (total)
	Cls. Collembola, Ord. Poduromorpha		
1	**Fam. Hypogastruridae** *Ceratophysella luteospina* (Stach, 1920)	Cer_lut	**16**
2	*Ceratophysella silvatica* Rusek, 1964	Cer_silv	**11**
3	*Hypogastrura purpurescens* (Lubbock, 1870)	Hyp_pur	**6**
4	**Fam. Onychiuridae** *Deuteraphorura cebennaria* (Gisin, 1956)	Deut_ceb	**48**
5	*Kalaphorura tuberculata* (Moniez, 1890)	Kal_tub	**53**
6	*Protaphorura armata* (Tullberg, 1869)	Prot_arm	**14**
7	*Onychiuroides granulosus* (Stach, 1930)	Ony_gran	**26**
8	*Onychiuroides subgranulosus* (da Gama, 1964)	Ony_sub	**24**
9	*Tetrodontophora bielanensis* (Waga, 1842)	Tetr_biel	**101**
	Ord. Entomobryomorpha **Fam. Tomoceridae**		
10	*Plutomurus carpaticus* Rusek & Weiner 1978	Plut_car	**52**
11	*Pogonognathellus flavescens* (Tullberg, 1871)	Pog_flav	**750**
12	**Fam. Lepidocyrtidae** *Lepidocyrtus cyaneus* Tullberg, 1871	Lep_cyan	**50**

13	*Lepidocyrtus lignorum* (Fabricius, 1775)	Lep_lig	**89**
14	*Lepidocyrtus serbicus* Denis, 1933	Lep_serb	**540**
	Fam. Orchesellidae		
15	*Orchesella pontica* Ionesco, 1916	Orc_pont	**7**
16	**Ord. Neelipleona** **Fam. Neelidae** *Neelides minutus* (Folsom, 1901)	Neel_min	**7**
17	*Neelus murinus* Folsom, 1896	Neel_mur	**148**
18	**Fam. Arrhopalitidae** *Pygmarrhopalites pygmaeus* (Wankel, 1860)	Pyg_pyg	**122**
19	*Pygmarrhopalites sericus* (Gisin, 1947)	Pyg_ser	**24**
20	*Caprainea marginata* (Schott, 1893)	Capr_mar	**6**
	Cls. Diplopoda, Ord. Polydesmida **Fam. Paradoxosomatidae**		
21	*Strongylosoma stigmatosum* Eichwald, 1830	Str_styg	**55**
	Fam. Polydesmidae		
22	*Polydesmus burzenlandicus* Verhoeff, 1925	Poly_burz	**6**
	Ord. Chordeumatida **Fam. Mastigophorophyllidae**		
23	*Heterobraueria scopifera* Verhoeff, 1898	Het_scop	**697**
	Ord. Julida **Fam. Julidae**		
24	*Megaphyllum projectum* Verhoeff, 1894	Meg_proj	**34**
25	*Leptoiulus trilobatus* Verhoeff, 1894	Lepto_tri	**38**
	Clasa Chilopoda, Ord. Geophilomorpha **Fam. Linotaeniidae**		
26	*Strigamia engadina* Verhoeff, 1935	Stri_eng	**29**
	Ord. Lithobiomorpha **Fam. Lithobiidae**		
27	*Harpolithobius radui* Matic, 1955	Harp_rad	**33**
	Cls. Insecta, Ord. Coleoptera **Fam. Carabidae**		
28	*Abax parallelepipedus* (Piller et Mitterpacher, 1783)	Ab_paralp	**7**
29	*Platynus glacialis* Reitter, 1877	Plat_glc	**30**
30	*Pterostichus pilosus wellensii* (Drapiez, 1819)	Pt_pilos	**11**
	Fam. Staphylinidae		
31	*Proteinus laevigatus* Hochhuth, 1872	Prot_laev	**9**
32	*Quedius mesomelinus* (Marsham, 1802)	Q_mesom	**9**
	Fam. Leiodidae		
33	*Catops picipes* (Fabricius, 1792)	Cat_pici	**23**
	Fam. Curculionidae		
34	*Otiorhynchus (Tournieria) coarctatus* Stierlin, 1861	Ot_coarc	**6**
35	*Otiorhynchus (Dorymerus) kollari* Gyllenhal, 1834	Ot_kollar	**5**
36	*Otiorhynchus (Dorymerus) obtusus* Boheman, 1843	Ot_obt	**7**

Using the Monte Carlo permutation test we have noticed significant correlations ($P<0.05$) between the associations of arthropod communities and the following environmental variables: the type of limestone substratum (Ca), the external temperature (Text) and the external humidity (Rhext), altitude (Alt) and the type of the habitat (Gmob) (Table 2).

The association of these significant environmental variables and arthropod abundance was depicted in the RDA ordination plot (Fig. 5).

In the RDA analysis, the first axis explains 15.2% of the total variance, and the second axis 5.3% (cumulative percentage variance 20.5). The first axis was very well correlated with the environmental data ($r = 0.928$).

The correlations between the environment variables (calcareous substrate, altitude) are best explained with the first axis, while the type of MSS – mobile gravel (Gmob) – is more correlated with the second axis.

The projection of the centroids of dummy environmental variables (Ca, Gmob) onto a species arrow (Fig. 5) approximate the average values of the species in the individual classes (Lepš & Šmilauer, 2003).

Table 2. Results of the Monte Carlo permutation test (199 permutations) on the significance of constrained ordination model (RDA). (F - statistic value of the data sets).

Variable	P	F
Ca/Si (limestone substrate/crystalline schist)	0.005	5.63
Gmob (mobile gravel)	0.005	1.69
Gfix (covered gravel)	0.345	1.07
Alt (altitude)	0.005	6.11
Text (exterior temperature)	0.005	2.72
Tint (interior temperature)	0.145	1.34
Rhext (exterior relative humidity)	0.005	2.02
Rhint (internal relative humidity)	0.510	0.98
Deep	0.325	1.13

For the centroids of dummy environmental variables, the distance between the species points and those centroids was used to approximate the correlations between species abundances and dummy variables (summed over all the samples in the particular class) (Lepš & Šmilauer, 2003).

For the interpretation of the correlations between the environmental variables and the species' associations, we have used the "Van Dobben circles" method Ter Braak & Šmilauer, 2002).

The length of the arrows and the angle between the species arrows and the one of the quantitative variables reflects the correlation degree between them.

A positive correlation between a species and an environmental variable it is predicted if both arrows (of species and environment variable) point in a similar direction.

The longer the arrow of a species is, and its angle with the arrow of an environmental variable (temp_ext, UR_Ext, Alt) sharper, the higher the correlation between them.

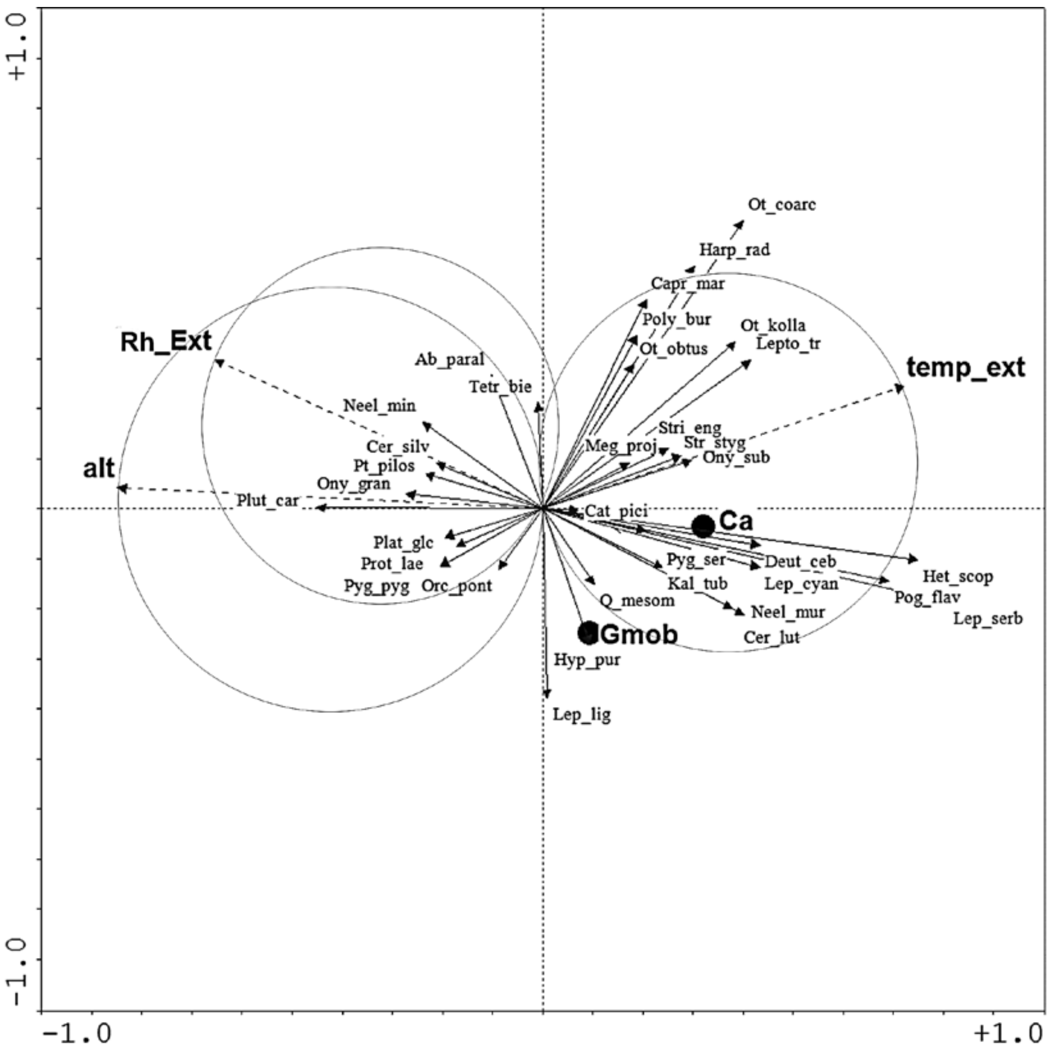

Figure 5. Species – environmental variables biplot diagram obtained with the RDA analysis

The species whose abundances are positively correlated to the external temperature (i.e: Ot_kolla, Lepto_tr, Str_Styg, Ony_sub) (the abbreviations are explained in Table 1) are placed in the upper right quadrant, while the species that are negatively correlated to the external temperature (i.e. Plat_glc, Prot_lae, Pyg_pyg) but, on the other side, are positively correlated to the altitude (i.e. Plat_glc, Prot_lae, Pyg_pyg) are displayed in the lower left quadrat.

The species whose abundances are significantly correlated to the limestone substratum (i.e. Het_socp, Pog_flav, Lep_serb, Lep_cyan, Deut_ceb) are placed in the lower right quadrant, close to the centroid of the limestone substratum (Ca), while two species (Hyp_pur, Lep_lig) are much better correlated to the mobile scree (Gmob).

The upper left quadrant displays the species whose abundances are strongly correlated to the external humidity (UR_ext) (i.e. Pt. pilos, Cer_silv, Neel_min) and with the altitude (Alt) (Plut_car). Species located near the origin do not show a strong relationship with any of the variables.

The species whose graphical projection is located outside the area of the Van Dobben circles (which are circumscribed to the vectors of the quantitative variables), and distanced from the centroids of the dummy variables (i.e. Harp_rad, Ot_coarc), are species whose abundances are correlated to other independent variables (variables not included in the present analysis; variability not explained by the ordination model – residual variability).

4. DISCUSSIONS

The RDA ordination analysis mainly emphasizes two large categories of species: the ones whose abundances within the MSS are positively correlated to the limestone substratum and the external temperatures (species located in the quadrates in the right side of the graphic) versus the species whose abundances are significantly correlated to the altitude and the external humidity (projected in the quadrates in the left side of the graphic).

Several species display a higher correlation to the mobiles scree (Gmob) (species displayed in the lower right quadrate close to the Gmob centroid).

The geographical position of the Leaota Mountains, relatively close to Piatra Craiului, where we have recently carried out studies on the limestone MSS (Nitzu *et al.*, 2014; Nitzu, 2016) has allowed the carrying of comparative analyses on the fauna similarities and particularities of the invertebrates in the two geographic areas, as well as their conditioning by the tested environmental factors. Thus, both in Piatra Craiului and Leaota, *Platynus glacialis* (Coleoptera, Carabidae) presented a significant correlation to the altitude. In Piatra Craiului both the gravels from high altitude (the under-alpine area) and the ones from lower altitude (the mountain area) were developed on limestone substratum. In the case studied in the present paper, the abundance of the species is correlated to the altitude, as well as in Piatra Craiului, but it is not correlated to the limestone substratum. *Pterostichus pilosus wellensii*, another ground beetle species, also recorded in the gravels from Piatra Craiului, is more abundant in MSS with the increase of the external humidity and the decreases of the external temperature at high altitudes and it does not present significant correlations with the type of geological substrate. The analysis of the RDA ordination method results shows, in fact, that these two species, together with *Plutomurus carpathicus*, *Onychiuroides granulosus*, *Ceratophysella silvatica, Tetrodontophora bielanensis*, *Pygmarrhopalites pygmaeus* (Collembola), *Abax parallelepipedus* (Coleoptera) form a community of invertebrates whose abundance inside the MSS is positively correlated with the altitude and the external relative humidity. Unlike the gravels developed on limestone (which display a community of preferential species), the gravels developed on schists are inhabited by a fauna influenced in a more significant manner by the altitude and humidity than by the geological substrate.

Lepidocyrtus serbicus (Collembola) is a species frequently observed in karst environments, both in caves and limestone MSS (Gruia & Ilie, 2001; Nitzu *et al.*, 2014). Other species like *Lepidocyrtus cyaneus* (Collembola) and *Catops picipes* (Coleoptera) (whose abundance is correlated with limestone MSS) are the eudaphic and sub-trogophile and identified both in Leaota and other areas of the Carpathians (Nitzu *et al.*, 2010; Nitzu, 2013).

Among the species with a significant positive correlation to the limestone substratum, but not obligatory to the underground environments, are the calciphilous *Pogonognathellus flavescens* (Collembola) and *Heterobraueria scopifera* (Diplopoda), frequently recorded in both the edaphic and the underground environment (Nitzu *et al.*, 2014).

The specific richness seems to be slightly higher in the limestone screes in comparison to the ones developed on other types of substrate (Mock et al., 2015). Our statistic study has revealed that in the

Leaota Mountains, the species richness is slightly higher in the limestone screes, but is not statistical significantly different between the MSS on limestone and the one in the crystalline schist (Jackknife estimation).

For *Pygmarrhopalites pygmaeus*, we observed a negative correlation with the external temperatures: the abundance of the species increases inside the MSS directly proportional with the soil temperature, without significant differences with the depth (0.5 m, 0.75 m and 1 m depth), as it had been noticed by Rendoš *et al.* (2016b) in the Western Carpathians.

Complementary to our results, Rendoš *et al*. (2016a) have shown that *Pogonognathellus flavescens* and *Caprainea marginata* (both also collected in the MSS in Leaota), display significant correlations to the "organic scree layers" in the MSS. Other species (i.e. *Strongylosoma stigmatosum*, *Leptoiulu strilobatus*) are a constant presence within the invertebrates communities both in the limestone MSS of the Romanian Carpathians (Nitzu *et al*., 2016) and in other areas of Slovakia (Mock *et al*., 2015; Rendoš et *al*., 2016b).

The anophtalmic species, *Duvalius dieneri* Csiki, 1910 (1 specimen) (Coleoptera, Carabidae) was recorded in the present study only in the mezometamorphic crystalline schist MSS (1081m high).

5. CONCLUSIONS

The statistical correlations between the fauna and some abiotic factors of different types of MSS developed especially limestone rocks (Gers, 1998; Pipan *et al.*, 2011; Jimenez-Valverde *et al*., 2015; Nitzu *et al*., 2014) underlined the importance of this habitat in species conservation, especially its refugial role for many edaphic and endemic species. Thus, the conservative importance of the MSS was sustained by previous studies (Culver & Pipan, 2014; Mammola *et al*., 2016), but the role of geological substratum was not statistical tested in the previous mentioned studies.

Our study illustrates that, compared to the arthropods communities from the crystalline schist MSS (for which we have not detected a correlation to the geological substrate), for the limestone MSS, there are species associations significantly correlated with this type of substrate (preferential species). In the RDA analysis, we detected a species community inhabiting the MSS strongly correlated with the external temperature. Our studies of thermometry revealed that the thermal transfer from the exterior to the interior of the MSS is much more rapid for the MSS developed in crystalline schist than that for the MSS developed in limestone, being significant for faunal structure of this environment. In further studies we intend to test if this positive influence of limestone substratum on species richness and structure could be observed for the epigeal species communities, which could be of high interest in the conservative plans of the karst areas.

Two species (*Pterostichus pilosus*, *Platynus glacialis*), recorded until now as dominant and constant in the sub-alpine limestone screes from the Piatra Craiului Massif (Nitzu, 2016), were also recorded, in this study, in the sub-alpine screes developed in the crystalline schist. For these two above mentioned species, we were able to observe (due to this comparative study) the correlation with the scree habitat in function of altitude and not in function of the geological substratum. However, the abundances of these species were higher in the limestone sub-alpine scree habitat from Piatra Craiului than in the crystalline schist from the Leaota Mountain.

The high diversity and complexity of the fauna from the scree slopes (some of them, like the one studied by us, protected as Natura 2000 habitats) require further studies for a better understanding of their importance and protection within the biosphere.

The large diversity of fauna and its complexity in the scree slopes, some of them (as in the case of the scree we have examined) protected as Natura 2000 habitats, require subsequent ecology studies in order to protect and decrypt the significance of these types of habitats to the biosphere, especially in the context of global climate changes.

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