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Factors of variation in beech forest understory communities on waste heaps left by historical Zn-Pb ore mining

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ABSTRACT

The species trait-environment relationships in understory vegetation were carried out on metalliferous sites created by historical Zn–Pb mining (S Poland), on which natural revegetation took place. The study sites were 31 small heaps of waste rock covered by an 80–120 year old beech forest. The sites were described in terms of plant coverage, species richness and composition, and the composition of plant traits. Three types of understory communities that were identified were compared for environmental variables and plant parameters. Despite a high concentration of heavy metals in soils, namely Cd, Pb, and Zn, the degree of shading by the tree canopy was the main factor determining variation in understory communities. The understories that developed in low and strong shading were similar to some extent: They had high number of species, and they were characterized by a high proportion of the ancient forest species. The species composition changed substantially with increasing coverage of trees; mixed strategy plants withdrew, while the stress tolerant species became more abundant. The other predictor of community structure was the ratio of Cd to Ca, which was responsible for the decrease of woody plants and the endangered species. This study proved that, in the case of highly complex and productive ecosystems, even with a high degree of contamination with heavy metals, the biotic factors play a primary role.

1. Introduction

Numerous studies on species diversity and the formation of metallicolous vegetation have been performed and showed that plant species richness and composition changed dramatically under the influence of soil contamination with heavy metals. Researches mainly focused on open metallicolous sites, where plant succession was in the early stages, and where calaminarian grassland issues were undertaken. There were either relatively young (decades old) polluted dumps of slags and waste rocks objects (Brown, 1994; Grodzińska and Szarek-Łukaszewska, 2009; Mapaure et al., 2011) or older (over a hundred years old), where difficult edaphic and climatic conditions inhibited the succession process in the early stages (Ernst, 1974; Simon, 1978; Becker and Dierschke, 2008; Brown, 2001; Becker, Brändel, 2007; Kapusta et al., 2015; Turisová et al., 2014, 2016; Woch et al., 2016; Becker and Brändel, 2007). There is still a lack of ecological research on factors affecting complex communities being in advanced succession as deciduous forests developed on metal-bearing sites (Podgórska, 2015; Woch et al., 2017).

In Western Małopolska (Krakow-Silesia industrial region, S Poland), there are numerous dolomite wastes remaining after centuries of ore Zn-Pb mining, most of which are covered with mature beech forests (80–120 years old). European beech (*Fagus sylvatica* L.) seems to be a late successional three naturally colonizing calcareous heaps in this region (Mazaraki, 1962; Podgórska, 2015; Woch et al., 2017). The old heaps covered with beech forests, in terms of geology, the history of origins and structure, are similar to those located in the same region of non-forested objects (Stefanowicz et al., 2014; Woch et al., 2016). They only differ in location within the ancient beech forest, which exists in the same boundaries at least since the second half of the 18th century (Woch et al., 2017). These usually are small heaps of rock, which often take the shape of a ring encircling a shallow pit. In the landscape, there are of islands of habitat with metal polluted, base-rich, and gravely/stony substrata (Stefanowicz et al., 2014; Woch et al., 2016). The concentrations of heavy metals in all heaps exceed environmental protection standards and widely vary between individual objects: 2–479 mg As kg^{-1}, 1.3–493.7 mg Cd kg^{-1}, 8–32,010 mg Pb kg^{-1}, 0–4.5 mg Tl kg^{-1} and 58–83,329 mg Zn kg^{-1}. Large variations of the contamination may result from differences in the content of metal ores as well as the different functions of the shaft that produced the remaining heap (ores exploitation, exploration, or ventilation using) (Woch, 2015). Skeletal and porous soils contain large amounts of calcium and magnesium, but they are often low in nitrogen and phosphorus (Pietrzykowski et al., 2011; Aleksander-Kwaterczak and Ciszewski, 2013; Stefanowicz et al., 2014). Calcium and magnesium originated from gangue dolomite (calcium magnesium carbonate –

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$CaMg[CO_3]_2$), while the source of nitrogen and phosphorus is organic matter, which depends on the amount of time that has elapsed since the abandonment of the object and the tree species composition (Pietrzykowski et al., 2011; Aleksander-Kwaterczak and Ciszewski, 2013; Stefanowicz et al., 2014).

In comparison to other European metalliferous areas, the alkalinity, the presence of some nutrients in the metallicolous Triassic dolomites, and the relatively humid climate at a low altitude above sea level result in more beneficial conditions for plant encroachment (Ernst, 1974; Smith, 1979; Grodzińska and Szarek-Łukaszewska, 2009). The phenomenon of the formation of close to the natural beech forest communities probably could also be contributed a small surface of heaps and its location in a large complex of the ancient forest. The patterns of primary succession in manmade island habitats depend on their distance from other habitats (Butaye et al., 2002; Novák, Konvička, 2006; Prach, Řehounková, 2006; Pen-Mouratov et al., 2014). Litter from the surrounding forests could greatly accelerate the rate of soil formation and succession on heaps and small clearings left after mining activities. Investigations of non-forest heaps showed that, on heaps located near the forest, the vegetation was the most advanced in the succession into woody communities (Woch et al., 2016). The proximity to the forest significantly modifies the rate and direction of succession through enriching the substrate with the litter and seeds of forest species (McDonnell and Stiles, 1983; Myster and Pickett, 1993; Naaf and Wulf, 2007; Kelemen et al., 2012; Loydi et al., 2013). Moreover, it cannot be excluded that local populations of species entering the heaps could have developed some metal tolerance in pre-industrial times, when they inhabited natural Zn-Pb ore outcrops (Woch et al., 2017).

Little is known about mature beech forest communities growing on metal-enriched sites. Analysis and interpretation of factors determining beech understory vegetation poses more difficulties in relation to the treeless metallicolous habitats covered by single-layer grasslands. Beech forest is characterized by higher biomass production, a complex multilayered structure, as well as a large translocation of elements due to deep roots and spreading the leaves (Augusto et al., 2002; Reich et al., 2005; Mölder et al., 2008). In addition, there is a small-scale differentiation of understory vegetation through small variations in soil chemistry, temperature, texture, and the content of organic matter (Beatty, 1984; Godefroid and Koedam, 2004; Naaf and Wulf, 2007; Brunet et al., 2010). Silvicultural management (thinning) could also strongly modify ground vegetation (Kirby, 1988; Brun et et al., 2010). In this matrix, the effects of heavy metals overlap with other ecological and edaphic factors controlling understory cover and composition.

The previous study indicated that the old heaps containing high concentrations of metals are more conducive to the abundant occurrence of forest species compared to the surroundings with the natural soil profile and the heaps stand out from the surroundings in terms of greater coverage and the number of species (Woch et al., 2017). It seemed that the heavy metal toxicity for the plants was low, and other habitat factors, including those typical for (semi)natural beech forests, were decisive for the shaping of understories. The most important factor influencing the richness and composition of understory was pH and Ca content originating from waste rock composed of dolomite and calcite, as well as from increased habitat heterogeneity, e.g., soil skeleton and steeper slopes. Another important factor was tree cover, which relates to the light transmissibility of the canopy (Woch et al., 2017). However, the previously sampling layout was unable to answer the question of how these factors shape understory communities purely between sites of heaps in the heavy metal gradient.

Therefore, the aim of present study is to answer several questions concerning the formation of understory vegetation on metal-enriched old heaps, namely: (1) What are the primary factors affecting understory communities? (2) Can heavy-metal contents in soil alter it? And (3) How does habitat properties influence different forest species?

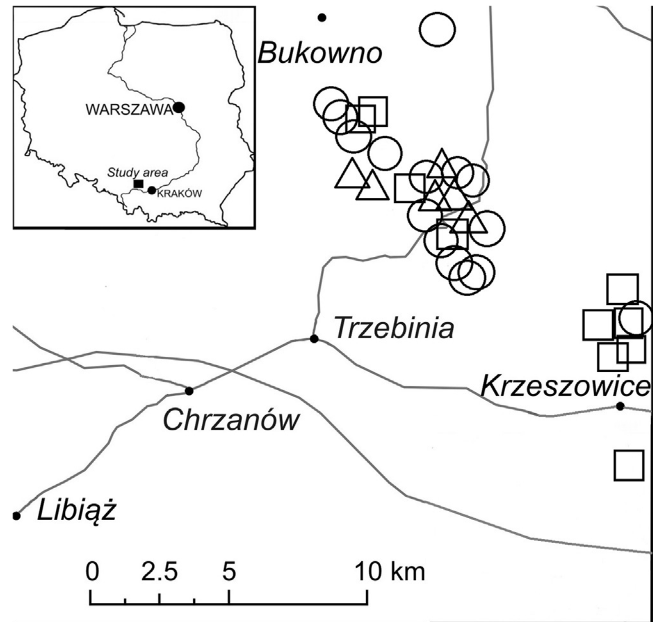

Fig. 1. Location of the study area in Poland and the 31 study plots. Plots were marked with different symbols according to the type of understory: squares – the *Galium odoratum* variant (*Go*), circles – the *Mercurialis perennis* variant (*Mp*) and triangles – the *Mycelis muralis* variant (*Mn*). Major cities and main roads are also indicated.

2. Material and methods

2.1. Study area

The study was conducted in western Małopolska (S Poland), between the towns of Bukowno, Krzeszowice and Trzebinia (Fig. 1). The area lies in the transitional climate zone between a temperate oceanic climate in the west and temperate continental climate to the east. Western Małopolska is known for its rich Zn-Pb ore deposits of Mississippi Valley-type (MVT) occurring in Triassic and Devonian rocks. Archaeological data indicate mining and processing of lead and silver ores dating back to the Hallstatt period (700–400 B.C.) (Godzik and Woch, 2015). At first, lead and silver were used, while the excavation of Zn ores started in the 16th century. This former mining activity has left a large number of heaps of metal-rich waste rock scattered over vast areas. The heaps are usually small – their average height ranges from 0.5 to 2 m and diameter from several to tens of m. The distances between heaps vary widely – they can be very small (from a half to several m) or large (several km). Detailed characteristics of the mine waste heaps, the history of their formation as well as geology and climate of the region are described in Woch (2015) and Woch et al. (2017). The study area is covered by an 80–120 year old beech stand that was either developed through planting or natural succession (Mazaraki, 1962; Pietrzykowski et al., 2011; Woch, 2015). The beech forest covering study area have existed in the same boundaries at least since the second half of the 18th century (possibly much longer), and forest management involving timber harvesting and planting threes has been carried out there since the beginning of the 19th century. Therefore, it can be considered as replanted ancient forest (Rotherham, 2011; Woch et al., 2017).

2.2. Vegetation analysis

Vegetation was sampled on 31 circular plots established on heaps (N = 31). The area of each plot was 25 m^2 – it was the maximum possible plot area due to the small size of the heaps. The vegetation was recorded twice (April-May and July-August) in the 2015 growing