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Waste heaps left by historical Zn-Pb ore mining are hotspots of species diversity of beech forest understory vegetation

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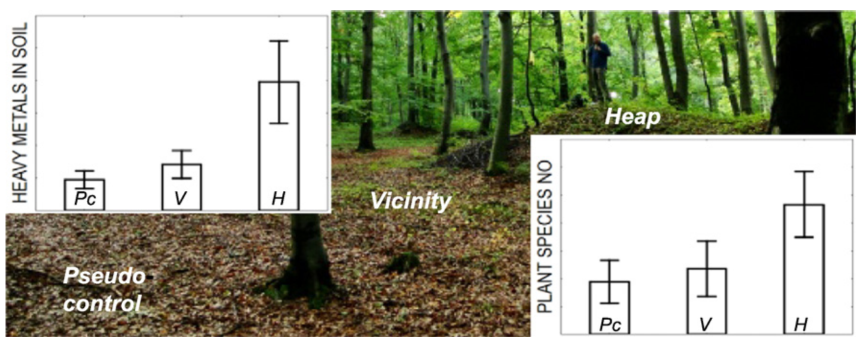
HIGHLIGHTS

- Old waste heaps and their surroundings in beech forest were analysed.
- Old heaps contained high concentrations of total and available Cd, Pb, Zn in soil.
- The heaps had high cover and species diversity of understory vegetation.
- Vegetation was probably affected by high pH, Ca and organic C content in heap soil.
- Tree cover related to light availability also influenced understory vegetation.

GRAPHICAL ABSTRACT



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ABSTRACT

Metalliferous mining and smelting industries are associated with very high levels of heavy metal(loid) contamination of the environment. Heavy metals have been proved to significantly influence the species diversity and composition of grassland communities, but little is known on their effects on forest understory vegetation. Therefore, the aim of this study was to investigate the effects of the presence of small heaps of waste rock left by historical Zn-Pb ore mining on understory vegetation. The heaps are scattered over vast areas of beech forests in southern Poland. Three types of study plots were established: (1) on waste heaps themselves, (2) in their vicinity (5–10 m from the foot of the heaps, with no waste rock but potentially influenced by the heaps through drainage water), and (3) at least 100 m from the foot of the heaps (pseudo-control). In all plots vegetation parameters, i.e., plant species number, cover and community composition, life forms and strategies, as well as basic soil properties were assessed. Although the heaps contained high concentrations of metals, namely Cd, Pb and Zn, they were characterised by higher cover and diversity of understory vegetation, including ancient forest and endangered species, in comparison to their surroundings. They were also characterised by the distinct species composition of their plant communities. This might have resulted from the beneficial influence of high 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 influencing the richness and composition of understory was tree cover, which relates to the light transmissibility of the canopy. Our study proved that the disturbance brought about by the former mining and processing of metal ores led to the formation of species-rich understory with high frequency and cover of naturally-valuable species.

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1. Introduction

The assessment of plant diversity at the local level is essential when investigating the factors determining the diversity of European vegetation. The highest plant diversity is often related to places with a high degree of small-scale habitat heterogeneity, which comprises topographical, microclimate and soil properties (Barthlott et al., 1999; Faith and Walker, 1996; Mutke and Barthlott, 2005). Human activities do not necessarily lead to the reduction of plant diversity. There are a number of somewhat transformed ecosystems such as extensively managed meadows and grasslands that are characterised by the richest plant communities in Europe (Myklestad and Sætersdal, 2004; Merunková et al., 2012). In addition, in recent decades the importance of maintaining the diversity of arable land and ruderal habitats has been stressed by many authors (Holzner and Numata, 1982; Rösch, 1998; Albrecht, 2003; Stehlik et al., 2007; Van Calster et al., 2008; Aavik and Liira, 2009; Chytrý, 2009; Storkey et al., 2010; Pinke et al., 2011).

Post-industrial remains, especially various types of pits and heaps left by mining, may provide habitats fostering plant diversity. Post-mining sites which have not been reclaimed but left for spontaneous succession are often richer in plant species in comparison with their surroundings, and even similar with naturally-valuable areas (Řehounková and Prach, 2008; Mudrak et al., 2010; Tropek et al., 2010; Tischew et al., 2013; Woch, 2015). Additionally, non-reclaimed post-mining sites can have a lower number of alien and a higher number of rare and/or protected species (Kirmer et al., 2008; Tomlinson et al., 2008; Tropek et al., 2010). This results from greater microhabitat heterogeneity and a low nutrient content in the soil in relation to reclaimed sites that are often levelled, fertilised and planted with a single tree species. The low fertility of non-reclaimed habitats favours the occurrence of stress-tolerant plants, which are characterised by weak competitive abilities. Such traits are usually typical for endangered species. Therefore, non-reclaimed post-industrial sites are potentially valuable for nature conservation (Marrs, 1993; Tischew et al., 2013).

Post-mining sites polluted with heavy metals are often covered by unique vegetation. So far, botanical studies have focused mainly on grasslands located in open metallicolous areas of different age (Ernst, 1974; Simon, 1978; Brown, 1994, 2001; Becker and Brändel, 2007; Becker and Dierschke, 2008; Grodzińska and Szarek-Łukaszewska, 2009; Mapaure et al., 2011; Woch et al., 2016). There are few studies on the vegetation of old waste heaps left over from historical mining and covered by closed mature forest (Mazaraki, 1962; Podgórska, 2015).

Western Małopolska is a region in southern Poland where numerous heaps of metal-polluted waste rock remain after centuries of Zn-Pb ore mining. These waste heaps are usually small and often take the shape of a ring encircling a shallow pit (Fig. 1). They frequently occur in areas covered by mature beech forests; their number can reach 50 heaps/km^2 (Aleksander-Kwaterczak and Ciszewski, 2013; Woch, 2015). The concentrations of heavy metals in the soil vary widely between heaps, but usually exceed allowable limits. Our previous study based on 14 waste heaps in beech forests revealed that average metal(oid) concentrations in topsoil amounted to 47 mg As kg^{-1}, 32 mg Cd kg^{-1}, 1162 mg Pb kg^{-1} and 4978 mg Zn kg^{-1} (Stefanowicz et al., 2016). The large variation in total metal concentrations in the soil on the heaps results from differences in the quality of metal ores as well as the different functions of pits (exploration, ventilation and ore exploitation) (Woch, 2015). The old heaps are also characterised by high Ca and Mg concentrations originating from gangue minerals – mainly dolomite and calcite (Stefanowicz et al., 2014, 2016).

Analysis of old maps and historical sources indicated that the beech forests covering our study area have existed at least since the second half of the 18th century (possibly much longer); therefore, they can be considered as ancient woodland. Taking into account human activity, the beech forests covering our study area should be considered as replanted ancient woodland (Rotherham, 2011). Only spatially-limited clearings had been created during the exploitation of Zn-Pb ores, and these have been spontaneously overgrown by forest vegetation after the cessation of mining activities (Mazaraki, 1962; Godzik and Woch, 2015). Forest management involving timber harvesting has been carried out there since the beginning of the 19th century (Mazaraki, 1962; Pietrzykowski et al., 2011).

The aim of our study was to (1) compare the diversity, cover and composition of understory vegetation between the heaps of waste rock and their surroundings in areas covered by beech forests, (2) assess

Fig. 1. A typical old heap of waste rock encircling a shallow pit located in beech forest. The understory vegetation in early spring (April) with *Dentaria enneaphyllos*.