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Differences in Soil Arthropod Communities along a High Altitude Gradient at Shergyla Mountain, Tibet, China

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Abstract

This is the first time that the soil arthropod community composition along a high-altitude gradient (3,837, 4,105, and 5,050 m a.s.l.) has been investigated in eastern Tibet, China. Five soil samples of 50 cm^2 were taken from each site and extracted for 7 days in Berlese/Tullgren funnels without heating. Acari was the dominant group of arthropods at all three elevations (79%, 53%, and 54%, respectively, from the lower site to the upper site). Prostigmata and Oribatida were more abundant than Mesostigmata and Astigmata at all three elevations. Mesostigmata and Oribatida were most abundant at the upper elevation (about 8,300 and 29,000 individuals/m^2, respectively). Prostigmata and Astigmata were most abundant at the lower elevation (about 170,000 and 20,000 individuals/m^2, respectively). Collembola was most abundant at the middle elevation (about 68,000 individuals/m^2). The insect taxa were most abundant at the lower elevation. Diptera larvae, Protura, and Homoptera were the most abundant taxa along the elevation gradient, while Hemiptera, Thysanoptera, and Protura occurred only at the lower elevation. A multivariate redundancy analysis (RDA) shows that 64% of the variance can be explained by altitude. A change in dominant mite taxa along the elevation gradient could be seen. From the lower to upper sites, the dominant taxa changed from Prostigmata to Prostigmata and Oribatida, and then to Oribatida. About 33 genera in 24 families of oribatid mites were found. The numbers of genera from the lower, middle, and upper elevation were 14, 20, and 19, respectively.

Introduction

Natural ecosystem responses to climate change are difficult to predict, because their mechanistic basis remains poorly understood (Bazzaz, 1990), especially in terms of system processes and the interactions among the system components (Morison, 1990).

Altitudinal gradients can be viewed as Nature's own field experiments (Körner, 1999). Baseline studies along such gradients are therefore much needed to understand past and predict future global changes. Climate is the major factor controlling global patterns of vegetation structure, productivity, and plant and animal species composition (Gitay et al., 2002).

Polar and high mountain regions are predicted to be the most sensitive to global warming. At high northern latitudes, the Global Circulation Models (GCMs) suggest that by the middle of this century, mean summer temperatures may have increased by 1.5–4.5°C (Mitchell et al., 1990; Kareiva et al., 1993). This increase in temperature can have profound implications for the organisms living at such latitudes (Callaghan et al., 1992; Chapin et al., 1992; Danks, 1992), and some studies on soil arthropods and the effect of temperature have been carried out in these regions (Hodkinson et al., 1996; Coulson et al., 1996).

Quantitative investigations of soil arthropods in the Himalayas are few, and completely lacking in Tibet. Shergyla Mountain is located in southeastern Tibet and offers a wide range of elevation over which changes in community structure, biodiversity, and the impact of temperature change can be investigated. The analysis of community structure across environmental gradients frequently reveals changes in dominance and component constitution within taxa. We have therefore chosen soil arthropods for study because they are important to ecosystem processes.

This research is a pioneering approach to the soil arthropod community structure and composition in Tibet and, especially, at such a high elevation (3800–5000 m a.s.l.), with an elevation gradient covering almost 1200 m.

Recently, 7 species new to science and 6 species new to China were found within the frame of the project (Shen et al., 1999; Wang et al., 2001), which significantly increased the number of known oribatid mite taxa in the region.

The aim of this study was to determine the composition and density of soil arthropods, and the structure of soil arthropod communities along a high elevation gradient on the west slope of Shergyla Mountain, Tibet, China.

Methods

STUDY SITES AND SAMPLING

Sampling was carried out on the west slope of Shergyla Mountain (29°35′–29°57′N; 94°25′–94°45′E) in the Shergyla Mountains (29°10′–30°15′N; 93°12′–95°35′E) in southeastern Tibet, China. This mountain area occupies about 2300 km^2 and ranges from 2100 to more than 5000 m in elevation. On the west slope, average annual air temperature at 2500–3000 m a.s.l. varies between 6°C and 12°C. Air temperature of the warmest month is 10–18°C, and precipitation is about 800 to 1000 mm (Xu, 1995).

Samples were taken at three different elevations. The habitat ranged from montane mixed-deciduous broad-leaf/pine forest to alpine meadow/heath. We choose similar open areas at the different elevations for soil arthropod sampling. The environmental gradient is considered to be similar to a change in mean annual air temperature from 14°C in the forested montane section to 4°C in the alpine section of the transect.

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TABLE 1

The community composition of arthropods at the three different elevations: L is the lower site, M is the middle site, and U is the upper site. The numbers are the densities of individuals per sample (50 cm^2) with S.E. in brackets.

		L	M	U
ACARI	Mesostigmata	33 (5.9)	39 (5.1)	42 (13.6)
	Prostigmata	861 (119.1)	241 (83.4)	91 (11.9)
	Astigmata	10 (2.0)	3 (1.5)	3 (1.8)
	Oribatida	109 (26.9)	112 (20.3)	147 (32.5)
COLLEMBOLA	Collembola	205 (38.3)	341 (62.9)	227 (25.3)
INSECTA	Homoptera	13 (2.3)	0.4 (0.2)	6 (2.7)
	Hemiptera	4 (1.7)	0 (0)	0 (0)
	Lepidoptera	2 (1.3)	0.2 (0.2)	0.4 (0.2)
	Diptera	26 (10.9)	12 (2.5)	3 (0.9)
	Coleoptera	4 (1.5)	4 (0.9)	1 (0.5)
	Thysanoptera	4 (1.7)	0 (0)	0 (0)
	Protura	14 (5.6)	0 (0)	0 (0)
ACARI		78.7%	52.5%	54.3%
COLLEMBOLA		16.0%	45.4%	43.7%
INSECTA		5.3%	2.1%	2.0%

The lower site (29°33′43.5″N, 94°34′39.4″E) is at 3837 m a.s.l. The habitat is open grassland in *Quercus* forests, and the understory is mainly *Prunella* sp., *Potentilla* sp., and *Hemiphragma* sp.

The middle site (29°37′5.90″N, 94°37′20.9″E) is at 4105 m a.s.l. The habitat is open grassland in a sparse forest of *Sabina wallichiana*, and the understory is mainly Rosaceae, Gramineae, and Caryophyllaceae.

The upper site (29°37′25.5″N, 94°40′37.2″E) is at 5050 m a.s.l. The habitat is alpine meadow/heath, with mostly mosses, lichens, *Stipa* sp., *Senecio* sp., *Primula* sp., and Euphorbiaceae.

Samples were taken on 28 September 1997. At each site, five replicates of soil samples, each 8 cm in diameter and about 7 cm deep, were taken. Each sample had a surface area of 50 cm^2 and an average dry weight of 99.4 g. Samples were kept under moist conditions and ambient temperatures for 6 days during transportation before extraction.

EXTRACTION

A traditional extraction method with Berlese/Tullgren funnels was used for soil arthropod extraction (Wallwork, 1970). The funnels were 16 cm in diameter and 13 cm in depth, and samples were dried under natural indoor conditions for 7 days. The soil arthropods were preserved in 90% alcohol and then sorted and counted, and the oribatids identified to genera under stereo- and compound microscope. Samples of the arthropods extracted are stored in the Institute of Zoology, Chinese Academy of Sciences, Beijing.

COMPARISON OF SOIL ARTHROPOD COMMUNITIES AT DIFFERENT ELEVATIONS

The community composition analysis is based on absolute counts of the arthropods for each sample. Untransformed values have been used in the statistical analyses. The multivariate tests, *DCA* (Detrended Correspondence Analysis), *PCA* (Principal Component Analysis), and *RDA* (Redundancy Analysis), were done with CANOCO 4.5 for Windows. The calculation of the relative abundance of Acari is based on the average mean of the percentages for each sample. The significance tests were made using one-way *ANOVA* (SPSS 8.0) among the three different elevations.

Results

THE COMMUNITY COMPOSITION OF SOIL ARTHROPODS

The community of soil arthropods at the three elevations is made up of Acari, Collembola and Insecta (Table 1). From the lower site to the upper site, the percentage of Acari to the total soil arthropod abundance was 79%, 53%, and 54%, respectively. At the lower site, the Acari had significantly higher relative abundance than that at the middle and upper site ($F = 6.1299$, $P = 0.0163$), but the difference in relative abundance of Acari between the middle and upper site was not significantly different.

Collembola was most abundant at the middle site (67,939 individuals/m^2). For Insecta, all taxa were more abundant at the lower site, where Diptera, Protura, and Homoptera were more abundant than other groups. Hemiptera, Thysanoptera, and Protura occurred only at the lower site.

The multivariate *DCA* test indicated clearly a linear distribution. Therefore, we proceeded with a *PCA* analysis, which showed that 98% of the observed variation in the data set can be explained by the two first axes (Fig. 1). When we added altitude and did an *RDA* analysis (Fig. 2), we found that 64% of the variance can be accounted for by the elevation factor.

THE COMPOSITION OF ACARI

The absolute density of Mesostigmata and Oribatida did not vary with elevation; with about 33 to 42 mesostigmatids and 109 to 147 oribatids per sample (Table 1).

The relative density of Mesostigmata, however, was significantly higher at the upper site than at the lower site ($F = 3.3133$, $P = 0.0715$), and that of Oribatida was significantly lower at the lower site than at the middle and upper sites ($F = 9.3623$, $P = 0.0035$) (Table 2).

The absolute densities of Prostigmata and Astigmata decreased markedly with elevation (Table 1). For Prostigmata, the density at the middle and upper site was about 30% and 10% of that of the lower level, while Astigmata densities was reduced to about 30% of the density at the lower site.

The relative abundance of Prostigmata was significantly higher at the lower site than at the middle and upper sites ($F = 13.1400$, $P = 0.0009$), while that of Astigmata did not change much with elevation change ($F = 0.0330$, $P = 0.9676$) (Table 2).

Comparing the distribution of the different taxa of Acari within each elevation (Table 2), the results indicate that at the lower site, the relative abundance of Prostigmata was significantly higher ($P < 0.05$) than these of Oribatida, Mesostigmata, and Astigmata, and that of Oribatida was significantly higher than that of Astigmata ($F = 191.118$, $P = 0.0001$).

At the middle site, the relative abundance of Prostigmata and Oribatida were significantly higher than these of Mesostigmata and Astigmata ($F = 11.302$, $P = 0.0003$).

At the upper site, the relative abundance of Oribatida was significantly higher than Prostigmata, Mesostigmata, and Astigmata, and that of Prostigmata was significantly higher than Mesostigmata and Astigmata ($F = 26.438$, $P = 0.001$). Therefore, at all the elevations sampled, the dominant taxa of Acari were always Prostigmata and Oribatida.

An obvious transition of dominant taxa along the elevation gradient could also be seen. From the lower site to the upper site, with the increase in elevation, the dominant order switched from

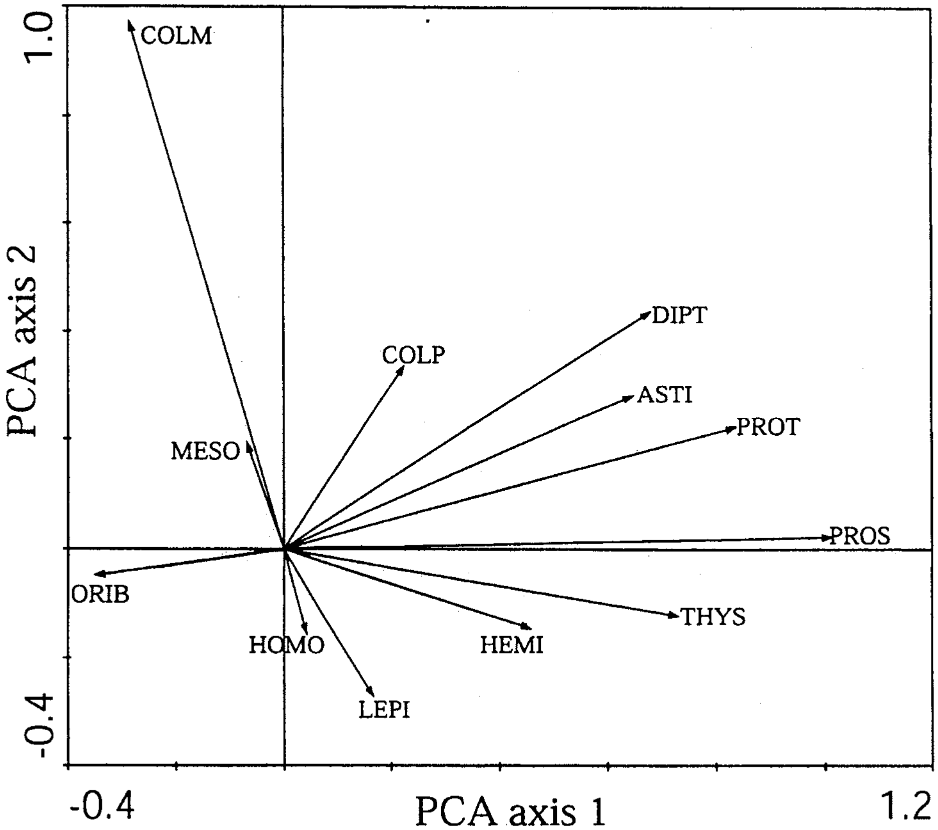

FIGURE 1. PCA *(Principal Component Analysis) for the different orders of the soil arthropods; 98% of the observed variation in the data set can be explained by the two axes. ASTI = Astigmata, COLM = Collembola, COLP = Coleoptera, DIPT = Diptera, HEMI = Hemiptera, HOMO = Homoptera, LEPI = Lepidoptera, MESO = Mesostigmata, ORIB = Oribatida, PROS = Prostigmata, PROT = Protura, THYS = Thysanoptera .*

Prostigmata to Prostigmata plus Oribatida (no significant difference between the two values) and then to Oribatida.

COMPOSITION OF GENERA OF ORIBATIDA

Only oribatids were identified to genus and species, but a few of the immature ones could not be determined at all. About 33 genera in 24 families of oribatid mites were found in the quantitative samples, with a dominance within the families Brachychthoniidae, Oppiidae, and Tectocepheiidae, and with 14, 20, and 19 genera respectively from the lowest to the highest site (Table 3). At the lower site, 4 genera had a relative abundance greater than 5%, while the numbers were 7 and 5 at the middle and upper sites, respectively. The 3 to 5 most dominant genera contain only small species with adult size of 0.2–0.3 mm. More than 90% of the genera have a wide Palearctic, Holarctic, or worldwide distribution (Balogh and Balogh, 1992).

The relative abundance values of the genera were more evenly distributed at the middle site than at the two other sites.

Discussion

(1) The community composition and density of soil arthropods depend to a great extent on the sampling and extraction procedures

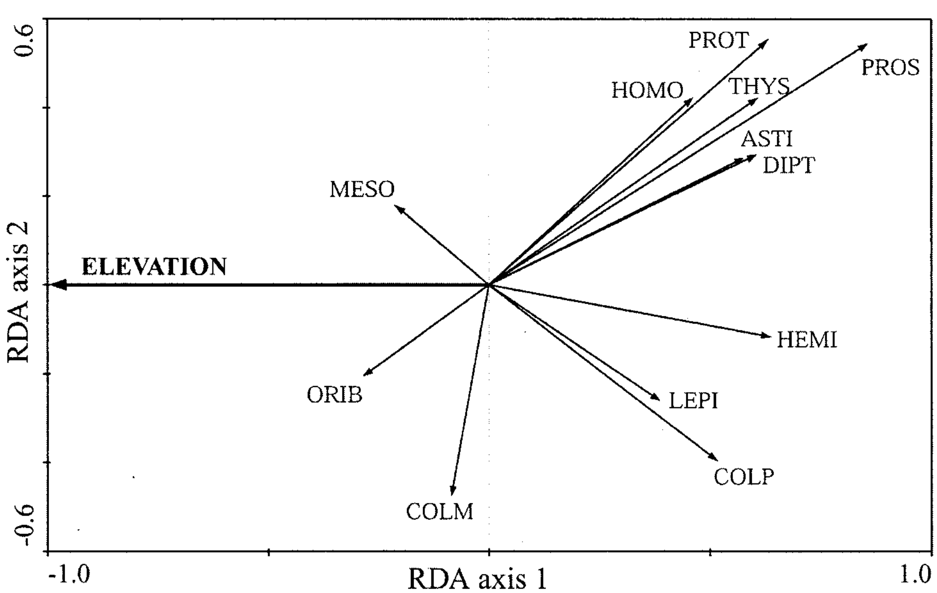

FIGURE 2. RDA *(Redundancy Analysis) for the different orders of the soil arthropods, with altitude added as an environmental variable. Note that only the first axis makes sense; 64% of the variation can be accounted for by the "elevation" variable. Abbreviations same as in Figure 1.*

TABLE 2

The relative abundance (%) of each order of Acari at the three different elevations. S.E. in brackets. Different letters within a row refer to significant differences (P < 0.05) of a taxonomic group among study sites.

Acari	Lower site	Middle site	Upper site
Mesostigmata	3.2 (0.4)[a]	10.9 (2.4)[ab]	15.1 (5.2)[b]
Prostigmata	84.1 (4.3)[a]	53.9 (10.5)[b]	33.6 (4.5)[b]
Astigmata	1 (0.1)[a]	1.1 (0.6)[a]	1.2 (0.7)[a]
Oribatida	11.7 (3.8)[a]	34.1 (9.1)[b]	50.2 (4.7)[b]

used (Wallwork, 1960, 1970, 1976; Huhta, 1972; Edwards, 1991). In particular, variable extraction efficiencies depend on extraction procedure, on animal taxa involved, and to a certain extent on the vegetation/soil types.

Our results rely on three sets of five rather small samples from mountain sites between 3800 and 5100 m a.s.l., which were extracted in conventional funnels by drying out the samples for 7 days at a room temperature between 22°C and 26°C in Beijing after about 1 week of storage at variable ambient temperatures during transportation. The sampling errors and extraction efficiencies are not known, but are probably of the same relative magnitude as in many similar investigations, so we think that comparisons can be made.

Our results also depict only a "snapshot" of the soil community structure on a particular date in a particular year. Differences between different parts of the year and between years may be substantial, but probably much more for soil insects than for mites and springtails (personal observations).

(2) The distribution and altitudinal records of terrestrial arthropods in the Indian and Nepalese parts of Himalaya have been dealt with by Mani (1962, 1968, 1990) and Janetschek (1990). All the groups found in our study have been recorded from at least 4000 to 5500 m a.s.l., and some even up to 6800 m a.s.l.

In our study, the multivariate analysis with altitude as an indirect environmental variable showed that this factor could explain as much as 64% of the variance. This is a value that is quite high and indicated the profound effect of climate change with elevation. That is as expected since the lower site is situated in forest, the middle in an ecotone of subalpine forest/scrubland/meadow, and the third on a windswept alpine hill.

At all sites, the smallest arthropods, i.e., springtails and mites, were dominant. That is especially true for montane and arctic soils (Schatz, 1981; Solhøy et al., 1975; Ryan, 1977; Coulson et al., 1996).

The composition of the soil insects in this study are quite similar to that found from Fennoscandian montane sites (Solhøy et al., 1975). However, in our study, the sap-sucking bugs (Hemiptera) and the thrips (Thysanoptera) were only found in the grassland within the forest, while in Fennoscandian mountains they are common in alpine vegetation (Solhøy et al., 1975). The reason may be that the species found were associated with plant species found only at the lower site. The Protura occur mostly in forest soils, which might reflect the availability of food.

The abundance of the insect groups recorded (more than 90% are immature) may seem quite high, but are within the density values reported from woodland and humid, well-developed alpine soils (Petersen and Luxton, 1983). The abundance of insects also decreases with altitude, which certainly reflects the increase in harshness of the environment and probably less available food. The Homoptera consist mainly of species of aphids and coccids, which are sap feeding from the plant roots. The low number of aphids and coccids at the middle site are probably only due to chance or the lack of appropriate food plants. Larvae of Coleoptera are most common at the lower site, which might also reflect a more limited food supply at the other sites.

In this study, the larvae of Coleoptera and Diptera are herbivore, detrivore, and predatory species. Especially, Diptera larvae (e.g., terrestrial Chironomidae) are very common in both alpine and arctic soil (Bengtson et al., 1974; Sendstad et al., 1976; Danks, 1992). The

TABLE 3

Genus composition of Oribatida at different elevations (L is the lower site, M is the middle site, and U is the upper site). Numbers as total counts of individuals for all samples (5) and their percentage for each elevation.

Lower			Middle			Upper		
		(%)			(%)			(%)
Liochthonius	280	51.2	*Hammerella*	67	15.6	*Tectocepheus*	258	55.6
Oppiella	138	25.2	*Tectocepheus*	64	14.9	Camisiid genus	51	10.9
Camisiid genus	48	8.7	Camisiid genus	47	10.9	*Liochthonius*	37	7.9
Moritzoppia	28	5.1	*Moritzoppia*	47	10.9	*Ramusella*	32	6.8
Suctobelbella	20	3.6	*Ramusella*	44	10.2	*Scheloribates*	28	6.0
Tectocepheus	12	2.1	*Oribatella*	38	8.8	*Eupelops*	19	4.0
Maerkelotritia	7	1.2	*Suctobelbella*	29	6.7	*Zygoribatula*	12	2.5
Scheloribates	4	0.7	*Oxybrachioppia*	16	3.7	*Suctobelbella*	7	1.5
Oxybrachioppia	3	0.5	*Achipteria*	14	3.2	*Oppiella*	4	0.8
Protoribotritia	2	0.3	*Scheloribates*	13	3.0	*Oxybrachioppia*	4	0.8
Palaeacarus	1	0.1	*Sphaerozetes*	12	2.8	*Neoribates*	3	0.6
Podopterotegaeus	1	0.1	*Cultroribula*	9	2.1	*Oppia*	2	0.4
Quadroppia	1	0.1	*Lepidozetes*	8	1.8	*Ceratozetes*	1	0.2
Liacarus	1	0.1	*Liochthonius*	5	1.1	Malaconothriid genus	1	0.2
			Quadroppia	5	1.1	Oribatulid genus	1	0.2
			Pterochthonius	4	0.9	*Pterochthonius.*	1	0.2
			Diapterobates	2	0.4	*Platynothrus*	1	0.2
			Unduloribates	2	0.4	*Quadroppia*	1	0.2
			Ceratoppia	1	0.2	*Unduloribates*	1	0.2
			Fuscozetes	1	0.2			
Total	546	99		428	98.9		464	99.2
Total number of genera	14			20			19	

patchy distribution reflects both abiotic and biotic factors. For instance, the highest densities of soil-living Diptera larvae in high arctic areas of Spitzbergen occur on south-facing slopes below bird colonies, where several thousands of individuals per square meter can be found (Solhøy, personal observation). The decrease in larval densities with altitude in our study probably also reflects declining nutrition and increasingly severe climatic conditions.

On the other hand, there is an effect of altitude that cannot be neglected. When the mean temperature decreases, as in our study area, from 14°C to 4°C from 3800 to 5100 m a.s.l., the length of the life cycle will increase, often to more than 1 yr (Sømme, 1997). This implies that more cohorts of immature and adult individuals can be in the soil simultaneously at higher than at lower altitudes. This would imply higher densities at higher altitudes, even when the primary and secondary production is low. In our study, however, the densities of all arthropod groups (except Collembola) decreased with altitude, which possibly mean that the effect of food shortage and harsh climatic conditions is very pronounced. The densities of Collembola were lower at the lowest and highest sites, compared to the middle site. That could be due to many factors; we think that food in the form of fungal hyphae is not a limiting factor, but possibly predation at the lower site and abiotic factors at the upper site are the limiting factors.

(3) The predatory mites (Mesostigmata) had about the same low densities at all three sites, which may reflect a scarcity of certain food. Astigmata usually occur at low densities in natural soils, and the decrease in numbers with altitude in our study must reflect an increasing habitat adversity or high sample variability. The density of Prostigmata at the highest site decreased to about 10% of that of the lower site. That may be due to the failure of lower altitude forest species to become established at the higher sites.

Oribatida is the most "robust" taxon of the mite groups and has roughly the same densities at all three sites. These values are lower than those reported from several alpine and arctic sites, similar to those of other sites, and higher than many densities found in high arctic sites (e.g., Convey, 1994). The densities in our study reflect a rather suitable alpine/heath habitat, but with a shortage of food and climatic harshness. As the densities of oribatids did not change with altitude, we may assume that they are little affected by the temperatures reported in this study, which seems to be in accordance with the results obtained by Coulson et al. (1996) from a high arctic site.

Only adult oribatids and the nymphs of a few species have been determined further into genera. Of about 33 genera found in the quantitative samples, about 80% to 90% are widespread Palearctic, Holarctic, or worldwide genera (Balogh and Balogh, 1992). In the lower and upper sites, 65%–75% of the specimens belong to only 2 genera, while in the middle site the individuals are more evenly distributed among the genera. This may be explained by the harsh climatic condition at the upper site and a possible grassland habitat of shorter existence within the forest at the lower site. Even if the conditions are favorable at the lower site, several of the species with a low dispersal rate may not have had time to settle in this rather small grassland within the woods.

The more even distribution of individuals between genera at the middle site may be due to the existence of more niches there, being situated in the ecotone between the forest and the alpine grassland/heath.

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