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Short research contribution

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MILLIPEDE (DIPLOPODA) COMMUNITIES IN MIXED OAK-HORNBEAM FOREST STANDS – EFFECT OF SELECTED SITE FACTORS

ABSTRACT: The influence of the site factors related to soil, forest stand and litter as well as to altitude, exposure and slope - on the composition/abundance structure of millipede communities (Diplopoda) was estimated. The research was carried out in 1999 to 2002 in 13 mixed oak-hornbeam forest stands in Malé Karpaty Mts. (South-Western Slovakia) ranged from 132 to 768 m a.s.l. In each locality, millipedes were collected by sieving of the litter taken at monthly intervals from 16 quadrates (25 × 25 cm) in each site. The redundancy analysis was applied. The most apparent influence on the community structure was ascertained for pH-value of litter and age of forest stand. Nitrogen content in litter was the most important factor, influencing the species richness of the millipede assemblages in studied sites.

KEY WORDS: Diplopoda, Millipedes, oak-hornbeam forest stands

Temperature and humidity of soils are the main factors influencing the structure of Diplopoda taxocoenoses (Branquart *et al.* 1995, Meyer *et al.* 1999, Gava 2004). However, in forest habitats the millipede communities are influenced by humus type (Branquart *et al.* 1995, Meyer and Singer 1997), nitrogen content in soil (Stašiov 2005),

carbon and humus content in soil (Stašiov 2002), carbon-nitrogen ratio (Branquart *et al.* 1995), pH- of soil (Scheu and Poser 1996, Smith *et al.* 2006), wood species composition (Meyer and Singer 1997, Gava 2004), age of forest stand (Morón-Ríos and Huerta-Lwanga 2006). The studies on the ecological requirements of the millipedes in oak-hornbeam forest ecosystems are presented in the papers of Rahmani and Mayvan (2003), Stašiov (2005) and Topp *et al.* (2006). The results of these papers reveal that the structure of millipede communities in oak-hornbeam forests is significantly influenced by nitrogen content in litter (Stašiov 2005), wood species composition and soil type (Rahmani and Mayvan 2003), content of nutrients in soil, pH-value of soil, and slope (Topp *et al.* 2007). However, the influence of environmental factors on millipede communities in deciduous forests are rather weakly investigated because the studies focused on this problem are sporadic.

The presented study is aimed especially at the examination of the effects of three selected site factors (nitrogen content in litter, litter pH and age of forest stand) on the species composition/abundance structure of millipede communities.

The research was carried out in 13 oak-hornbeam forest stands, located in Malé Karpaty Mts. (Fig. 1). The studied territory is situated in Western Slovakia within geographic coordinates of 48°10'–48°33' N and 16°59'–17°33' E. The altitude of Malé Karpaty Mts. ranges from 132 to 768 m a.s.l. This region belongs to the West-Carpathian flora with the prevalent occurrence of the mixed oak-hornbeam forest stands.

The studied localities differed by their altitude, slope, exposure, mean age of forest stands, dimensions of trees, species and spatial structure of forest stands, amount of dead wood on the surface of soil, and human impact (pollution by the lime dust). Additional differences resulted from the different degree of forest fragmentation (small forest patches in agricultural landscape vs large forest complexes) and from the local characters of vegetation communities and soil. The latter were assessed separately for the mineral layer of soil and for the litter. Specification of studied localities by chosen parameters is presented in Table 1. The detailed ecological characteristics of studied sites (soil, phytosociological

and climatic conditions) are available in the paper of Zlinská *et al.* (2005).

The studies were carried out in the vegetation periods of 1999–2002. The millipede material was collected from the litter using the sieving method (Stašiov 2006). In each locality, the litter was sampled at approximately monthly intervals from 16 quadrat plots with the dimensions of 25 × 25 cm. In this way, 1 m² of litter was sampled at monthly intervals from each studied site. The millipedes from the sieved samples were separated in the lab using the dry extraction in Tulgren's xeroelectors. The collected individuals were fixed in 70% ethanol and deposited in the author's archive.

All the species found were pooled into three categories according to their abundance in studied localities (Table 2). Each species was classified as *rare* (only 1 individual recorded per locality), *less abundant* (less than 50 individuals recorded in locality), and *abundant* (at least 50 individuals recorded in locality).

The clustering process was performed for classification of sites and species. The Bray-

Table 1. Selected characteristics of localities: AL – altitude, EX – exposure, SL – slope, %C1 – carbon content in litter, %C2 – carbon content in mineral layer of soil, %N1 – nitrogen content in litter, %N2 – nitrogen content in mineral layer of soil, %OS1 – content of organic substances in litter, %OS2 – content of organic substances in mineral layer of soil, pH1 – pH-value of litter (measured in H₂O), pH2 – pH-value of the mineral layer of soil (measured in H₂O), AF – age of forest stand in years. Study sites (compare Fig. 1): BB – Bratislava-Briežky, BK – Bratislava-Koliba, CA – Cajla, DK1 – Devínska Kobyla 1, DK2 – Devínska Kobyla 2, DH – Dúbravská hlavica, FU – Fúgelka, LH – Lošonecký háj, LL – Lošonec-om, NK1 – Naháč-Katarínka 1, NK2 – Naháč-Katarínka 2, NA – Naháč-Kukovačník, VI – Vinosady.

Characteristics	Sites												
	BB	BK	CA	DK1	DK2	DH	FU	LH	LL	NK1	NK2	NA	VI
AL	340	380	270	340	300	350	350	260	340	340	320	300	280
EX	SW	SW	S	S	N	E	S	N	SW	NW	SE	NE	NW
SL	6	0	7	15	10	5	4	1	9	4	45	2,5	6
%C1	26.2	18.0	6.5	8.8	10.0	12.0	14.4	7.4	3.8	7.4	5.4	7.2	8.0
%C2	5.9	4.7	2.8	1.4	3.6	2.0	3.5	3.8	2.7	1.7	3.2	1.8	2.6
%N1	1.1	1.2	0.5	0.4	1.0	0.6	1.0	0.6	0.4	0.9	0.5	0.5	0.7
%N2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.3	0.3	0.2	0.4	0.2	0.2
%OS1	45.2	31	11.2	15.2	17.2	20.7	24.8	12.8	6.6	12.8	9.3	12.4	13.8
%OS2	10.2	8.1	4.8	2.4	6.2	3.5	6.0	6.5	4.7	3.0	5.5	3.1	4.4
pH1	3.8	3.7	4.8	4.7	7.3	4.1	3.9	4.3	6.7	4.2	6.5	4.2	4.5
pH2	3.7	3.7	4.3	4.1	7.5	3.9	3.8	4.4	6.6	3.9	6.4	4.1	4.2
AF	90	95	90	70	50	90	90	90	90	50	90	50	70

Table 2. The list of millipede species recorded in studied area and their categorization according to their abundance in studied localities: * – rare species (1 individual collected in locality), ** – less abundant species (1-50 individuals collected), *** – abundant species (more than 50 individuals collected). Study sites – see Table 1 and Fig. 1 for codes and names of localities.

Taxon	Sites (code)												
	BB	BK	CA	DK1	DK2	DH	FU	LH	LL	NK1	NK2	NA	VI
<i>Glomeris tetrasticha</i> Brandt, 1833													**
<i>Glomeris hexasticha</i> Brandt, 1833		*	**	**	**	**	**	**	**	**	**	**	**
<i>Trachysphaera costata</i> (Waga, 1857)										*			
<i>Polyzonium germanicum</i> Brandt, 1837										*	**		
<i>Cylindroiulus boleti</i> (C.L. Koch, 1847)	**	***	***	***	***	***	**	***	**	**	***	***	***
<i>Enantiulus nanus</i> (Latzel, 1884)	*			**	**	**		**			**		
<i>Julus curvicornis</i> Verhoeff, 1899				**	**					**	***	***	
<i>Kryphioiulus occultus</i> (C.L. Koch, 1847)									*		**		
<i>Leptoiulus proximus</i> (Nemec, 1896)	***	***	**	***	***	**	***	***	**		**		**
<i>Megaphyllum projectum</i> (Verhoeff, 1894)			**	**				*	**				**
<i>Megaphyllum unilineatum</i> (C.L. Koch, 1838)	**		*		**	*					**		
<i>Ommatoiulus sabulosus</i> (Linnaeus, 1758)	**	**	***	***	***	**	*	**	***	**	*	**	***
<i>Unciger foetidus</i> (C. L. Koch, 1838)			**	**		**	**	**		**	**	**	
<i>Unciger transsilvanicus</i> (Verhoeff, 1899)			***	**	**	**		*	**			**	**
<i>Haploporatia eremita</i> (Verhoeff, 1909)	***	**			***	***	**	**	**	**	**	**	
<i>Craspedosoma rawlinsii</i> Leach, 1815	**	***	**	***		**		**	**		**	*	**
<i>Strongylosoma stigmatosum</i> (Eichwald, 1830)		*			**					**	***	**	
<i>Polydesmus complanatus</i> (Linnaeus, 1761)	*	**		**		**	**	*		**	**	**	**

Curtis coefficient and the Pearson product-moment correlation coefficient were used as dissimilarity measures for the clustering of sites and species, respectively. The unweighted pair-group average algorithm (UPGMA) was applied as a clustering method.

The potential influence of environmental factors on the structure of millipede communities was evaluated by the canonical ordination analysis. The data on individual millipede species formed as a matrix of species presence/absence on corresponding localities. Two species, *Glomeris connexa* C.L. Koch 1847 and *Trachysphaera costata* (Waga 1858), were excluded from the analysis due to their very rare occurrence (recorded on the single locality with a very low number of individuals). The method of redundancy analysis (RDA) (ter Braak and Šmilauer 1998) was used due to the relatively homogenous conditions on studied sites and the results of the detrended correspondence analysis (gradient length = 2.065). From among 35 quantified environmental factors, the strongly inter-correlated variables were omitted. After

this selection, following factors entered the analysis as variables: soil acidity (pH-values in H₂O), percentage of carbon and nitrogen in litter, percentage of nitrogen in mineral layer of soil, altitude, exposure, age of forest stand, density of tree, shrub and herb layer. The forward selection with the Monte Carlo permutation test ($P < 0.05$, 999 permutations) was used in order to choose the environmental variables with the greatest potential influence on the millipede communities.

The influence of environmental factors on the species richness of millipedes was evaluated using the non-parametric multiple regression. The process of the selection of environmental variables was identical to the ordination analysis.

In total, 18 species of millipedes from 8 families and 5 orders were found on the studied sites. The list of species and their categorisation according to their abundance on studied localities are shown in Table 2. *C. boleti*. Was the most abundant species in study area. It was classified as abundant on 9 localities. This species together with *O. sabulosus* was also the most

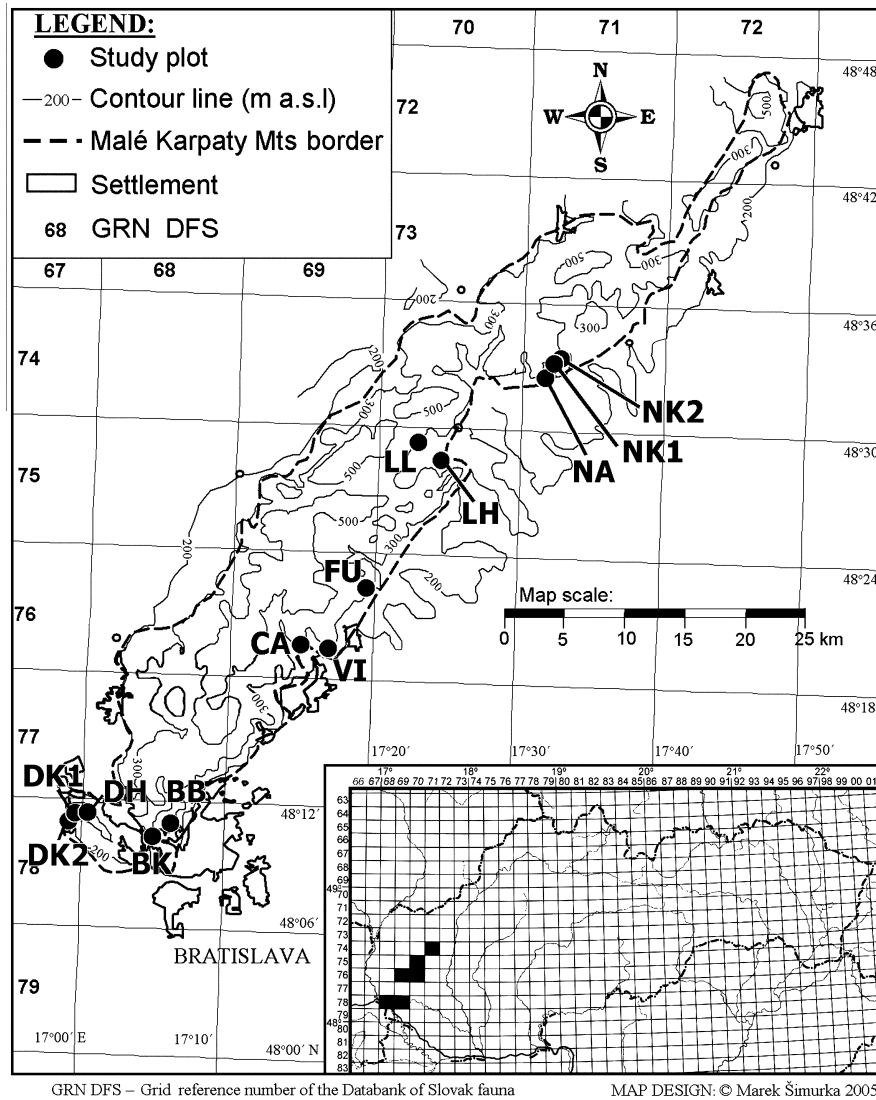


Fig. 1. Location of the studied sites (BB – Bratislava-Briežky, BK – Bratislava-Koliba, CA – Cajla, DK1 – Devínska Kobyla 1, DK2 – Devínska Kobyla 2, DH – Dúbravská hlavica, FU – Fúgelka, LH – Lošonecký háj, LL – Lošonec-lom, NK1 – Naháč-Katarínka 1, NK2 – Naháč-Katarínka 2, NA – Naháč-Kukovačník, VI – Vinosady).

frequent species occurring on all the localities. *L. proximus* belonged to more abundant and frequent species too. *G. hexasticha* belonged to less abundant species, but at the same time it was considered one of the most frequent. The mentioned 4 species can be considered the characteristic representatives of millipede communities in mixed oak-hornbeam forest stands in Malé Karpaty Mts. (Western Slovakia). The rarest and also the least frequent species were following: *G. tetrasticha*, *T. costata*, *P. germanicum* and *K. occultus*.

The results of canonic analysis indicate that the structure of the millipede communi-

ties is affected especially by the nitrogen content in litter and the age of the forest stand (Fig. 2). In total, these factors caused 27.5% of total variability of analysed data on the occurrence of corresponding species. In particular, the nitrogen content caused 14.4% and the age of the forest stand 13.1% of total variation of data in analysed matrix. The results of this analysis divided the species and the sites into the four quadrants. The upper left quadrant is represented by sites with older forest stands and the millipede species which these localities favoured (Table 1). *L. proximus* seems to have the most apparent preference for the

sites with older forest stands. The upper right quadrant contains three localities, characterised by the highest nitrogen content in litter and the lowest number of presented species (Table 1). *H. eremita* appeared to be the species most apparently preferring these localities and thus, the higher content of nitrogen in litter as well. The lower right quadrant grouped the sites with the youngest forest stands (Table 1) and the millipede species that these localities preferred (above all, *J. curvicornis* and *S. stigmatosum*). The last, lower left quadrant, is represented mainly by locality with a relatively young forest stand and the low nitrogen content in litter (Table 1). This locality was favoured by *U. transsilvanicus*, *U. foetidus* and *G. hexasticha*.

The content of nitrogen in litter was the most important factor influencing the total number of species (Fig. 3). The correlation between this factor and the richness (number)

of species was negative. The content of nitrogen caused 30% of total variability of species numbers on corresponding localities. Nevertheless, the influence of this factor was marginally significant ($P = 0.0546$).

The influence of three studied environmental factors (content of nitrogen in litter, pH-value of litter and age of forest stand) on the species structure and richness of diplopodocoenoses was demonstrated by other authors as well. For example, Topp *et al.* (2006) collected millipedes in four primeval forests (including 3 oak-hornbeam forest stands) of West Carpathians, Central Slovakia. They found that the gradient of the chemistry of the upper soil layer, *i.e.* pH and nutrient content, strongly influenced the structure of species assemblages. The influence of the age of the forest stand on the density of millipedes was demonstrated in the evergreen maritime forests of Cerro Huitepec National Nature

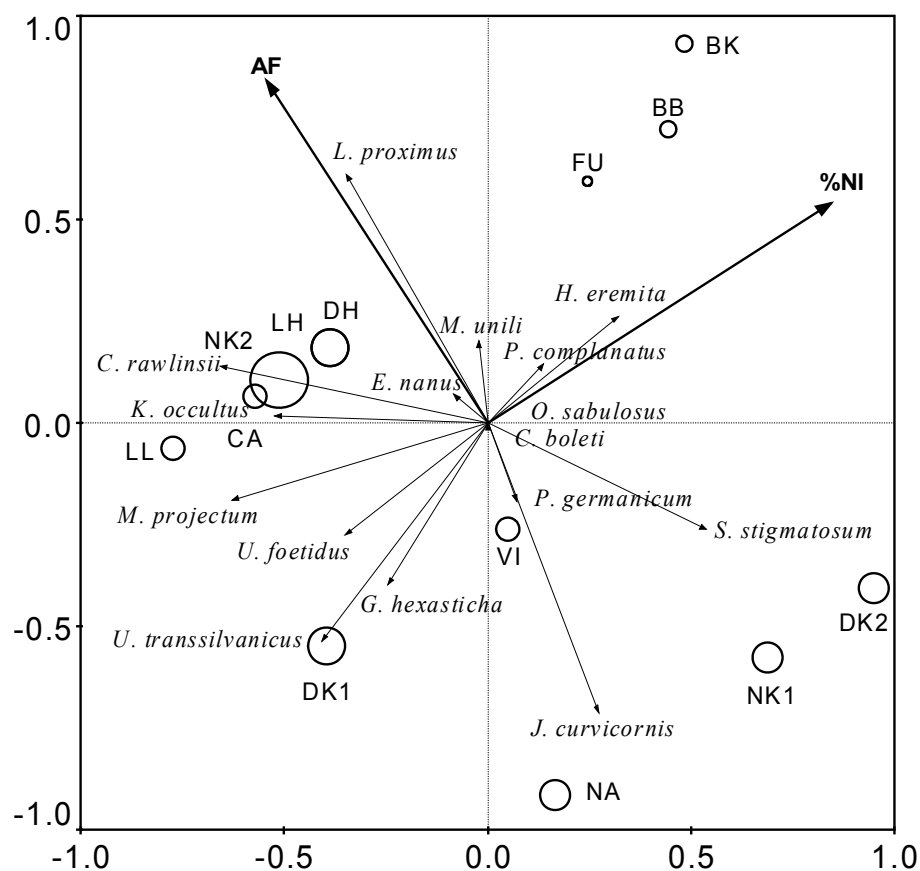


Fig. 2. Results of the redundancy analysis (RDA). The size of the circles indicating the study sites corresponds to the number of species found; names of species – see Table 1. %NI – nitrogen content in litter, AF – age of forest stand. Study sites: BB, BK, CA, DK1, DK2, DH, FU, LH, LL, NK1, NK2, NA, VI – see Table 1 and Fig. 1 for codes and names of localities.

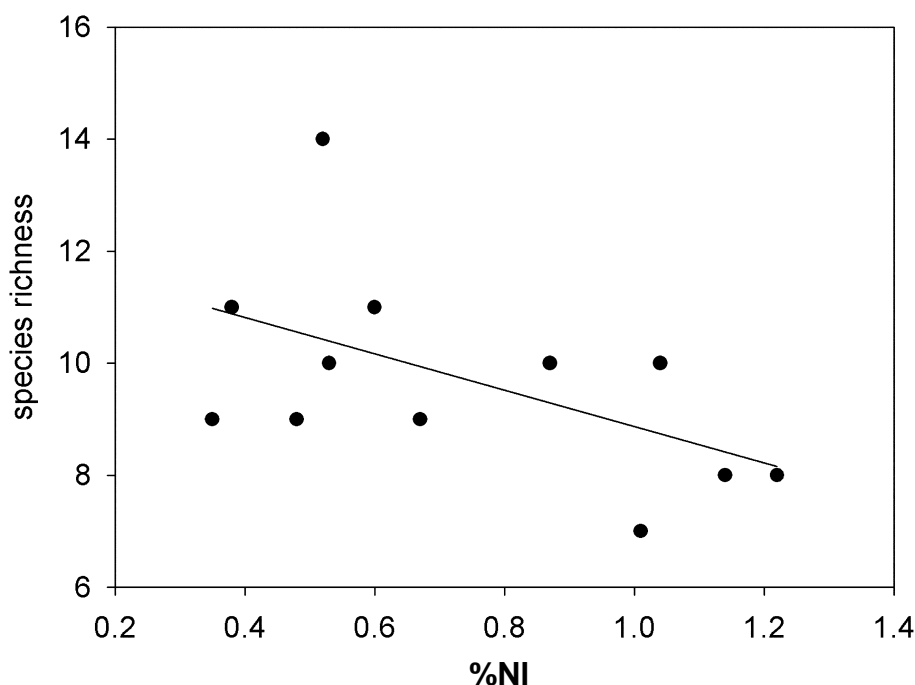


Fig. 3. Relation between the species richness (number of species) of the millipedes and nitrogen content (%) in the litter for 12 study sites (Table 1).

Reserve in Chiapas (Mexico) by Morón-Ríos and Huerta-Lwanga (2006). They ascertained that the millipedes represented at least 54% of all the invertebrate decomposers in a mature forest stand and their density was markedly higher than in the immature forest.

The influence of the nitrogen content in forest litter on the abundance and species richness of the millipede communities was slightly negatively correlated to the acidity of litter. That is because the litter with higher content of nitrogen was usually characterised by the lower pH-value. Although the significance of this correlation was not approved statistically ($r = -0.29$, $P = 0.34$), the data from the studied localities suggest that the sites with the highest nitrogen contents in litter were usually characterised by the lowest pH-values (Table 1). An only exception was the site DK 2 with one of the highest contents of nitrogen in litter and also the highest pH-value among all the localities studied. The relatively high pH-value of the litter from this locality resulted probably from its carbonate bedrock and the high content of calcium in the soil (calcisol). This enhanced content of calcium (compared to the other

localities) caused probably the higher pH-value of litter from this site. Similarly, the mineral layer of the soil was characterised by the highest pH-value from among the all localities compared. However, when the data from the above mentioned locality were omitted and the correlation analysis was computed repeatedly, the significant correlation was demonstrated between the nitrogen content in the litter and the pH-value ($r = -0.86$, $P < 0.01$). When the potential influence of environmental factors on the structure of the millipede communities was evaluated using the RDA analysis and the data from locality DK 2 were excluded, the new results indicated that the millipede community structure was significantly influenced mainly by the pH-value of litter and the age of forest stands. Both these factors caused at least 46.9% of total variability of data on the occurrence of individual species at the significance level of $P < 0.001$. From these two most important factors, the pH-value of litter explained 26.6% and the age of forest stands 23.1% of total variation. When the data from above mentioned locality were omitted, the significant relationship between the species

richness and the nitrogen content in litter was demonstrated as well ($P < 0.05$). In this case, the nitrogen content in litter caused as high as 55% of the variability of species richness, *i.e.* by 25% more than after the same type of analysis, when the data from those three localities were included.

The influence of the acidity on the soil macrofauna including the millipedes was also demonstrated by other authors. For example, Smith *et al.* (2006) mention that the percentage of the cover area by litter, the sampling season and the pH-value of the soil are the most important factors, affecting the population density of five investigated groups of the soil invertebrates (Lumbricidae, Isopoda, Diplopoda, Chilopoda and Formicidae) in the urban parks and gardens of London. Influence of the soil acidity on the communities of the millipedes was studied also by Scheu and Poser (1996). They analysed differences between density, biomass, species composition and vertical distribution of four groups of soil macrofauna (Diplopoda, Isopoda, Lumbricidae, Chilopoda) at various distances from trees in the beech forest on the limestone geological bedrock in Northern Germany. Their findings demonstrated that the soil at shorter distance from the beech trees had lower pH-value than the soil from the sites, located farther from the trunks. CCA showed that the pH-value of soil was a significant factor, affecting the structure of the millipede communities in the vicinity of the trunks of trees, whereas its importance was less remarkable on the more distant sites.

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