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Comparison of collembolan assemblages (Hexapoda, Collembola) of thermophilous oak woods and *Pinus nigra* plantations in the Slovak Karst (Slovakia)

Ľubomír Kováč[a,b,*], Natália Kostúrová[b], Dana Miklisová[b]

[a]*Department of Zoology, Institute of Biology and Ecology, Faculty of Sciences, University of P.J. Šafárik, Moyzesova 16, SK-041 54 Košice, Slovakia*
[b]*Institute of Zoology, Slovak Academy of Sciences, Löfflerova 10, SK-040 01 Košice, Slovakia*

Summary

From the 1950s to 1970s degraded pastures located on the south exposed slopes of the Slovak Karst were extensively afforested by introduced tree species *Pinus nigra*. The study was performed on contiguous sites of native cornel-oak woods and secondary pine monocultures in three different localities of the region (Hrušov, Hrhov, Zádiel) to assess influence of this forest practice on the communities of soil Collembola. *Folsomia quadrioculata*, *Isotomiella minor*, *Megalothorax minimus* and *Pseudosinella horaki* were correlated with soil-chemical parameters of the organo-mineral layer. The mean abundance of Collembola on plots varied between 9100 and 16,700 ind m^{-2}. In total 83 species were collected, the species richness ranged between 31 and 41 per site. The differences in mean abundance and species richness among compared cornel-oak woods and pine plantations were not distinct, except one locality with mean abundance, species richness and indices of diversity significantly lower at plantation compared to oak wood. Altogether 20 collembolan species occurred exclusively in oak-wood stands, *Pseudachorutes dubius* having clear affinity to this habitat. Abundance of *Ceratophysella luteospina*, *I. minor*, *P. horaki* and *Oncopodura crassicornis* obviously prevailed in oak woods. At pine sites, 17 species presented character of exclusivity. *Pseudachorutes parvulus*, *Mesaphorura critica*, *Orchesella bifasciata* and *Lipothrix lubbocki* apparently preferred pine plantations. The occurrence of Carpathian and Western-Carpathian endemics was random, i.e. in very low density and frequency. CCA ordination technique demonstrated minimal impact of

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*Corresponding author. Department of Zoology, Institute of Biology and Ecology, Faculty of Sciences, University of P.J. Šafárik, Moyzesova 16, SK-041 54 Košice, Slovakia.

E-mail address: kovaclu@science.upjs.sk (L. Kováč).

secondary pine growths on the soil collembolan communities. The similarity of Collembola assemblages in thermophilous oak woods and pine monocultures may be explained by similar environmental conditions (microclimate, humus form and soil type) at contiguous sites. Relatively small area of black pine stands likely played a role in faster re-colonisation by epigeic and hemiedaphic Collembola. Time scale of 30 yr (age of young pine plantations) enabled re-establishment of assemblages similar to those of adjacent native oak-wood stands.

Introduction

In the past clear cutting of thermophilous oak woods and subsequent extensive grazing of southern facing slopes by cattle caused in the Slovak Karst erosion of shallow rendzina soils. From the 1950s to 1970s the damaged patches were afforested with various woody plants, e.g. autochthonous manna ash (*Fraxinus ornus*), but especially with introduced black pine (*Pinus nigra*). The latter is well adapted to limestone bedrock producing great woody mass and exhibiting modest demands to soil moisture and nutrients (Tokár, 1985). Therefore, black pine is the most spread and economically important exotic tree planted in karstic regions of Slovakia.

The impact of reafforestation with allochthonous tree species upon Collembola has been studied by several authors, e.g. Jordana et al. (1987), Ferreira et al. (1994), Deharveng (1996), Gama et al. (1997), Pinto et al. (1997), Sousa et al. (1997, 2000) and Barrocas et al. (1998). This type of reafforestation generally causes: (1) habitat alteration (removal of bush vegetation and litter) as consequence of forest practices, (2) rupture of Collembola community structure and dynamics in exotic monocultures and (3) decrease of endemic species abundance and overall decrease of their number. On the other hand, in soils of compared native woods the species richness and abundance of Collembola is usually higher.

The present study aimed to (1) compare structure and diversity of Collembola assemblages of parallel stands of thermophilous oak woods and black pine growths, (2) assess the effect of *Pinus nigra* plantations on the community parameters of soil Collembola and (3) analyse the presence of endemic species at the study plots, the most valuable and vulnerable components of native ecosystems.

Materials and methods

The study was carried out in the Slovak Karst National Park—Biosphere Reserve located in the south-east Slovakia on the junction between oceanic and continental climatic zones. The warmest month is July (+19.4 °C), and the coldest is January (−3.9 °C). Mean annual air temperature is +8.6 °C. The annual average precipitation is 630 mm with a growing season average of 440 mm (Čermák, 1994). Climatic data are based on long-term observations and refer to the nearest meteorological station—Moldava n. Bodvou.

The investigations were performed in three different localities, where the bedrock is Triassic limestone. In each locality two sites were selected, the first one with thermophilous oak wood of submediterranean type (*Corneto–Quercetum*) typical of the south slopes (A), and the second with *Pinus nigra* plantation (B). Both sites were situated at most 500 m apart. Pine plantations represented patchy woods planted in native oak-wood growths:

(1) "Hrušov" (Hrušovská Forest Steppe): 1.7 km north of the village Hrušov (48°35′57″N, 20°38′04″E).

(1A) Dense growth of *Quercus pubescens*, *F. ornus* and *Cornus mas* with dense and diverse herbal undergrowth (*Vincetoxicum* sp., *Melampyrum* sp., *Alliaria petiolata*, *Fragaria vesca*, *Galium* sp., *Lunaria rediviva*, *Polygonatum* sp., *Ranunculus* sp., *Taraxacum officinale*, *Veronica* sp. and grass species). Soil profile (depth 8–10 cm): 0–2 cm litter layer, 0–1 cm fermentation layer, rest of the profile—dark brown organo-mineral (OM) horizon with well-developed rhizosphere; humus form: oligomull.

(1B) Old pine plantation with younger tree species (see Table 1): *Quercus robur*, *Acer campestre*, *Carpinus betulus*, *Fraxinus* sp., *Tilia* sp., and with sparse bush (*C. mas*) and herbal undergrowth (*Mercurialis perennis*, *A. petiolata*, *Dentaria bulbifera*, *Urtica dioica*). Soil profile (depth 8–10 cm): 1–2 cm layer of pine needles and leaves, 5 cm brown layer with sparse rhizosphere, rest of the profile—dark brown layer without rhizosphere; humus form: oligomull.

(2) "Hrhov": 2 km north-east of the village Hrhov (48°36′45″N, 20°46′25″E).

(2A) Moderately dense tree growth of *Q. pubescens*, *F. ornus* and *C. betulus*, dense bush growth with *C. mas*, *Berberis vulgaris* and *Crataegus* sp., and sparse herbs with grass species, *Fragaria* sp., *T. officinale* and *Veronica* sp. Soil profile (depth 7–8 cm): 1 cm litter layer, 0.5 cm fermentation layer, 5 cm dark soil with dense rhizosphere, rest of the profile — dark brown layer with dense rhizosphere and visible patches of cottony hyphal masses of fungi; humus form: dysmull.

(2B) Young and very dense *Pinus nigra* plantation, bush undergrowth very poor with *C. mas* and *Crataegus* sp. Herbal layer very weak with *F. vesca*, *Glechoma* sp. and grass species. Soil profile (depth 9–10 cm): 2 cm layer of pine needles, rest of the profile — layer of pale brown soil almost without rhizosphere; humus form: oligomull.

(3) Zádiel: 0.5 km north-east of the village Zádiel (48°36′57″N, 20°50′28″E).

(3A) Sparse tree growths with *Q. pubescens*, *F. ornus* and *Sorbus* spp., bush layer dense with *C. mas* dominated and *Berberis* sp., *Lonicera* sp., herbal layer dense with *Melampyrum* sp., *Inula ensifolia*, *Galium* sp., *Glechoma* sp. and grass species. Soil profile (8–10 cm deep): 0.5 cm thick litter layer, 2–3 cm layer of dark brown soil with dense rhizosphere and visible hyphal foci of soil fungi, rest of the profile — rhizosphere less dense; humus form: oligomull.

(3B) Young and dense *Pinus nigra* plantation with few younger specimens of *F. ornus*, bush undergrowth dense with *C. mas*, *Crataegus* sp. and *A. campestre*, herbal layer almost absent with sparse grass. Soil profile (depth 8–10 cm): 1.5 cm thick layer of pine needles, 1 cm fermentation layer, 5 cm layer of dark brown soil with dense rhizosphere and hyphal strands of fungi, rest of the profile — dark brown soil with weak rhizosphere; humus form: dysmull.

Soil and site characteristics are given in Table 1. Principally, mull form of humus was present at all investigated sites. Two horizons were separately analysed for soil-chemical parameters, litter layer and mixed OM horizon. Humus forms were estimated according to Brethes et al. (1995). From each site nine soil samples/cores were taken in two sampling occasions (28.IV.2000 and 14.XI.2000) with a soil corer 6 cm in diameter and 7–10 cm deep (Table 1). The sites were sampled randomly, at least 15 m from the edge of the wood growth. Cores were subsequently extracted in the labora-tory in a high-gradient apparatus (Crossley and Blair, 1991). From 108 soil cores 4328 Collembola specimens were extracted and identified to species level following principally taxonomical keys by Babenko et al. (1994), Zimdars and Dunger (1994), Jordana et al. (1997), Fjellberg (1998), Pomorski (1998), Bretfeld (1999) and Potapov (2001).

Abundance (*A*), species richness (*S*), dominance (*D*), frequency (*F*), Shannon's diversity index (*H′*) and Pielou's index of evenness (*J′*) were used as community parameters. Mann–Whitney (non-parametric) test was performed to compare differences between soil-chemical factors and Collembola mean abundance of oak woods, on the one hand, and pine monocultures, on the other hand.

Effect of environmental variables (edaphic factors) on collembolan community composition was estimated using CCA ordination technique by CANOCO software program (ter Braak, 1988). Species present in equal or in less than five samples (frequency $< 4.6\%$) were discharged from analysis (40 from total 83 species) due to uncertain relationship with environmental factors. From soil-chemical parameters measured in OM horizon organic C (C_{org}) content and pH were involved as explanatory variables, from microclimatic factors average soil temperature was used.

Results

Oak leaves had generally higher pH and content of both nitrogen and phosphorus compared to pine needles. In contrary, needle litter had higher content of organic carbon and C/N ratio (Table 1). Chemical parameters of OM layer reflected decom-position status and interactions with limestone bedrock, i.e. higher pH and phosphorus, while lower carbon content compared to litter layer. Content of nitrogen in OM layer was lower compared to litter at most sites. Old pine planta-tion (1B) situated on the hill plateau showed high content of soil nutrients in OM horizon. However, no general pattern of soil nutrient contents may be outlined for two investigated vegetation types, i.e. oak vs. pine. As to the microclimate at sites, old pine stand had the lowest soil temperature and the highest soil moisture compared to all other studied sites as a conse-quence of particular site topography (Table 1). Temperature measured during summer was clearly higher at oak-wood sites compared to pine growths. Soil moisture, on the other hand, did not depend from the habitat types involved.

Table 1.   Soil characteristics and ecological parameters of Collembola at sites in the Slovak Karst

	1A	1B	2A	2B	3A	3B
Altitude a.s.l. (m)	510	525	360	290	420	345
Exposition	SE	NE	S	S	SW	SW
Slope	42°	11°	16°	10°	30°	25°
Soil type	Rendzina	Cambisol	Rendzina	Cambisol	Rendzina	Rendzina
Plantation age (yr)	−	90	−	30	−	30
Plantation size (m)	−	50 × 30	−	100 × 50	−	100 × 50
Number of soil cores	18	18	18	18	18	18
Soil core depth (cm)	8–10	8–10	7–8	9–10	8–10	8–10
Litter						
pH_{H_2O}	4.85	4.85	5.31	4.83	4.96	4.82
C_{org} (%)	43.38	48.24	31.97	38.72	35.53	41.24
N_{org} (%)	1.90	1.51	1.65	1.01	1.18	1.08
P_t (mg kg^{-1})	1555	1153	1144	790	965	881
OM layer						
pH_{H_2O}	4.91	5.18	6.51	5.98	5.94	6.47
C_{org} (%)	22.35	33.65	9.90	8.78	8.97	14.05
N_{org} (%)	1.69	2.16	0.78	0.59	0.65	1.29
P_t (mg kg^{-1})	1601	2262	1203	805	961	938
T (°C) − a	9.1	7.3	8.2	8.5	8.2	8.4
T (°C) − b	16.2	12.8	15.2	14.2	18.1	15.2
W (%)	33.3 ± 19.3	51.4 ± 4.2	25.3 ± 2.7	22.6 ± 4.5	17.3 ± 1.7	19.0 ± 0.4
Species richness	45	41	37	40	41	31
A (ind.m^{-2})	14,900	15,200	16,700	16,600	12,900	9100
St. dev.	± 11,700	± 12,700	± 8700	± 5700	± 6000	± 7800
H'	2.35	2.27	2.56	2.56	2.24	1.56
J'	0.62	0.61	0.71	0.69	0.60	0.45

OM layer, organo-mineral layer; pH_{H_2O}, soil acidity; C_{org}, content of organic C; N_{org}, content of organic N; P_t, content of total P; T, temperature in 10 cm soil depth (a, 14.XI.2000; b, 27.VI.2003); W, gravimetric soil moisture (27.VI.2003); A, mean abundance; St. dev., standard deviation of abundance mean; H', Shannon's diversity; J', Pielou's evenness; abbreviations of sites, see text; A, oak wood; B, pine plantation.

Table 2.   Correlation coefficients and significance levels for the relations between edaphic parameters of OM layer and Collembola abundance, average soil temperature (T_{av}) and soil humidity of sampling sites (for other abbreviations see Table 1)

	pH_{H_2O}	C_{org}	N_{org}	P_t	A	T_{av}	W
pH_{H_2O}	●						
C_{org}	−0.740	●	0.01	0.01			0.01
N_{org}	−0.694	0.977	●	0.05			
P_t	−0.722	0.950	0.895	●			0.01
A	−0.278	0.036	−0.107	0.252	●		
T_{av}	0.104	−0.581	−0.493	−0.557	−0.274	●	
W	−0.708	0.935	0.856	0.970	0.365		●

Relationships between abiotic factors measured and Collembola abundance means were tested and Pearson's coefficients calculated. For correlation analysis chemical parameters of OM layer were used. Positive significant correlation between soil nutrients and soil humidity was observed (Table 2). Neither soil pH nor Collembola abundance means (total or seasonal) were associated with any of the factors measured. Several species revealed significant relationships to soil-chemical parameters of

the OM layer: *Folsomia quadrioculata* with C_{org} ($r = 0.896$; $p < 0.05$), P_t ($r = 0.900$; $p < 0.05$) and W ($r = 0.932$; $p < 0.01$), *Isotomiella minor* with P_t ($r = 0.817$; $p < 0.05$), *Megalothorax minimus* with W ($r = -0.840$, $p < 0.05$) and *Pseudosinella horaki* with average soil temperature ($r = 0.897$; $p < 0.05$).

The mean abundance of Collembola at research sites varied between 9100 and 16,700 ind m^{-2} (Table 1). There was no clear difference in this parameter between oak-wood and pine plantation sites. Moreover, no general pattern in abundance monthly means at sites was observed (Fig. 1). The increase in autumn was detected at two sites (1B and 3A). On the other hand, abundance decreased in the same season at three sites (1A, 2A and 3B), again indifferent of type of vegetation. With exception of old pine plantation (1B), standard deviation of April/November abundance at sites was higher in April, indicating aggregation pattern of population distributions, connected with the reproduction of dominant species at that time.

This was confirmed by high proportion of juveniles in April samples. Extremely high standard deviation of Collembola abundance at site 1A in April was caused by high aggregation of *I. minor* population and partly also by *Parisotoma notabilis*. In old pine forest (1B), the standard deviation was very high in November, where populations of several species were strongly aggregated: *I. minor*, *P. notabilis*, *Folsomia manolachei* and *F. quadrioculata*.

In total 83 species were collected. "*Ceratophysella* sp. juv.", "*Protaphorura* sp. juv." and "*Entomobryidae* sp. juv." were not considered as species in right sense (due to immaturity of individuals we were not sure what species of the genus/family they belonged to). In whole material species *I. minor*, *P. notabilis* and *F. manolachei* were

dominant. Among the most frequent *P. notabilis*, *I. minor*, *P. horaki*, *L. lignorum* and *Protaphorura subarmata* were counted. Species richness at sites ranged between 31 and 41. Similar to abundance means, no apparent difference was seen in this parameter and in diversity indices between sites of both vegetation types (Table 1). The difference was detected just in the locality 3, where mean abundance, species richness and indices of diversity were significantly lower at pine plantation (3B) compared to native oak wood (3A).

Altogether 20 species occurred exclusively in thermophilous oak woods (Table 3), but 12 of them were represented only by one or two individuals, respectively. Clear affinity to oak biotopes was found in exclusive species *Pseudachorutes dubius*. Abundance of *Ceratophysella luteospina*, *I. minor*, *P. horaki* and *Oncopodura crassicornis* prevailed in oak woods. At pine sites, 17 species presented character of exclusivity. Eleven from these species were represented by one or two individuals only. *Pseudachorutes parvulus*, *Mesaphorura critica*, *Orchesella bifasciata* and *Lipothrix lubbocki* were detected in both oak and pine stands, but apparently preferred pine plantations.

Endonura szeptyckii (Weiner, 1973) was the only endemic species recorded during the study, one specimen in plantation 3B (Table 3). Three Collembola species were newly identified and may be "a priori" considered to be endemic. Both *Friesea* cf. *afurcata* and *Metaphorura* cf. *denisi* were detected in very low abundance at one oak site only, and *Pumilinura* cf. *loksai* being distributed in two oak stands (1A and 2A) and in the old pine plantation (1B).

Data set of species with frequency higher or equal to 4.6% and their related abundance were performed by CCA ordination technique. The combination of OM layer chemical factors (pH,
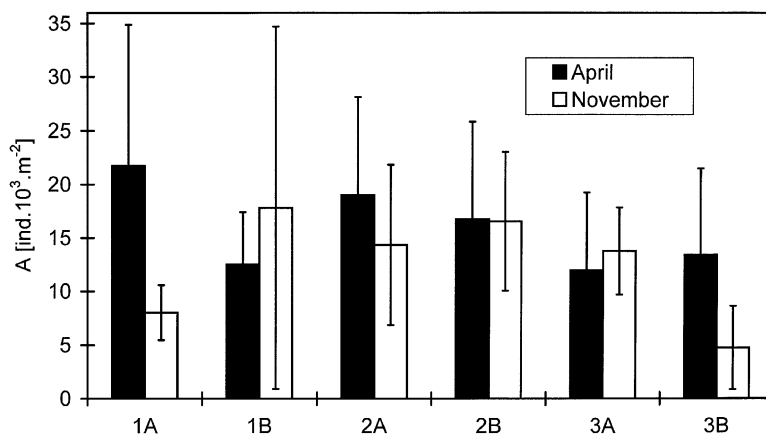

Figure 1. Mean abundance of Collembola at research sites in the Slovak Karst in 2000 (vertical abscissa − standard deviation, abbreviation for sites see Table 1).

Table 3. Abundance of soil collembola species at oak woods (A sites) and pine plantations (B sites) and their mean abundance (*A*), dominance (*D*) and frequency (*F*) in three localities in the Slovak Karst

	Species	1A	1B	2A	2B	3A	3B	A (ind m^{-2})	D (%)	F (%)
	Hypogastrura sp. *juv.*	—	—	—	—	20	—	3	0.02	0.93
	Ceratophysella sp. *juv.*	—	79	236	39	196	—	92	0.65	15.89
CELU	*Ceratophysella luteospina* (Stach, 1920)	79	—	570	373	1356	39	403	2.84	32.71
CESL	*Ceratophysella silvatica* (Rusek, 1964)	—	—	570	39	98	—	118	0.83	10.28
	Choreutinula inermis[a] (Tullberg, 1871)	—	—	39	—	—	—	7	0.05	0.93
WLIN	*Willemia intermedia*[b] Mills, 1934	—	20	—	—	—	86	18	0.12	4.67
WLSC	*Willemia scandinavica* Stach, 1949	39	98	—	59	59	—	43	0.30	9.35
XEBS	*Xenylla brevisimilis* Stach, 1949		59	39	39	20	20	29	0.21	8.41
XESU	*Xenylla subacauda* Stebaeva and Potapov, 1994	806	118	—	—	—	—	154	1.09	6.54
	Friesea cf. *afurcata*[a] Denis, 1926	—	—	—	—	39	—	7	0.05	0.93
	Friesea mirabilis (Tullberg, 1871)	20	—	—	—	—	20	7	0.05	1.87
	Friesea truncata[a] Cassagnau, 1958	20	—	—	—	—	—	3	0.02	0.93
	Superodontella cf. *montemaceli*[b] Arbea and Weiner, 1992	—	—	—	20	—	—	3	0.02	0.93
	Superodontella cf. *pseudolamellifera*[a] (Stach, 1949)	—	—	20	—	—	—	3	0.02	0.93
	Superodontella lamellifera[b] (Axelson, 1903)	—	—	—	20	—	—	3	0.02	0.93
	Micranurida pygmaea[b] Börner, 1901	—	—	—	79	—	20	16	0.12	2.8
	Micranurida spirillifera[a] Hammer, 1953	20	—	20	—	59	—	16	0.12	3.74
PCDU	*Pseudachorutes dubius*[a] Krausbauer, 1898	20	—	118	—	20	—	26	0.18	4.67
PCPA	*Pseudachorutes parvulus* Börner, 1901	59	196	196	393	157	206	201	1.41	27.1
	Deutonura albella (Stach, 1920)	39	20	—	—	—	—	10	0.07	2.8
DECO	*Deutonura conjuncta* (Stach, 1926)	118	79	—	20	—	—	36	0.25	8.41
	Endonura szeptyckii[b] (Weiner, 1973)	—	—	—	—	—	20	4	0.02	0.93
NEPS	*Neanura pseudoparva* Rusek, 1963	79	20	—	550	314	—	160	1.13	14.02
PULO	*Pumilinura loksai* (Dunger, 1973)	—	—	20	—	236	133	65	0.44	10.28
PU01	*Pumilinura* cf. *loksai* (Dunger, 1973)	39	39	79	—	—	—	26	0.18	5.61
	''*Onychiurus*'' sp. *juv.*	20	—	—	—	—	—	3	0.02	0.93
	Heteraphorura variotuberculata[b] (Stach, 1934)	—	20	—	—	—	—	3	0.02	0.93
	Protaphorura sp. *juv.*	39	452	177	747	157	20	266	1.87	20.56
PRAU	*Protaphorura aurantiaca* (Ridley, 1880)	20	157	20	—	59	—	43	0.3	7.48
PRCM	*Protaphorura campata*[a] (Gisin, 1952)	236	—	—	—	216	—	75	0.53	7.48
	Protaphorura pannonica (Haybach, 1960)	216	—	—	—	—	—	36	0.25	2.8
PRSA	*Protaphorura subarmata* (Gisin, 1957)	314	531	845	1847	216	84	639	4.51	52.34
PRSG	*Protaphorura subuliginata* (Gisin, 1956)	216	432	236	668	157	20	289	2.03	40.19
	Protaphorura tricampata[a] (Gisin, 1956)	—	—	—	—	20	—	3	0.02	0.93
	Deuteraphorura silvaria[a] (Gisin, 1952)	—	—	20	—	20	—	7	0.05	1.87
MSCR	*Mesaphorura critica* Ellis, 1976	79	196	—	138		79	82	0.58	14.95
MSFL	*Mesaphorura florae* Simón et al., 1994	—	157	39	648	—	—	141	0.99	11.21
MSHY	*Mesaphorura hylophila* Rusek, 1982	196	39	39	79	236	140	122	0.85	19.63
MSIT	*Mesaphorura italica*[b] (Rusek, 1971)	—	157	—	—	—	—	26	0.18	6.54
	Mesaphorura simoni[b] Jordana and Arbea, 1994	—	—	—	20	—	—	3	0.02	0.93
MSYO	*Mesaphorura yosii*[b] (Rusek, 1967)	—	—	—	196	—	—	33	0.23	4.67

Code	Species							Mean	%	%
MPAF	*Metaphorura affinis*[a] (Börner, 1902)	–	–	–	–	196	–	33	0.23	5.61
	Metaphorura cf. *denisi*[a] Simón, 1985	20	–	–	–	–	–	3	0.02	0.93
KSAN	*Karlstejnia annae* Rusek, 1974	20	20	20	118	–	20	33	0.23	6.54
DOXE	*Doutnacia xerophila* Rusek, 1974	118	39	98	236	20	393	151	1.06	20.56
	Jesenikia sp.[b]	–	20	–	–	–	–	3	0.02	0.93
FOMA	*Folsomia manolachei* Bagnall, 1939	3105	3832	20	3596	118	–	1778	12.55	51.4
FOPE	*Folsomia penicula* Bagnall, 1939	943	59	1454	20	1808	2827	1185	8.27	51.4
FOQU	*Folsomia quadrioculata* (Tullberg, 1871)	138	1297	–	20	–	–	242	1.71	15.89
	Proisotoma cf. *franzi* Haybach, 1962	–	–	20	39	–	–	10	0.07	2.8
ILMI	*Isotomiella minor* (Schäffer, 1896)	4146	3655	3183	648	1100	995	2288	16.1	63.55
ISNO	*Parisotoma notabilis* (Schäffer, 1896)	1592	1592	2437	3144	2004	1636	2067	14.51	84.11
	Desoria tigrina[b] Nicolet, 1842	–	20	–	–	–	–	3	0.02	0.93
	Vertagopus sp. *juv.*[b]	–	–	–	20	–	–	3	0.02	0.93
	Entomobryidae juv.	98	59	727	373	413	42	285	2.01	27.1
ENMA	*Entomobrya marginata* (Tullberg, 1871)	39	157	–	177	157	66	99	0.69	17.76
	Entomobrya multifasdata (Tullberg, 1871)	–	–	–	–	20	39	10	0.07	1.87
	Orchesella albofasciata[b] Stach, 1960	–	–	–	–	–	20	3	0.02	0.93
ORBI	*Orchesella bifasciata* Nicolet, 1842	39	138	79	177	39	61	89	0.62	14.95
ORFL	*Orchesella flavescens*[b] (Bourlet, 1839)	–	20	–	79	–	–	16	0.12	4.67
	Heteromurus nitidus (Templeton, 1835)	–	–	20	–	–	20	7	0.05	1.87
	Pseudosinella cf. *petterseni* Börner, 1901	–	–	–	–	59	20	13	0.09	1.87
	Pseudosinella horaki Rusek, 1985	982	255	825	393	1199	437	682	4.78	62.62
PSHO	*Pseudosinella* cf. *horaki* Rusek, 1985	–	–	–	–	59	–	10	0.07	1.87
	Lepidocyrtus lanuginosus[a] (Gmelin, 1788)	39	–	–	–	–	–	7	0.05	1.87
LELI	*Lepidocyrtus lignorum* (Fabricius, 1775)	138	255	1886	472	491	44	548	3.86	54.21
LE01	*Lepidocyrtus* cf. *lignorum* (Fabricius, 1775)	118	–	–	–	20	39	29	0.21	5.61
	Lepidocyrtus peisonis[b] Traser and Christian, 1992	–	–	–	–	–	59	10	0.07	0.93
	Lepidocyrtus serbicus[b] Denis, 1936	–	20	–	–	–	–	3	0.02	0.93
	Plutomurus sp.[a]	20	–	–	–	–	–	3	0.02	0.93
	Tomocerus sp. *juv.*[b]	–	–	–	39	–	–	7	0.05	1.87
OPCR	*Oncopodura crassicornis* Shoebotham, 1911	98	20	196	–	79	–	65	0.46	10.28
	Megalothorax incertus[a] Börner, 1903	–	–	–	–	20	–	3	0.02	0.93
MGMI	*Megalothorax minimus* Willem, 1900	59	20	648	570	1258	1339	649	4.57	40.19
	Sminthwides sp. *juv.*[a]	–	–	–	–	20	–	3	0.02	0.93
SPPU	*Sphaeridia pumilis* (Krausbauer, 1898)	118	20	39	59	–	–	39	0.28	8.41
	Arrhopalites cf. *pygmaeus*[a] (Wankel, 1860)	20	–	118	–	–	–	23	0.16	2.8
	Arrhopalites cf. *caecus*[a] (Tullbeig, 1871)	–	–	79	–	20	–	16	0.12	3.74
SNAU	*Sminthurinus aureus* (Lubbock, 1862)	157	255	747	39	20	20	206	1.46	14.95
SNEL	*Sminthurinus elegans* (Fitch, 1863)	39	79	648	–	39	20	138	0.97	8.41
	Sminthurinus flammeolus Gisin, 1957	39	–	–	216	–	–	43	0.3	2.8
	Sminthurus cf. *ghilarovi* Stebaeva, 1966	20	20	–	20	20	–	13	0.09	3.74
LILU	*Lipothrix lubbocki* (Tullberg, 1872)	59	59	20	157	–	79	62	0.44	10.28
	Caprainea marginata[a] (Schött, 1893)	–	–	39	–	–	–	7	0.05	0.93
SMFL	*Spatulosminthurus flaviceps* (Tullberg, 1871)	–	314	98	39	20	–	79	0.55	12.15
DSBI	*Deuterosminthurus bicinctus* (Koch, 1840)	59	79	–	20	–	–	26	0.18	5.61
	Total abundance (ind m^{-2})	14,894	15,169	16,682	16,643	12,851	9066			

[a]Exclusive species of native oak stands.
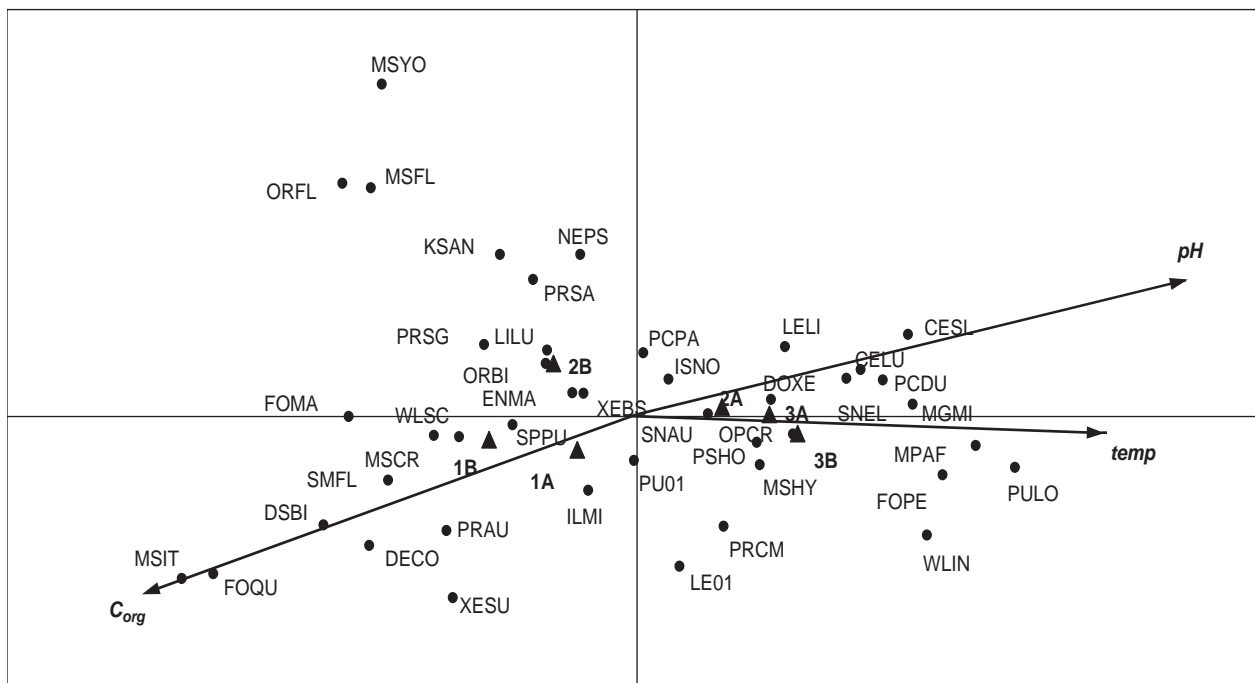[b]Exclusive species of black pine monocultures.

Figure 2. CCA ordination diagram of the sites, species, chemical parameters of OM layer (pH, C_{org}) and average temperature (*T*) of soil according to axes 1 and 2 (eigenvalues 0.34 and 0.16, respectively). For abbreviations see Tables 1 and 3.

C_{org}) and mean soil temperature resulted in Fig. 2. When plotted the most important axes (1 and 2), the sites and associated species were clustered irrespective of the vegetation type. The sites belonging to the same locality were put together showing the effect of the species pool of the particular habitat on the species composition. From dominant species *F. quadrioculata* and *F. manolachei* were affected by higher C_{org} content in OM horizon. On the other hand, *F. penicula*, *L. lignorum* and *C. luteospina* were positively influenced by higher pH.

Discussion

In rendzina soils bacteria and actinomycetes are the main constituents of soil microflora (Szabó, 1974). The Collembola are preferably fungal feeders and may be favoured by high population densities of microfungi in moder or mor soils (e.g. Wallwork, 1976; Rusek, 1989; Schaefer and Schauermann, 1990). This explains lower mean abundance of Collembola at investigated sites with rendzina soil and mull humus. Similar to our results Kubíková and Rusek (1976) observed collembolan abundance range between 6000 and 26,000 ind m^{-2} in xerothermic rendzina soils of the oak wood in the Bohemian Karst in different seasons of the year.

From the previous studies we may summarise that Collembola associated with native forests are more abundant than in reafforested plots (Gama et al., 1994; Sousa and Gama, 1994; Sousa et al., 1997). However, controversial results have been reported by Ferreira et al. (1994) and Gama et al. (1995), who found higher Collembola abundance in *Eucalyptus globulus* plantations compared to native *Pinus pinaster* woods. Reverse results documenting Collembola abundance in two investigated localities, each with parallel plots of native beech forest and conifer plantation, were reported by Deharveng (1996) from French Pyrenees. In the present study, considering the mean abundance of individuals, no statistically significant differences were observed among the studied habitats (oak vs. black pine), except pine site 3B.

Affinity of dominant species *I. minor* to oak biotopes was revealed when compared two contiguous stands. It may be concluded that this species is not primarily affected by the tree origin but rather by the presence of litter with higher decomposition rate, i.e. the litter of lower C/N ratio (Gama et al., 1991, 1994; Sousa and Gama, 1994; Deharveng, 1996; Pinto et al., 1997; Sousa et al., 1997; Barrocas et al., 1998). The positive relationship of the species with nitrogen content in the litter is well supported by the present study. *Oncopodura crassicornis* was restricted by its distribution to oak stands. Pinto et al. (1997)

detected the species in native wood of *Alnus glutinosa* exclusively, compared to native wood of *Populus nigra* and plantations of *Acacia dealbata* and *E. globulus*.

Another set of species reached higher mean abundances in black pine plantations compared to oak stands. *Pseudachorutes parvulus* is known to inhabit different types of forests and plantations without any preferential relationship (Sousa and Gama, 1994; Sousa et al., 1997), or exhibited preference to stands with litter of higher C/N ratio (Deharveng, 1996; Pinto et al., 1997; Barrocas et al., 1998). The same tendency is probable for *M. critica* (Barrocas et al., 1998). On the other hand, literature data concerning the presence of *L. lubbocki* in various types of native forests and plantations (Pinto et al., 1997; Barrocas et al., 1998) show that factors other than litter quality control the distribution of this species. From the species exclusive to black pine plantations two are classified acidophilic — *Micranurida pygmaea* and *Mesaphorura yosii* (Ponge, 1993). Gama et al. (1995) registered the same abundance of the latter species in an oak wood and *E. globulus* plantation. Nevertheless, other data indicates slight preference of *M. yosii* to litter with higher C/N ratio (Ferreira et al., 1994; Barrocas et al., 1998).

Reafforestation generally leads to an increase of ubiquitous and euedaphic species populations and strong reduction of stenotopic forest species, i.e. Neanuridae (Bonnet et al., 1977, 1979; Barrocas et al., 1998). Plantations seem to support a lower diversity and richness of species than autochthonous forests (Jordana et al., 1987; Gama et al., 1991, 1995; Sousa and Gama, 1994; Deharveng, 1996; Sousa et al., 1997; Barrocas et al., 1998). However, Ferreira et al. (1994) and Pinto et al. (1997) observed no clear change in both diversity and similarity of collembolan populations as a consequence of eucalyptus reafforestation. Gama et al. (1994) reported even more diverse community under the *E. globulus* plantation.

Importance of endemic species presence as biodiversity indicators was stressed by Deharveng (1996). The restricted geographical distribution attests to the level of their sensitivity. The author noted evidently higher number and abundance of endemic Collembola in native beech forests than in plantations of introduced conifers in French Pyrenees. On the other hand, no decrease, either in the richness of endemic Collembola or in the abundance of their populations, was observed under *Eucalyptus* plantations compared to native oak stands by Barrocas et al. (1998). Several authors (Sousa et al., 1994, 1997; Barrocas et al., 1998) stated that plantations usually cause a perturbation on species with more specific requisites, independently of their character of endemicity. Deharveng (1996) concluded that the effects of artificial reafforestation on biodiversity are weaker in endemic poor habitats, which is likely the case of the present study, too. The possible reason of generally low number of endemic species at our sites is that in Collembola the majority of such species are known to prefer more suitable mesophilous conditions. The thermophilous oak forests of the southern slopes of the Slovak Karst are considered microclimatically extreme habitats (Čermák, 1994; Tužinskỳ, 1999), with limited number of species, mostly ubiquitous or xerotolerant, that are able to cope with specific environmental conditions of higher soil temperature in summer and low moisture during most parts of the year. During the early summer measuring the soil temperature in majority sites with roughly south slope reached over +15 °C in depth of 10 cm. This value is considered upper limit of thermo-biological span for the majority of Collembola species (Rusek, 1989). This microclimatic situation manifests xerothermic type of microhabitat, and it is clear that only several species are active during summer period of drought. Deharveng (1996) carried out his investigations in mountain mesophilous forests, where coniferous litter lead to significant decrease of soil pH. As consequence, endemic Collembola species were almost totally absent in coniferous plantations.

In reafforested plots patterns of soil biota depends on substrate qualities as well as tree species used for afforestation (Frouz et al., 2001). Based on general literature on coniferous litter decomposition (e.g. Wallwork, 1976), we could expect that pine litter initiate the change of soil-chemical properties which subsequently leads to alteration of community structure of Collembola. Oak and pine litter of particular sites differed obviously in pH and content of nutrients. However, it was not the case for mixed OM layer. Pinto et al. (1997) stressed the importance of nitrogen content influencing the densities and structure of the soil collembolan communities. It is well demonstrated by the present study, where abundance of dominant *I. minor* was correlated with N content of the litter. Content of this nutrient controls palatability of the leaves to soil fauna and supports higher fungal biomass (Wallwork, 1976; Petersen and Luxton, 1982; Vannier, 1988; Ponge, 1999). Deharveng (1996), however, did not detect any soil characteristic that may have mediated the strong effect of a plantation on the collembolan communities in general, and on the depletion of endemics in particular. Gauquelin et al. (1996) studied

physico-chemical parameters of the OM layer in native forests and plots reafforested by conifers in French Pyrenees in four localities with cambisol. Similarly, changes in these parameters remained low and often not significant between native forests and plantations. Pilko (1999) reported from a karstic region of Slovakia (Strážovské Mts.) minimal effect of secondary pine growths on chemical attributes of rendzinas. The author explained it as soil "resilience", i.e. ability of carbonatic soils to compensate fulvic acids released during decomposition of pine needles. This is due to contact of shallow rendzina soils with limestone skeleton, which continuously enriches the soil with cations (Kubíková and Rusek, 1976). It has been stressed by Szabó (1974) and Wolters (1991) that transport of base-rich soil occluded in mesofauna faeces is very important feature of the buffering effect of mesofauna in calcareous soils.

From the ordination analysis based on the same data set and temperature plus chemical factors of OM layer the importance of local species pool/stock for community composition of Collembola may be concluded. Jordana et al. (1987) came up with conclusion that Collembola populations of different soils of the particular geographic region were more similar compared to soils of the same forest type within several regions in Navarra (Spain). Deharveng (1996) suggested that the stock of species available in a given area or habitat is related to the biogeographical history of its fauna and might be the determining factor for understanding and forecasting the modifications induced by any kind of disturbance in local fauna. Geographical location and ecological history of the locality determine in great extent a given set of species and their response to disturbance (Liss et al., 1986; Jordana et al., 1987; Deharveng, 1996).

The similar diversity of Collembola species in young pine monocultures, compared to that of oak woods in this study, is likely connected with area of pine growth patches.

Plantation area is important especially considering ability of particular species to disperse actively from the surrounding habitats. The smaller area might support faster colonisation by such species from adjacent native woods. Recent studies give confirmation that some epigeic or even hemiedaphic Collembola may have great colonisation activity (Petersen, 1995; Mebes and Filser, 1997; Alvarez et al., 2000). In hemiedaphic species the estimated dispersal distance for time scale 30 yr may be over 30 m (Ojala and Huhta, 2001). It is probable, that majority of species in the present study were able to found their populations from in situ surviving animals, or re-colonised these plots from surrounding habitats. The colonisation ability of *Pumilinura* cf. *loksai*, however, is likely low that may explain the absence of this species in two sites with young pine plantations (2B and 3B).

From various studies (e.g. Sousa and Gama, 1994; Sousa et al., 1997), the effect of plantations upon soil fauna in considerable extent seems to depend on particular forest management practices during planting and running the stand. They lead to the changes in habitat configuration, particularly at the organic horizon and vegetation cover levels. In the presently studied plantations, however, no forest practices were applied after planting and this partly explains low differences in community parameters of Collembola of the studied vegetation types.

Finally, for the results of our study implies conclusion of Ponge (1993) that the dominant vegetation type, pine or oak, does not influence soil animal communities to a great extent, except when changes in humus form are to be expected. The author stated that humus form is a decisive factor in the establishment of soil Collembola communities and that the way in which the litter is decomposed is more important than the nature of the litter.

Cultivation of black pine as introduced tree species and subsequent accumulation of needle litter on formerly degraded pastures in the Slovak Karst positively affected development of soil profile and, as a consequence, soil Collembola assemblages. They gained characters very close to those of native forest stands relatively short time after planting (roughly 30 yr).

Acknowledgements

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