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High concentrations of heavy metals in beech forest understory plants growing on waste heaps left by Zn-Pb ore mining

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ABSTRACT

This study investigated (1) concentrations of pollutants such as As, Cd, Pb, Tl and Zn, as well as Ca, Fe and Mn, in soils developed on old heaps of waste rock localized in beech forests (2) concentrations of these elements in shoots and roots of forest herbaceous species – *Mycelis muralis*, *Melica nutans* and *Mercurialis perennis*, and in leaves of young *Fagus sylvatica* trees growing on the heaps (3) ratios of plant/soil and shoot/root concentrations to assess metal accumulation strategy of herb species. Total soil concentrations of all pollutants except Tl were high, up to 156 mg As kg^{-1}, 62.9 mg Cd kg^{-1}, 2853 mg Pb kg^{-1}, 3.6 mg Tl kg^{-1} and 13,508 mg Zn kg^{-1}. Element concentrations in the tissues of herbaceous plants depended on plant species and organ (shoot vs. root). Cd, Pb, Tl and Zn, but not As, were elevated in both herb species and *F. sylvatica* in comparison to reference values, reaching up to 0.21 mg As kg^{-1}, 47.4 mg Pb kg^{-1} and 8.2 mg Tl kg^{-1} in roots of *M. perennis*, and 63.6 mg Cd kg^{-1} and 752 mg Zn kg^{-1} in roots of *M. nutans*. The efficiency of pollutant transfer from soil to roots and/or shoots varied among plant species and elements. Some heavy metals were effectively taken up from soil (Cd, Tl) or translocated to shoots (Cd, Zn), though it depended on plant species. Our study indicates a risk of the dispersion of heavy metals in the environment.

1. Introduction

Metalliferous mining and smelting industries, which extract and process metal ores and gangue minerals, are associated with very high levels of heavy metal(loid) contamination of the environment (Alloway, 2013). Metal mining and processing have centuries-old tradition and remnants of these activities such as waste heaps, can be found worldwide (Adams et al., 2007; Adlassnig et al., 2012; Andráš et al., 2012; Medas et al., 2012; Pyatt et al., 2000). However, visible traces of former metal industry may gradually disappear from the landscape, for example due to denudation process or later human activity, hindering identification of metal-polluted post-industrial sites (Woch, 2015). Contaminated areas are sometimes neither recorded in written documents nor known to authorities or local inhabitants. Eckel et al. (2001) identified over 400 former secondary Pb-smelting sites in the United States that had been unrecognized before, though they might have posed a threat to public health. Pollution elements cannot be degraded and persist at mining and smelting sites, affecting the environment for centuries or millennia (Grattan et al., 2003; Pyatt et al., 2000; Teršič et al., 2009; Turisová et al., 2013).

Plants may contain excessive amounts of heavy metals in their tissues if grow on waste heaps; metal accumulation level depends on plant species and metal identity (Stefanowicz et al., 2016; Wierzbicka et al., 2004; Wójcik et al., 2014; Xiao et al., 2004). Two basic strategies of metal accumulation may be discerned, in which metals are either concentrated in aboveground plant parts or, conversely, their translocation to shoots is restricted (Baker, 1981). Although much information on metal concentration in herbaceous plants from heaps left by metal mining and processing is available, it usually concerns non-forest species (Stefanowicz et al., 2016; Wierzbicka et al., 2004; Wójcik et al., 2014; Xiao et al., 2004). This is understandable as waste heaps are characterized by unfavorable environmental conditions such as pollution, coarse texture, steep slopes, deficiency of some nutrients and water, which hinder colonization by plants; therefore, the heaps are often bare in large part or covered by sparse vegetation patches dominated by tolerant cryptogams or grassland and ruderal vascular plants, especially if they are newly heaped and/or built of coarse material resistant to weathering (Adlassnig et al., 2012; Banásová et al., 2006; Cabala et al., 2011; Houben et al., 2013; Wójcik et al., 2014). Little is known about heavy metal accumulation in forest floor species growing on heaps, though there are some data for plants affected by airborne

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deposition of heavy metals (Adlassnig et al., 2012; Luwe, 1995; Salemaa et al., 2004).

Western Małopolska in southern Poland is a region where mining and processing of Zn-Pb ores have lasted for at least ten centuries, but much earlier exploitation cannot be excluded (Godzik and Woch, 2015). Numerous relics of former mining can still be found there; these usually are small heaps of waste rock, which often take the shape of a ring encircling a shallow pit (Fig. 1). Heaps located in agricultural landscape have been subjected recently to investigation, which showed that they contain up to 520 mg Cd kg^{-1}, 23,000 mg Pb kg^{-1}, 50 mg Tl kg^{-1} and 70,400 mg Zn kg^{-1}, and are covered mostly by heavy metal grassland with the dominance of a metal-tolerant grass, *Festuca ovina* (Stefanowicz et al., 2014; Woch et al., 2016). The heaps are hot-spots of polymetallic contamination surrounded by areas containing lower, though not necessarily background, amounts of heavy metals (Stefanowicz et al., 2014). Further studies showed that grassland plant species growing there accumulated elevated concentrations of heavy metals, which were the highest in the tissues of *Euphorbia cyparissias*, *Fragaria vesca*, *Potentilla arenaria* and *Plantago lanceolata* (Stefanowicz et al., 2016). It should be noted, however, that most old heaps in the region are located in areas that were afforested more than a century ago with either *Pinus sylvestris* or *Fagus sylvatica*; at present beech forests dominate there. Aleksander-Kwaterczak and Ciszewski (2013) reported that the number of old heaps in the forests can be very high, reaching 50 heaps per km^2. The properties of ore-bearing rocks – dolomite and limestone, which are not very resistant to weathering, deposition of foliar litter by trees, as well as the age of heaps, fostered the development of organic and organo-mineral soil horizons, though very thin in some parts of heaps, and the growth of forest floor vegetation. Average total cover of herb species on heaps exceeds 40% and is considerably higher than herb cover in heap surroundings. High number of heaps in the forests and herb plants covering the heaps indicate that large amounts of heavy metals may possibly be transferred from soil to forest floor vegetation and to higher strata of the food chain. Additionally, the concentrations of other elements, including important nutrients - Ca, Fe and Mn, may be altered in plant tissues due to high concentrations of these metals in ore-bearing dolomite, as well as synergistic and antagonistic interactions between elements in the uptake and transport processes (Cabala et al., 2008; Siedlecka, 1995; Stefanowicz et al., 2016).

Therefore, the aim of this study was to investigate (1) concentrations of As, Ca, Cd, Fe, Mn, Pb, Tl and Zn in soils developed on old heaps of waste rock localized in beech forests (2) concentrations of these elements in shoots and roots of forest herbaceous species – *Mycelis muralis*, *Melica nutans* and *Mercurialis perennis*, and in leaves of young *Fagus sylvatica* trees growing on the heaps (3) ratios of plant/soil and shoot/root concentrations to assess the strategy of metal accumulation of herb species and potential risk of heavy metal dispersion in the environment.

Fig. 1. Small heap of waste rock encircling a shallow pit located in beech forest.

2. Materials and methods

2.1. Study area and sampling

The study area was localized in the south-eastern part of the Silesia-Cracow Upland (western Małopolska, southern Poland). Geology of the region as well as the history of mining was described in more detail by Stefanowicz et al. (2014). Remains of former mining are over 100 years old small heaps of waste rock (Fig. 1), built mostly of dolomite and calcite. Their height ranges typically from 0.5 to 2 m, and diameter from several to tens of m. Heap soils are mostly sandy loam characterized by skeletal structure, which can be classified as Luvic Anthrosols (Pietrzykowski et al., 2011; Stefanowicz et al., 2014). The thickness of soil O and A horizons varies considerably both within and between heaps; it is the highest (10–20 cm) at the foot of the heaps and in mine shafts and the lowest (0–5 cm) on the top and the slopes of the heaps.

The study sites were established on 14 heaps located on about 70 km^2 area. The area was covered by 80–130 years old beech forest of the *Mercuriali perennis-Fagetum sylvaticae* community. Tree layer cover ranged from 60 to 100% and was dominated by *Fagus sylvatica*, which was occasionally accompanied by single specimens of *Pinus sylvestris* or *Picea abies*. Herbaceous layer cover varied between 5 and 80% and the most frequent species (>50% sites) were *Asarum europaeum*, *Cruciata glabra*, *Epipactis helleborine*, *Galium odoratum*, *Hepatica nobilis* and *Melica nutans,* followed by *Aegopodium podagraria*, *Maianthemum bifolium*, *Mercurialis perennis* and *Mycelis muralis* (40–50% sites). The highest cover (25–50%) was reached by *Mercurialis perennis*, followed by *Asarum europaeum*, *Oxalis acetosella* and *Aegopodium podagraria* (5–25%).

Three herbaceous species were collected from ten heaps (Fig. 2) in summer 2013: *Mycelis muralis* (L.) Dumort. (Asteraceae), *Melica nutans*

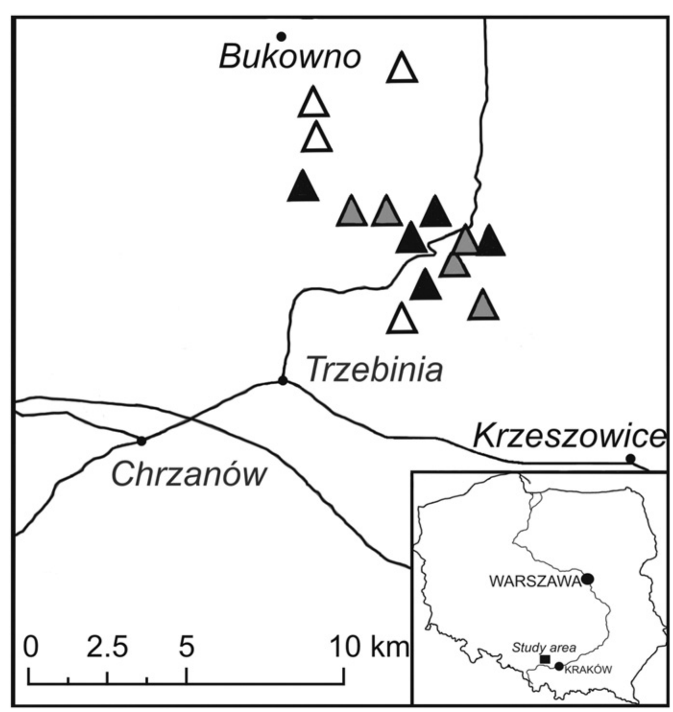

Fig. 2. Location of heaps, from which herbaceous plants (black triangles), beech leaves (white triangles) or both (grey triangles) were collected. Major cities and main roads are also indicated.