DE GRUYTER

Biologia **72**/2: 184—193, 2017
Section Zoology
DOI: 10.1515/biolog-2017-0021

Harvestmen (Opiliones) communities in an arboretum: Influence of tree species

Slavomír Stašiov[1], Eva Michalková[1], Ivan Lukáčik[2] & Marek Čiliak[3]

[1]*Department of Biology and General Ecology, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, T. G. Masaryka 24, SK-96053 Zvolen, Slovakia; e-mail: stasiov@tuzvo.sk*
[2]*Borová hora arboretum, Technical University in Zvolen, Borovianská cesta 66, SK-96053 Zvolen, Slovakia, e-mail: lukacik@tuzvo.sk*
[3]*Department of Applied Ecology, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, T. G. Masaryka 24, SK-96053 Zvolen, Slovakia; e-mail: marek.ciliak@tuzvo.sk*

Abstract: Although harvestmen (Opiliones) are among the best studied groups of arachnids in Europe from the faunistic point of view, there is still lack of available information on ecological requirements of the particular species. Habitat preferences that determine the distribution of species are largely determined by the habitat structure and microclimate. Besides other factors, these characteristics of habitats are also influenced by the nature of the vegetation. Therefore, our study dealt with the influence of tree species on harvestmen communities. We conducted the research on nine sites in the Borová hora arboretum (Zvolen town, Central Slovakia). Each studied site represents a monoculture of one of nine tree species. On each site also some attributes of soil and leaf litter (pH, conductivity, content of H, C, N and P) were evaluated. Harvestmen were collected by pitfall trapping during vegetation periods in 2008–2012. In total, 2515 individuals of 17 species and 3 families were obtained. Significant differences were revealed between the compared forest stands in terms of total epigeic activity and species richness of harvestmen. The hierarchical cluster analysis divided harvestmen communities into two main clusters (except community of the site with European hornbeam). The first one represented four sites with relatively lower canopy ($< 50\%$) and with the higher number of captured individuals, the second cluster grouped four sites with higher canopy ($> 50\%$) and with the lower number of captured individuals. The results of research confirmed statistically significant relationships between the litter conductivity and equitability and between the litter pH and equitability of harvestmen communities.

Key words: arboretum; harvestmen; Opiliones; tree species

Introduction

Harvestmen are terrestrial arachnids. They live mainly on the soil surface, but occasionally can occur in deeper layers of the soil, on walls and the inside of buildings. Harvestmen have several functions in the ecosystems. These arachnids are known as polyphagous organisms, but prefer animal food. They prey on various invertebrates in different growth stages. This way, harvestmen participate in the maintenance of the natural equilibrium in a wide range of habitats. The other food sources for harvestmen are dead invertebrates and other organic remains. Harvestmen thus contribute to the material cycle and energy flow in nature (Pinto-da-Rocha et al. 2007).

Temperature and humidity of soil are considered the main abiotic factors influencing the structure of harvestmen communities (Almeida-Neto et al. 2006; Pinto-da-Rocha et al. 2007). However, in forest habitats the distribution of harvestmen is markedly influenced, besides other factors, also by tree species because they affect microclimatic conditions. Only little attention has been paid to the study of tree species influence on the species structure of harvestmen communities (Proud et al. 2011; Merino-Sáinz & Anadón 2015). Although some works include data on species composition of harvestmen communities in different forest stands, they are rather faunistic and do not deal with the comparison of harvestmen communities among studied forest stands (Maršalek 1999, 2004; Maršalek & Stašiov 2015; Mihál 2005; Mihál & Mašán 2006; Stašiov 2000; Stašiov et al. 2003, 2010).

The aim of our research is to specify the influence of tree species and related attributes of soil and leaf litter (pH, conductivity, content of H, C, N and P) on harvestmen communities. The Borová hora arboretum is especially suitable for this purpose due to the possibility to assess the different ecological properties of various tree species in a single homogenous area.

Material and methods

Study sites
The Borová hora arboretum is an important educational and research facility, belonging to the Technical University in Zvolen. The planting of trees started here in 1965

Table 1. Measures of chemical parameters of soil (s) and leaf litters (l) in the study sites.

Site/layer	Tree species	pH/H_2O	κ (MS.CM^{-1})*	H (%W) **	C (%$_W$) **	N (%$_W$) **	P (mg kg^{-1})
BP/s	*Betula pubescens*	5.6	428	2.04	6.0	0.38	19.8
BP/l	*Betula pubescens*	5.8	1000	6.37	45.6	0.45	204
PS/s	*Pinus sylvestris*	4.7	175	1.76	2.9	0.24	14.5
PS/l	*Pinus sylvestris*	4.5	350	4.84	35.3	0.56	104
LD/s	*Larix decidua*	5.0	146	1.56	2.2	0.00	6.6
LD/l	*Larix decidua*	4.2	740	4.64	33.9	0.46	130
CB/s	*Carpinus betulus*	6.5	500	1.74	4.2	0.31	24.3
CB/l	*Carpinus betulus*	5.5	770	4.52	30.6	0.66	228
AA/s	*Abies alba*	4.8	310	1.59	4.1	0.32	37
AA/l	*Abies alba*	5.4	970	4.06	29.0	0.85	199
PA/s	*Picea abies*	4.5	98	1.48	2.6	0.21	8.1
PA/l	*Picea abies*	5.6	790	4.13	29.5	0.66	130
AI/s	*Alnus incana*	7.0	380	1.48	5.0	0.43	15.5
AI/l	*Alnus incana*	5.6	770	4.76	33.8	0.73	161
PN/s	*Populus nigra*	7.2	315	1.41	3.8	0.27	6.8
PN/l	*Populus nigra*	6.9	1300	3.55	24.8	0.93	177
UL/s	*Ulmus laevis*	7.1	473	1.74	8.4	0.63	102
UL/l	*Ulmus laevis*	6	745	4.64	29.5	0.78	249

(Lukáčik et al. 2005). The arboretum is located near the middle reach of the Hron River in Central Slovakia, about 3 km northwest from the centre of Zvolen, between 48°35′42″ and 48°36′06″ N, and 19°07′58″ to 19°10′00″ E. It lies on the south-western foot of the Zvolenská pahorkatina hills, which belongs, from the viewpoint of zoogeography, to the Zvolenská kotlina basin. In the arboretum there are hills ranging in altitudes from 290 m (north-western part) to 377 m a.s.l. in the eastern part (Labanc & Čížová 1993).

Zvolen town belongs to the warm region and warm, moderately humid district with cold winters. The mean annual temperature of this region is +8.8 °C, the mean temperature in the vegetation period is +15.6 °C. Mean annual amount of precipitations is 640 mm, 399 mm in the vegetation period (Čížová 2005).

The research was carried out on nine sites. The minimum distance between sites was 100 m. They differed by the tree species, but also by some attributes of soil and leaf litter (Table 1). An overview and brief description of the studied sites is given below according to the data of Pagan et al. (1975):

PB – stand of Downy birch (*Betula pubescens* Ehrh.), geographic coordinates (GC) – 48°35′45.8″ N and 19°08′09.3″ E, stand canopy (SC) – 50%, altitude (A) – 340 m, exposure (E) – north-north-west, pedogenic substrate (PS) – tuff material slope deposits, sporadically with small addition of silt loams and silicious gravels, soil (S) – saturated cambisols typical;

PS – stand of Scots pine (*Pinus sylvestris* L.), GC – 48°35′47.2″ N and 19°08′16.5″ E, SC – 50%, A – 345 m, E – north, PS – silt loam slope deposits and slope deposits of kaolinized andesite tuff, S – albic luvisols;

LD – stand of European larch (*Larix decidua* (Mill.)), GC – 48°35′49.1″ N and 19°08′23.0″ E, SC – 60%, A – 350 m, E – north, PS – tuff material slope deposits and slope deposits of kaolinized andesite tuff, S – saturated cambisols typical;

CB – stand of European hornbeam (*Carpinus betulus* L.), GC – 48°36′03.8″ N and 19°08′42.1″ E, SC – 80%, A – 310 m, E – north-north-east, PS – tuff material slope deposits with larger addition of silicious gravels, S – saturated cambisols typical with addition of silicious gravels;

AA – stand of European silver fir (*Abies alba* Mill.), GC – 48°35′55.1″ N and 19°08′30.1″ E, SC – 100%, A – 330 m, E – north, PS – tuff material slope deposits with larger addition of silicious gravels, P – two-substratum albic luvisols;

PA – stand of Norway spruce (*Picea abies* (L.) Karst.), GC – 48°35′51.1″ N and 19°08′26.7″ E, SC – 80%, A – 335 m, E – north, PS – silt loam slope deposits and slope deposits of kaolinized andesite tuff, S – two-substratum albic luvisols;

AI – stand of Grey alder (*Alnus incana* (L.) Moench), GC – 48°35′57.8″ N and 19°08′02.8″ E, SC – 80%, A – 290 m, E – none, PS – mainly medium grain size alluvial deposits of the Hron river, S – carbonate glei patterns;

PN – stand of Black poplar (*Populus nigra* L.), GC – 48°35′58.7″ N and 19°08′06.5″ E, SC – 50%, A – 290 m, E – none, PS – mainly medium grain size alluvial deposits of the Hron river, S – carbonate glei patterns;

UL – stand of European white elm (*Ulmus laevis* Pall.), GC – 48°35′54.0″ N and 19°07′58.0″ E, SC – 70%, A – 315 m, E – north-north-west, PS – silt slope deposit with addition of travertine in top layers (20–30 cm), S – calcareous cambisols.

Methods

The research was carried out between 2008 to 2012. Harvestmen were captured by pitfall trapping (Stašiov 2015), using the glass cups with the opening diameter of 5.5 cm and the volume of 0.3 L. Fixation fluid in a trap (approximately one third of the volume) was 1% formaldehyde. On each site we placed three traps in a line at a 5 m distance between neighbouring cups in the common line (27 traps on all the tested sites in total). The traps were active from mid-March to mid-December in all years and were emptied in three-month intervals. The content of three traps of each site and date was pooled. In this way, one joined collection was obtained from each site for one period.

The obtained biological material was sorted in the laboratory. Harvestmen were prepared and subsequently identified to the species level according to Avram (1971), Martens (1978) and Chemini (1984). Specimens were fixed in 80% ethyl alcohol and deposited at the Faculty of Ecology and Environmental sciences of the Technical University in Zvolen, Department of Biology and General Ecology.

Samples of soil and leaf litter for chemical analyses were taken on 28th December, 2009. Five samples of soil (to a

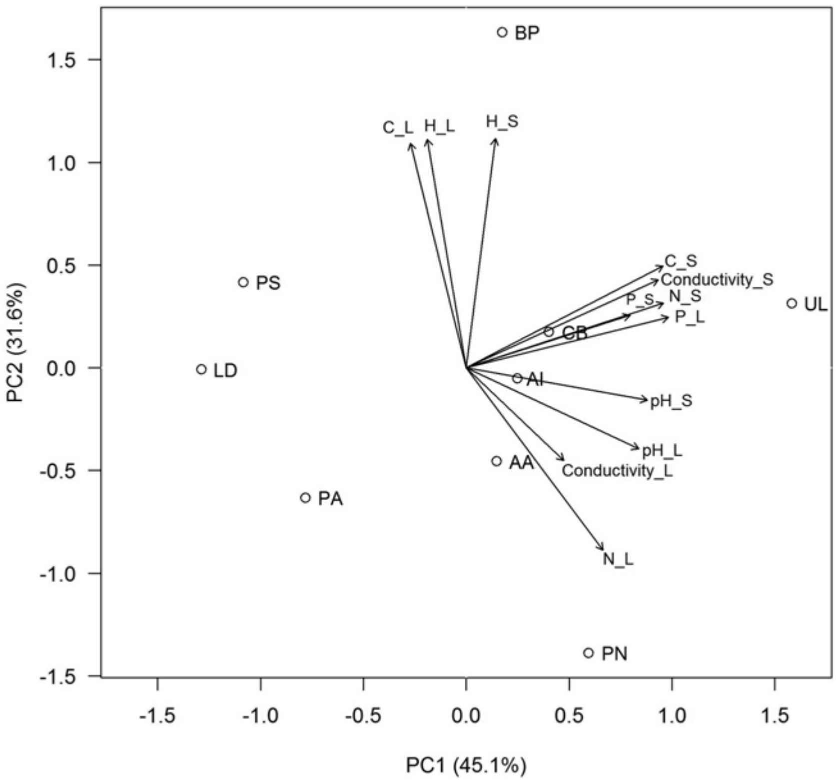

Fig. 1. Principal component analysis (PCA) plot on the correlation matrix of environmental (chemical) data. The variance explained by a particular component is displayed in parentheses. For abbreviations of site names see Table 1.

depth of 10 cm) and five samples of leaf litter, both approximately 100 g, were taken from five different, randomly chosen spots on each site. Multiple samples of soil from one site were pooled into one common sample. The same procedure was also used for samples of leaf litter.

From the primary data, the mean species epigeic activity per 1 day and 1 trap was calculated in order to assess the diversity, equability and similarity of harvestmen communities.

The species diversity was quantified as species richness (S) and by the Shannon index of diversity (H') using natural logarithm (Shannon 1948). The calculation of equitability of harvestmen communities (E) was based on H' (Begon et al. 1997).

In order to assess the relationships between measured environmental variables and epigeic activity, species richness, Shannon index of diversity (H') and equitability (E), we calculated the matrix of pair-wise Pearson correlation coefficients. The significance of correlations was based on 9999 permutations. Only significant relationships were visualized and modelled using the simple regression analysis. Besides simple linear models, polynomial models of second order were tested.

Principal component analysis (PCA) was applied to visualize major trends in the environmental data set. Due to the fact that chemical predictors were measured in different units, data were standardized and PCA was carried out on a correlation matrix. Subsequently, the broken stick model was employed to determine the number of significant principal components (PCs), i.e., only those PCs with eigenvalues larger than values generated by broken stick model were chosen and used for further analyses.

We performed the hierarchical cluster analysis based on Bray-Curtis index to identify similarities between sampling sites based on species composition. Unweighted Pair-Group Method using arithmetic Averages (UPGMA) was chosen as an agglomeration method. Species characteristics for each cluster of sampling sites were obtained using the analysis of indicator species (Dufręne & Legendre 1997). Indicative weight of species was tested by Monte Carlo permutation test (9999 permutations). Significance of differences in species composition of the clusters was tested using the analysis of similarities (ANOSIM, 9999 permutations, Clarke 1993).

Following the hierarchical cluster analysis, metric multidimensional scaling (MDS) was conducted with the Bray-Curtis dissimilarity index to visualize major directions of compositional variation in species data.

Since the number of variables was higher than the sample size (12 vs. 9) and environmental predictors were highly correlated (Fig. 1), we had to use indirect measures of species-environment relationships.

Significant principal components of environmental PCA were used in the analyses instead of original chemical variables. They were overlain on the MDS ordination of the species data as a smooth environmental surface using the ordisurf function (Oksanen et al. 2015). It fits the surfaces of environmental variables to ordinations using generalized additive models (GAMs) with thin plate splines. The smoothing parameter was selected by restricted maximum likelihood (REML). GAMs were also used to determine which species fit significantly to the ordination space of MDS, based on epigeic activity of harvestmen. Only species with the significant fit ($P < 0.05$) to the first two MDS axes were plotted into the ordination diagram.

Furthermore, we performed the simple Mantel test (Mantel 1967) to relate the species and environmental (chemical) data by measuring the correlation between their dissimilarity matrices. Both data sets were transformed to matrices of pair-wise dissimilarities among sampling sites using the Euclidean distance. The Mantel statistic (r) was calculated as the Spearman correlation coefficient between the dissimilarity matrices. The permutation test with 10,000 permutations was used to assess the statistical significance of the Mantel test. 95% bootstrapped confidence interval for the Mantel statistic was obtained from 10,000 iterations.

We were further interested in which of the environmental characteristics (soil or litter) explain more variability in harvestmen species data. To be consistent with the previous analyses (cluster analysis, MDS), we performed two distance-based redundancy analyses (db-RDA) with the Bray-Curtis distance to evaluate marginal effects of soil and litter characteristics separately.

Analyses were performed in R language (R Core Team 2015) using the libraries ecodist (Goslee & Urban 2007), labdsv (Roberts 2015) and vegan (Oksanen et al. 2015).

Results

Community composition

In total, 2515 individuals of harvestmen from 17 species and 3 families were obtained during the whole investigation. The values of total epigeic activity of harvestmen, recorded on individual sites during the research, are shown in Table 2. *Lacinius ephippiatus* (918 captured individuals), *Zachaeus crista* (466 ind.) and *Rilaena triangularis* (270 ind.) were the dominant species. *Lacinius ephippiatus*, *Lophopilio palpinalis*, *R. triangularis* and *Z. crista* were recorded on all studied sites and *Nelima sempronii*, *Oligolophus tridens* and *Trogulus tricarinatus* were recorded on 8 studied sites, i.e., they are also characterised by the highest frequency. *Astrobunus laevipes*, *O. tridens* and *Nemastoma lugubre* (recorded on 7 sites) are considered to be the frequent species as well. On the contrary, *Leiobunum rotundum* and *Mitostoma chrysomelas* were recorded only at one site for the entire period of research, as well as *Lacinius horridus* (2 sites) and *Trogulus nepaeformis* (3 sites) belonging thus to the rarest species.

Most individuals (597 ind.) as well as most species (14) were recorded on the site PA with Norway spruce (Table 2). The site with Black poplar (PN) was on the second place concerning the number of captured individuals (580 ind.). Thirteen species were recorded on this site and on site with Scots pine (PS).

The sites with European hornbeam (CB), Grey alder (AI) and European white elm (UL) were the poorest concerning the number of captured individuals (59, 96 and 111 ind., respectively) (Table 2). The sites with European hornbeam (CB) and European larch (LD) were the poorest in terms of the number of recorded species (7 and 10 species, respectively) (Table 2).

The highest values of the Shannon index of species diversity were recorded on the sites PS with Scots pine (1.94), LD with European larch (1.89) and UL with European white elm (1.88). The lowest value of this index was recorded on the sites CB with European hornbeam (1.30) and PN with Black poplar (1.47) (Table 2).

The highest values of the equitability index (E) were calculated for the sites LD with European larch (0.82) and UL with European white elm (0.78). The lowest value of this index was recorded on the sites PN with Black poplar (0.57) and PA with Norway spruce (0.61) (Table 2).

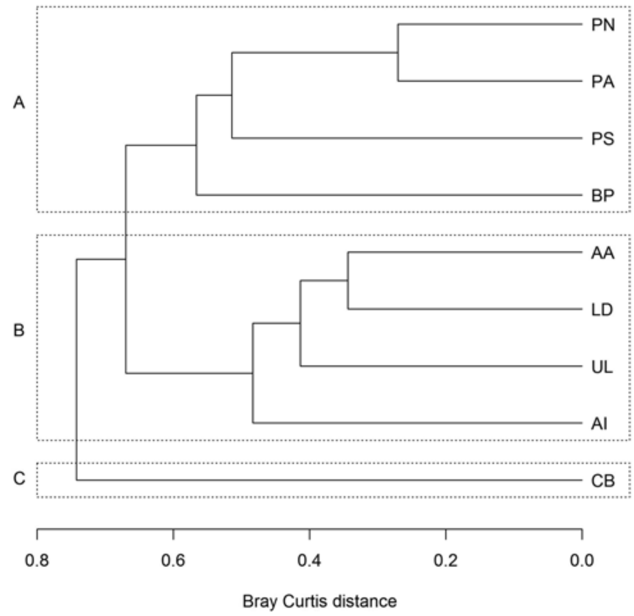

Fig. 2. Hierarchical cluster analysis of similarity between sampling sites based on species composition of harvestmen communities. For abbreviations of site names see Table 1.

The hierarchical cluster analysis separated the site CB with European hornbeam (cluster C) as the most different in terms of the species composition (Fig. 2). As stated above, this site was characterized by the lowest number of captured individuals and recorded species as well as by the lowest value of the Shannon index of species diversity within all studied sites. The remaining sites were divided into two clusters. Clusters A and B were statistically significantly different in terms of their species composition (ANOSIM; $P < 0.05$). The first one (A), consisting of sites PN, PA, BP, PS, represented sites with relatively lower canopy (< 50%, except site PA with Norway spruce) and with the higher number of captured individuals. The second cluster (B) grouped sites with higher canopy (> 50%, sites AA, LD, UL, AI) and with the lower number of captured individuals. Within the first cluster, site PA with Norway spruce and site PN with Black poplar were more similar in terms of species composition comparing to sites BP and PS. The sites PA and PN were also similar by the highest nitrogen and phosphorus content in leaf litter and by lowest carbon content in leaf litter and phosphorus content in soil within the sites of the first cluster (Table 1). This result may suggest that environmentally similar sites also had similar community compositions. Indeed, when considering all sites, the simple Mantel test revealed significant correlation between species and environmental (chemical) matrices (Mantel r (95% CL) = 0.45 (0.16, 0.66); $P < 0.05$). In the second cluster, sites LD with European larch and AA with European silver fir were shown to be the most

Table 2. Total number of harvestmen specimens and chosen parameters of harvestmen communities recorded in the study sites.

Taxon/Parameter			Site									∑
			BP	PS	LD	CB	AA	PA	AI	PN	UL	
Phalangiidae												
Astrobunus laevipes (Canestrini, 1872)	♂	A		9	21		5		1	6	7	49
	♀	A		31	42		15	1		14	19	122
	♀	S			1		1			1		3
	?	J		3	6		3			1		13
Lacinius ephippiatus (C. L. Koch, 1835)	♂	A		8	1	1	1	7	1	19	1	39
	♀	A	6	54	5	11	9	264	1	222	21	593
	♀	S		3		5	1	14		20	1	44
	♀	J		1		2				5		8
	?	J	57	36	10	1	3	32	1	88	6	234
Lacinius horridus (Panzer, 1794)	♂	A	1					1				2
	♀	A	1									1
Leiobunum rotundum (Latreille, 1798)	♂	A						12				12
	♀	A						5				5
Leiobunum rupestre (Herbst, 1799)	♂	A		1				12		5		18
	♀	A	1			1		5		4		11
	?	J						3				3
Lophopilio palpinalis (Herbst, 1799)	♂	A	1	10	1		3	4		1	3	23
	♀	A	3	21	2		6	11	3	4	7	57
	♀	S	1	7	1		1	2		1	1	14
	?	J	1	14	3	1		5	2	3		29
Mitopus morio (F., 1799)	♀	A							1			1
	♀	S	2						3	1		6
	♀	J	1						6			7
	?	J	20					14	4	18		56
Nelima sempronii Szalay, 1951	♂	A		1					1	1		3
	♂	S							1			1
	♀	A	1	2			4	2	3	2	2	16
	♀	S			3		3	1			1	8
	?	J	1	1	1		4	4	1	1	1	14
Oligolophus tridens (C. L. Koch, 1836)	♂	A	1	1	5		2	2		6	2	19
	♂	S			1		3			2		6
	♀	A	2	4	3		2	1		4	3	19
Phalangium opilio L., 1758	♂	A	16	3	2		1	3				25
	♂	S		2								2
	♀	A	19	17	1		1	8	3	1		50
	♀	S	1		1							2
	?	J	63	16	6	2		56	1	1		145
Platybunus bucephalus (C. L. Koch, 1835)	♂	A								1		1
	?	J		1					2	19	2	24
Rilaena triangularis (Herbst, 1799)	♂	A	24	40	21	28	10	47	8	87	5	270
	♂	S	1	1				3		5	1	11
	♂	J	1	2		1	1	7		7		19
	♀	A			2							2
	♀	S	1	4	3	1	2	8		15		34
	♀	J	5	2	1	3		4		9		24
	?	J	6	8	2	4				18	1	39
Zachaeus crista (Brullé, 1832)	♂	A	11	3	10	1	17	14	8	2	3	69
	♂	S	7	1	2		3	2	1		1	17
	♂	J	7									7
	♀	A	51	17	35	1	68	54	34	11	18	289
	♀	S	17	1	3		1	2	1		1	26
	♀	J	6		1							7
	?	J	31	2	3		6	4	2	1	2	51
Nemastomatidae												
Mitostoma chrysomelas (Hermann, 1804)	♂	A									1	1
Nemastoma lugubre (Müller, 1776)	♂	A		8	11		2	2	2	21	2	48
	♀	A		2	5					7		14
Trogulidae												
Trogulus nepaeformis (Scopoli, 1763)	♂	A		1							1	2
	♀	A					1					1
Trogulus tricarinatus (L., 1767)	♂	A				1	1					2
	♀	A	1	2	5	4	3	3	2	3		23
	J	S					2			1		3
Total abundance			354	323	212	59	182	597	96	580	111	2515
S			11	13	10	7	11	14	11	13	11	17
H'			1.59	1.94	1.89	1.30	1.65	1.61	1.72	1.47	1.88	
E			0.66	0.76	0.82	0.67	0.69	0.61	0.72	0.57	0.78	

Explanations: ♂ – males, ♀ – females, ? – unidentified sex, A – adult, S – subadult, J – juvenile, S – number of recorded species, H' – Shannon index of diversity, E – equitability.

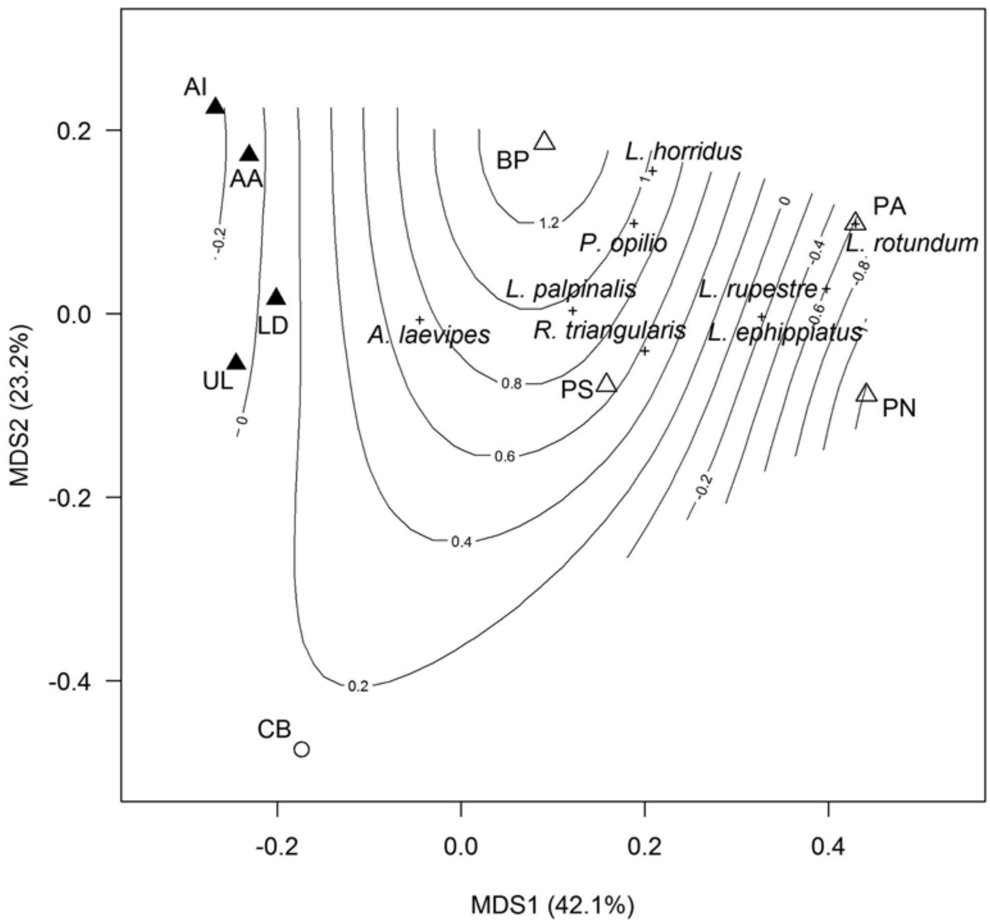

Fig. 3. Metric multidimensional scaling (MDS) ordination plot of the harvestmen community composition in Borová hora arboretum. Contour lines represent the smooth surface of environmental PC2 (see Fig. 1) fitted using a GAM. Classification of sites follows the results of hierarchical cluster analysis (Fig. 2): cluster A – empty triangles; cluster B – full triangles; cluster C – empty circle. Only species with significant fit to the first two MDS axes according to GAMs ($P < 0.05$) are shown. The variance explained by a particular axis is displayed in parentheses. For abbreviations of site names see Table 1.

Table 3. Relationships between measured environmental variables, epigeic activity, species richness, Shannon index of diversity (H') and equitability of harvestmen communities (E). Pearson correlation coefficients and corresponding probabilities based on 9999 permutations are displayed. Significant correlations are in bold.

	Epigeic activity		Species richness		H'		E	
	Pearson r	P	Pearson r	P	Pearson r	P	Pearson r	P
pH_S	–0.27	0.461	–0.29	0.464	–0.30	0.436	–0.14	0.713
pH_L	0.34	0.389	0.18	0.638	–0.56	0.104	**–0.73**	**0.025**
Conductivity_S	–0.57	0.113	–0.63	0.058	–0.42	0.258	–0.05	0.878
Conductivity_L	0.38	0.326	0.05	0.907	–0.59	0.084	**–0.67**	**0.045**
P_S	–0.47	0.085	–0.18	0.471	0.27	0.566	0.37	0.362
P_L	–0.46	0.219	–0.55	0.122	–0.42	0.266	–0.10	0.781
C_S	–0.41	0.240	–0.20	0.546	0.06	0.910	0.14	0.744
C_L	–0.16	0.743	–0.13	0.665	0.19	0.642	0.25	0.525
H_S	–0.29	0.427	–0.32	0.404	0.05	0.929	0.22	0.569
H_L	–0.19	0.677	–0.21	0.506	0.10	0.848	0.20	0.607
N_S	–0.35	0.358	–0.07	0.837	–0.02	0.954	–0.02	0.971
N_L	0.10	0.803	0.19	0.646	–0.30	0.428	–0.44	0.244

similar in terms of species composition. Their species composition was almost identical and differed from each other only by species *T. nepaeformis* (Table 2). Characteristic species for cluster A were *Leiobunum rupestre* (Indval = 100%; $P < 0.05$), *L. ephippiatus* (Indval = 93.4%; $P < 0.05$) and *R. triangularis* (Indval = 82.3%; $P < 0.05$). None species was significantly indicative for clusters B and C.

MDS ordination plot of the harvestmen community composition showed a more pronounced preferences of species *L. rotundum* and *L. rupestre* which dominated at site PA with Norway spruce and species *L. palpinalis*

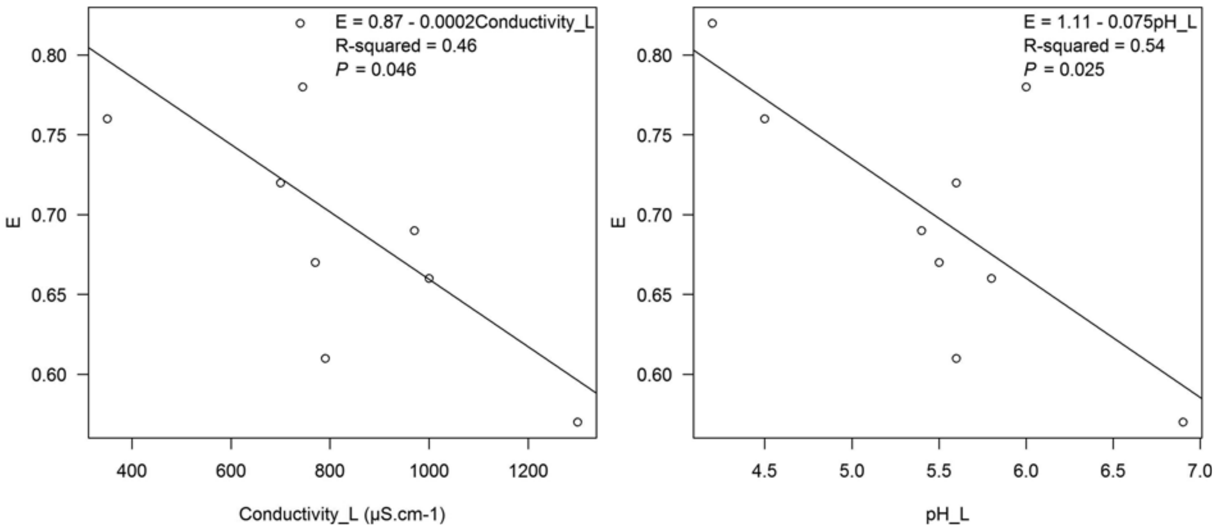

Fig. 4. Relationships between litter conductivity (Conductivity_L) and equitability of harvestmen communities (E) (left) and between litter pH (pH_L) and equitability of harvestmen communities (E) (right) in Borová hora arboretum. Regression equations, least squares lines of linear models, R-squared and corresponding probabilities are displayed.

reaching the highest abundances at site PS with Scots pine (Fig. 3).

Influence of environmental factors on harvestmen communities

Correlation and regression analysis revealed statistically significant relationships between the litter conductivity and equitability and between the litter pH and equitability (Table 3, Fig. 4). Simple linear models showed that this community characteristic decreased with the increase of corresponding environmental predictor values (Fig. 4). Polynomial models of second order did not show better fit than simple linear models (not shown). We did not find any statistically significant relationships between measured environmental predictors and epigeic activity, species richness and Shannon index of diversity. Similarly, as in case of pH, conductivity reached the lowest values in coniferous stands – PS with pine and LD with larch and highest ones in deciduous stands – BP with birch and PN with poplar (Table 1). Therefore, harvestmen communities generally showed higher values for equitability in coniferous stands.

The broken stick model revealed two first principal components of environmental PCA to be significant. The first principal component (PC1) by itself accounted for 45.1% and second principal component (PC2) explained 31.6% of the total variability in the chemical data. While PC1 probably represents gradient of soil conductivity, PC2 seems to express the gradient of C:N in leaf litter (Fig. 1), since the upper side of the ordination space is characterized by higher carbon content in litter, and towards the bottom side, nitrogen content in litter increases.

The PCA ordination of harvestmen was overlain with the fitted smooth surface of PC1 and PC2. However, the GAM showed that harvestmen community composition was significantly related only to the fitted surface of the second principal component (approximate $P < 0.05$, Fig. 3).

According to the db-RDA results, litter characteristics seem to be somewhat more important for harvestmen communities than soil predictors. The former explained 77.2% of variability in species data comparing to 71% of variability explained by the latter ones.

Discussion

The variable species composition of harvestmen communities, recorded in the territory of the Borová hora arboretum, is probably related to the diversity of local habitats. This diversity is affected by the vegetation and soil conditions (modified by vegetation) as well as by the location of the arboretum on the boundary of closed forest (in the northern part), grassland (on the eastern side) and urbanized environment (in the south and west). Species with different ecological demands can disperse from these habitats into the arboretum. Therefore, it is not surprising that *Lacinius ephippiatus* as a species of hygrophilic deciduous and mixed forests dominated in the arboretum along with *Z. crista*, a species typical of thermophilic deciduous and mixed forests and their ecotons (Stašiov 2004).

Besides species recorded during this research, *Opilio canestrinii* (Thorell, 1876) was found in the Borová hora arboretum, too. One male of this species was captured in the local greenhouse by individual collection on 7^{th} July, 2016. The original geographic range of *O. canestrinii* comprises Tunisia, the Apennine Peninsula together with the neighbouring islands (Sicily, Malta, Elba) and parts of southern Alps (Martens 1978; Gruber 1985, 1988; Komposch 1993; Delfosse 2004). The species was observed in Slovakia for the first time by Klimeš (1999). The invasion of this species was mentioned, e.g., by Rozwalka & Staręga (2012).

In addition to species recorded in the territory of arboretum Borová hora within our research, two other species of harvestmen were found in the cadastre of Zvolen town, which includes the arboretum – *Opilio parie-*

tinus (De Geer, 1778) and *Opilio saxatilis* (C. L. Koch, 1839) (Stašiov et al. 2010). Thus, the cadastre of Zvolen town represents an exceptionally species-rich territory from the harvestmen viewpoint (20 recorded species). For comparison, Pinto-da-Rocha et al. (2007) considered the species richest communities of harvestmen to occur in the Atlantic forests of Brazil (25 species in certain territory).

The achieved results revealed significant differences between the harvestmen communities of the studied sites in their total epigeic activity, species structure, Shannon index of diversity and also in the species equability. The main factor, which probably greatly determined the observed microclimatic conditions and soil properties as well, was the tree species.

The effect of tree species on harvestmen communities was confirmed by other authors as well. For instance, Rahmani & Mayvan (2003) compared several groups of soil invertebrates including harvestmen in different forest stands in Neka, northern Iran (Caspian forests). They found that the diversity and evenness of edaphic communities was higher in beech forests than in hornbeam forests. Tree species composition affects the structure of harvestmen communities by influencing the microclimatic conditions, especially temperature and humidity. Stašiov et al. (1997) also confirmed the effect of tree species composition on species structure of harvestmen communities. They investigated harvestmen communities at six sites differing in spruce, fir and beech representation in National nature reserve Malý Polom (Slovakia). They concluded that tree species composition of stands played a more important role than exposure of terrain and altitude.

The results of the hierarchical cluster analysis indicated the effect of microclimatic conditions on the structure of harvestmen communities within the study sites (Fig. 2). Furthermore, the clustering of sites based on species composition of harvestmen communities reflected the canopy of sites. Stašiov (2001) found the highest diversity of harvestmen communities in a stand with the highest canopy and vice versa in the submountain beech forest (Kremnické vrchy Mts, Central Slovakia).

The canopy stand has an impact not only on the lighting conditions, but also on temperature and humidity. Several authors declared that temperature and humidity of soil are the main abiotic factors influencing the structure of harvestmen communities (Almeida-Neto et al. 2006; Pinto-da-Rocha et al. 2007). Edgar (1971) recorded various harvestmen species in different types of vegetation in floodplain forests of Michigan. According to the author, it was due to the different species preferences to microclimatic conditions determined by a particular type of vegetation rather than specific preferences of harvestmen to vegetation properties.

Besides the specific microclimatic conditions that are depended on the tree species, the influence of woody plants on harvestmen communities is also related to the quality of the leaf litter and soil. Especially leaf litter can be an important food source for harvestmen as polyphagous organisms. The db-RDA results revealed that leaf litter characteristics seem to be more important for harvestmen communities than soil predictors. Leaf litter properties can affect the species number and structure of harvestmen communities in a similar way as in other organisms consuming leaf litter. Stašiov (2009) studied the influence of the locality factors on the composition/abundance structure of millipede communities (Diplopoda) in mixed Oak-Hornbeam forest stands in Malé Karpaty Mts (Slovakia). The most apparent influence on their community structure was ascertained for pH-value of litter. The effect of litter pH on harvestmen showed to be important in our study as well. We observed statistically significant relationships between the litter pH and harvestmen equitability (Table 3, Fig. 4). Values of the equitability decreased with the increase of litter pH. The lowest values of litter pH were observed at three sites with coniferous tree species (ranked from the lowest pH values – larch (LD), pine (PS), and fir (AA)) and the highest ones at three sites with deciduous tree species (birch (BP), elm (UL) and poplar (PN)) (Table 1). This means that the harvestmen communities generally had a higher equitability in coniferous stands than in deciduous ones. The reason of lower equitability values observed at two (BP, PN) out of three mentioned sites with deciduous tree species was a dominant representation of one particular harvestmen species in community. At site BP with Downy birch, *Z. crista* dominated (36.6%) and *L. ephippiatus* was a dominant species at site PN (59.4%). For a more comprehensive assessment of the effect of litter pH on the equitability of harvestmen communities, it is essential to obtain more data on this relationship, which may be provided by future research.

In addition to pH, the leaf litter of various tree species might differ in other variables such as the C/N ratio. The results of GAM indicated a potential importance of the C/N ratio on species composition of harvestmen communities (Figs 1, 3). Dunger (1958) reported that the leaf litter of different woody plant species varied in C/N ratio that affected the different speed of decomposition under the same conditions. Wallwork (1970) referred the much quicker leaf litter decomposition of broadleaves, compared to most of conifers. In leaf litter with a low C/N ratio, there is a relatively large amount of nitrogen. Leaf litter rich in nitrogen is an attractive source of food for harvestmen or for saprophages – the prey of harvestmen. Similar to harvestmen, they use nitrogen to build their bodies.

Another important leaf litter feature is electrical conductivity. Electrical conductivity has been used as a surrogate measure for such soil properties as salinity, moisture content, topsoil depth, and clay content (Sudduth et al. 2001). According to Atul Kumar (2015) the electrical conductivity is a strong soil health indicator and positively correlates with the content of organic C, P, K, Fe, S and Mn in the soil. Positive correlation of electrical conductivity of soil samples with organic carbon content and available nutrients in soil samples was also confirmed by Chaudhari & Ahire (2013). The scope and focus of our research does not allow to reliably clarify the negative effect of litter conductivity on harvestmen communities. For instance, conductivity may have a direct (through the litter quality) or an indirect impact (through the litter consumers) on food offer for harvestmen and thus also on competitive relationships among species. This may result in changes in species composition and proportions of species in community.

Two sites which offered the most favourable conditions for harvestmen in terms of total epigeic activity and species richness (PA with Norway spruce and PN with Black poplar) (Table 2) markedly differed by type of tree species (coniferous versus deciduous), canopy (80% versus 50%), herb layer (without versus dense) compactness of leaf litter (dense versus loose), pH of litter and soil (low versus high) and certainly also by microclimatic conditions. These sites were similar only in terms of relatively low contents of nitrogen and phosphorus in the soil (Table 1). A site which was the least favourable biotope for harvestmen communities (CB with European hornbeam) in terms of the aforementioned characteristics differed from sites PA and PN by higher soil conductivity and by higher content of all measured elements in the soil (H, C, N, P), however, especially by content of phosphorus in the soil. The design of our study did not allow answer the question whether just these soil properties exclusively determined favourableness or disagreeableness of habitat conditions for harvestmen and why. However, low sample size and missing information on the other important environmental factors (e.g., temperature, humidity) render the drawing of general conclusions difficult.

Strong preference to some of the studied forest stands, which was observed in individual species, corresponds to their ecological requirements (Stašiov 2004). This preference was determined especially by microclimatic conditions in the forest stands, which significantly correlated with their canopy. For example, species of more humid forests (e.g., *Trogulus tricarinatus*) dominated especially in the forest stands with denser canopy (AA, CB), while species of open habitats (e.g., *Phalangium opilio*) preferred the forest stands with more open canopy (BP, PS) (Table 2).

Nevertheless, the distribution of some species on individual sites was also influenced by their relatively large mobility. Thanks to this mobility, harvestmen can temporarily occur on sites that do not offer optimal conditions for them, but harvestmen go through the sites when they are looking for suitable habitats. This is especially true of adjacent forest stands that are not separated by open habitats. Therefore, the species composition of surrounding habitats has a major impact on the structure of harvestmen communities of the individual sites, in particular, for their species richness. Distinguishing between permanent and temporary members of harvestmen communities on individual sites is difficult, particularly for such a small area as the arboretum, where some forest stands are only a few tens of meters apart.

The results of research revealed that an arboretum could provide favourable conditions for harvestmen communities with high species richness. Incidentally, the Borová hora arboretum has the highest species richness of harvestmen in Slovakia with respect to its area (51.4% of previously known Slovak harvestmen fauna occur here).

Conclusions

The results of research confirmed the influence of tree species on harvestmen communities. It affected the species composition and percentage representation of species in communities, as well as the total epigeic activity of harvestmen. Tree species influenced harvestmen communities by modification of environmental conditions – properties of the soil and leaf litter and apparently also microclimatic conditions. Statistically significant relationships were confirmed only between the leaf litter conductivity and equitability and between the leaf litter pH and equitability of harvestmen communities. Nevertheless, the hierarchical cluster analysis indicated also the effect of canopy of the forest stand on the structure of harvestmen communities. Canopy, together with the other factors (e.g., relief, the habitat structure etc.), affects microclimatic conditions of habitats that greatly determine the distribution of harvestmen. Therefore, more information about the importance of these relationships might be revealed by further research, within which not only the influence of the soil and leaf litter properties on harvestmen communities, but also microclimatic conditions will be studied.

Acknowledgements

This study was supported by the Slovak grant agency VEGA, grant number 1/0186/14. We are grateful to Mr. Ben Sorensen (Ashford University) for editing the language and comments on the manuscript.

References

Almeida-Neto M., Machado G., Pinto-da-Rocha R. & Giaretta A.A. 2006. Harvestmen (Arachnida: Opiliones) species distribution along three Neotropical elevational gradients: an alternative rescue effect to explain Rapoport's rule? J. Biogeography **33 (2):** 361–375. DOI: 10.1111/j.1365-2699.2005.01389.x

Atul Kumar H.P. 2015. Electrical conductivity in relation with macro-micro nutrients of agricultural soil of Amereli district. Int. J. Human. Art. Med. Sci. **3 (8):** 25–30.

Avram S. 1971. Quelques speces nouvelles ou connues du genre *Trogulus* Latr. (Opiliones). Travaux de l'Institut de Spéologie "Émile Racovitza", Bucharest **10:** 245–272.

Begon M., Harper J.L. & Townsend C.R. 1997. Ekologie: jedinci, populace a společenstva [Ecology: individuals, populations and communities]. Vydavatelství Univerzity Palackého, Olomouc, 949 pp. ISBN: 80-7067-695-7

Čížová M. 2005. Meteorologické pozorovania v Arboréte Borová hora. In: Lukáčik I. & Škvareninová J. (eds), Autochtónna dendroflóra a jej uplatnenie v krajine, Zborník odborných a vedeckých prác, vydaný pri príležitosti 40. výročia založenia

Arboréta Borová hora, TU vo Zvolene, Zvolen, CD-ROOM, 135 pp. ISBN: 8022814814, 9788022814812

Chaudhari P.R & Ahire D.V. 2013. Electrical conductivity and dielectric constant as predictors of chemical properties and available nutrients in the soil. J. Chem. Biol. Phys. Sci. **3 (2):** 1382–1388.

Chemini C. 1984. Sulla presenza di *Trogulus closanicus* Avram in Austria, Baviera e Slovenia (Arachnida: Opiliones). Ber. Nat.-Med. Verein Innsbruck **71:** 57–61. Clarke K.R. 1993. Non-parametric multivariate analysis of changes in community structure. Austr. J. Ecol. **18 (1):** 117–143. DOI: 10.1111/j.1442-9993.1993.tb00438.x

Delfosse E. 2004. Catalogue préliminaire des Opilions de France métropolitaine (Arachnida, Opiliones). Bull. Phyllie **20:** 34–58.

Dufręne M. & Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. **67 (3):** 345–366. DOI: 10.1890/0012-9615(1997)067[0345:SAAIST]2.0.CO;2

Dunger W. 1958. Über die der Zersetzung Laubstreu durch die Boden-Makrofauna im Auenwald. Zool. Jahrb. Abt. Syst. Ökol. Geogr. Tiere **86:** 139–180.

Edgar A.L. 1971. Studies on the Biology and Ecology of Michigan Phalangida (Opiliones). Miscellaneous Publications (University of Michigan. Museum of Zoology)**144**, 64 pp.

Goslee S.C. & Urban D.L. 2007. The ecodist package for dissimilarity-based analysis of ecological data. J. Statist. Softw. **22 (7):** 1–19. DOI: 10.18637/jss.v022.i07

Gruber J. 1985. Über *Opilio canestrinii* (Thorell) und *Opilio transversalis* Roewer (Arachnida: Opiliones, Phalangiidae). Ann. Naturhist. Mus. Wien **86 B:** 251–273.

Gruber J. 1988. Neunachweise und Ergänzungen zur Verbreitung von *Opilio canestrinii* (Thorell) und *Opilio transversalis* Roewer. Ann. Naturhist. Mus. Wien**90 B:** 361–365.

Klimeš L. 1999. Přehlížení synantropní sekáči (Opiliones): novinky z česko-slovenského pomezí i odjinud [Neglected synanthropic harvestmen (Opiliones): novelties from the Czech-Slovak borderland and other areas]. Sbornik Přírodovědeckeho Klubu Uherské Hradiště **4:** 68–71.

Komposch C. 1993. Neue synanthrope Arachniden für Kärnten und die Steiermark (Arachnida: Opiliones, Araneae). Carinthia II **183 (103):** 803–814.

Labanc J. & Čížová M. 1993. Arborétum Borová hora Technickej univerzity vo Zvolene. Technická univerzita vo Zvolene, 34 pp.

Lukáčik I., Čížová M., Ježovič V. & Škvareninová J. 2005. Arborétum Borová hora 1965-2005. Technická univerzita vo Zvolene, 91 pp. ISBN:80-228-1479-2

Mantel N. 1967. The detection of disease clustering and a generalized regression approach. Cancer Res. **27 (2 Part 1):** 209–220. PMID: 6018555

Maršalek P. 1999. Niekoľko poznámok k faune koscov (Opilionida) Slanských vrchov. Natura Carpatica **40:** 225–230.

Maršalek P. 2004. Opiliofauna Volovských vrchov. Natura Carpatica **45:** 117–124.

Maršalek P. & Stašiov S. 2015. Kosce (Arachnida, Opiliones) pohoria Čergov. Folia Faun. Slov. **20 (2):** 131–134.

Martens J. 1978. Spinnentiere, Arachnida: Weberknechte, Opiliones. Die Tierwelt Deutschlands. 64. VEB Gustav Fischer Verlag, Jena, 464 pp.

Merino-Sáinz I. & Anadón A. 2015. Local distribution patterns of harvestmen (Arachnida: Opiliones) in a Northern Temperate Biosphere Reserve landscape: influence of orientation and soil richness. Belg. J. Zool. **145 (1):** 3–16.

Mihál I. 2005. Kosce (Opiliones) Národného parku Muránska planina. Reussia **2 (1):** 7–14.

Mihál I. & Mašán P. 2006. Príspevok k poznaniu koscov (Opiliones) stredného a východného Slovenska. Natura Carpatica **47:** 89–96.

Oksanen J., Blanchet F.G., Kindt R., Legendre P., Minchin P.R., O'Hara R.B., Simpson G.L., Solymos P., Stevens M.H.H. & Wagner H. 2015. Vegan: Community Ecology Package. R package version 2.3-1. http://CRAN.R-project.org/package=vegan.

Pagan J., Čížová M., Greštiak M., Labanc J., Obr F., Petrík M. & Višňovská V. 1975. Arborétum Borová hora 1965–1975. VŠLD vo Zvolene, 319 pp.

Pinto-da-Rocha R., Machado G. & Gibert G. 2007. Hatvestmen: The Biology of Opiliones. Harvard Univ. Press, Cambridge, Massachusetts, London, 608 pp. ISBN-13: 978-0674023437

Proud D.N., Tibbetts J.A., Moore M.K. & Townsend V.R.Jr. 2011. Diversity of Neotropical harvestmen (Arachnida: Opiliones) inhabiting logs and palm fronds in the rain forests of Trinidad. Ann. Entomol. Soc. Amer. **104 (2):** 241–248. DOI: 10.1603/AN10077

Rahmani R. & Mayvan H.Z. 2003. Diversity and assemblage structure of soil invertebrates in beech, hornbeam and oak-hornbeam forest types. Iran. J. Nat. Resour. **56 (4):** 425–436.

R Core Team 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Roberts W.D. 2015. labdsv: Ordination and Multivariate Analysis for Ecology. R package version 1.7-0. http://CRAN.R-project.org/package=labdsv.

Rozwalka R. & Staręga W. 2012. The invasive harvestman *Opilio canestrinii* (Thorell, 1876) (Opiliones: Phalangiidae) in Poland. Fragm. Faun. **55 (2):** 161–168.

Shannon C.E. 1948. A mathematical theory of communication. Bell System Technical Journal **27 (3):** 379–423 DOI: 10.1002/j.1538-7305.1948.tb01338.x, **27 (4):** 623–656. DOI: 10.1002/j.1538-7305.1948.tb00917.x

Stašiov S. 2000. Opiliofauna Ondavskej vrchoviny. Natura Carpatica **41:** 39–43.

Stašiov S. 2001. Vybrané skupiny epigeickej makrofauny (Opilionida, Diplopoda a Chilopoda) ako indikátory stavu vrchnej pôdnej vrstvy v podhorskej bučine. Vedecké štúdie. Technická univerzita vo Zvolene, Zvolen, 88 pp. ISBN: 80-228-1111-4

Stašiov S. 2004. Kosce (Opiliones) Slovenska. Vedecké štúdie, 3/2004/A. Technická univerzita vo Zvolene, Zvolen, 118 pp. ISBN: 80-228-1318-4

Stašiov S. 2009. Millipede (Diplopoda) communities in mixed oak-hornbeam forest stands – effect of selected site factors. Pol. J. Ecol. **57 (4):** 785–792.

Stašiov S. 2015. Ekológia pôdnych organizmov (pôdne živočíchy). Vysokoškolská učebnica. Technická univerzita vo Zvolene, 150 pp. ISBN: 978-80-228-2830-7

Stašiov S., Bitušík P. & Šamaj J. 1997. Kosce (Opiliones) NPR Malý Polom (CHKO Kysuce). Ochrana prírody, Banská Bystrica **15:** 119–125.

Stašiov S., Hazuchová L. & Mihál I. 2010. Harvestmen (Opiliones) of Zvolen. Sekáči (Opiliones) Zvolena. Acta Rer. Nat. **8:** 37–41.

Stašiov S., Maršalek P., Mihál I., Mašán P., Astaloš B. & Jarab M. 2003. Kosce (Opiliones) Ondavskej vrchoviny. Natura Carpatica **44:** 261–266.

Sudduth K.A., Drummond S.T. & Kitchen N.R. 2001. Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Computers and Electronics in Agriculture **31 (3):** 239–264. DOI: 10.1016/S0168-1699(00)00185-X

Wallwork J.A. 1970. Ecology of Soil Animals. (European Animal Biology Series). McGraw-Hill, London, 283 pp. ISBN-10: 0070941246

Received April 13, 2016
Accepted January 10, 2017