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Soil fauna across Central European sandstone ravines with temperature inversion: From cool and shady to dry and hot places

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ABSTRACT

Sandstone massifs with their deep ravines or gorges offer the instructive opportunity to study the response of organisms to steep environmental gradients. In 2008–2010, many groups of soil fauna were studied along transects across three ravines in the Bohemian Switzerland National Park (north-western Czech Republic), a part of the Elbe Sandstone Massif. Each transect included five sampling positions: two opposite edges, two opposite mid-slope positions, and the ravine bottom. The ravines had a specific microclimate characterized by temperature inversion. In general, the cooler and more humid ravine bottoms had also less acid soil with lower carbon content but enriched by litter of deciduous trees and herbs. The other transect positions were characterized by spruce (mid-slopes) and pine (edges) stands with mor humus, exposed to drought in the upper parts. The soil animal communities (identified to species level) differed substantially in dependence on their position along the transects. Ravine bottoms hosted a diverse soil fauna, including a rich macrofauna. The thick duff layer of acid soils on the slopes and edges hosted a poorer fauna but supported high densities of important decomposers such as enchytraeids, oribatid mites and microbivorous nematodes. In general, these were higher on the slopes, presumably due to the drought exposure of the edges. Vertical position in the ravine and soil pH were the most important factors explaining community composition. This confirmed that the area's high geomorphological diversity, leading to steep microclimatic gradients and heterogenous soil conditions, is a major cause of its high biodiversity. A shift in community structure in the lower parts of the ravines, observed after the first half of the study period, was possibly caused by summer flash floods. An increased frequency and severity of dry spells and flash floods due to heavy rains, predicted by relevant climate warming scenarios, will probably have an detrimental effect on the ravines'soil fauna.

1. Introduction

Steep environmental gradients within small segments of the landscape provide valuable opportunities to study distribution and ecological preferences of organisms and increase our understanding of the underlying mechanisms (e.g., Hasegawa et al., 2006; Melamud et al., 2007; Sinclair and Sjursen, 2001; Wytwer and Tajovský, 2009). These might be microclimatic gradients on a small geographical scale due to differences in altitude, or – particularly important for plants and soil fauna – gradients in soil properties such as pH, moisture, texture or nutrient availability. Currently the utility of such studies can also been looked upon from the perspective of climate change scenarios and connected issues of the adaptability of species and entire communities to rising temperatures and frequencies of droughts and floods (Briones et al., 1997; David and Handa, 2010; Dollery et al., 2006). Furthermore, diverse environmental conditions on a small geographical scale also provide for extremely diverse habitats and thus high biodiversity (Burnett et al., 1998; Tews et al., 2004). An area very suitable for the study of several such phenomena is the Bohemian Switzerland National Park in the sandstone massif along the Elbe River at the border between the Czech Republic and Germany. This landscape of high geomorphological diversity offers a wide range of habitats, from warm and dry habitats on the plateaux to cold and damp ones on the bottoms of deep ravines or gorges with inverted temperature conditions. Surprisingly, only few soil biological studies from sites with temperature inversion are available (Raschmanová et al., 2008, 2013). In our study we assessed the soil fauna across some of these ravines, which promised to host a high diversity of soil

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fauna. The area is characterized by the presence of species with an Atlantic type of distribution. Within the groups included in our study, these are for instance the earthworms *Aporrectodea icterica* and *A. limicola* (Pižl, 1997) and the millipedes *Cylindroiulus punctulatus* and *Polydesmus angustus* (Tajovský, 1998). Some preceding records also indicated that the ravines and gorges of the Bohemian Switzerland represent a refuge and migration corridor for montane and submontane species, such as the earthworm *Octodrilus argoviensis* (Pižl, 2007) and the millipedes *Mycogona germanica* and *Haasea germanica* (Tajovský, 1998).

The objective of the present study was to assess the effect of the steep microclimatic gradient in these sandstone ravines on the abundance and diversity of soil fauna. As soil conditions change also considerably from the bottoms of the ravines to their edges, they have to be considered and their effects – as far as possible – separated from the effect of microclimate. The microclimatic gradient is not only one of temperatures decreasing and humidity increasing from the ravines' edges to their bottom; at the same time these factors are substantially more stable on the bottoms, with winter temperatures above those at the ravine edges (Holec and Wild, 2011). It could therefore be expected that the ravine edges would host poorer assemblages of species better adapted to disturbances by drought and frost (r-strategists) than the bottoms, where more diverse assemblages and species requiring stable conditions would prevail.

2. Material and methods

2.1. Study area and sites

The Bohemian Switzerland National Park (Národní park České Švýcarsko, ca 79 km^2) is situated within the Czech part of a Cretaceous sandstone massif (with local basaltic intrusions of Tertiary origin) along the Elbe River at the border between Bohemia (Czech Republic) and Saxony (Germany), Central Europe. The area is moderately warm with a mean annual temperature of 7–8 °C. The mean annual precipitation is 750–850 mm, with a rather even distribution between the summer and winter half year. Erosion has modelled the sandstone into blocks, cliffs, and ravines or gorges that are usually deep and narrow (Mikuláš et al., 2007). Due to the phenomenon of temperature inversion these ravines have a typical microclimate. Continuous measurements showed that their bottoms, functioning as ever-cool buffers, are significantly colder than their slopes and edges during the vegetation period, but not so during the winter period, during which they even have a higher average minimal temperature than the upper parts of the ravines, very probably due to a lower intensity of heat fluxes to and from the sheltered ground surface, and longer lasting snow cover. They also confirmed a higher soil moisture on the bottoms during both vegetation and winter periods (Holec and Wild, 2011; see also for additional data based on measurements across five ravines, including two covered in this study).

The vegetation of the ravines is formed by a mosaic of close to natural forest stands of the *Luzulo-Fagetum* association, and *Picea abies* plantations established since the 18th century (with admixed *Pinus sylvestris*, *Fagus sylvatica* and the introduced *Pinus strobus*). *P. sylvestris* is the characteristic tree of the sandstone outcrops. Derived from acid sandstone, soils are in general acidic and of coarse, sandy texture, thus being susceptible to drought. Various subtypes of Cambisols, Podzols and Rankers are the predominant soil types, with Gley soils and Fluvisols on the bottoms of ravines and wider valleys.

Three transects across three ravines were studied, these were from west to east: the Kachní Potok Ravine (KP) with the sampling position on its bottom at 215 m a.s.l. (50°51.726′N, 14°18.547′E) and the highest point sampled at the edge of the slope at 270 m a.s.l., the Häuschengrund Ravine (HG) at a distance of ca 5 km, with the sampling position on its bottom at 345 m a.s.l. (50°52.596′N, 14°22.348′E) and the highest sampling position at 383 m a.s.l., and in ca 7 km distance northnorthwest of HG the Brtnický Potok Ravine (BP) with the sampling position on its bottom at 347 m a.s.l. (50°56.022′N, 14°24.314′E) and the highest one at 390 m a.s.l. (for slope aspects see Table 1). The Brtnický Potok Ravine was the widest, with a rather large permanent stream (the Brtnický potok) and a small floodplain with a rather open tree layer of *Acer pseudoplatanus*, *Fraxinus excelsior* and *Alnus glutinosa*, and a herb layer dominated by grasses on sandy alluvial deposits. The streams in the other two, narrower ravines were intermittent, sandy deposits covered by grass were only present in some spots, and deciduous trees were represented by a few beech trees interspersed among spruce in the lowest portions of the slopes. The slopes of the ravines were steep and covered by spruce stands, whereas their upper edges were mostly formed by sandstone walls and blocks covered by stands of Scots pine on very shallow soil.

2.2. Soil sampling

Along each transect five positions were sampled, covering edge (plateau) and mid-slope habitats (below referred to as "slopes") on both slopes of the ravine and its bottom (Fig. 1). Soil pH, organic (oxidable) carbon, and several macro- and microelements were measured at each sampling position from composite samples. Temperature and soil moisture were measured close to our sampling positions along two of the transects (Kachní Potok and Häuschengrund Ravines) by a collaborating research team (J. Wild, unpublished data). Temperature was measured at 15 cm above ground, at ground level and at 6 cm depth, moisture at 6 cm depth, both every 15 min, throughout June and October 2010 (year-round measurements were conducted but are not available for all transect positions because of downtimes of the measuring devices, for instance due to frequent damage caused by wild boar).

2.3. Sampling of soil fauna

Sampling was conducted along all transects in the same two days twice per year (June, October) from June 2008 to October 2010. At each transect position (see above) samples for Nematoda, Rotifera (microfauna), Enchytraeidae, Oribatida (mesofauna), Lumbricidae, Chilopoda, Diplopoda, and Oniscidea (macrofauna) were taken. For microfauna and oribatid mites five soil cores down to 10 cm depth were taken per transect position and date using a soil corer of 10 cm^2 surface area. Nematodes were extracted from subsamples of mixed soil (15 ml per core) using modified Baermann funnels (1 d, 25 °C), for further details see Háněl (2010). Rotifers were extracted using a L-C extractor (Devetter, 2010) from 15 g of mixed soil from each soil core. Oribatid mites were extracted from soil using modified (Fujikawa, 1970) Berlese-Tullgren funnels (5 d, 35 °C). For enchytraeids two soil cores per transect position and date were taken using a soil corer of 17 cm^2 surface area; soil was sampled down to 12 or 15 cm depth (depending on the presence of stones or roots). Enchytraeids were extracted by the wet funnel method (2 d, without heating, water changed after 24 h, extracted specimens retrieved after 24 h and 48 h). Macrofauna was sampled from 0 to 5 cm depth using a steel frame (25 cm × 25 cm, i.e. 1/16 m^2 surface area). Three samples per transect position and date were taken and extracted using a Kempson apparatus (7 d, heating up to 45–58 °C). In addition, soil to a depth of ca. 20–30 cm was digged and hand-sorted for earthworms at the sites with deeper soil (almost exclusively on the ravine bottoms).