

Abundance of ten common Collembola species in spruce forests in the High Tatra Mts. (Slovakia) three years after windthrow

Peter ČUCHTA¹⁾, Ľubomír KOVÁČ²⁾ & Dana MIKLISOVÁ³⁾*

^{1,2)}Institute of Biology and Ecology, Faculty of Science, P. J. Šafárik University,
Moyzesova 11, SK–046 54 Košice, Slovakia

³⁾Parasitological Institute, Slovak Academy of Sciences, Hlinkova 3, SK–040 01 Košice, Slovakia

¹⁾corresponding author: peter.cuchta@post.sk

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Abstract. Abundance of ten species of Collembola was studied in spruce forests in the High Tatra Mts. damaged by severe wind in November 2004, viz. *Anurophorus cuspidatus* Stach, 1922, *Anurophorus laricis* Nicolet, 1842, *Desoria duodecemoculata* (Denis, 1927), *Folsomia penicula* Bagnall, 1939, *Friesea mirabilis* (Tullberg, 1871), *Isotomiella minor* (Schäffer, 1896), *Parisotoma notabilis* (Schäffer, 1896), *Protaphorura armata* (Tullberg, 1869), *Protaphorura aurantiaca* (Ridley, 1880) and *Tetracanthella fjellbergi* Deharveng, 1987. The aim of this study was to compare the abundance of dominant species at the different sites and assess the possible reasons for the differences. The study was carried out in three differently managed stands: an undamaged forest stand (control site, REF), windthrow forest stand with harvested fallen wood (EXT), and unmanaged windthrow forest stand left to natural succession (NEX). Soil samples were taken in spring and autumn in 2005, 2006 and 2007. At each locality 3 different plots were sampled. Material comprised a total of 5,434 specimens. Based on the effect of different management treatments the species may be sorted into four groups: (1) species that were most abundant at REF stands and less abundant at both NEX and EXT stands (*D. duodecemoculata*, *F. mirabilis*); (2) species that were most abundant at REF and NEX stands, and significantly less abundant in EXT stands (*F. penicula*, *T. fjellbergi*); (3) species that were most abundant at EXT stands and very much less abundant at both REF and NEX stands (*A. cuspidatus*, *P. aurantiaca*); (4) species that did not differ in abundance in the three treatments (*I. minor*). To test relations between species and microclimatic and soil-chemical parameters a correlation analysis (Spearman coefficient, $\alpha=0.05$) was performed. The analysis showed some significant correlations, for example a positive correlation between soil temperature and abundance for *Anurophorus cuspidatus* and *A. laricis* ($r=0.75$ and $r=0.88$) and a negative correlation between soil temperature and abundance for *I. minor* ($r=-0.68$). Particular Collembola species can be used as indicators of alterations in soil environment associated with natural disturbance (windstorm) and subsequent clear cut management in Central Europe.

Key words. Soil zoology, ecology, abundance, spruce forest, windthrow, Collembola, High Tatra Mts., Slovakia.

INTRODUCTION

In November 2004 a severe wind (bora) damaged roughly 12,600 hectares (about 50%) of the spruce forests in the High Tatras National Park (Falt'an et al. 2008). Windthrow is considered to be a natural driving force in the dynamics of forest ecosystems, constituting a sudden change in a habitat that affects structures, resources and microclimate (Wermelinger et al. 2003). Most of the damaged spruce stands in the High Tatra Mts. were clear cut and the fallen trunks harvested. Only a small area of damaged spruce forest was left to natural succession. Since then a scientific project has focused on the initial stages of succession of soil Arthropoda communities, with particular reference to Collembola, in three differently managed stands: unharmed (reference) forest, windthrow forest subsequently clear cut and unmanaged windthrow forest left to natural

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succession. Brůhova & Rusek (2005) did a similar study in the Šumava National Park, in which they recorded surface activity of eight common epigeic collembolan species in spruce forests, dead spruce forests and forest clearings.

The aim of this study was: (1) to determine the abundance of ten common species of soil Collembola over a period of three years following the windthrow event, (2) to compare the abundance of individual species in the different stands, and (3) to assess possible differences between species abundance and microclimatic and soil-chemical parameters in all three stands.

MATERIAL AND METHODS

Three differently managed stands of spruce forests in the High Tatras National Park were selected for this study:

REF stands (reference, control sites) – intact forest stands undamaged by severe wind, locality Smrekovec near the Vyšné Hágy village (49° 7' 22.3" N, 20° 6' 5.6" E, 1,268 m a. s. l.; 49° 7' 19.1" N, 20° 6' 12.1" E, 1,241 m a. s. l.; 49° 7' 16.5" N, 20° 6' 12.6" E, 1,237 m a. s. l.). Forest floor covered with cushions of *Polytrichum* sp. moss, spruce litter, *Vaccinium myrtillus*, grass or patches of *Oxalis acetosella*; soil type cambisol, soil profile: 0–2 cm litter (spruce needles), 2–6 cm humus layer, 6–10 (15) cm dark brown mineral layer, 15 cm and lower transition to paler mineral layer with stones.

EXT stands – windthrow stands subsequently clear-cut and tree stumps harvested, locality Danielov dom near Nová Polianka village (49° 7' 17.4" N, 20° 9' 45.6" E, 1,066 m a. s. l.; 49° 7' 19.6" N, 20° 9' 46.3" E, 1,070 m a. s. l.; 49° 7' 22" N, 20° 9' 48.2" E, 1,074 m a. s. l.). Forest floor covered with remnants of coniferous litter, patches of dry moss, patches of former herb understorey vegetation (*Oxalis acetosella*, *Vaccinium myrtillus*) and pioneer grasses (*Calamagrostis* sp.); soil type cambisol, soil profile: 0–2 cm litter (spruce needles), 2–6 cm humus layer, 6–10 (15) cm dark brown mineral layer, 10–15 cm transition to grey or pale brown mineral layer with stones.

NEX stands – unmanaged windthrow stands left to natural succession, locality Jamy near Tatranská Lomnica (49° 9' 31.8" N, 20° 15' 5" E, 1,078 m a. s. l.; 49° 9' 31.2" N, 20° 15' 6" E, 1,078 m a. s. l.; 49° 9' 30" N, 20° 15' 5.2" E, 1,075 m a. s. l.).

Forest floor covered with coniferous litter, mosaic cover of *Polytrichum* sp. moss with sparse blueberry bushes and pioneer grasses; soil type cambisol, soil profile: 0–2 cm litter (spruce needles), 2–6 cm humus layer, 6–10 (15) cm dark brown mineral layer, 10–15 cm sandy mineral layer with stones.

Soil samples were taken in spring and autumn during the period 2005–2007. At each locality three study plots were selected roughly 100 m apart. Plots were about 25×25 m in area and 6 replicate soil cores were taken randomly from each individual plot. The samples consisted of soil cores 3.6 cm in diameter (10 cm² in area) and 7–12 cm long depending on soil depth. The microarthropods were subsequently extracted in a modified high-gradient apparatus (Crossley & Blair 1991) in the laboratory over a period of 7 days.

The ten common collembolan species selected showed different responses (abundance patterns) to forest management: *Anurophorus cuspidatus*, *Anurophorus laricis*, *Desoria duodecemoculata*, *Folsomia penicula*, *Friesea mirabilis*, *Isotomiella minor*, *Parisetoma notabilis*, *Protaphorura armata*, *Protaphorura aurantiaca* and *Tetracanthella fjellbergi*. For each species their abundance (A) was determined, differences in abundance of each species in particular study plots were tested using non-parametric alternative of ANOVA – Kruskal-Wallis test (StatSoft CR s.r.o. 2007). Soil temperature was measured continually from October 2006 – November 2007 using data-loggers placed at a depth of 5 cm at each site. Soil moisture was measured gravimetrically. Soil-chemical parameters of homogenised soil samples taken from the organo-mineral horizon (5–10 cm depth) at sites in October 2007 were analysed. Correlation analysis using Spearman coefficient with significance level $\alpha=0.05$ was used to test the relations between species and microclimatic and soil-chemical parameters.

RESULTS

Comparing soil temperature and moisture (Table 1) revealed that the soil in clear-cut windthrow stands (EXT) was warmer and drier than in the other two types of stand. Control forest stands (REF) and damaged forest stands left to natural development (NEX) had lower average soil temperatures and higher soil moisture levels. The lowest values for soil acidity were recorded in REF stands, while in both NEX and EXT stands the values were similarly high. NEX and EXT stands had lower content of soil carbon and nitrogen compared to REF stands. REF stands had

Table 1. Soil characteristics of differently managed windthrow spruce stands in the High Tatra Mts. (2005–2007). T – average soil temperature (10 cm depth); W – average gravimetric soil moisture (% of initial weight); St. dev. (W) – standard deviation of moisture values; pH – soil acidity; C – soil carbon content (% of initial weight); N – soil nitrogen content (% of initial weight); P_{tot} – total phosphorus content of the soil. For abbreviations of localities see text

	REF1	REF2	REF3	EXT1	EXT2	EXT3	NEX1	NEX2	NEX3
T [°C]	4.79	5.48	5.23	6.92	6.71	7.37	6.64	6.56	6.17
W [%]	42.30	37.72	40.23	41.96	34.88	34.54	48.43	39.61	42.52
St. dev. (W)	6.95	5.05	6.11	7.42	5.14	5.59	13.23	2.31	7.55
pH	3.38	3.26	3.43	4.06	4.17	4.14	4.24	4.42	4.24
C [%]	13.57	17.29	17.26	9.29	10.06	9.16	8.18	10.24	10.18
N [%]	0.71	0.79	0.82	0.51	0.58	0.53	0.50	0.53	0.52
C/N ratio	19.11	21.89	21.05	18.22	17.35	17.28	16.36	19.32	19.58
P _{tot} [mg.kg ⁻¹]	842	793	859	739	762	731	647	611	657

also the highest content of total soil phosphorus, which was in some extent lower in EXT stands with the lowest value recorded in NEX stands.

A total of 5,434 Collembola belonging to 10 species were collected. Significant correlations were found between the abundance of several of the species and soil temperature and/or soil-chemical parameters. Abundances of *Anurophorus cuspidatus* and *Anurophorus laricis* were positively correlated with soil temperature ($r=0.75$ and $r=0.88$). That of *A. laricis* negatively correlated with soil carbon ($r=-0.71$). The correlation between soil temperature and abundance of *Isotomiella minor* was negative ($r=-0.68$). *I. minor* was also negatively correlated with soil pH ($r=-0.73$), but positively correlated with soil phosphorus ($r=0.75$). A negative correlation was

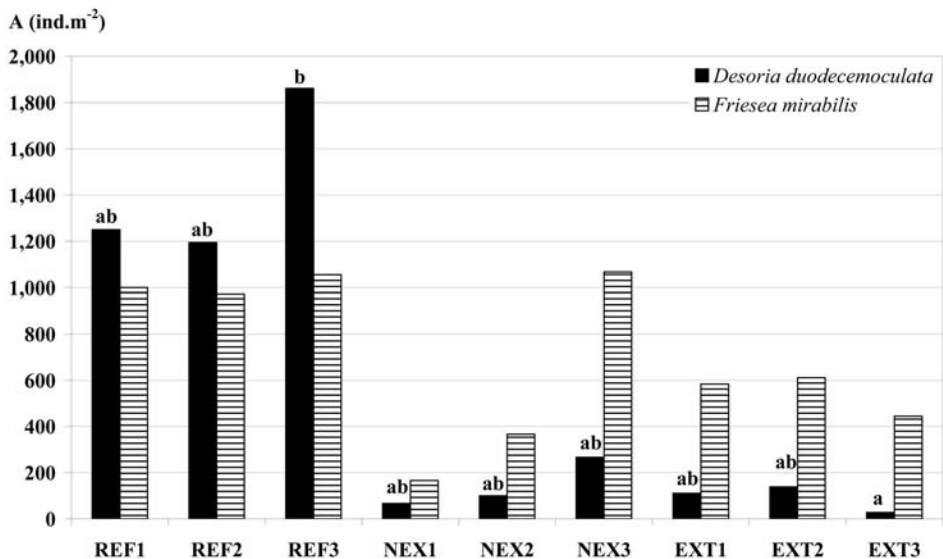


Fig. 1. Abundance of *Desoria duodecemoculata* and *Friesea mirabilis* during 2005–2007. Statistically significant differences marked. For abbreviations of localities see text.

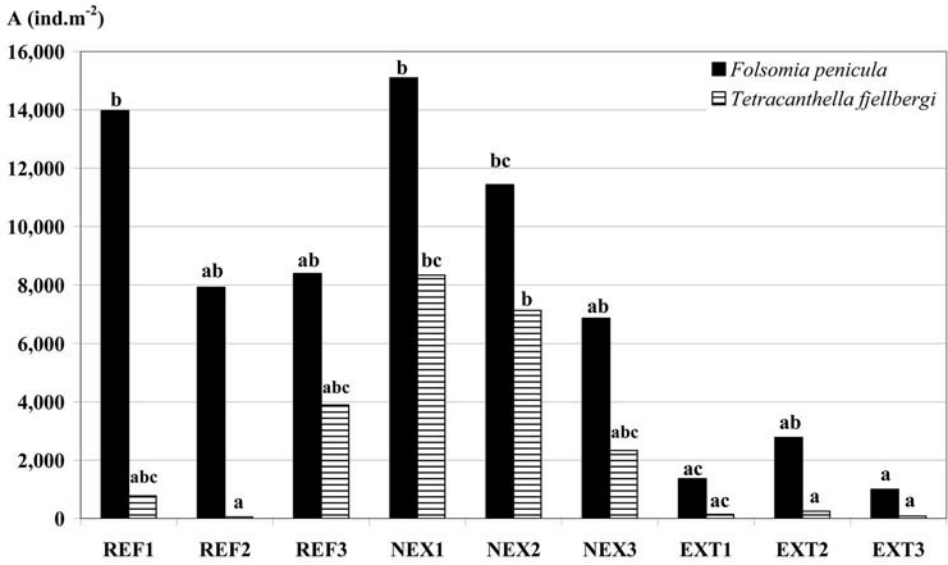


Fig. 2. Abundance of *Folsomia penicula* and *Tetracanthella fjellbergi* during 2005–2007. Statistically significant differences marked. For abbreviations of localities see text.

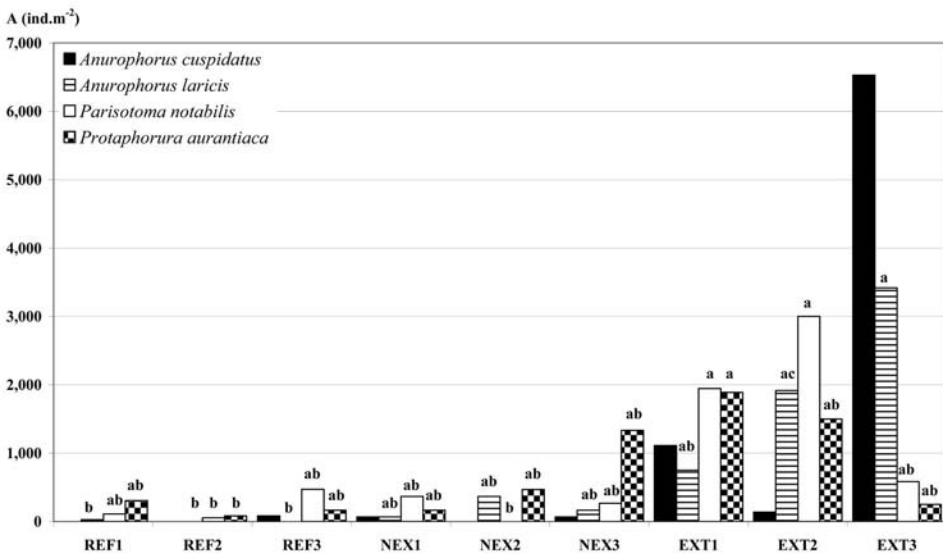


Fig. 3. Abundance of *Anurophorus cuspidatus*, *Anurophorus laricis*, *Parisotoma notabilis* and *Protaphorura aurantiaca* during 2005–2007. Statistically significant differences marked. For abbreviations of localities see text.

recorded between soil temperature and the abundance of *Desoria duodecemocolata* ($r=-0.85$). Moreover, the abundances of the species were positively correlated with the soil nutrients measured (C, N, P_{tot}). Finally, a positive correlation was recorded between the C/N ratio and abundance of *Friesea mirabilis* ($r=0.68$).

Based on the effect of different treatments species could be sorted into four groups.

(1) First group consists of species that were most abundant in REF stands but less so in both NEX and EXT stands (Fig. 1): *Desoria duodecemocolata* with a mean abundance in REF-NEX-EXT stands of 1,435; 144 and 93 ind.m⁻² and *Friesea mirabilis* with 1,009; 533 and 546 ind.m⁻², respectively. The difference in the abundance of *D. duodecemocolata* in the REF3 and EXT3 plots was statistically significant ($p=0.0371$).

(2) Second group consists of species that were most abundant in REF and NEX stands, however, with apparently lower values in EXT stands (Fig. 2): *Folsomia penicula* with a mean abundance in REF-NEX-EXT stands of 10,093; 11,133 and 1,713 ind.m⁻² and *Tetracanthella fjellbergi* with 1,574; 5,933 and 157 ind.m⁻², respectively. There were statistically significant differences between the abundance values at particular study plots of both species: EXT1 and NEX1 ($p=0.0083$), EXT1 and REF1 ($p=0.0122$), EXT3 and NEX1 ($p=0.0035$), EXT3 and NEX2 ($p=0.0237$) and EXT3 and REF1 ($p=0.0051$) for *F. penicula*; EXT1 and NEX2 ($p=0.0253$), EXT2 and NEX1 ($p=0.0462$), EXT2 and NEX2 ($p=0.0162$), EXT3 and NEX1 ($p=0.0264$), EXT3 and NEX2 ($p=0.0089$), NEX1 and REF2 ($p=0.0393$) and finally NEX2 and REF2 ($p=0.0136$) for *T. fjellbergi*.

(3) Third group consists of species that were most abundant in EXT stands and much less so in both REF and NEX stands (Fig. 3): *Anurophorus cuspidatus* with a mean abundance in REF-NEX-EXT stands of 28, 55 and 2,593, respectively; *Anurophorus laricis* with 9, 200 and 2,028 ind.m⁻²,

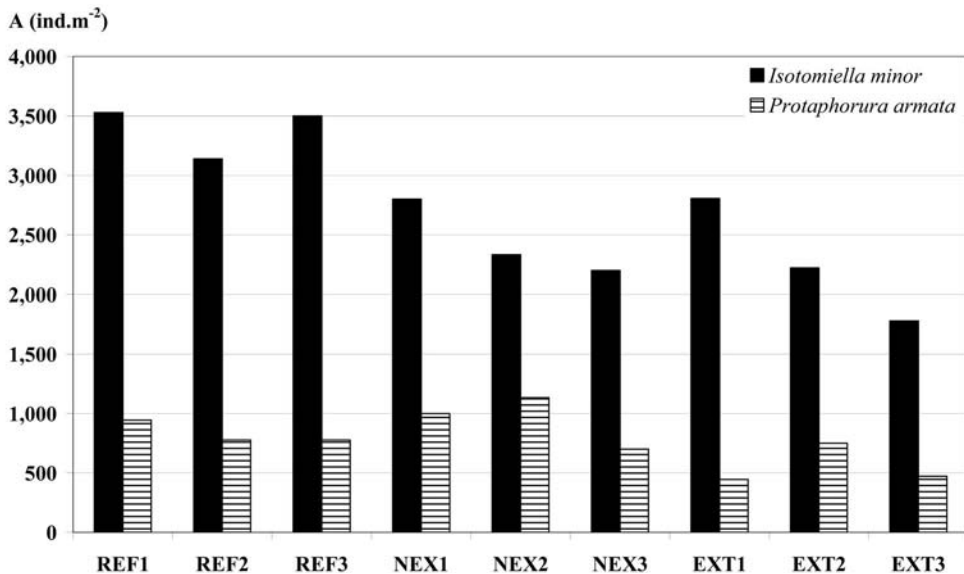


Fig. 4. Abundance of *Isotomiella minor* and *Protaphorura armata* during 2005–2007. For abbreviations of localities see text.

respectively; *Parisotoma notabilis* 213, 211 and 1,843 ind.m⁻², respectively; and *Protaphorura aurantiaca* with 185, 656 and 1,213 ind.m⁻², respectively. There were statistically significant differences between the abundances at particular study plots: EXT2 and REF2 (p=0.0302), EXT2 and REF3 (p=0.0302), EXT3 and REF1 (p=0.0323), EXT3 and REF2 (p=0.0112) and EXT3 and REF3 (p=0.0112) for *A. laricis*, EXT1 and NEX2 (p=0.0193), EXT2 and NEX2 (p=0.0102), EXT1 and REF2 (p=0.0426) and EXT2 and REF2 (p=0.0227) for *P. notabilis*, and EXT1 and REF2 (p=0.0398) for *P. aurantiaca*.

(4) Fourth group consists of species that did not differ in abundance in the three treatments (Fig. 4): *Isotomiella minor* with a mean abundance in REF-NEX-EXT stands of 3,389, 2,444 and 2,269 ind.m⁻² and *Protaphorura armata* with 833, 944 and 556 ind.m⁻², respectively. Therefore, there were no statistically significant differences in abundance between study plots.

DISCUSSION

Abundance of ten common species of Collembola was studied in windthrow spruce forest stands in the High Tatra Mts. over a period of three years. The aim of the study was to compare abundance of individual species between sites and assess the possible reasons for the observed differences. Based on the effect of the different management treatments the species may be sorted into four groups: (1) species that were most abundant in undamaged forest stands (REF stands) and less so in both unmanaged windthrow forest stands left to natural succession (NEX stands) and windthrow forest stands subsequently clear-cut (EXT stands); (2) species that were most abundant in REF and NEX stands, and significantly less so in EXT stands; (3) species that were most abundant in EXT stands and considerably less so in both REF and NEX stands; (4) species for which there were no obvious differences in abundance in the three treatments. Brůhová & Rusek (2005) and Rusek & Brůhová (2007) did a similar study on eight common epigeic collembolan species in the Šumava National Park. These authors divided them into 3–4 groups based on their surface activity in spruce forests, dead spruce forests and forest clearings.

In the current study the first group consisted of species that were most abundant in REF stands and less so in both NEX and EXT stands, e.g., *Desoria duodecemoculata* and *Friesea mirabilis*. These litter-dwelling species prefer coniferous forest stands with mesic soils. There are few records of *Desoria duodecemoculata* and its biology is completely unknown. It belongs to the „*nivalis*-complex” of the *violacea*-group (Potapov 2001). Based on other data and the present study *D. duodecemoculata* is a species that prefers sites that are consistently cold and humid in high mountains, which is supported by the negative correlation between soil temperature and abundance of this species recorded in this study. *Friesea mirabilis* is a cosmopolitan species abundant in many types of habitats (forests, meadows, seashores and alpine heaths), avoiding only the driest sites (Fjellberg 1998). There are many records documenting its high abundance in coniferous forest stands. It is found in Scots pine forests (Juceviča & Melecis 2006) and spruce forests (Materna 2004, Lindberg & Bengtsson 2005, Kuznetsova 2006, 2007). Similarly Lindberg & Bengtsson (2005) reported the negative effect of drought on *F. mirabilis*. The abundance of both species was positively correlated with soil nutrient content and they preferred coniferous forest stands with steady mesic conditions. On the other hand, they were significantly less abundant at disturbed sites.

The second group includes species that are most abundant in REF and NEX stands and significantly less so in EXT stands, i.e. *Folsomia penicula* and *Tetracanthella fjellbergi*. *F. penicula* is an abundant mesophilic, mostly forest species (Potapov 2001), which does not occur at altitudes above 1,800 m a. s. l. (Loranger et al. 2001, Raschmanová et al. 2008). It is likely that this species

generally avoids more open and dry habitats. *Tetracanthella fjellbergi*, which is a bryophilous species with a preference for alpine sites, has a similar distribution (Potapov 2001). It inhabits soils in spruce (Čuchta et al. 2009) and deciduous beech forests (Rusek 2001). It is likely, that *T. fjellbergi* prefers colder and more humid forest stands to open habitats exposed to direct sunlight and consequently warmer and drier.

The third group includes four species that are most abundant in EXT stands and considerably less so in both REF and NEX stands namely *Anurophorus cuspidatus*, *A. laricis*, *Parisotoma notabilis* and *Protaphorura aurantiaca*. *Anurophorus cuspidatus* inhabits leaf litter in coniferous and woods in the mountains (Potapov 2001). The results indicate it is ecologically associated with *A. laricis*. The latter is a xeroreistant dweller of mosses and lichens growing in dry exposed habitats, i.e. on tree trunks, boulders and rocks (Potapov 2001). Their similar ecological preferences are fully consistent with the result that the abundances of both species are positively correlated with soil temperature. However, there are several somewhat contradictory reports in the literature. Loranger et al. (2001) reported that *A. laricis* is abundant in the soil of a mountain coniferous forest at a high altitude (above 1,500 m a. s. l.) in Savoy, France. This species is less frequently recorded at the edges of plantations of coniferous trees (Shaw et al. 2007). Finally, there are records documenting the negative effect of climate warming on *A. laricis* in Scots pine forests in Latvia (Juceviča & Melecis 2006). *Parisotoma notabilis* is among the most ubiquitous collembolan species in the Western Palaeartic, with the optimum conditions for this species located in Central Europe and the southern half of the forest belt of the European part of Russia. It is abundant in forests and open grasslands and even prefers moderately disturbed biotopes (Potapov 2001). In spruce forests in the High Tatra Mts. it clearly prefers disturbed EXT stands. Many authors reported a high abundance of *P. notabilis* in forests (Juceviča & Melecis 2006, Kuznetsova 2006, 2007, Raschmanová et al. 2008) and grassland soils (Kuznetsova 2006, 2007). There are more records of positive correlations with temperature (Kuznetsova 2006, 2007, Raschmanová et al. 2008) than of negative correlations (Juceviča & Melecis 2006). According to Pomorski (1998) it is impossible to define precisely the ecological preferences of *Protaphorura aurantiaca* as there is little information on this species. In Poland it is only recorded from mountains and highlands, probably because it prefers rather wet and cool habitats. Based on their study of soil Collembola in floodplain forests Russell et al. (2004) classified this species as hygrophilous. In contrast, the current results indicate that *P. aurantiaca* prefers warmer and drier windthrow sites.

The fourth group includes the two species that did not differ in abundance in the three management treatments, i.e. *Isotomiella minor* and *Protaphorura armata*. The first species is a eurytopic litter-dweller and one of the most generalist species in the Western Palaeartic (mostly Central and Northern Europe), abundant in forests in the mountains and lowlands, and less abundant in open damp grassland (Potapov 2001). It is very abundant in termophilous lime wood (Raschmanová et al. 2008), termophilous oak wood (Kováč et al. 2005), Scots pine forests (Juceviča & Melecis 2006) and spruce forests (Kuznetsova 2006, 2007, Čuchta et al. 2009) and considerably less abundant in natural dry meadows (Kuznetsova 2006, 2007). *I. minor* was very abundant at REF sites, less so at both disturbed (NEX and EXT) sites and its distribution negatively correlated with soil temperature. Although a generalist it is likely that *I. minor* is better adapted to live in colder and more humid habitats. This is supported by Juceviča & Melecis (2006) who reported that this species is negatively affected by climate warming. In contrast, there are records of positive correlations with temperature for *I. minor* (Kuznetsova 2006, 2007). The distribution of *I. minor* was also negatively correlated with soil pH ($r=-0.73$). This, however, does not accord with Rusek (2001) who classified this species as acidophobic and Chagnon et al. (2001) who recorded that it is dominant in limed plots of sugar maple in Quebec. Moreover, the abundance of this species is positively correlated with soil phosphorus. According to Kováč et al. (2005) *I. minor* is abundant

in oak woods and oak litter, which generally has a higher pH and greater content of both nitrogen and phosphorus than pine needles. In this study, however, it was not more abundant at sites with high phosphorus contents (REF stands). *Protaphorura armata* appears to be widely distributed in all the Nordic countries, but in the mountains. It occurs in various habitats, both in forests and open countryside, often at rather dry sites (Fjellberg 1998). Russell et al. (2004) considered this species to be intolerant of flooding. According to Pomorski (1998), *P. armata* lives in different habitats: flowerpots, compost and anthropogenic soil, dry and wet meadows and in litter of different forests. Kuznetsova (2006, 2007) in a study of two contrasting ecosystems recorded *P. armata* in spruce forest and dry natural meadows, especially meadows where it can be abundant and dominant. In addition, *P. armata* is abundant in arable land with a high content of organic matter, even intensively managed fields (Filser et al. 2002). The results presented indicate that this species was abundant at all sites and showed no preference for a particular site. Furthermore, there were no significant correlations between its abundance and the soil-microclimatic or soil-chemical parameters. Accepting this, *P. armata* was classified as species with no obvious differences in abundance in the three treatments.

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