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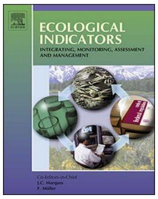

Original Articles

Cryptogamic communities as a useful bioindication tool for estimating the degree of soil pollution with heavy metals

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ABSTRACT

Lichens and bryophytes have commonly been used as bioindicators of environmental conditions, especially in relation to air quality. However, their diagnostic role in the assessment of soil pollution is relatively poorly recognised. The aim of this study was to find a pattern of cryptogamic biota structure associated with zinc and lead soil pollution and to thereby identify common signal species useful for bioindication purposes. The study area encompassed various types of anthropogenic and semi-natural habitats directly associated with the processing of Zn-Pb ores in southern Poland. Detailed analysis of cryptogamic biota with respect to the chemical parameters of the corresponding soil enabled us to identify three different pollution classes related to the concentration of heavy metals and four distinct groups of ecologically close species with similar responses to the prevailing level of pollution. The significant relationship between soil chemical parameters and cryptogamic biota structure implies the high bioindicative value of the defined lichen and bryophyte assemblages. Consequently, specific sets of distinct species reflecting levels of pollution were instrumental in the development of a practical tool. This approach may constitute a first step in soil quality assessment in a broad landscape scale. It provides an opportunity for preliminary verification of the sites that are potentially the most contaminated and which require further attention, for example, within the framework of restoration projects, reclamation interventions, or conservation strategies. The proposed bioindication approach involves common, widespread lichens and bryophytes, thus increasing the potential for its wide application in post-industrial areas associated with the mining and processing of Zn-Pb ores.

1. Introduction

Lichens and bryophytes, commonly treated as cryptogams, are the first to colonise new or damaged ecosystems. Lichens constitute a symbiotic association composed of a fungus and an alga and/or cyanobacterium which combine to form a coherent organism (Ahmadjian, 1993). Their nature is often much more complex and they may be composed of mixtures of many entities including another fungal partner or multiple types of photobionts (Lücking et al., 2014; Libby et al., 2016). Since lichens are devoid of absorptive organs, protective cuticles, and filtration mechanisms, both necessary nutrients and toxic elements can be absorbed through whole surface of the thalli (Tyler, 1989; Bačkor and Loppi, 2009). The ectohydric nature of lichens often makes them highly sensitive to various pollutants present in the environment (Nimis et al., 2002). On the other hand, lichens are known to be stress tolerators (Grime, 1979); therefore, many of them are well adapted to contamination (Gilbert, 1990; Cuny et al., 2004a). Some lichens representing *Acarospora*, *Sarcosagium*, *Steinia* and *Vezdaea* genera seem to be even associated with or wholly restricted to metal-rich habitats (Shaw, 1990; Purvis and Halls, 1996). Bryophytes may be also important constituents of vegetation in anthropogenic and affected habitats (Denayer et al., 1999). Many bryophytes demonstrate a high tolerance for pollution; there are also species largely confined to artificial substrates or natural soils rich in metal elements (e.g. Brown and House, 1978; Palice and Soldán, 2004). Because of their worldwide prevalence and high bioaccumulation capacity, bryophytes are ideal organisms for assessing pollution levels (e.g. LeBlanc and Rao, 1975; Genoni et al., 2000).

The usefulness of lichens and bryophytes as bioindicators of air quality has been confirmed worldwide (e.g. Hawksworth and Rose, 1970; LeBlanc and Rao, 1975; Nash III and Wirth, 1988; Tyler, 1990; Nimis et al., 2002; Osyczka et al., 2007; Guttová et al., 2011). Contrastingly, the role of cryptogams as indicators of soil contamination is studied more rarely; although, it is known that the presence of certain lichen and bryophyte species may be diagnostic for substrates enriched with heavy metals (e.g. Purvis and Halls, 1996; Denayer et al., 1999;

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Table 1
The sites included in the study with specification of the habitat type and number of examined plots.

Habitat type	Study site	Number of plots examined in terms of cryptogamic biota and chemical properties (in parentheses)	Plot code
Psammophilous grassland	Pustynia Starczynowska desert	30 (14)	01–14 (PG-PS)
Psammophilous grassland	Bukowno surroundings	20 (3)	56–58 (PG-BU)
Grassland/industrial wastes – smelter environ	Bukowno	24 (8)	42–49 (GW-BU)
Grassland/industrial wastes – smelter environ	Miasteczko Śląskie	20 (3)	50–52 (GW-MS)
Post-smelting dump	Piekary Śląskie-1	6 (3)	15–17 (SD-PS)
Post-smelting dump	Piekary Śląskie-2	6 (3)	18–20 (SD-PS)
Post-smelting dump	Piekary Śląskie-3	6 (3)	21–23 (SD-PS)
Post-smelting dump	Bytom	5 (3)	24–26 (SD-BY)
Post-smelting dump	Radzionków	5 (3)	27–29 (SD-R)
Post-smelting dump	Ruda Śląska-1	3 (3)	30–32 (SD-RS)
Post-smelting dump	Ruda Śląska-2	3 (3)	33–35 (SD-RS)
Post-smelting dump	Ruda Śląska-3	3 (3)	36–38 (SD-RS)
Post-smelting dump	Świętochłowice	3 (3)	39–41 (SD-S)
Post-smelting dump	Trzebinia	20 (3)	67–69 (SD-T)
Post-flotation dump	Chorzów	10 (3)	64–66 (PF-C)
Post-flotation dump	Piekary Śląskie	10 (3)	70–72 (PF-PS)
Post-flotation dump	Tarnowskie Góry	20 (3)	53–55 (PF-TG)
Post-mining dump	Bolesław	16 (5)	59–63 (PM-BO)
		210 (72)	

Cuny et al., 2004a; Banásová et al., 2010). Various bioindicative methods based on individual species presence, proportion of functional groups of species and phytosociological approach are routinely used (see van Haluwyn and van Herk, 2002). Nevertheless, there are scarce studies in which indicator values are not assigned to a single species or syntaxa, but to groups of species with similar habitat requirements. Ecological aspects concerning cryptogams at the level of their communities are relatively poorly recognised; therefore, less attention has been paid so far to the effects of heavy metals on cryptogamic assemblages treated as whole ecological functional groups (Purvis and Halls, 1996). Notwithstanding, since communities derive from the overlap of species with similar ecological requirements in a given portion of ecological space (Nimis, 1991), community structure may be often a better indicator of the condition of the environment than the presence of individual species (van Haluwyn and van Herk, 2002). This approach turns out to be more relevant for bioindication studies in situations where individual species strictly confined to soils enriched with heavy metals are absent, for example, due to their geographical range or rarity.

Significant changes in soil chemical parameters are one of the negative effect associated with the mining and processing of Zn-Pb ores. High levels of metal contamination have commonly been considered the principal factor limiting the development of vegetation (e.g. Gilbert, 1975; McCall et al., 1995; Baumbach, 2012). Anthropogenic disturbances frequently contribute to the formation of lichen- and/or bryophyte-dominated communities (e.g. Paus, 1997) making them the main visual component in many heavy-metal-polluted sites (Cuny et al., 2004a; Rola et al., 2014, 2015; Rola and Osyczka, 2014). Since different species demonstrate different degrees of sensitivity to heavy metals, the presence of particular elements in the environment may induce changes at the community level (Tyler, 1990; Bačkor and Loppi, 2009). Certain assemblages of the most resistant pioneer lichens, for example those forming cryptogamic community *Cladonietum rei*, are generally widespread and tolerant of, but not dependent on, heavy-metal-polluted soils (Paus, 1997; Osyczka and Rola, 2013a). Similarly, bryophyte assemblages found in heavy-metal-contaminated soils sometimes include species that depend exclusively upon this soil type, along with more ubiquitous species characterised by high pollution tolerance (Sotiaux et al., 1987). Nevertheless, in contrast to areas associated with Fe-rich or Cu-rich soils, neither species nor syntaxon has not been identified as an indicator of Zn-Pb-rich environments (cf. Purvis and Halls, 1996).

The aim of the study was to relate cryptogamic community structure to the corresponding level of soil pollution with heavy metals, and thereby to identify its bioindicative value. We assumed that this pattern would reveal typical assemblages of species attributed to a soil with certain chemical properties, and that these assemblages would prove to be composed essentially according to the sensitivity or resistance of their components to metal contamination. In principle, we focused on the identification of groups composed of common signal species that might be useful for bioindication purposes. All of this was considered in relation to cryptogams for which poor and dry grasslands constitute a natural habitat and with regard to areas affected by the Zn-Pb processing industry. In referring to these issues, we set the following hypotheses: (1) Heavy-metal content in soil is a significant factor which arbitrarily determines the presence and cohabitation of epigeic cryptogams with similar ecological requirements and levels of pollution tolerance. (2) Certain cryptogams demonstrate non-specificity in regard to habitat parameters, including contamination of the host soil. (3) The total absence of certain cryptogams indicates extreme levels of soil contamination.

2. Material and methods

2.1. Study area

The fieldwork was conducted in the Silesia-Cracow Upland area, one of the most polluted regions in Poland, associated for centuries with the processing of Zn-Pb ores (Cabała and Sutkowska, 2006). The primitive metal smelting technology used in the past has resulted in large quantities of wastes deposited in post-industrial areas in the form of various dumps. These can be divided into three main types: post-mining, post-flotation, and post-smelting dumps; for their general characteristics, see Maciak (1996) and Skubała (2011). Ten post-smelting, three post-flotation, and one post-mining dump, along with two sites directly adjacent to large zinc smelters, were selected for the study. Additionally, two sites representing semi-natural poor psammophilous grasslands, located in the same geographic area, were also included (Table 1, the map with detailed location is provided in Rola and Osyczka 2018). These communities, belonging to the class Koelerio glaucae-Corynephoretea canescentis Klika in Kluka et Novak 1941, are