UNIVERSITY OF PALACKY IN OLOMOUC
Faculty of Science
Department of Ecology and Environmental Sciences

Mosses as living environment for invertebrates

Bachelor of Science thesis

Bojana Božanić
Ecology and environmental protection

Supervisor: Mgr. et Mgr. Ivan H. Tuf, Ph.D.
Consultant: RNDr. Zbyněk Hradílek, Ph.D.

Olomouc 2008

Proclamation

I, Bojana Božanić hereby proclaim that I made this study on my own, under the supervision of Dr. Ivan H. Tuf and Dr. Zbyněk Hradílek and using only cited literature.

May 11th, 2008 in Olomouc

Acknowledgement

First of all, I would like to thank my supervisor, Dr. Ivan H. Tuf, for the help given and his time and patience invested in this work. Then I’d like to thank my supervising, Dr. Zbyněk Hradílek, for help with identification of mosses and for providing the further necessary information needed. I’d also like to thank the specialists who identified the collected zoological material: Dr. V. Pižl (earthworms), Dr. F. Šťáhlavský (false scorpions), A. Véle M.Sc. (ants), O. Machač (spiders) and J. Tufová, M.Sc. (millipedes). Special thanks goes to my roommate, Marea Grinval, and my family for giving me peace and support while writing my thesis

May 11th, 2008 in Olomouc

Božanić B.: Mosses as living environment for invertebrates. Bachelor thesis, Department of Ecology and Environmental Sciences, Faculty of Science, Palacky University in Olomouc, 28 p

Abstract

Mosses (Bryophyta) represent an important natural habitat for different species of invertebrates that can live there, search for food or shelter, hunt and laying of their eggs. Mosses have an interesting microclimate and are capable of water preservation. Invertebrates can be advantageous for mosses as well, for example by spreading their spores.

The main aim of this study was to detect species living in mosses and find how a moss, as a habitat, and environmental factors effect them. We obtained 66 moss samples and the animals were heat-extracted from them using Tullgren apparatuses. For each sample environmental variables were recorded: type of substrate, moss species, altitude above soil ground, diameter of tree, thickness of moss, size of moss growth, and shading of moss.

Totally we had 15 moss species and 13 invertebrate taxa. Eight taxa (Chilopoda, Diplopoda, Araneae, Pseudoscorpionida, Opilionida, Isopoda, Lumbricidae and Formicidae) were identified to species level and altogether we evaluated a distribution of 45 species. The richest assemblages of invertebrates were found in *Brachythecium curtum* growing at a dead tree. The most abundant taxa were Isopoda (439 specimens) and Diplopoda (240 specimens). From the environmental factors, the most important ones, in terms of taxa, were type of substrate, height above ground and moss/sample area. In terms of species, the most important factors were type of substrate, height above ground and tree diameter.

Božanić B.: Mechy jako životní prostředí pro bezobratlé živočichy. Bakalářská práce, Katedra ekologie a životního prostředí, Přírodovědecká fakulta, Univerzita Palackého v Olomouci, 28 s.

Abstrakt

Mechy (Bryophyta) představují důležité přirozené stanoviště pro různé druhy bezobratlých, které tam žijí, hledají potravu nebo úkryt, loví nebo tam kladou vajíčka. Mechy mají oproti prostředí stabilnější mikroklima a zadržují vodu. Bezobratlí mohou být také užiteční pro mechy například rozšiřováním jejich spor.

Hlavním cílem této práce bylo zjistit, které druhy bezobratlých živočichů žijí v meších a jak mechy, spolu s environmentálními faktory, působí na bezobratlé. Bylo sebráno 66 vzorků mechu a živočichové byly tepelně extrahováni s použitím Tullgrenových aparátů. Pro každý vzorek byly při odběru zaznamenány tyto envoronmentální proměnné: typ substrátu (živý strom, mrtvý strom, povrch půdy), druh mechu, výška nad zemí, průměr stromů, tloušťka a velikost mechového polštáře a oslunění mechu.

Dohromady jsme měli 15 druhů mechů a 13 taxonů bezobratlých. Osm taxonů (Chilopoda, Diplopoda, Araneae, Pseudoscorpionida, Opilionida, Isopoda, Lumbricidae a Formicidae) byly zpracovány na druhovou úroveň, celkově jsme hodnotili distribuci 45 druhů bezobratlých. Nejhojnější taxony byly suchozemští stejnonožci (439 exemplářů) a mnohonožky (240 exemplářů). Nejvýznamnější environmentální faktory, predikující abundanci daných vyšších taxonů, byly typ substrátu, výška nad zemí a velikost mechového polštáře (ve vztahu ke vzorku). Pro distribuci jednotlivých druhů měly největší význam vedle typu substrátu také výška nad zemí a průměr stromu.

Contents

List of tables

List of figures

Introduction

Mosses represent an important part of ecosystems. They are an irreplaceable role in peat bogs, forests, tundra, alpine ecosystems, spring areas etc. They have the ability to absorb water quickly and to release it gradually (Váňa, 2006). In ecosystems they represent component part of biomass and participate in photosynthesis, hydrological, chemical, decomposing and some other processes (Váňa, 2006). They were and still are the first colonizers of new areas among plants – they stabilize substrate, restrain erosion and produce litter. Now-a-days mosses are used as indicators – they can indicate air and water pollution. They are also used in monitoring of heavy metals, because they are able to accumulate and retain heavy metals of up to 60 times higher concentrations (Váňa, 2006).

They also prevent from drying-out of their underlying substrate; in the milder regions they represent water refuge (Smith, 1982). Therefore they can provide microhabitat for aquatic invertebrates, many of which are capable of adaptation to a regime of repeated drying and remoistening (Merrifield & Ingham, 1998). The ability of mosses to provide a humid terrestrial microenvironment may have had a role in the evolution of Dipterans (Gerson, 1969). This may also explain bryobiont's habitat preferences – they prefer moss' microclimatic factors (Drozd et al., 2007). The ecological role of mosses lies also in their abilities to protect invertebrates from climate oscillation. They provide insulation against rapid temperature and humidity changes (Merrifield & Ingham, 1998). Their structure shapes available air spaces within a framework of plant tissue (Gerson, 1969). Under extreme conditions survival and abundance of some invertebrates fully depends on the mosses present (Gerson, 1969). Mosses can modify soil conditions and thereby affect the distribution of certain arthropods (Gerson, 1969). Acarina are one of the most common species living in mosses; one group, Cryptostigmata, is, due to their habitat, known as moss-mites (Gerson, 1969). Other invertebrates, typical inhabitant of moss, are nematodes and tardigrades (Merrifield & Ingham, 1998).

There are species, such as crane fly *Dolichopeza* or mite *Eustigmaeu*s that oviposit their eggs in mosses (Smith, 1982). Cricket species *Pteronemobius palustris* and *Pteronemobius fasciatus* are laying their eggs on *Sphagnum* (Gerson, 1969). Some insect, temporarily using Bryophytes, may also pupate therein.

Bryophytes can also serve as food for some invertebrates (Gerson, 1969) such as beetles, orthopterans, collembolan, caterpillars or aphids. For example, mosses represent a food component of groundhopper *Tetrix ceperoi*, whose main diet component is *Bryum argenteum* (Kočárek & al., 2008). Several detritophagous species (as millipedes, woodlice, earthworms) find food recourses in bryophyte growths too.

Some predators have abilities to hunt within mosses, although mosses are representing great shelter for hiding from predators. Mosses can be used as camouflage by invertebrates, which live in bryophytes. Tipulid, *Trigoma trisulcata*, lives in mountain streams where its larvae lives attached to moss *Fontinalis antipyretica* (Gerson, 1969) and the result of this association is that perfect mimicry as larvae resemble moss. This kind of disguise helps them only when they are inside or nearby moss growth. Several Bryophytes were found covering living curculionid beetles in New Guinea too (Geressitt et al., 1968).

Invertebrates can be also useful for mosses. *Dicranum flagellare* depends mostly on the dispersal of asexual branches to colonize disturbance gaps on decaying logs, and it is discovered that forest slugs are good dispersal vector (Kimmerer & Young, 1995). Coprophilous species of flies can be enticed by color of also coprophilous moss Splachnaceae or their secretion and are helping them with dissemination (Gerson, 1969). The important factor here is also the morphology of moss spores, which are sticky and usually attaches to bodies of flies.

Aims of this research were:

1) To describe the invertebrate communities inhabiting mosses in the Litovelské Luhy NR.
2) To compare invertebrates depending on species, size and thickness of moss growth.
3) To compare them depending on environmental characteristics such as type of substrate (dead wood, living tree, ground), height above ground, insulation, tree diameter, and decay level of dead tree.

Materials and Methods

Description of locality

Research was done inside the area of National Reserve Litovelské luhy (49º 42’ 30.5’’ N, 17º 5’ 46.2’’ E, altitude 208 m), which is a part of protected landscape area Litovelské Pomoraví, The Czech Republic. Litovelské Luhy NR has the total area of 344.45 ha, with the altitude of 229-231 meters above sea level. The center of NR is made of continental river delta of river Morava and binding complexes of flood-plain forests, wet alluvial meadows and wetlands, situated between city of Litovel and village Střeň. Dominant is hard wood *Querco-Ulmetum* flood-plain forest (Šafář et al., 2003) but here can be also found growths of soft wood *Salicetum albae*. Dominant tree species are *Quercus robur*, *Fraxinus excelsior*, *Ulmus laevi*) and *Populus nigra*. Spring flora consists of *Alanthus nivalis*, *Leucojum vernum*, *Isopyrum thalictroides*, *Pulmonaria obscura*, *Primula elatior*, *Corydalis cava* and *Corydalis solida*, *Stellaria holostea*, *Ranunculus lanuginosus* and others. Dominant in summer flora are *Allium ursinum* and *Urtica dioica*. In the growths could be found mountain and submontane plants such as *Anthriscus nitida*, *Veronica montana* and *Silene dioica*. The age of the forest in the precise location where research took place is ca 130 years.

Sampling and extraction

In all, 66 bryophyte samples were collected, half of them at spring (May 21st) and the remainder in autumn (October 5th) in year 2007. The samples that were taken from the dead tree or ground were taken together with a layer or substrate (bark or layer of soil). Samples, taken from the living tree were mostly scratched off the tree into a net. Invertebrates were heat-extracted from the mosses later on in the laboratory using Tullgren funnels (Tuf & Tvardík, 2005). The samples were placed in the apparatuses for seven days. Extracted invertebrates were sorted, counted, and identified at species level eventually.

Measured parameters

Each sample was characterised by evaluation of several environmental parameters. **Moss species** – taken samples consisted from the one moss species, mixed growths were ignored; **size of sample** – size was chosen by the size of the moss pillow (i.e. 20 × 20 cm, 5 × 20 cm or 5 × 15 cm , respectively); **substrate** – taken samples of moss were growing on either fallen tree, living tree or ground; **tree diameter** – if the samples were taken from decomposing fallen tree or living tree, the tree diameter was measured; **height above ground** – was measured on all the samples except for the ones living on the ground; **shading** of the sampled moss – was evaluated as proportion of canopy closure at photography taken towards the sky perpendicularly to the ground, shading was scaled in percents (e.g. 80 % means that biggest part lies in shades, only 20 % in sun); **moss/sample area** – was scaled from 1-4 (sample covered part of whole moss growth: 1 = 100 %, 2 = 50 %, 3 = 20-50 %, 4 = 0-10 %); **decay level** – was scaled from 1-4 (1 = wood is hard, bark everywhere, 2 = wood is softish, bark on more than 50 %, 3 = wood is pretty soft, bark on less than 50 %, 4 = wood is completely soft, without bark); **thickness** of the moss growth.

Statistical analysis

Quantitative data from the sample collection were analysed in the CANOCO programme for Windows 4.5© (Ter Braak & Šmilauer 1998). The effect of environmental parameters on the distribution of invertebrates, both in taxon or species groups, were evaluated by unimodal *canonical correspondence analysis* (CCA), and evaluated using Monte-Carlo permutation tests. To see relation (dependence) between species and environmental factors from CCA analysis, we used *generalised additive models* (GAM) imaged in programme CanoDraw for Windows 4.0© (part of CANOCO software).

Results

Sampled invertebrate communities

In total 66 samples, we had 15 species of Bryophyte (Tab. 1). *Hypnum cupressiforme* was the most abundant species. There were 14 altogether (13 pure and 1 mixed with another species).

We evaluated 13 invertebrate's groups in moss samples. The most abundant taxa were Isopoda (439 specimens) and Diplopoda (240 specimens), and the least abundant were Opilionida (12 specimens) and Araneae (16 specimens). We identified to the species level all together 45 species: 9 species of Chilopoda, 7 species of Diplopoda, 4 species of Pseudoscorpionida, 6 species of Isopoda, 4 species of Opilionida, 6 species of Lumbricidae, 4 species of Formicidae and 5 species of Araneae (juveniles were identified at genus or family level).

Moss *B. curtum* had the biggest mean number of species per sample (7) and also the highest mean Simpson's index of diversity (0.7). Another two *Brachythecium*, *B. salebrosum* and *B. rutabulum*, had high number of species per sample, 4 and 5.5 respectively. Interesting is that all three species with the highest mean number of species were growing on the dead tree (*Homalia cupressiforme* with 5 species in sample grew at both live and dead trees). *B. salebrosum*, growing on dead tree, and, *P. cuspidatum* growing on both ground and live tree, had one of the highest mean Simpson's index of diversity, 0.5.

Cluster analysis of dissimilarity (Fig. 1) of 15 moss' species after presence/absence of invertebrate species in this mosses divided species into two bigger groups. First group of mosses (*A. serpens, I. alopecuroides, A. attenuatus, P. repens, B. salebrosum* and *H. trichomanoides*) were mostly growing on the dead and living tree, but second group (*B. curtum, P. undulatum, E. hians, P. rostratum* and *P. cuspidatum*) were mostly growing on the ground and dead tree. Interesting is that the most dissimilar was *A. undulatum* (growing on the dead tree), that had relatively high mean number of species in sample (4) and *B. rutabulum* and *H. cupressiforme* (growing on the living tree), that were similar to each other.

Table 1: List of invertebrate species extracted from moss samples with basic ecological characteristics. Abbreviations: D – dead tree, G – ground, L – live tree

	Amblystegium serpens	*Anomodon attenuatus*	*Atrichum undulatum*	*Brachythecium curtum*	*Brachythecium rutabulum*	*Brachythecium salebrosum*	*Eurhynchium hians*	*Homalia trichomanoides*	*Hypnum cupressiforme*	*Isothecium alopecuroides*	*Metzgeria furcata*	*Plagiomnium cuspidatum*	*Plagiomnium rostratum*	*Plagiomnium undulatum*	*Platygyrium repens*
Chilopoda	0	3	6	1	3	1	1	3	6	0	1	1	3	2	0
Geophilus flavus	-	-	-	-	+	-	+	-	+	-	-	-	-	-	-
Lithobius borealis	-	-	-	-	-	-	-	+	+	-	+	-	-	-	-
Lithobius erythrocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithobius forficatus	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-
Lithobius microps	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Lithobius mutabilis	-	-	+	-	-	-	-	-	+	-	-	+	+	+	-
Lithobius spp. (juv)	-	+	+	-	+	+	-	+	+	-	-	-	-	-	-
Strigamia acuminata	-	-	+	-	-	-	-	-	+	-	-	-	+	-	-
Schendyla nemorensis	-	+	+	+	+	-	-	-	+	-	-	-	+	+	-
Diplopoda	1	0	5	2	4	2	2	2	1	0	0	1	3	1	1
Brachydesmus superus	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Glomeris conexa	-	-	+	+	+	-	+	-	-	-	-	+	+	+	-
Leptoiulus proximus	-	-	+	+	-	+	-	+	-	-	-	-	+	-	-
Melogona broelemanni	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-
Nemasoma varicorne	-	-	-	-	+	+	-	-	+	-	-	-	-	-	+
Polydesmus denticulatus	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-
Unciger transsilvanicus	-	-	+	-	+	-	+	-	-	-	-	-	-	-	-
Isopoda: Oniscidea	1	2	2	2	4	2	3	3	4	1	0	4	4	4	4
Androniscus roseus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Hyloniscus riparius	-	+	+	+	+	-	+	+	+	-	-	-	+	+	+
Porcellium collicolla	-	+	+	-	+	+	+	+	+	+	-	+	+	-	+
Protracheoniscus politus	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Trachelipus rathkei	+	-	-	-	+	+	-	+	+	-	-	+	+	+	+
Trichoniscus pusillus	-	-	-	+	+	-	+	-	+	-	-	+	+	+	-
Araneae	0	0	2	1	4	0	0	2	1	0	0	0	0	1	0
Clubiona sp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Diplocephalus sp.	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-
Linyphiidae gen. sp.	-	-	+	+	+	-	-	+	+	-	-	-	-	+	-
Trochosa sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Xysticus sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Opilionida	0	0	0	0	1	1	2	0	2	0	0	1	0	1	0
Mitostoma chrysomelas	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Platybunus bucephalus	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Rilaena triangularis	-	-	-	-	-	+	+	-	+	-	-	-	-	-	-
Trogulus tricarinatus	-	-	-	-	+	-	+	-	-	-	-	-	-	+	-
Pseudoscorpionida	0	0	1	0	1	1	0	1	2	0	0	0	0	0	1
Chernes hahnii	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+
Pselaphochernes scorpioides	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-
Neobisium sylvaticum	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Neobisium carcinoides	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-

Table 1 (continuing): List of invertebrate species extracted from moss samples with basic ecological characteristics. Abbreviations: D – dead tree, G – ground, L – live tree

	Amblystegium serpens	*Anomodon attenuatus*	*Atrichum undulatum*	*Brachythecium curtum*	*Brachythecium rutabulum*	*Brachythecium salebrosum*	*Eurhynchium hians*	*Homalia trichomanoides*	*Hypnum cupressiforme*	*Isothecium alopecuroides*	*Metzgeria furcata*	*Plagiomnium cuspidatum*	*Plagiomnium rostratum*	*Plagiomnium undulatum*	*Platygyrium repens*
Formicidae	0	0	1	0	1	0	0	2	3	0	0	0	0	2	0
Lasius brunneus	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Lasius fuliginosus	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Leptothorax gredleri	-	-	-	-	-	-	-	+	+	-	-	-	-	+	-
Myrmica rubra	-	-	+	-	+	-	-	-	+	-	-	-	-	+	-
Annelida: Lumbricidae	0	0	1	1	3	0	2	1	2	0	0	1	2	1	1
Aporrectodea caliginosa	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Dendrobaena octaedra	-	-	+	-	+	-	+	-	+	-	-	-	+	+	+
Dendrodrilus rubidus	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-
Lumbricus castaneus	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Lumbricus rubellus	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-
Octolasion lacteum	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
main type of substrate	D	L	G	D	D	D	G	LD	DL	L	L	GL	G	G	DL
number of samples	2	2	6	1	6	2	6	4	13	1	1	3	5	3	6
number of species in samples	2	5	18	7	21	7	10	14	21	1	1	8	12	12	7
mean number of species in sample	1	3	4	7	5.5	4	2.8	5	2.9	1	1	3	3.2	3.3	1.7
mean Simpson´s index of diversity	0	0.4	0.4	0.7	0.3	0.5	0.3	0.3	0.3	0	0	0.5	0.4	0.3	0.2

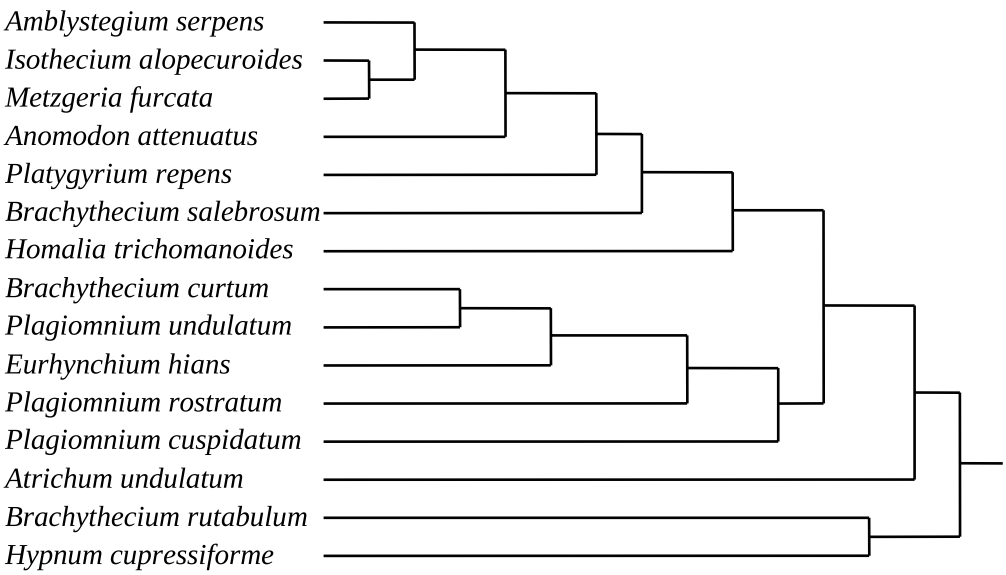

Figure 1: Dissimilarity of mosses species after presence/absence of invertebrate species

Environmental analysis of taxa distribution

Lengths of gradient species data were from 5.387 to 7.235, from this reason we used CCA (Fig. 2). Whole model was significant (F = 2.956, p = 0.0020). Variability, explained by main axes is shown in the table 3. First canonical axe shows 37.2 % of variability, second axe shows 20.9 %. Results of CCA analysis of environment factors are visualised in Tab. 4. According to the results of CCA, significant factors were height above ground, moss/sample area, season (i.e. spring vs. autumn), and living tree vs. dead tree or ground. All the other factors were not significant.

It is evident (Fig. 2) that height above ground had significant influence on Diplopoda only, even though it was statistically the most important (F = 7.41). Taxa Collembola and Opilionida were numerous in spring season (F = 5.48). As visible from the figure 2, Gastropoda, larvae and Formicidae were mostly found on ground level. Decay level had the influence on Pseudoscorpionida, even though this parameter was not significant.

Table 2: Description of CCA model for taxa distribution with conditional effects of environmental variables

Axes	1	2	3	4	Total inertia
Eigenvalues	0.372	0.209	0.131	0.069	2.407
Species-environment correlations	0.866	0.809	0.709	0.531	
Cumulative percentage variance					
of species data	15.5	24.1	29.6	32.4	
of species-environment relation	42.7	66.6	81.6	89.5	
Sum of all eigenvalues					2.407
Sum of all canonical eigenvalues					0.872

Variable	Lambda	P	F
height above ground	0.26	0.002	7.41
spring	0.18	0.002	5.48
live tree	0.12	0.002	3.98
moss/sample area	0.08	0.012	2.51
ground	0.08	0.008	2.69
shading	0.04	0.162	1.44
decay level	0.04	0.152	1.37
thickness	0.03	0.34	1.06
sample area	0.03	0.65	0.76
tree diameter	0.01	0.822	0.56

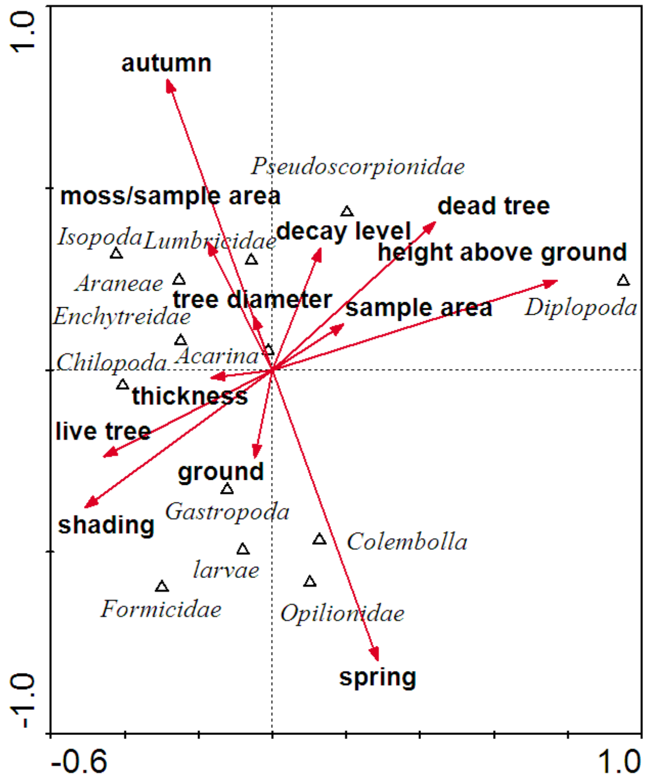

Figure 2: Ordination plot of influence of environmental parameters on invertebrate taxa

Using GAM, we showed the influence and importance of significantly studied parameters – height above ground and moss/sample area on studied taxa (Acarina, Araneae, Collembola, Diplopoda, Enchytreidea, Formicidae, Gastropoda, Chilopoda, Isopoda, larvae, Lumbricidae, Opilionida and Pseudoscorpionida). We discovered a significant relation between height above ground and 6 taxa: Acarina, Collembola, Diplopoda, Formicidae, Chilopoda and Pseudoscorpionida, the strongest relation was found for millipedes (Tab. 5). Ants and centipedes preferred habitats on the ground or very near to it (Fig. 3). Mites and false scorpions inhabited mosses growing at the base of a tree and dead fallen trees lying on the ground. Millipedes were living in mosses, very high on trees, at the heights up to 160 cm. Relation between moss/sample area and invertebrates was significant in the case of Diplopoda, Enchytreidea, Chilopoda, Isopoda, larvae (the strongest) and Lumbricidae (Tab. 5). Larvae, millipedes, centipedes and woodlice were numerous in the samples where we were taking whole or almost whole moss pillow (Fig. 4), i.e. they were abundant in small moss growths. On the other hand pot-worms were mostly in bigger moss pillows where we were taking only parts of it.

Table 3: Influence of height above ground and moss/sample area to abundance of invertebrate taxa (F-test of GAM)

	height above ground	moss/sample area
Acarina	4.50**	n.s.
Araneae	n.s.	n.s.
Colembolla	2.81*	n.s.
Diplopoda	13.51**	3.05*
Enchytreidea	n.s.	2.82*
Formicidae	3.23**	n.s.
Gastropoda	n.s.	n.s.
Chilopoda	2.78*	3.56*
Isopoda	n.s.	0.113*
larvae	n.s.	4.99**
Lumbricidae	n.s.	0.072*
Opilionida	n.s.	n.s.
Pseudoscorpionida	4.42**	n.s.

** - p< 0.01; * - p< 0.05; n.s. - not significant

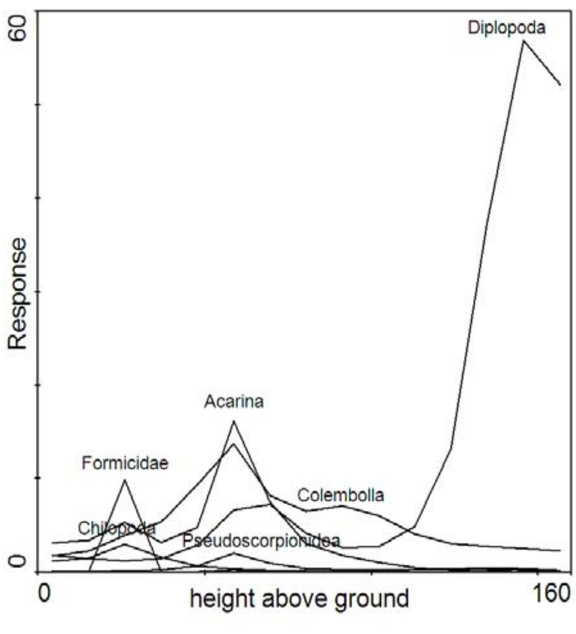

Figure 3: Dependence of taxa distribution on height above ground

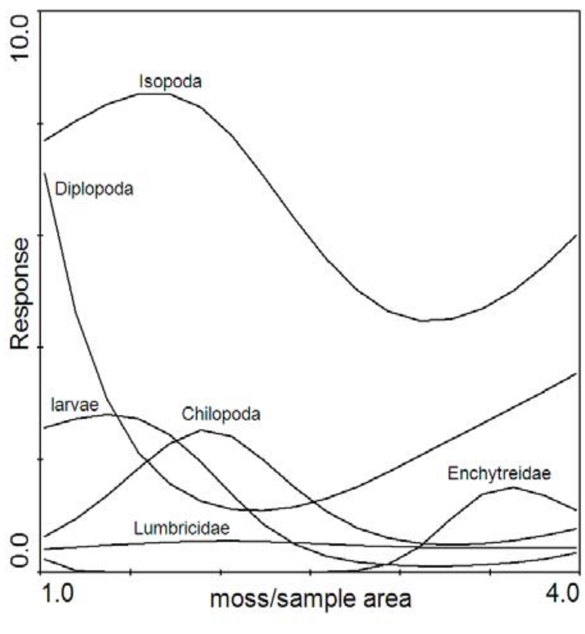

Figure 4: Dependence of taxa distribution on moss/sample area

Environmental analysis of species

Method, we used for analysis of species was CCA. First canonical axe shows 77.6 % of variability, second axe shows 72.8 % (Tab. 6). Whole model was significant (F = 2,264, p = 0.0020). According to the results of CCA, significant factors were height above ground, tree diameter, season (i.e. spring vs. autumn) and substrate (i.e. living tree & ground vs. dead tree) (Tab. 7). Obviously, group consisting of three *Lithobius* centipedes – *L. erythrocephalus, L. borealis* and *Lithobius* spp., and ants *Lasius brunneus, Lasius fuliginosus* and *Leptothorax gredleri* were living on live trees (Fig.5). At the opposite side of this graph we can see species that preferred the dead tree, millipede *Nemasoma varicorne*, false scorpion *Chernes hahnii* and earthworm *Dendrodrillus rubidus*. Harvestman *Rilaena triangularis* was present in the spring season.

Table 4: Description of CCA model for species distribution with conditional effects of environmental variables

Axes	1	2	3	4	Total inertia
Eigenvalues	0.776	0.728	0.424	0.341	9.5
Species-environment correlations	0.975	0.919	0.861	0.801	
Cumulative percentage variance					
of species data	8.2	15.8	20.3	23.9	
of species-environment relation	25.9	50.1	64.2	75.6	
Sum of all eigenvalues					9.5
Sum of all canonical eigenvalues					3.002

Variable	LambdaA	P	F
live tree	0.75	0.002	4.94
height above ground	0.65	0.002	4.63
spring	0.36	0.002	2.55
tree diameter	0.29	0.012	2.16
ground	0.23	0.014	1.7
shading	0.19	0.064	1.49
moss/sample area	0.19	0.078	1.43
decay level	0.14	0.424	1.02
thickness	0.1	0.644	0.82
sample area	0.1	0.794	0.73

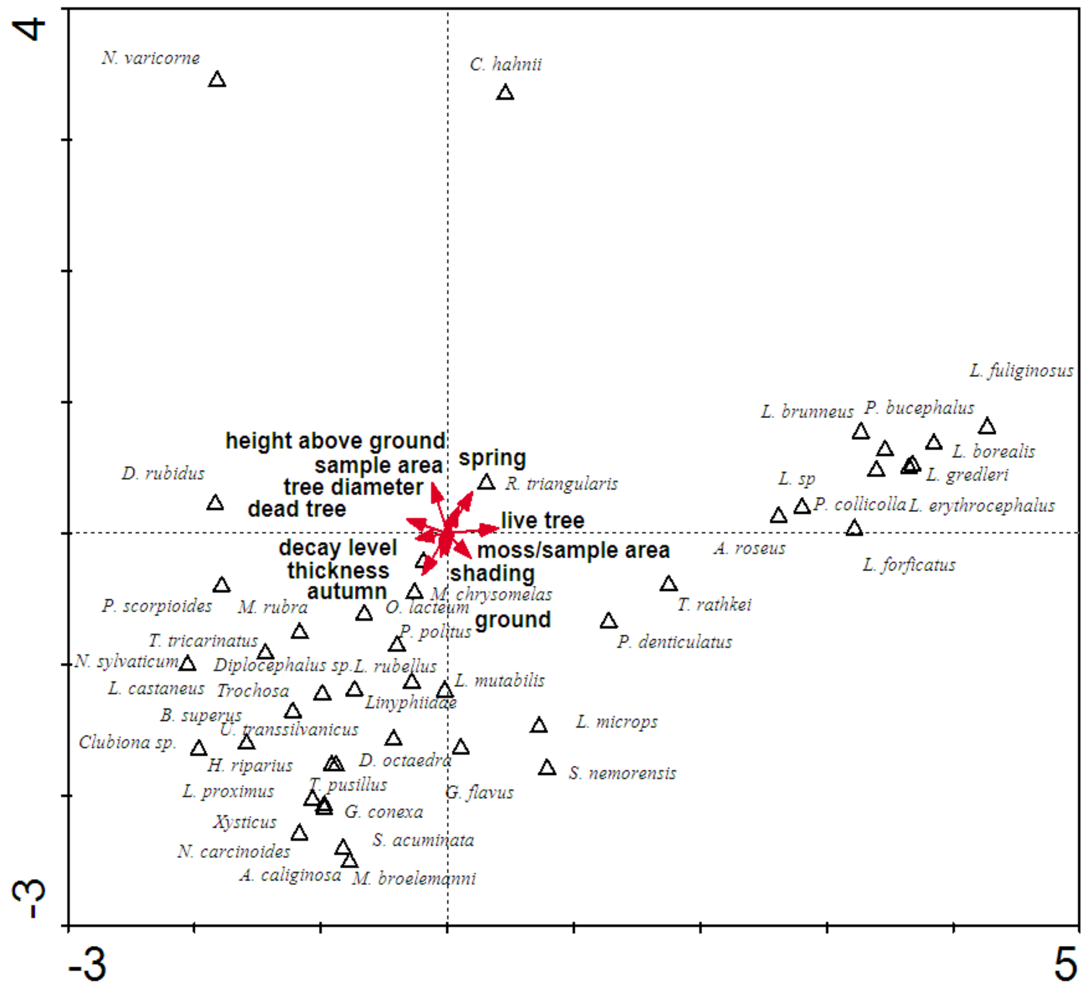

Figure 5: Ordination plot of influence of environmental parameters on invertebrate species

Height above ground showed significant effect on 8 species, and of those it had the strongest effect on millipede *N. varicorne* (F = 37.53) and false scorpion *Pselaphochernes scorpioides* (F = 22.49). Millipede *Glomeris connexa* and isopod *Trichoniscus pusillus* were found on the ground, centipedes *Schendyla nemorensis*, *Lithobius* spp. And isopod *Porcellium collicolla* on the other hand were found on the lower parts of the living trees or dead trees lying close to the ground (Fig. 6 and 7). *N. varicorne* was living in the mosses growing on approximately 160 cm above ground.

Tree diameter had significant effect on 10 species and had also very strong effect on *N. varicorne* (F = 21.25). Tree diameter had, after *N. varicorne*, the biggest effect on *G. conexa* (F = 7.58) and isopod *Trachelipus rathkii* (F = 7.30). Smaller trees (tree diameters) were preferred by *G. connexa* and *T. pusillus*, middle ones by ant *Myrmica rubra*, *N. varicorne*, *P. collicolla* and *P. scorpioides*. Isopods *Hyloniscus riparius*, *T. rathkii*, centipedes *Lithobius* sp. and *Lithobius mutabilis* preferred larger tree diameters.

Table 5: Influence of height above ground and tree diameter to abundance of invertebrate species (F-test of GAM), evaluated only for species with more than 10 specimens

	height above ground	tree diameter
D. octaedra	n.s.	n.s.
G. connexa	2.41*	5.74**
H. riparius	n.s.	7.58**
L. fuliginosus	n.s.	n.s.
L. mutabilis	n.s.	3.34**
Lithobius spp. juv	5.65**	4.38**
Linyphiidae gen. spp.	n.s.	n.s.
M. rubra	n.s.	0.366*
N. varicorne	37.53**	21.25**
P. collicola	3.62**	5.10**
P. scorpioides	22.49**	2.96**
S. nemorensis	2.43*	n.s.
T. pusillus	5.36**	4.98**
T. rathkii	3.44**	7.30**

** - p< 0.01 ; * - p< 0.05 ; n.s. - not significant

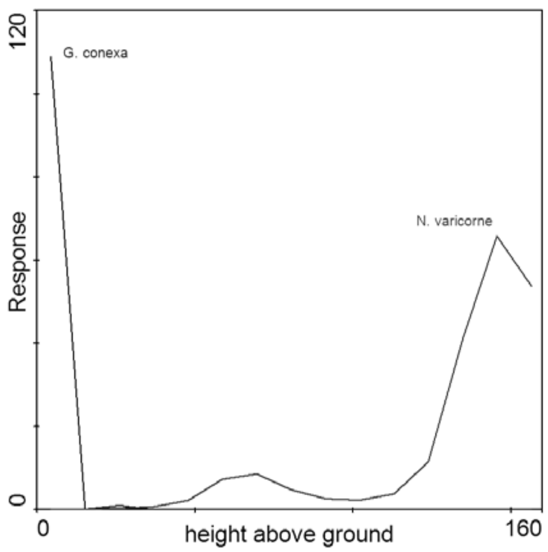

Figure 6: Dependence of millipede species distribution on height above ground (only species with significant model)

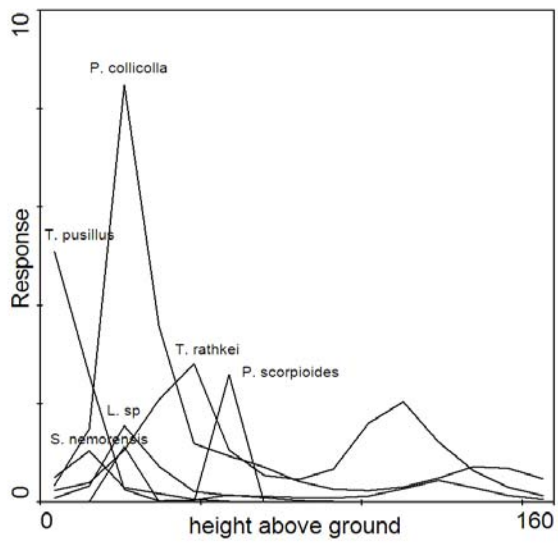

Figure 7: Dependence of invertebrate species distribution on height above ground (only species with significant model)

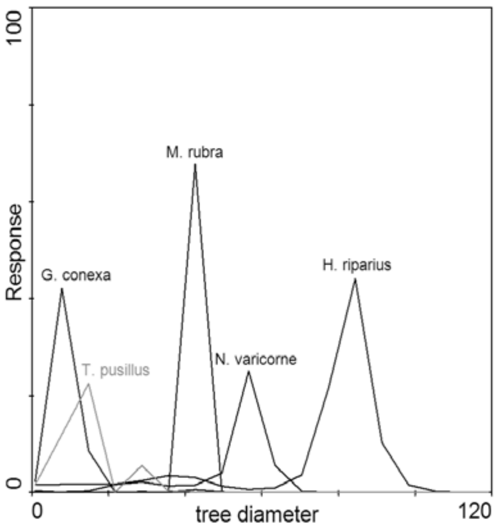

Figure 8: Dependence of invertebrate species distribution on tree diameter (only species with significant model and strong response)

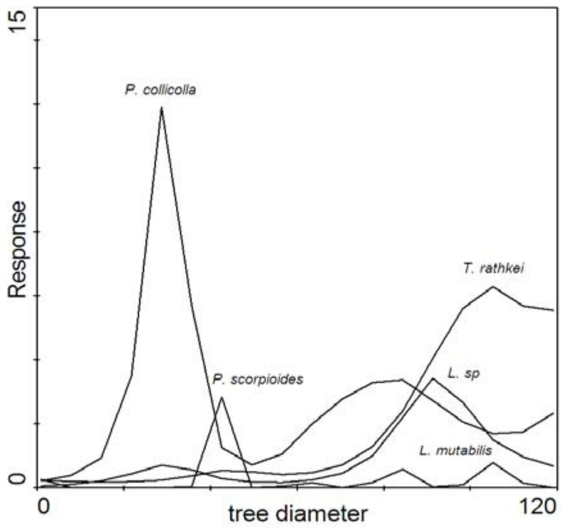

Figure 9: Dependence of invertebrate species distribution on tree diameter (only species with significant model and weak response)

Discussion

Comparison of moss species after their inhabitants

Mosses *B. curtum, B. salebrosum* and *B. rutabulum* were mosses with most different species per sample, according to mean number of species per sample and Simpson's index of diversity. It is interesting that among the most abundant ones were three mosses of the same genus. We should consider their thickness as well. Genus *Brachythecium* had the highest growths of all (they were oscillating around 2 cm). All three species of genus *Brachythecium,* common on rotten wood (Fenton & Frego, 2005) as underlying substrate, showed quite a lot of dissimilarity on the clusters analysis. *A. undulatum* showed least similarity to other mosses. It seems like this species, which was growing on ground, was interesting for centipedes and millipedes. We collected six samples of this species and in these samples we had six out of nine centipede and five out of seven millipede species. Isopods were present the most in the samples where moss belonged to genus *Plagiomnium*, growing on ground; *T. pusillus* and *H. riparius* are mainly upper soil layer inhabitants (Tuf, 2002).

Clusters analysis showed dissimilarity between mosses growing on living trees and ground, but mosses growing on dead trees were similar to both mosses growing on living trees and ground. This depends on the decay level – when smaller decay level, mosses are more similar to ones on live trees. The examples for this are *B. curtum* and *P. undulatum* that are showing strong similarity, though *B. curtum* is growing on dead tree and *P. undulatum* is growing on ground.

Analysis of factors

Analysis of factors showed that most significant for taxa were height above ground and moss/sample area. It was interesting that Enchytreidae were numerous in moss pillows where we were taking only 50-10 % of the whole moss pillow. Code 1 was assigned for the samples where we took a whole moss pillow and 2 for ones where we took 50 %.

Concerning that our biggest sample was less than 30 cm in diameter it was expected that Enchytreidae wouldn't be numerous in these moss pillows, because they have ability to form multi-species aggregates of 30 to 50 cm in diameter caused by their search for best a biotic conditions and food availability (Lavelle & Spain, 2001), but in the bigger ones from which we took only smaller parts. Larvae, Diplopoda and Isopoda were mostly in smaller and more compact moss pillows (code 1 and partly 2) probably because they found shelter against predators there.

It is very interesting that Diplopoda were mostly found at the higher positions, around 160cm above ground. Mosses growing at these heights were usually growing on dead, decaying trees, which are known to be suitable for Diplopoda (significant *N. varicorne*), as detritophagous species, because their food occurs there (Lavelle & Spain, 2001). Although this species was found mainly in moss growths covering dead trees, *N. varicorne* is millipede extremely tolerant to high temperature and desiccation (Haacker, 1968, Enghoff, 1976). On the other hand *G. conexa* was the most numerous in lower heights, but also present in higher levels. *G. connexa* is one know as species with relatively good protection to desiccation, this millipede is active through whole day (Tuf et al., 2006). Isopods *P. collicola, T. pusillus* and *T. rathkii* are sensitive to water loss and depend on wet, sheltered areas (Lavelle & Spain, 2001), as mosses are, and were also present in lower parts of trees or at ground. Centipedes *S. nemorensis* prefer soils, especially ones which facilitate their movement e.g. ones that have Lumbricidae galleries (Lavelle & Spain, 2001). All the samples of *Lithobius* sp. that we had were juveniles, is evident, that young specimens of this genus avoid to predation pressure of adults inhabiting soil (Rawcliffe, 1988) by escaping to mosses at lower parts of living trees. *P. scorpioides* was present in the same area as Acarina and that may be explained by the fact that their food consists of Acarina, even hard-shelled Oribatidae (Kühnelt, 1976).

Conclusion

As we can see from our work, mosses are representing habitat for large scale of invertebrates. Our work showed that even though they are not rich in nutrients as other plants nor as big as them, they still are valuable biotopes which are invertebrates using in different ways. We saw that both moss size and spatial position have influence on their spatial distribution. Genus *Brachythecium* in general had the biggest diversity and species with the richest community of invertebrates was *B. curtum*, growing on the dead tree. Species belonging to the genus *Brachythecium* were growing on the dead tree as an underlayer and other genus *Plagiomnium* preferred ground as substrate. From the environmental characteristics the biggest role in invertebrates' densities played height above ground, tree diameter and moss/sample area. Habitats existing on higher levels above ground were the most preferred among millipedes especially species *N. varicorne*. Acarina, Pseudoscorpionida and Formicidae stayed in the lower levels. In terms of tree diameter, isopods *T. pusillus* and *P. collicolla* were in mosses living on smaller trees, where another isopod *T. rathkii*, together with centipede *L. mutabilis* and juveniles of *Lithobius* sp. stayed in the mosses growing on larger trees.

This project should contribute to the better knowledge of the ecology of both mosses and soil invertebrates. Mosses, considered as a habitat for many species, haven't been studied thoroughly enough. They still, in a certain way, present a mystery. If we think that mosses were one of the first species to leave the ocean and adjust to the land life we should be aware that, as we are facing climate changes, they could be one of the last resorts of some invertebrates. It is necessary to continue studying and observing them globally as a complex together with invertebrates.

References

- **Drozd, P., Plášek, V., Dolný, A., Kočárek, P., Jašík, M. (2007):** Factors or mosses - What the bryobionts prefer? Nowellia Bryologica, Belgium, 34: 9-10
- **Enghoff, H. (1976):** Parthenogenesis and bisexuality in the millipede, *Nemasoma varicorne* C.L. Koch, 1847 (Diplopoda: Blaniulidae). Morphological, ecological, and biogeographical aspects. Videnskabelige Meddelelser fra Dansk Naturhistorisk Forening, 139: 21-59
- **Fenton J. N., Frego A. K. (2005):** Bryophyte (moss and liverwort) conservation under remnant canopy in managed forests. Biological conservation, 122: 417-430
- **Geressitt J.L.,Samuelson A.,Vitt D.H. (1968):** Moss growing on living Papuan moss-forest weevils. Nature, 217: 765-767
- **Gerson U. (1969)**: Moss-arthropod association. The Bryologist, 72: 495-500
- **Haacker U. (1968):** Deskriptive, experimentelle und vergleichende Untersuchungen zur Autökologie rhein-mainischer Diplopoden. Oecologia, 1: 87-129
- **Kimmerer W.R., Young C.C. (1995)**: The role of slugs in dispersal of the asexual propagules of *Dicranum flagellare*. The Bryologist, 98: 149-153
- **Kočárek P., Grucmanová Š., Filipcová Z., Bradová L., Plášek V., Holuša J. (2008):** Mosses as a food component of groundhopper *Tetrix ceperoi* (Orthoptra: Tetrigidae). In: Kočárek, P., Plášek, V., Malachová, K. (Eds.): Environmental changes and biological assessment IV, Book of abstract. Faculty of Science, University of Ostrava, Ostrava: 43-44
- **Kühnelt W. (1976):** Soil Biology, with Special Reference to Animal Kingdom (revised edition). Faber and Faber, London
- **Lavelle P., Spain V.A. (2001):** Soil Ecology. Kluwer Academic Publishers, Dordrecht, Boston, London
- **Merrifield K., Ingham E.R. (1998)**: Nematodes and other aquatic invertebrates in *Eurhynchium oreganum* from Mary's Peak, Oregon Coast Range. The Bryologist, 101: 505-511

- **Rawcliffe C.P. (1988):** Cannibalism in a lithobiid centipede. Bulletin of the British Myriapod Group, 5: 39
- **Šafář J. et al. (2003):** Olomoucko. In: Mackovčin P., Sedláček M. (eds.): Chráněná území ČR, svazek VI., Agentura ochrany přírody a krajiny ČR a EkoCentrum, Brno & Praha
- **Smith A.J.E. (Ed.) (1982):** Bryophyte Ecology. Chapman & Hall, London & NY
- **Ter Braak C.J.F., Šmilauer P. (1998)**: CANOCO Reference Manual a User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power, Ithaca
- **Tuf, I.H. (2002):** Contribution to the knowledge of vertical distribution of soil macrofauna (Chilopoda, Oniscidea). In: Tajovský K., Balík, V., Pižl V. (Eds.): Studies on Soil Fauna in Central Europe. Institute of Soil Biology, AS CR, České Budějovice: 241-246
- **Tuf, I.H., Tvardík, D. (2005):** Heat-extractor – indispensable tool for soil zoological studies. In: Tajovský K., Schlaghamerský J., Pižl V. (Eds.): Contributions to Soil Zoology in Central Europe I. ISB AS CR, České Budějovice: 191-194
- **Tuf I.H., Tufová J., Jeřábková E., Dedek P. (2006):** Diurnal epigeic activity of myriapods (Chilopoda, Diplopoda). Norwegian Journal of Entomology, 53: 335-344
- **Váňa J. (2006):** Obecná bryologie. Univerzita Karlova v Praze, Karolinum

- http://www.litovelskepomoravi.ochranaprirody.cz/index.php?cmd=page&id=561, date 28.4.2008. 23.57 h