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Brachythecium rutabulum and *Betula pendula* as bioindicators of heavy metal pollution around a chlor-alkali plant in Poland

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ABSTRACT

Chlor-alkali plants are known to be major sources of Hg emissions into the air. Therefore level of this metal in their surrounding must be carefully controlled. The aim of this work was to study the impact of the chlor-alkali industry in Brzeg Dolny (SW Poland) on the length of the vegetative short shoots of the pollution tolerant *Betula pendula* using the concentrations of Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn in the ubiquitous, terrestrial moss *Brachythecium rutabulum* as the pollution indicator of the environment. This investigation showed up to 14 mg kg^{-1} elevated concentrations of Hg in mosses from sites the most close (0–500 m) to the chlor-alkali factory. This concentration decreased with increasing distance from the factory. Two and half km away from the factory the Hg concentration falls to values of 0.1–0.2 mg kg^{-1} being still higher than background concentrations of 0.03–0.04 mg kg^{-1}. Decreasing concentrations of Co, Cr, Fe and Ni were also correlated with increasing distance from the plant. The results indicate that *B. rutabulum* may be a suitable ecological indicator of metal pollution by chlor-alkali industry. Higher concentration of accumulated metals by this moss corresponds with longer vegetative short shoots of *B. pendula*. Vegetative short shoots may be used as bioindicators of metal pollution where mosses are absent. This study demonstrates the importance of controlling the emissions of chlor-alkali industry especially if situated in the midst of densely populated areas with potential risks to the inhabitants.

1. Introduction

The elemental composition of plant tissues is of interest for ecology and environmental protection (Kozlov, 2005). The best way to determine the extent and threat of contamination in the environment for living organisms is by measurement of the levels of contaminants in the specimens themselves (Fernández et al., 2000a; Cesa et al., 2014). The most effective for biomonitoring are bryophytes characterized by a widespread occurrence and abilities to intercept, retain and accumulate pollutants mostly via direct absorption by dry and wet deposition (Aničić et al., 2007; Grangeon et al., 2012). Mosses are widely used as bioindicators of atmospheric metal pollution including pre-alerting elevated concentrations of these elements (Sun et al., 2011). Mosses are more useful than other higher plants because they are perennial without deciduous periods with absence of a cuticle and a root system, high surface to volume ratio enabling particles to be trapped as well as a high cation exchange capacity (Zechmeister et al., 2003; Sabovljević et al., 2007; Kłos et al., 2011; Salo et al., 2012). The use of mosses enables simultaneous monitoring of a large number of contaminants with the same sample (Aboal et al., 2012). Due to morphological and physiological characteristics, these plants can accumulate large quantities of e.g. metals over the entire plant surface to levels far greater than those found in air (Sun et al., 2011; Achotegui-Castells et al., 2013). According to Couto et al. (2004) there exists a state of unstable equilibrium between inputs and outputs of elements in mosses determined by the characteristics of the surrounding environment. For this investigation we selected: *Brachythecium rutabulum* (Hedw.) Schimp. a terrestrial, carpet-forming, pleurocarpous species, more or less linked to areas with human impact, accumulating mostly from atmospheric deposition (Sabovljević et al., 2007; Vukojević et al., 2009; Bonanno et al., 2012). This species was used for evaluation of its bioindication abilities of environmental pollution in the examined area.

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The other selected species *Betula pendula* Roth is regarded as tolerant to effects of industrial pollution (Bojarczuk and Przybył, 2005; Reimann et al., 2007a,b). Vegetative short shoots of this tree were proved to be significantly longer in polluted sites than those of trees growing in clean areas (Samecka-Cymerman et al., 2009a). It was interesting to find out if this vegetative short shoots will be significantly longer in sites where moss contains elevated levels of metals pointing pollution of the environment.

Chlor-alkali factories that use elemental mercury for the production of chlorine and caustic-soda are known to be major sources of Hg emissions into the atmosphere (Calasans and Malm, 1997; Sensen and Richardson, 2002; Pyta et al., 2009). The chlor-alkali factory in Brzeg Dolny produced chlorine by mercury electrolysis which is now substituted by membrane electrolysis. However there still exists a threat of mercury pollution in the surrounding, densely populated environment (Euro Chlor, 2012; PCC Rokita SA, 2011). Once released in the air, mercury can be dispersed and transported globally and then removed from the atmosphere through both wet and dry processes (Lindberg and Stratton, 1998; Schroeder and Munthe, 1998; Lodenius, 2013). Mercury and its compounds of high mobility in ecosystems are among the main toxic environmental pollutants (Lodenius, 2013; Rodriguez Martin et al., 2014). The factory is situated within the center of the city where additional sources of metals are car and railway transportation, incinerator emissions and weathering and corrosion of building materials (Wei and Yang, 2010; Apeagyei et al., 2011). Despite reductions in deposition metals, as non degradable, once discharged into the environment they become an built in part of the habitats (Shotbolt et al., 2007; Kabata-Pendias, 2001). Thus concentrations of Hg and other metals must be carefully controlled.

The aim of this work was to study the impact of the agglomeration of Brzeg (SW Poland) with the chlor-alkali factory on the concentration of metals including mercury in the terrestrial moss *B. rutabulum* and on the length of *B. pendula* vegetative short shoots both used as ecological indicators. The tested hypotheses are: (i) whether ubiquitous, widespread *B. rutabulum* may be a suitable bioindicator of metal pollution for the chlor-alkali industry and (ii) whether a higher concentration of metals accumulated by *B. rutabulum* corresponds with longer *Betula pendula* vegetative short shoots when sampled in the same sites.

2. Materials and methods

2.1. Sampling design

In the Brzeg Dolny a total of 57 sampling sites (Fig. 1) with *B. rutabulum* were selected around the chlor-alkali plant (51°16′2″N; 15°43′47″). In 30 sites (no 1–15, 19–21, 25–30, 34–36, 40–42) where *B. pendula* was found together with *B. rutabulum* also vegetative short shoots of this tree were collected. The sites were selected in all directions (N, S, W, E) from the chlor-alkali plant according to Wallin (1976) and Sensen and Richardson (2002). These authors state that the sphere of influence of mercury deposition was estimated to extend 2.4–3.4 km from the emitter being extremely high within a 1 km radius. Sites were divided into six groups related to the distance from the plant: group 1 covering a distance of 0–500 m including sites 1–6, 16–18, 28–30; group 2 covering a distance of 500–1000 m including sites 7–12; 22–27, 31–33; group 3 covering a distance of 1000–1500 m including sites 19–21, 34–42; group 4 covering a distance of 1500–2000 m including sites 52–57; group 5 covering a distance of 2000–2500 m including sites 49–51; and group 6 covering a distance of >2500 m including sites 13–15, 43–48. Sites were additionally labeled as influenced by heavy, low and no traffic and as influenced by railways (0–15 m, 15–50 m, 55–600 m and >600 m).

From each of the 57 sites within a 15 m × 15 m square, five replicates of moss and in 30 sites with *Betula pendula* fifty vegetative short shoots (from each of five trees per site) were collected randomly. Several branches were sampled in all directions from the center of the canopy, 2 m above the soil. The trees were ca. 50-year-old (Rautio and Huttunen, 2003; Marguì et al., 2007). The total number of moss samples was 57(sites) × 5(replicates per site) = 285 and of short shoots samples was 30 × 5(number of trees per site) × 50(short shoots per tree) = 7500. As required by the rules set by the Environmental Monitoring and Data Group (Markert et al., 1996) and within the European Heavy Metal Survey (ICP Vegetation, 2005), the collected moss had not been exposed directly to canopy throughfall. Dead material, soil particles and litter were manually removed from the moss (green parts of gametophytes). The moss and short shoots were not washed as recommended by Markert et al. (1996), Kozlov et al. (2000), Oliva and Rautio (2004)

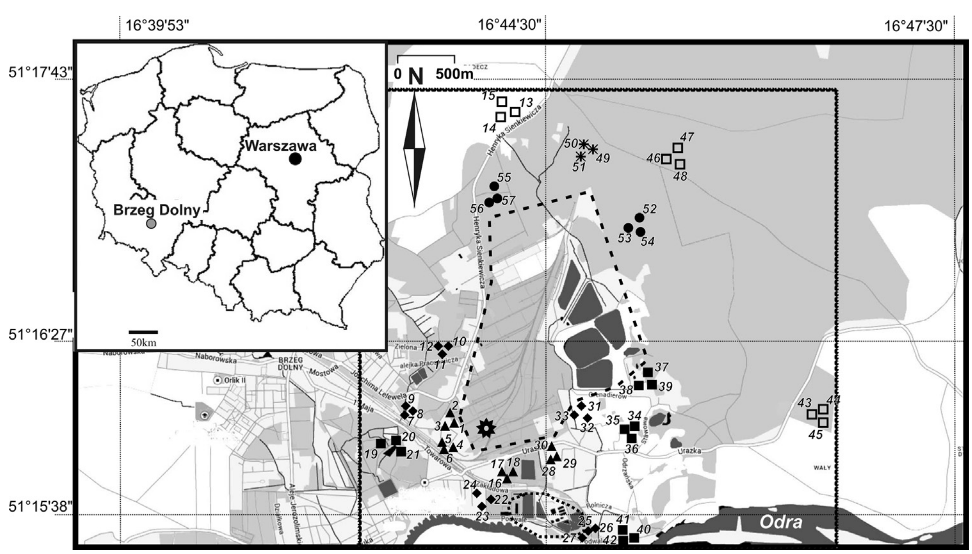

Fig. 1. Map showing the study areas and sampling locations. Filled triangle: mosses of group 1 (0–500 m). Filled diamond: mosses of group 2 (500–1000 m). Filled square: mosses of group 3 (1000–1500 m). Filled circle: mosses of group 4 (1500–2000 m). Star: mosses of group 5 (2000–2500 m). Open square: mosses of group 6 (>2500 m). The chor-alkali plant (51°16′2″N; 15°43′47″) zone, chlor alkali plant sewage purification zone, probable location of the chor-alkali electrolysis; area presented on the isoline plots (Electronic Supplementary Material ESM 1–10).