



Tree species and microhabitat affect forest bog spider fauna

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Abstract

Peat bogs are among the most threatened habitats in Central Europe. They are characterized by stagnant water with low pH and lower nutrient content compared to the surrounding habitats. The flora and fauna of peat bogs comprised of many habitat specialist and rare species. We explored the differences in spider fauna of European spruce and Scots pine forests. Furthermore, we assessed the effect of microhabitat diversity in the bog forests of the Poiana Stampei peat bog complex, Bucovina, Romania. We collected numerous rare and cold-adapted species. We found a strong effect of forest type, presumably due to the different microclimatic conditions of the forests. European spruce forests had lower species richness of ground-dwelling fauna than Scots pine forests; however, we found contradictory results for vegetation-dwelling species richness. Hummocks had a more positive effect on the ground-dwelling spiders of Scots pine than in European spruce forests, presumably due to the more open structure of sphagnum hummocks than ground level. However, this effect was negative for vegetation dwellers. The cold-adapted species with restricted ranges are vulnerable to climate change, and bogs may serve as important micro-refugia for them. Central European bogs are isolated and highly threatened by anthropogenic activities, such as drainage, peat extraction, and eutrophication. The deterioration habitat quality of peat bogs will result in a significant loss in the regional species pool of the Carpathians.

Keywords Carpathians · European spruce · Hummock · Microclimate · Scots pine · Peat bog

Introduction

Heterogeneity of microhabitat structure is an inherent feature of habitats and is considered as an important driver of animal diversity (Tews et al. 2004). Structurally complex habitats may provide diverse food resources and refuges, and thus increase species diversity (McCoy and Bell 1991). Furthermore, more heterogeneous habitats are thought to be more resilient to disturbances (Bellone et al. 2017). Thus, habitat heterogeneity at multiple spatial scales has been revealed as key for biodiversity conservation (Benton et al. 2003; Moreno et al. 2016). However, the effects of habitat

heterogeneity vary considerably between taxonomic groups depending on whether structural heterogeneity is perceived as heterogeneity or habitat fragmentation (Tews et al. 2004).

Temperate forests harbour a high diversity of arthropods. The importance of fine-scale habitat heterogeneity on arthropod communities was explored by several studies in Europe (e.g. Hsieh and Linsenmair 2011; Kosulič et al. 2016; Šipoš et al. 2017). Habitat features and microhabitat parameters, such as decaying woody material, and shrubs are correlated with the distribution of species (e.g. Gallé et al. 2014; Ziesche and Roth 2013) and the functional diversity of their communities (Gallé et al. 2017).

Peat bogs are nutrient-poor habitats characterized by a high water table and low pH (Spitzer and Danks 2006). Their specific microclimate, acidity, and food scarcity act as an environmental filter and determine their unique, specialized flora and fauna with rare and threatened species (Kamayev 2012). Bog forests are common in the northern taiga zone, but very rare in the temperate climate zone, and they are usually located in drainless depressions. Peat bogs and bog forests are among the most sensitive and endangered habitats in Central Europe (Haase and Balckenhol 2015).

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Spiders are an abundant group of ground-dwelling as well as vegetation-dwelling arthropods and are among the most abundant predators of other arthropods, thus performing an ecologically important role in almost all of the terrestrial ecosystems (Wise 1995). Ground-dwelling spiders are mostly comprised of cursorial species that wander across diverse microhabitats in search of their prey. Whereas vegetation-dweller species, either web-builders or active hunters are more dependent on habitat structures that are necessary for web placement or constitute the substrate for foraging (Barton et al. 2017; Gollan et al. 2010).

Our study aims to demonstrate the differences between the spider fauna of Scots pine and European spruce bog forests and the effect of hummocks on the species composition of spiders. More specifically we hypothesized that (1) European spruce forests with close canopy have lower species richness than Scots pine forests with open canopy due to the colonization of open habitat species in the latter; and (2) hummocks have an effect on species composition of spider communities, and this effect is stronger for vegetation-dwelling species.

Materials and methods

Study sites and sampling

Our study was conducted in the largest peat bog (Tinovul Mare Poiana Stampei) of the Eastern-Carpathians in Bucovina, Eastern-Romania, part of the Călimani National Park (N 47° 17' 41"; E 25° 06' 45") with a total area of 695 ha (Fig. 1). The bog lies at the altitude of 900–1024 m asl. It is situated in the temperate continental climatic zone; however, the mean annual temperature is relatively low (4.2 °C). The mean annual precipitation is circa 740 mm (Danu and Chifu 2007). The soil is acidic with a pH of 3.6–5 (Cazacu et al. 2018). Tinovul Mare Poiana Stampei is part of the Natura 2000 ecological network (ROSCI0247 Tinovul Mare Poiana Stampei), and it was included in the List of Wetlands of International Importance (Ramsar Site no. 2003) (Danu and Irimia 2009). The main tree species are Scots pine (*Pinus sylvestris* forma *turfosa*) and European spruce (*Picea abies*), both species form relatively homogeneous forests.

We selected 15 hummocks for sampling ground-dwelling spiders in each of the two forest types keeping a minimum distance of 30 m between them. We assessed the microclimatic differences using data loggers (Testo 176H2), two loggers were placed on top of separate, randomly selected hummocks and two loggers were placed on the ground near the focal hummock in both forest types.

At each sampling site, we used a pair of pitfall traps to survey spiders. One trap was placed on top of the hummocks,

and the other on the ground level near the focal hummock (two forest types × 15 hummocks × two positions = 60 traps in total). The traps were plastic cups with a diameter of 8.5 cm filled with a 50:50 ethylene–glycol/water solution to which we added a few drops of detergent. To minimize spatial autocorrelation, sampling sites were at least 40 m apart, and we kept five metres between the traps of the same pair. We performed our sampling in the frost-free period, traps were open for two months: 14 June–21 August 2019 (emptied on 06 July 2019). For each pitfall trap, we pooled the data from the two collection periods.

Furthermore, we used a 'D-vac' suction sampler to survey vegetation-dwelling spiders. We conducted sampling on 06 July and 25 August 2019. We collected 10 samples from hummocks and 10 samples between hummocks (two forest types × 10 hummocks × two positions × two periods = 80 samples in total). Each sample consists of 10 subsamples. The 'D-vac' head was placed on the ground 10 times. Spiders caught with suction sampling were placed in 70:30 alcohol/water solution. All adult spider specimens were identified to species level using standard keys (Nentwig et al. 2019). Juvenile spiders cannot be identified precisely to species level, therefore we excluded them from further analyses. We listed species included in Red Lists of Central European Countries (Czech Republic, Germany, Poland, and Carpathian Red list of spiders) to assess the conservation importance of the spider fauna (Řezáč et al. 2015).

Data analysis

We used generalized linear models to determine the effect of forest type (Scots pine or European spruce) and sample position (top of hummock or ground) on the mean daily temperature, and minimum and maximum temperature. We determined the effect of forest type and sample position on species richness and activity density of spiders with generalized linear models. We calculated separate models for pitfall trap and D-vac data. We used the Poisson error term for species richness and negative binomial error term for activity density of spiders after checking for overdispersion of the data. For the D-vac data, sampling period was used as a random variable in the models.

The multivariate response of spider communities to forest type and sample position was studied with nonmetric multidimensional scaling (NMDS) based on a Bray–Curtis dissimilarity matrix. A Hellinger transformation was applied to the activity density data before the ordination. We tested the differences in spider species composition of Scots pine and European spruce forests and the effect of sample position with permutational multivariate analysis of variance (PERMANOVA) using a Bray–Curtis dissimilarity matrix with 4999 permutations and the "adonis" function in the "vegan" R package (Oksanen et al. 2016). We

tested differences in multivariate dispersion of forest and sample position types using a multivariate homogeneity of group dispersion test (PERMDISP) with the "betadisper" function in "vegan". Both PERMANOVA and PERMDISP analyses were run with the Bray–Curtis distance metric and 4999 permutations. We applied the indicator value analysis (IndVal) to identify characteristic spider species of habitat types (Dufrêne and Legendre 1997). We calculated the IndVal value on the basis of the relative frequency and relative average abundance of the species. The statistical significance of the species indicator values was evaluated by a Monte Carlo procedure.

Results

Mean daily temperature and daily maximum temperature was higher in spruce forests than in pine forests ($\beta = 1.11$, $p < 0.001$; $\beta = 7.32$, $p < 0.001$); however, daily minimum temperature was lower in spruce forests than in pine forests

($\beta = -2.27$, $p < 0.001$), indicating a more fluctuating temperature in spruce forests than in pine forests. Sample position did not have a significant effect on the temperature (Appendix 1).

We collected 1571 ground-dwelling spiders with pitfall traps, 1178 adults and 393 juveniles belonging to 40 species. Furthermore, we recorded a total number of 3646 vegetation-dwelling specimens from D-vac samples, 943 adults and 2703 juvenile spiders belonging to 53 species (Appendix 2). More than 35% (30 out of 78 species) of the collected species are listed in Central European Red Lists. Furthermore, *Taranucnus carpaticus* Gnelitsa, 2016 *Zora distincta* Kulczynski, 1915 were new to the Romanian spider fauna (Weiss and Urák 2000).

Ground-dwelling spiders

Hummocks had higher species richness than the ground level in Scots pine forests; however, this effect was weak in European spruce forests (Table 1; Fig. 2a). We found a

Fig. 1 Location of study site and the two sampled habitat types **a** Scots pine forest, **b** European spruce

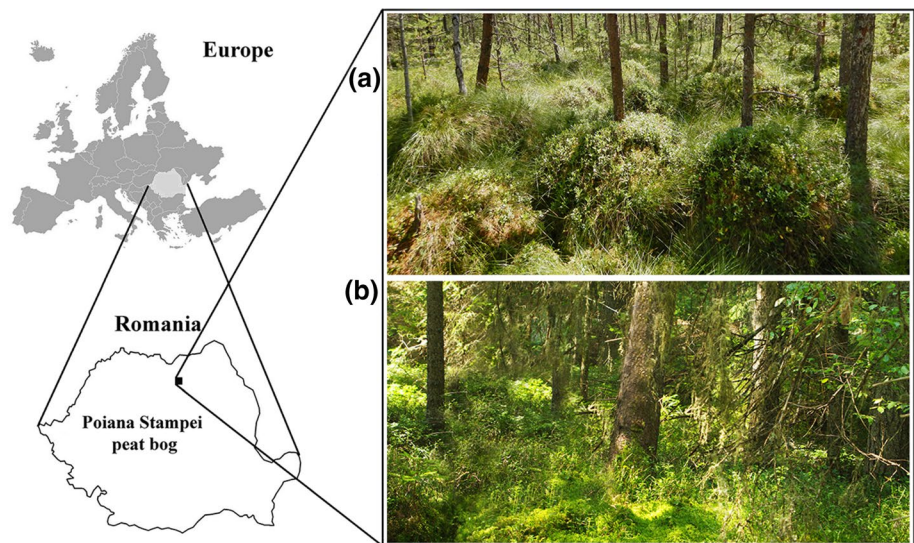


Table 1 Effect of forest type and microhabitat on species richness and total number of collected spiders according to generalized linear models. Parameter estimates \pm 95% CI values and F-values are given in parenthesis

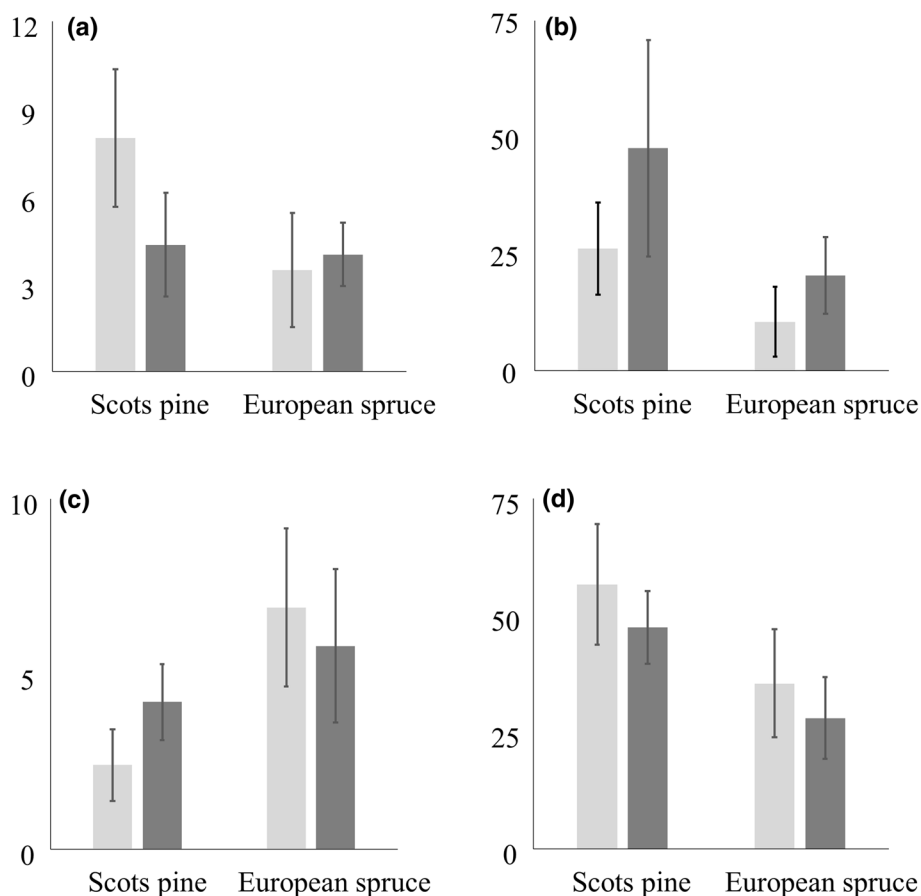
	Forest type (scots pine/European spruce)	Microhabitat (hummock/ground)	Forest type: microhabitat
<i>Pitfall traps</i>			
Species richness ^α	-0.836 ± 0.315 (- 5.037)***	-0.613 ± 0.298 (- 3.981)***	0.756 ± 0.477 (3.097)**
Abundance ^β	-0.917 ± 0.365 (- 4.941)***	0.598 ± 0.337 (3.483)***	0.068 ± 0.500 (0.271)
<i>D-vac samples</i>			
Species richness ^α	-0.773 ± 0.287 (- 5.196)***	0.342 ± 0.311 (2.131)*	-0.543 ± 0.397 (- 2.670)**
Abundance ^β	-0.491 ± 0.197 (- 4.900)***	-0.140 ± 0.192 (- 1.430)	-0.128 ± 0.281 (- 0.894)

^αModels fitted with Poisson error term

^βModels fitted with negative binomial error term

Significance levels: *: <0.05, **: <0.01, ***: <0.001

Fig. 2 Effect of forest type and microhabitat on the spider fauna. Light grey bars: hummocks, dark grey bars: ground level. **a** Species richness of ground-dwelling spiders, **b** abundance of ground-dwelling spiders, **c** species richness of vegetation-dwelling spiders, **d** abundance of vegetation-dwelling spiders

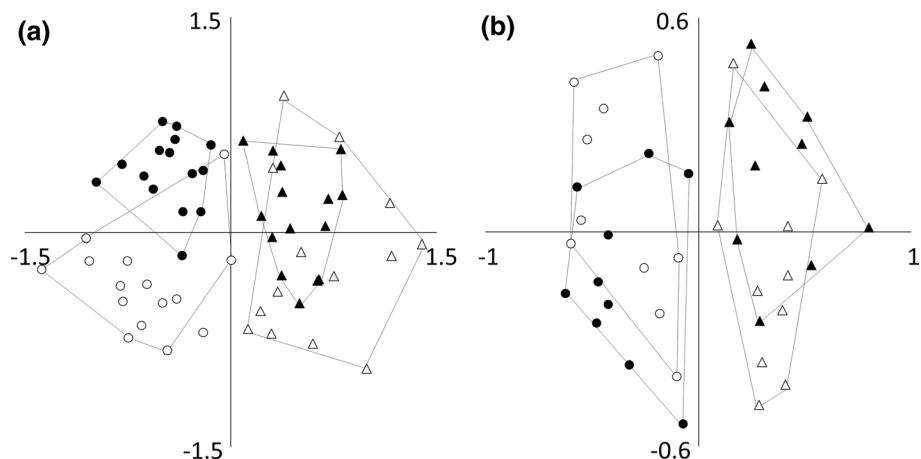


higher abundance of spiders in Scots pine than in European spruce forests, and lower abundances on hummocks than on the ground level (Table 1; Fig. 2b).

We found a significant effect of microhabitat ($F=9.965$, $R^2=0.099$, $p<0.001$), forest type ($F=27.271$, $R^2=0.272$, $p<0.001$), and their interaction ($F=8.001$; $R^2=0.0798$, $p<0.001$) on species composition according to the PERMANOVA model. We found higher overlap between the community composition of hummocks and ground level in

Scots pine than in European spruce forests (Fig. 3a). Furthermore, PERMDISP test showed that dissimilarity due to species composition did not differ for Scots pine and European spruce forests ($F=0.123$, $p=0.72$); however, hummocks had greater variation than the ground level ($F=7.079$, $p=0.014$). We identified 12 significant indicator species, 8 species for hummocks 2 species of ground level of European spruce, 1 species for hummocks 1 species of ground level of Scots pine.

Fig. 3 NMDS ordination plot of spider communities. **a** Ground-dwelling spiders; **b** vegetation dwellers. Circles: Scots pine forests, triangles: European spruce forests, open symbols: hummocks, dark symbols ground level



Vegetation-dwelling spider

Hummocks had lower species richness than the ground level in Scots pine forests; however, species richness was higher on hummocks than on the ground level in European spruce forests (Table 1; Fig. 2c). Spider abundances were higher in Scots pine than in European spruce forests (Table 1; Fig. 2d).

Forest type had a strong effect on the species composition of spiders (Fig. 3b; $F=22.302$, $R^2=0.344$, $p<0.001$). However, microhabitat and the interaction between microhabitat and forest type had a significant, but relatively weak effect on the species composition ($F=3.11$, $R^2=0.048$, $p=0.016$; $F=3.294$, $R^2=0.050$, $p=0.013$, respectively) according to the PERMANOVA. Dispersion analysis indicated within-group dispersion did not differ significantly between Scots pine and European spruce forests ($F=4.083$, $p=0.055$), furthermore, hummock and ground-level samples also had similar dispersion ($F=0.245$, $p=0.623$). We identified 11 significant indicator species, 3 species of ground level of European spruce, 6 species for hummocks 2 species of ground level of Scots pine.

Discussion

In this study, we aimed to assess the effect of forest tree species and microhabitat on the spider fauna of bog forests. Following our hypothesis (1), European spruce forests had lower species richness of ground-dwelling fauna than Scots pine forests; however, we found contradictory results for vegetation-dwelling species richness. Our supporting hypothesis was that (2) hummocks, and the ground level had different species compositions of ground-dwelling spider communities; however, this effect was weaker for vegetation-dwelling species.

Shading and moisture conditions are the most important environmental factors for spiders (Entling et al. 2007). Bog forests are partly shaded to shaded with wet conditions. Ziesche and Roth (2008) and Černecká et al. (2020) also found that canopy openness has an important effect on spider species richness and activity density of the forest floor. Canopy affects light penetration, which in turn influences the ground and lower vegetation layers, and also modifies temperature and moisture conditions (Lindh and Muir 2004; Oxbrough et al. 2012).

In general, the temperature within a bog can be several degrees lower than the temperature of the surrounding terrain outside of the bog (Spitzer and Danks 2006). Furthermore, we found that microclimatic conditions vary between forests of different tree species, with more stable

temperatures in European spruce forests than in Scots pine forest, presumably due to the open canopy of the latter. European spruce forests maintained a temperate microclimate due to lower solar transmission during the day and the thermal insulation provided by thick canopy during the night (Weng et al. 2007; Ingle et al. 2020). Temperature differences may affect the species composition of spiders. Kamayev (2012) also emphasized the effect of temperature regime and humidity of the soil in shaping spider assemblages of bog forests. The relatively open canopy of Scots pine forests may support higher diversity of understory vegetation (Nilsson et al. 2008; Oxbrough et al. 2012) and in turn a higher spider diversity (Docherty and Leather 1997). Presumably, forest structure and microclimate have a higher relative importance in shaping spider community composition than the effect of tree species per se (Vehviläinen et al. 2008; Ziesche and Roth 2008).

Hummocks form a separate microhabitat. The ground level is covered by stagnant water for a long period of the year (from autumn until early summer), and hummocks form a drier microhabitat even when the stagnant water disappeared (Stańska et al. 2016). The loose arrangement of the Sphagnum branches below the surface has a very high water-holding capacity and maintain stable moisture conditions throughout the year (Kajak et al. 2000). This may affect the temperature (Van der Molen and Wijnstra 1994); however, we did not find significant differences between the temperature of hummocks and the ground level. The structures of hummocks are more complex due to the thickness of the Sphagnum layer; thus, hummocks may have a higher number of spider species living on the surface and within the moss layer than on the ground level (Koponen 2004). We found that variation in species composition of ground-dwelling spiders was higher on hummocks than on the ground level, indicating a high diversity of hummocks. We also found a higher number of ground-dwelling spider species and lower abundance on hummocks than on the ground level in Scots pine forests presumably due to the more complex structure of hummocks than the ground level. However, this pattern was the opposite for vegetation-dweller species of Scots pine forests.

Peat bogs are relatively common and widespread worldwide. Although their overall surface area is small, cca 3%, they have a key role in carbon storage (Joosten and Clarke 2002; Urák et al. 2017) and harbour a disproportionately high number of specialist species (Gajdos et al. 2016; Gallé et al. 2019). This distinct arthropod community of bog forests have numerous, mainly cold-adapted arthropod species that significantly contribute to the regional species richness (Sławska et al. 2017). Scott et al. (2006) found

that the richness of specialist spider species can serve as a surrogate for the conservation value of the invertebrate fauna of bogs. We collected 30 rare spider species with high conservation importance and two new species to the Romanian fauna, indicating a high natural value of Poiana Stampei peat bog. This is in line with several studies of the spider fauna Eastern Carpathian peat bogs emphasizing the unique nature conservation value of peat bogs (e.g. Gallé and Urák 2002, 2006; Gallé et al. 2019, Samu and Urák 2014). Our results show that the patchy microhabitat structure further increases the spider diversity of bog forests.

The cold-adapted species with restricted ranges are vulnerable to climate change, and bogs may serve as important micro-refugia for them (Ohlemüller et al. 2008; Gallé et al. 2019). Central European bogs are highly threatened by anthropogenic activities, such as drainage, peat extraction, and eutrophication (Haase and Balckenhol 2015). Changes in peat bog hydrology and soil properties negatively affect the species composition of peat bog flora and fauna (Brigić et al. 2017). Furthermore, they are highly isolated habitats, and this isolation increases as bog habitats degraded. The decay of peat bogs will result in a significant loss in the regional species pool. Biodiversity conservation is key for the long-term sustainability of peat bog ecosystems; conservation strategies should promote abandonment or very extensive management practices aimed at maintaining habitat and microhabitat diversity, hence supporting high biodiversity. The regular monitoring of the stenotopic peat bog flora and fauna should become a target for Romanian nature protection as it is crucial to initiate early restoration efforts to avoid an irreversible habitat degradation of small and isolated peat bogs.

Appendix 1

See Fig. 4.

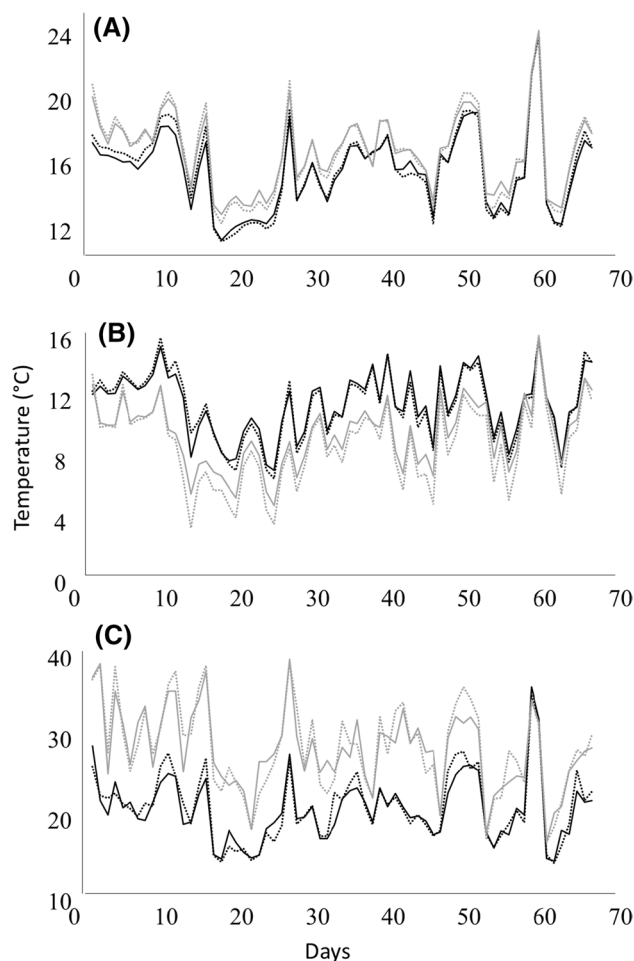


Fig. 4 Temperature profile of European spruce (black) and Scots pine (grey) forests. Hummocks are indicated with dotted line and ground level with solid line. **a** Mean daily temperatures, **b** daily minimum values and **c** daily maximum values

Appendix 2

See Table 2.

Table 2 List of collected species

Pitfall trap samples	European spruce		Scots pine	
	Hummock	Ground	Hummock	Ground
<i>Agroeca brunnea</i> (Blackwall, 1833)	3	0	3	0
<i>Araneus marmoreus</i> Clerck, 1757	0	0	1	0
<i>Callobius claustrarius</i> (Hahn, 1833)	0	3	46	39
<i>Centromerus arcanus</i> (O. P.-Cambridge, 1873)	0	1	0	0
<i>Coelotes terrestris</i> (Wider, 1834)	20	6	13	21
<i>Cybaeus angustiarum</i> L. Koch, 1868	4	5	24	112
<i>Dicymbium tibiale</i> (Blackwall, 1836)	3	4	3	5
<i>Diplostyla concolor</i> (Wider, 1834)	0	0	0	1
<i>Drassodes pubescens</i> (Thorell, 1856)	1	0	0	0
<i>Ero furcata</i> (Villers, 1789)	0	0	1	1
<i>Euryopis flavomaculata</i> (C. L. Koch, 1836)	1	0	0	0
<i>Macrargus rufus</i> (Wider, 1834)	1	0	0	1
<i>Maso sundevalli</i> (Westring, 1851)	1	0	0	0
<i>Metellina merianae</i> (Scopoli, 1763)	0	1	0	0
<i>Micaria pulicaria</i> (Sundevall, 1831)	1	0	0	0
<i>Micrargus herbigradus</i> (Blackwall, 1854)	0	0	1	3
<i>Neon reticulatus</i> (Blackwall, 1853)	3	2	0	0
<i>Neriere radiata</i> (Walckenaer, 1841)	8	1	1	0
<i>Ozyptila trux</i> (Blackwall, 1846)	16	1	1	0
<i>Pardosa lugubris</i> (Walckenaer, 1802)	0	1	0	0
<i>Pardosa spider</i>	1	0	0	0
<i>Pardosa riparia</i> (C. L. Koch, 1833)	10	2	0	0
<i>Phrurolithus festivus</i> (C. L. Koch, 1835)	6	3	0	0
<i>Piratula hygrophila</i> (Thorell, 1872)	34	167	8	52
<i>Piratula uliginosa</i> (Thorell, 1856)	41	382	0	5
<i>Pocadicnemis pumila</i> (Blackwall, 1841)	1	1	0	0
<i>Stemonyphantes lineatus</i> (Linnaeus, 1758)	0	0	1	0
<i>Taranucnus carpaticus</i> Gnelitsa, 2016	3	4	1	1
<i>Tenuiphantes alacris</i> (Blackwall, 1853)	0	0	6	7
<i>Tenuiphantes cristatus</i> (Menge, 1866)	2	1	1	0
<i>Trochosa spinipalpis</i> (F. O. P.-Cambridge, 1895)	17	3	0	0
<i>Walckenaeria atrotibialis</i> O. P.-Cambridge, 1878	1	1	5	1
<i>Walckenaeria cucullata</i> (C. L. Koch, 1836)	7	3	0	0
<i>Walckenaeria furcillata</i> (Menge, 1869)	2	0	0	0
<i>Walckenaeria mitrata</i> (Menge, 1868)	1	0	0	0
<i>Zelotes clivicola</i> (L. Koch, 1870)	3	0	0	0
<i>Zelotes latreillei</i> (Simon, 1878)	3	0	0	0
<i>Zora distincta</i> Kulczynski, 1915	11	0	0	0
<i>Zora silvestris</i> Kulczynski, 1897	5	0	0	0
<i>Zora spinimana</i> (Sundevall, 1833)	9	1	0	1
D-vac samples	European spruce		Scots pine	
	Hummock	Ground	Hummock	Ground
<i>Anguliphantes tripartitus</i> (Miller & Svaton, 1978)	0	0	2	1
<i>Centromerus arcanus</i> (O. P.-Cambridge, 1873)	10	11	38	17
<i>Centromerus pabulator</i> (O. P.-Cambridge, 1875)	0	0	0	5
<i>Centromerus silvicola</i> (Kulczynski, 1887)	0	0	0	1
<i>Ceratinella brevis</i> (Wider, 1834)	1	0	3	3

Table 2 (continued)

D-vac samples	European spruce		Scots pine	
	Hummock	Ground	Hummock	Ground
<i>Clubiona subsultans</i> Thorell, 1875	0	0	0	1
<i>Cryphoea silvicola</i> (C. L. Koch, 1834)	0	0	23	7
<i>Cybaeus angustiarum</i> L. Koch, 1868	0	0	1	2
<i>Cyclosa conica</i> (Pallas, 1772)	0	0	1	0
<i>Dicymbium tibiale</i> (Blackwall, 1836)	0	3	13	8
<i>Ero furcata</i> (Villers, 1789)	0	0	0	4
<i>Evarcha falcata</i> (Clerck, 1757)	5	6	1	0
<i>Gonatium rubellum</i> (Blackwall, 1841)	2	7	3	2
<i>Gongylidiellum murcidum</i> Simon, 1884	0	0	1	0
<i>Hahnia pusilla</i> C. L. Koch, 1841	6	14	0	0
<i>Kaestmeria pullata</i> (O. P.-Cambridge, 1863)	0	1	0	0
<i>Lepthyphantes nodifer</i> Simon, 1884	0	0	44	12
<i>Macrargus rufus</i> (Wider, 1834)	0	2	1	4
<i>Mansuphantes arciger</i> (Kulczynski, 1882)	0	3	1	0
<i>Maso sundevalli</i> (Westring, 1851)	0	0	13	4
<i>Mecopisthes silus</i> (O. P.-Cambridge, 1872)	0	0	3	0
<i>Megalepthyphantes nebulosus</i> (Sundevall, 1830)	0	0	0	1
<i>Metellina mengei</i> (Blackwall, 1870)	0	0	0	1
<i>Micrargus apertus</i> (O. P.-Cambridge, 1871)	1	2	1	3
<i>Micrargus herbigradus</i> (Blackwall, 1854)	1	0	4	1
<i>Micrommata virescens</i> (Clerck, 1757)	0	1	0	0
<i>Minyriolus pusillus</i> (Wider, 1834)	2	1	23	45
<i>Neon reticulatus</i> (Blackwall, 1853)	8	1	3	1
<i>Notioscopus sarcinatus</i> (O. P.-Cambridge, 1872)	0	26	0	0
<i>Ozyptila trux</i> (Blackwall, 1846)	3	2	7	0
<i>Pelecopsis elongata</i> (Wider, 1834)	0	0	3	0
<i>Phrurolithus festivus</i> (C. L. Koch, 1835)	1	0	0	0
<i>Piratula hygrophila</i> (Thorell, 1872)	1	2	0	0
<i>Piratula uliginosa</i> ' (Thorell, 1856)	1	1	0	0
<i>Pocadicnemis pumila</i> (Blackwall, 1841)	4	9	0	3
<i>Sintula corniger</i> (Blackwall, 1856)	13	7	25	7
<i>Stemonyphantes lineatus</i> (Linnaeus, 1758)	0	0	2	2
<i>Talavera aperta</i> (Miller, 1971)	0	0	0	1
<i>Talavera parvistyla</i> Logunov & Kronstedt, 2003	0	1	0	0
<i>Tallusia experta</i> (O. P.-Cambridge, 1871)	0	1	0	0
<i>Taranucnus bihari</i> Fage, 1931	0	0	0	2
<i>Tenuiphantes alacris</i> (Blackwall, 1853)	0	20	34	15
<i>Tenuiphantes cristatus</i> (Menge, 1866)	95	185	10	18
<i>Tenuiphantes mengei</i> (Kulczynski, 1887)	0	1	0	0
<i>Tenuiphantes tenebricola</i> (Wider, 1834)	1	0	0	2
<i>Tenuiphantes tenuis</i> (Blackwall, 1852)	0	1	0	0
<i>Trochosa spinipalpis</i> (F. O. P.-Cambridge, 1895)	0	0	1	0
<i>Walckenaeria cucullata</i> (C. L. Koch, 1836)	0	2	4	3
<i>Walckenaeria cuspidata</i> Blackwall, 1833	0	0	0	1
<i>Walckenaeria mitrata</i> (Menge, 1868)	0	0	1	2
<i>Xysticus audax</i> (Schrank, 1803)	1	0	2	1
<i>Zora distincta</i> Kulczynski, 1915	0	2	2	4
<i>Zora spinimana</i> (Sundevall, 1833)	3	5	10	3

Appendix 3

See Table 3.

Table 3 Spider species listed in Central European Red Lists (Řezáč et al. 2015)

Spider species	Czech republic	Carpathian red list	Germany	Poland
<i>Agyneta conigera</i> (O.P.-Cambridge, 1863)		LC		
<i>Anguliphantes tripartitus</i> (Miller & Svatoň, 1978)		LC		
<i>Araneus alsine</i> (Walckenaer, 1802)	VU		LC	
<i>Centromerus silvicola</i> (Kulczyński, 1887)		VU		DD
<i>Clubiona subsultans</i> Thorell, 1875	LC			
<i>Dicymbium tibiale</i> (Blackwall, 1836)	LC			
<i>Dolomedes fimbriatus</i> (Clerck, 1757)	VU		LC	
<i>Drassodes pubescens</i> (Thorell, 1856)				VU
<i>Gongylidiellum murcidum</i> Simon, 1884	VU			
<i>Hahnia pusilla</i> C.L.Koch, 1841		LC		
<i>Kaestneria pullata</i> (O.P.-Cambridge, 1863)	VU		VU	
<i>Lasaeola tristis</i> (Hahn, 1833)	LC			
<i>Lepthyphantes nodifer</i> Simon, 1884	LC			
<i>Mansuphantes arciger</i> (Kulczyński, 1882)	LC	VU	LC	
<i>Mecopisthes silus</i> (O.P.-Cambridge, 1872)	LC	EN		
<i>Metopobactrus prominulus</i> (O.P.-Cambridge, 1872)	VU			
<i>Micaria pulicaria</i> (Sundevall, 1831)		LC		
<i>Micrargus apertus</i> (O.P.-Cambridge, 1871)				VU
<i>Notioscopus sarcinatus</i> (O.P.-Cambridge, 1872)	LC		VU	
<i>Pardosa lugubris</i> (Walckenaer, 1802)				EN
<i>Pelecopsis elongata</i> (Wider, 1834)	LC			
<i>Pirata uliginosus</i> (Thorell, 1856)	VU			VU
<i>Piratula hygrophila</i> (Thorell, 1872)			LC	VU
<i>Sibianor aurocinctus</i> (Ohlert, 1865)	LC			
<i>Sintula corniger</i> (Blackwall, 1856)	LC		LC	VU
<i>Talavera aperta</i> Miller, 1971	LC	LC		
<i>Trochosa spinipalpis</i> (F.O.P.-Cambridge, 1895)	LC			
<i>Walckenaeria mitrata</i> (Menge, 1868)				VU
<i>Zelotes clivicola</i> (L.Koch, 1870)			LC	
<i>Zora distincta</i> Kulczyński, 1915	RE	EN		EN

EN endangered, VU vulnerable, LC least concern, RE regionally extinct

Appendix 4

See Table 4.

Table 4 List of significant indicator species

Pitfall trap samples	Habitat	IndVal	<i>p</i>
<i>Neriere radiata</i> Walckenaer 1841	European spruce, hummock	0.26	0.013
<i>Pardosa riparia</i> C L Koch 1833	European spruce, hummock	0.50	<0.001
<i>Phrurolithus festivus</i> C L Koch 1835	European spruce, hummock	0.17	0.083
<i>Trochosa spinipalpis</i> F O P Cambridge 1895	European spruce, hummock	0.51	<0.001
<i>Walckenaeria cucullata</i> C L Koch 1836	European spruce, hummock	0.32	0.003
<i>Zora distincta</i> Kulczyski 1915	European spruce, hummock	0.46	<0.001
<i>Zora silvestris</i> Kulczynski 1897	European spruce, hummock	0.26	0.011
<i>Zora spinimana</i> Sundevall 1833	European spruce, hummock	0.27	0.011
<i>Piratula hygrophila</i> Thorell 1872	European spruce, ground	0.63	<0.001
<i>Piratula uliginosa</i> Thorell 1856	European spruce, ground	0.89	<0.001
<i>Callobius claustrarius</i> Hahn 1833	Scots pine, hummock	0.38	0.005
<i>Cybaeus angustiarum</i> L Koch 1868	Scots pine, ground	0.76	<0.001
D-vac samples	Habitat	IndVal	<i>p</i>
<i>Hahnia pusilla</i> C L Koch 1841	European spruce, ground	0.42	0.016
<i>Notioscopus sarcinatus</i> O P Cambridge 1872	European spruce, ground	0.9	<0.001
<i>Tenuiphantes cristatus</i> Menge 1866	European spruce, ground	0.54	<0.001
<i>Centromerus arcanus</i> O P Cambridge 1873	Scots pine, hummock	0.45	0.008
<i>Cryphoea silvicola</i> C L Koch 1834	Scots pine, hummock	0.69	<0.001
<i>Dicymbium tibiale</i> Blackwall 1836	Scots pine, hummock	0.37	0.019
<i>Lepthyphantes nodifer</i> Simon 1884	Scots pine, hummock	0.78	<0.001
<i>Maso sundevalli</i> Westring 1851	Scots pine, hummock	0.38	0.021
<i>Tenuiphantes alacris</i> Blackwall 1853	Scots pine, hummock	0.39	0.024
<i>Ero furcata</i> Villers 1789	Scots pine, ground	0.30	0.047
<i>Minyriolus pusillus</i> Wider 1834	Scots pine, ground	0.63	<0.001

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