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Soil Collembola communities in montane coniferous forests of the Bohemian Forest

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Abstract
Collembola communities were studied within the catchments of Čertovo Lake and Plešné Lake in the Bohemian Forest for three years. To sample wider spectrum of microhabitats due to high heterogeneity of the area, four differently treated forest stands were selected for the study within both catchments. A total of 7,294 Collembola specimens were recorded belonging to 93 species of 46 genera and 11 families. In the catchment of Čertovo Lake, 4,199 specimens of Collembola were recorded belonging to 71 species with a total mean abundance 34,992 ind.m^{-2}. In the catchment of Plešné Lake, 3,095 Collembola specimens were recorded belonging to 69 species with a total abundance 25,792 ind.m^{-2}. The most abundant species in the both areas under study was *Isotomiella minor*. Due to occurrence of the species like *Protaphorura parallata, P. s-vontoernei, Tetracanthella stachi*, and the newly recorded species *Anurophorus konseli*, we could consider Collembola communities of the Bohemian Forest (Šumava in Czech) closely associated to the fauna of the Alps, unlike other districts of the Czech Republic, as it was already stated in previous studies.

Keywords: Collembola, soil microarthropoda, Alpine fauna, montane forest, coniferous forest, Šumava

Introduction

Montane coniferous forest ecosystems are characterised by thick humus layers, low decomposition rates and strong limitations by nutrients, particularly N deposition of organic matter is therefore likely to be especially important for maintaining ecosystem functions in these ecosystems (Dehlin et al. 2006). Although coniferous forests are predominant in the colder northern or alpine regions, where the annual range of temperature is often greater than in the more southern deciduous forests, the persistence of foliage throughout the year often creates more moist microclimatic conditions and attenuates the seasonal variation in air temperature, which is such a characteristic feature of deciduous forests. Equally significant, as far as the soil fauna is concerned, is the type of litter and humus produced by conifers (Wallwork 1976).

In most terrestrial ecosystems, Collembola are an important part of the soil mesofauna. In addition, soil mesofauna frequently includes mites, nematodes, and enchytraeids, as well as small millipedes, earthworms, ants, small gastropods, isopods, and larvae of insects (Tebbe et al. 2006). Collembola are small, easily overlooked invertebrates, but they are widespread

and abundant, commonly reaching densities of tens to hundreds of thousands per square meter in the top few centimetres of soils through the world (Wallwork 1976). By feeding on dead organic matter and soil microorganisms, Collembola have significant influences on soil microbial ecology and fertility and thus, through their influence on microorganisms, decomposition and nutrient cycling, Collembola are important inhabitants of soil worldwide (Culik & Zeppelini Filho 2003).

Besides ecological studies, there are also some summarising studies referring about recently known species of particular soil macro- and mesofauna groups of the Bohemian Forest, e.g. earthworms (Pižl 2002), millipedes (Tajovský 2002), oribatid mites (Matějka & Starý 2009), and springtails (Rusek 2001). However, many of them, including the study on Collembola, are quite outdated. Therefore, the aim of this contribution is to update the recent knowledge of soil Collembola of this region after more than a decade since last studies were published.

Material and methods

The study was conducted in the central European mountain region, the Bohemian Forest (Šumava) in the Czech Republic. Within the mountain range, two different research localities were chosen – the catchments of Čertovo Lake and Plešné Lake (Fig. 1). To sample the most of microhabitats due to high heterogeneity of the area, four differently treated forest stands were selected for the study on both study areas: undamaged forest stands, "dead" forest stands damaged by bark beetles, previously slightly managed windthrown forest stands left for the natural succession, and freshly harvested windthrown stands.

The catchments of Čertovo Lake and Plešné Lake were characterised as follows; thin (0

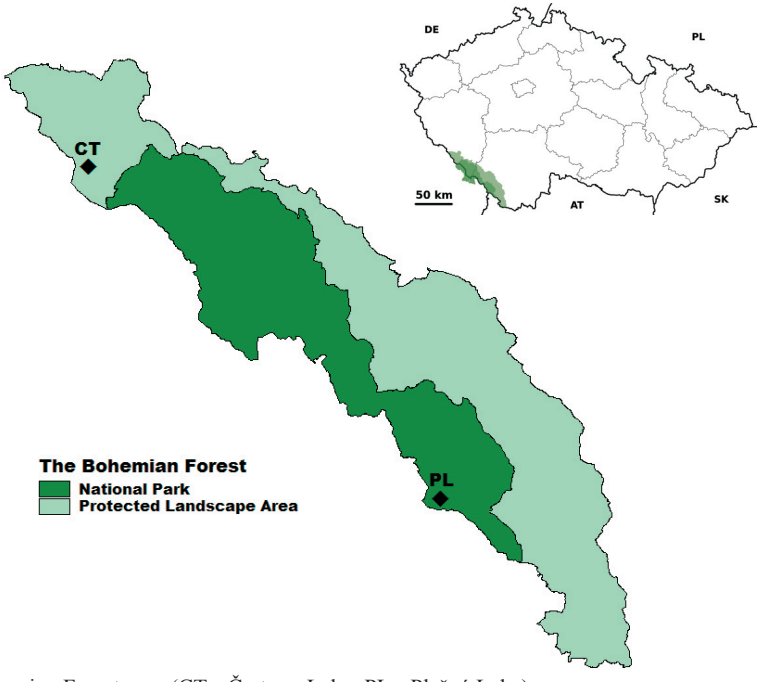

Fig. 1 The Bohemian Forest area (CT - Čertovo Lake, PL - Plešné Lake)

to 30 cm thick) brown podsolic soils with a moor soil of humus on boulders commonly occur there. The altitude of sampling sites in the catchment of Čertovo Lake ranged from 1,047 to 1,339 m a.s.l. and of those in the catchment of Plešné Lake ranged from 1,001 to 1,316 m a.s.l. While the forest around Čertovo Lake is dominated by Norway spruce 90–150 years old, with sparse fir and beech and the bedrock is predominately made up of mica-schist (muscovite gneiss) with quartzite intrusions, the forest around Plešné Lake is on average 160 years old, dominated by Norway spruce (99%), with a minor contribution of mountain ash and beech with the bedrock made up of granites (Veselý et al. 1998).

Soil samples were taken within each locality from four different forest management treatments twice a year for three years (July and October 2012, June and October 2013, June and September 2014). During each sampling occasion five replicate soil cores were taken randomly with a steel corer from individual research plot. Each sample represented soil core of 3.6 cm in diameter (10 cm^{-2} in area) to a maximum depth of 7–12 cm (depending on the soil depth). The soil microarthropods were subsequently extracted in a modified high-gradient apparatus (Crossley & Blair 1991) in the laboratory for seven days. Collembola were identified to the species level using basic taxonomic keys for Symphypleona (Bretfeld 1999), Poduromorpha (Fjellberg 1998), Hypogastruridae (Thibaud et al. 2004), Isotomidae (Potapov 2001), Onychiurinae (Pomorski 1998), and Tullbergiinae (Zimdars & Dunger 1994). Finally, community parameters such as mean abundance, species richness, Shannon's diversity index, and Pielou's evenness index were calculated for comparison of the collembolan assemblages.

Results and discussion

A total of 7,294 Collembola specimens were recorded belonging to 93 species of 46 genera and 11 families (see Appendix 1). Community parameters of Collembola in both catchments calculated for individual years are shown in Table 1.

In the catchment of Čertovo Lake, 4,199 specimens of Collembola were recorded belonging to 71 species with a total abundance 34,992 ind.m^{-2}. Significantly the most abundant species was *Isotomiella minor* (14,942 ind.m^{-2}), followed by *Pseudisotoma sensibilis* (4,375 ind.m^{-2}) and *Parisotoma notabilis* (3,108 ind.m^{-2}). The next considerable abundant species were *Friesea truncata* (1,617 ind.m^{-2}), *Protaphorura pseudovanderdrifti* (1,442 ind.m^{-2}), and *Friesea mirabilis* (1,417 ind.m^{-2}). In sume 23 exclusive species for this area under study were found, e.g. *Anurophorus konseli* or *Schaefferia emucronata* (for a complete list see

Table 1. Community parameters of soil Collembola in the catchments of Čertovo Lake and Plešné Lake in the Bohemian Forest during three years.

Sampling years:	**2012**	**2013**	**2014**
Čertovo Lake:			
mean abundance ± SD (ind.m^{-2})	40,200±8,202	34,500±2,546	30,275±530
species richness	42	45	50
H' – Shannon's diversity index	2.43	2.43	2.81
J' – Pielou's evenness index	0.65	0.64	0.72
Plešné Lake:			
mean abundance ± SD (ind.m^{-2})	14,875±12,127	27,575±6,187	34,925±15,945
species richness	37	48	57
H' – Shannon's diversity index	2.66	3.11	3.03
J' – Pielou's evenness index	0.74	0.80	0.75

Appendix 1).

In the catchment of Plešné Lake, 3,095 Collembola specimens were recorded belonging to 69 species with a total abundance 25,792 ind.m^{-2}. The most abundant species in this area under study was *I. minor* (3,717 ind.m^{-2}). Next most abundant species were *Friesea truncata* (2,533 ind.m^{-2}) and *Mesaphorura tenuisensillata* (2,058 ind.m^{-2}), followed by *Folsomia quadrioculata* (1,967 ind.m^{-2}), *Tetracanthella stachi* (1,917 ind.m^{-2}), and *Pseudisotoma sensibilis* (1,650 ind.m^{-2}). We observed 19 species exclusive for this area, e.g. *Protaphorura tricampata* or *Folsomides angularis* (for the complete list see Appendix 1).

Within three years of the present study, we recorded in total 93 Collembola species. Thus the list of 174 species so far known from the Bohemian Forest (Rusek 2001) has been completed by another 35 species recorded for this region for the first time, e.g. *Desoria ruseki*, *Mesaphorura sensibilis*, *Micranurida granulata*, *Pseudosinella thibaudi*, *Schoetella ununguiculata*, and *Sminthurides schoetti*. Therefore the actual complete list has been extended to 209 Collembola species. Moreover, we found one new species, *Metaphorura* sp. nov., and three possible new species *Lepidocyrtus* sp. 1, *Lepidocyrtus* sp. 2, and *Pseudosinella* sp.; however, they were not completely determined to the species level due to their juvenile stage (see Appendix 1).

The record of *Schaefferia emucronata* in the catchment of Čertovo Lake is very interesting, since this species is considered primarily as an inhabitant of subterranean habitats and hypogean environment known as mesovoid shallow substratum (MSS), which are typical for karst areas (Thibaud et al. 2004). Unlikely, the bedrock of Čertovo Lake catchment is characterised as metamorphic rock, which makes this record even more peculiar.

Rusek (2001) defined specific relation of the collembolan fauna of the Bohemian Forest to the Alps unlike other districts of the Czech Republic. Within the newly recorded species, however, we found also some species like *Hymenaphorura polonica* or *Tetracanthella fjellbergi*, which are associated with the Carpathian fauna. We further recorded some already known Alpine species like *Protaphorura parallata*, *Protaphorura s-vontoernei*, *Tetracanthella stachi*, as well as the newly recorded species *Anurophorus konseli*, which was up to the present time known only from eastern part of the Alps (Potapov 2001). Therefore, due to the occurrence of the species mentioned above, we could confirm close association of Collembola communities of the Bohemian Forest to the fauna of the Alps.

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Appendix 1. List of Collembola species found in the Čertovo Lake (CT) and Plešné Lake (PL) catchments in the Bohemian Forest, Czech Republic, 2012–2014. The newly recorded species for the Bohemian Forest collembolan fauna are in bold.

Order **Entomobryomorpha**	
Superfamily **Entomobryoidea** Family **Entomobryidae:**	
Lepidocyrtus lanuginosus (Gmelin, 1788)	CT
Lepidocyrtus lignorum (Fabricius, 1775)	CT, PL
***Lepidocyrtus serbicus* Denis, 1936**	CT
Lepidocyrtus violaceus (Geoffroy, 1762)	PL
Lepidocyrtus sp. 1 juv.	CT
Lepidocyrtus sp. 2 juv.	CT
Orchesella flavescens (Bourlet, 1839)	PL
Pseudosinella* cf. *albida	CT
Pseudosinella* cf. *biguttata	CT, PL
***Pseudosinella thibaudi* Stomp, 1977**	PL
Pseudosinella sp. juv.	CT
Willowsia nigromaculata (Lubbock, 1873)	CT, PL
Entomobryidae juv.	CT, PL
Superfamily **Isotomoidea** Family **Isotomidae:**	
***Anurophorus atlanticus* Fjellberg, 1974**	CT, PL
***Anurophorus konseli* Kseneman, 1936**	CT
***Anurophorus satchelli* Goto, 1956**	CT
Cryptopygus bipunctatus (Axelson, 1903)	CT
Desoria hiemalis (Schött, 1893)	CT
***Desoria ruseki* (Fjellberg, 1979)**	CT, PL
Desoria violacea (Tullberg, 1876)	CT
Folsomia inoculata Stach, 1947	CT, PL
***Folsomia manolachei* Bagnall, 1939**	CT, PL
Folsomia quadrioculata (Tullberg, 1871)	CT, PL
Folsomia sensibilis Kseneman, 1936	CT, PL
***Folsomides angularis* (Axelson, 1905)**	PL
***Folsomides parvulus* Stach, 1922**	PL
Isotoma viridis Bourlet, 1839	CT
Isotomiella minor (Schäffer, 1896)	CT, PL
Parisotoma notabilis (Schäffer, 1896)	CT, PL
Proisotoma cf. *minuta* juv.	CT
***Proisotoma* cf. *subminuta* juv.**	CT
Pseudanurophorus binoculatus Kseneman, 1934	CT, PL
Pseudisotoma sensibilis (Tullberg, 1876)	CT, PL
***Tetracanthella fjellbergi* Deharveng, 1987**	CT, PL
Tetracanthella stachi Cassagnau, 1959	CT, PL

Appendix 1. Continued.

Superfamily **Tomoceroidea** Family **Tomoceridae:**	
Pogonognathellus flavescens (Tullberg, 1871)	CT, PL
Tomocerina minuta (Tullberg, 1876)	CT, PL
Tomocerus minor (Lubbock, 1802)	PL
Order **Poduromorpha**	
Superfamily **Hypogastruroidea** Family **Hypogastruridae:**	
Ceratophysella armata (Nicolet, 1841)	CT, PL
Ceratophysella denticulata (Bagnall, 1941)	CT, PL
Hypogastrura socialis (Uzel, 1891)	CT, PL
***Schaefferia emucronata* Absolon, 1900**	CT
***Schoetella ununguiculata* (Tullberg, 1896)**	CT
Willemia anophthalma Börner, 1901	CT, PL
***Willemia denisi* Mills, 1932**	PL
Xenylla boerneri Axelson, 1905	CT
***Xenylla brevicauda* Tullberg, 1869**	PL
***Xenylla mediterranea* Gama, 1964**	CT
Superfamily **Neanuroidea** Family **Neanuridae:**	
***Deutonura albella* (Stach, 1920)**	CT
***Deutonura sinistra* (Denis, 1935)**	CT, PL
Friesea mirabilis (Tullberg, 1871)	CT, PL
Friesea truncata Cassagnau, 1958	CT, PL
***Micranurida balta* Fjellberg, 1998**	CT
***Micranurida granulata* (Agrell, 1943)**	CT, PL
Micranurida pygmea Börner, 1901	PL
Neanura muscorum (Templeton, 1835)	CT, PL
***Neanura parva* Stach, 1951**	CT, PL
***Neanura pseudoparva* Rusek, 1963**	CT, PL
***Pseudachorutes corticicolus* (Schäffer, 1896)**	PL
***Pseudachorutes crassus* Gama, 1964**	PL
***Pseudachorutes laricis* Arbea & Jordana, 1984**	PL
Pseudachorutes parvulus Börner, 1901	CT, PL
Superfamily **Onychiuroidea** Family **Onychiuridae:**	
Heteronychiurus stiriacus (Stach, 1946)	CT, PL
***Hymenaphorura parva* Skarzynski & Pomorski, 1996**	CT, PL
***Hymenaphorura polonica* Pomorski, 1990**	CT, PL
Micraphorura absoloni (Börner, 1901)	CT, PL
***Oligaphorura* sp. juv.**	CT
Protaphorura armata (Tullberg, 1869)	CT, PL
Protaphorura austriaca (Butschek, 1948)	CT, PL

Appendix 1. Continued.

Protaphorura cancellata (Gisin, 1956)	PL
***Protaphorura glebata* (Gisin, 1952)**	CT, PL
Protaphorura parallata (Gisin, 1952)	CT, PL
Protaphorura pseudovanderdrifti (Gisin, 1957)	CT, PL
Protaphorura subuliginata (Gisin, 1956)	CT
Protaphorura s-vontoernei (Gisin, 1957)	CT, PL
Protaphorura tricampata (Gisin, 1956)	PL
Protaphorura vanderdrifti (Gisin, 1952)	CT, PL
***Protaphorura vontoernei* (Gisin, 1957)**	CT, PL
Protaphorura sp. juv.	CT, PL
Family **Tullbergiidae:**	
Mesaphorura hylophila Rusek, 1982	CT, PL
Mesaphorura cf. *hylophila* juv.	PL
Mesaphorura macrochaeta Rusek, 1976	CT, PL
***Mesaphorura sensibilis* Rusek, 1973**	PL
Mesaphorura tenuisensillata Rusek, 1974	CT, PL
***Metaphorura* sp. nov.**	CT, PL
Order **Neelipleona**	
Family **Neelidae:**	
Megalothorax minimus Willem, 1900	CT, PL
Order **Symphypleona**	
Superfamily **Katiannoidea** Family **Katiannidae:**	
Sminthurinus aureus (Lubbock, 1862)	PL
***Sminthurinus elegans* (Fitch, 1863)**	CT, PL
Superfamily **Sminthuridoidea** Family **Sminthurididae:**	
***Sminthurides schoetti* Axelson, 1903**	PL
Sphaeridia pumilis (Krausbauer, 1898)	CT, PL
Superfamily **Sminthuroidea** Family **Bourletiellidae:**	
Deuterosminthurus cf. *pallipes* juv.	PL
Heterosminthurus sp. juv.	CT
Family **Sminthuridae:**	
Lipothrix lubbocki (Tullberg, 1872)	CT, PL
Sminthurus sp. juv.	PL