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Bryophytes of Cu-mine heaps in the vicinity of Banská Bystrica (Central Slovakia)

Introduction

Mine heaps and wastes created by mining industry are one of the extreme habitats made by human activity. For plants mine heaps are distinctive habitats with specific ecological conditions: the lack of soil as well as nutrients and moisture. Mine heaps are characterized by a skeletal substrate from 52.90%–87.38% and a lack or complete absence of humus layer (Banásová, 1976). In addition, compared to natural soils, mine heaps contain a higher content of heavy metals. All these conditions significantly limit the list of plant species and vegetation types that can grow on such habitats (Baker et al., 1988; Banásová, Hajdúk, 2006).

In Slovakia, a land with rich mining history, there are numerous old mine heaps – remainders of exploitation of different ores. On mine heaps, we encounter plant succession which takes place in strange and complex conditions consequently forming new, unknown or very little known plant communities (Banásová, 1976). Because mine heaps originate from different space of time, the vegetation formed on them is present in different successional stages (Banásová, 1983).

Banásová (1976) stated that plants on mine heaps mostly colonize depressions or parts with more disintegrated material that are more humid and where dead plant material accumulates, forming raw humus. Thus a mosaic vegetation cover is formed. On mine heaps perennial plants predominate, while annual and biannual plants occur sparsely. On the rock surface and among grass and herbs grow tolerant species of bryophytes and lichens. Mine heaps with anomalous metal content are like ecological islands because in comparison to their surroundings they have a very specific vegetation. Throughout many decades some plants (immigrants) that had no ability to adapt were excluded by natural evolution. A result of this evolution is

Fig. 1. Initial succesional stage with bryophytes (Photo. I. Turisová)

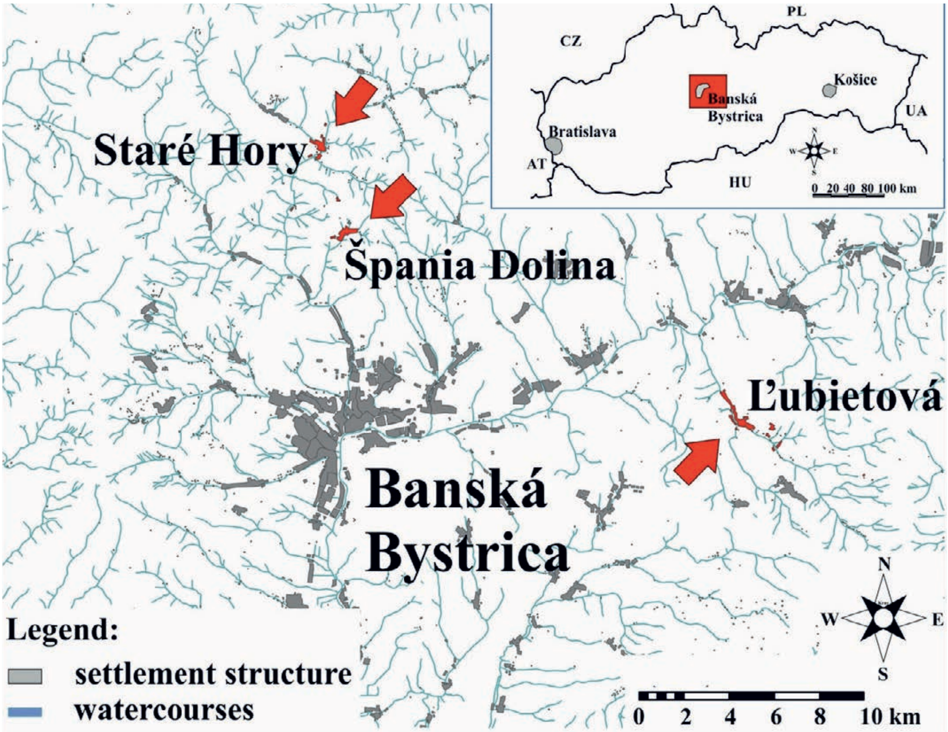

Fig. 2. Location of Ľubietová, Staré Hory and Špania Dolina within Slovakia (Source: by courtesy of Turisová et al., 2014)

a small group of plants with strange species combination capable of existing in these phytotoxical conditions.

Bryophytes represent a very significant group of organisms that sensibly react and indicate changes in the natural environment, especially changes of anthropogenic character (Kubinská et al., 2001). In recent decades they have been successfully used as biomonitors of heavy metal accumulation throughout Europe (Harmens et al., 2013). Bryophytes play an important role in primary successional stages when colonizing anthropogenic substrate (Fig. 1), where they significantly participate in soil cover formation. Some bryophyte communities may be particularly important as a successive stage to some other vegetation types. Bryophytes are often omitted in botanical studies, especially those of mine heaps.

The aim of this article is to present basic information on bryophyte species composition in the chosen metal-contaminated areas in central Slovakia.

Materials and methods

Study area

Three mine heaps near the city of Banská Bystrica in central Slovakia were studied: Podlipa (cadaster Ľubietová), Richtárová (cadaster Staré Hory) and Maximilián in the village of Špania Dolina (Fig. 2).

Mine heap Ľubietová – Podlipa (Fig. 3) is situated in the north-eastern part of Slovenské Stredohorie Mts which include the northern part of neovolcanic massif Poľana and the northern part of Veporské vrchy (Mazúr, Lukniš, 2002). The mine heap lies approximately 1 km to the east of the center of the village on the southern slope of Vysoká (995 m a.s.l.). The Podlipa deposit was dug by 18 tunnels ranging from 570–700 m a.s.l. (Bergfest, 1951). In the dump material the content of copper was stated to be from 0.9–2.4 mass percent. The mine heap represents an area visibly changed by the historic exploitation of copper ore especially from 15th and 16th century until the end of the 19th century (Koděra, 1990). Small mining activities persisted until the beginning of the 20th century when the last mining works were shut down in April 1915 during the First World War (Andráš, 2009). The whole body of the mine heap is surrounded by forest and is drained in a thalweg of Zelená valley by a brooklet which draws on the water from the hillsides and also water percolating in the mine heap sediment into a shallow depression. From here the water is led to a flood pool on the base of the mine heap through a system of wooden and tinny channels (Andráš et al., 2007). On this mine heap the substrate mostly has a high proportion of rock and vegetation cover is poorly developed (only on about 10% of the dump-field area). In a mosaic of plant communities, especially on less steep slopes with shallow soil, dominate species-poor grassland islets with *Agrostis capillaris* and *Acetosella vulgaris* or only islets of bryophytes with lichens in steep areas and places with a thin soil layer. Flat areas are colonized by groups of pioneer tree species dominated by *Pinus sylvestris*, sporadically by *Quercus petraea* and *Picea abies*. Černý (2015) recorded here a total of 74 taxa of vascular plants.

Mining region Špania Dolina – Staré Hory is geographically divided into two parts: northern (Staré Hory) and southern (Špania Dolina). They are named after two most distinguished sites where copper and silver ore mining was carried out throughout several centuries. The border between the northern and southern part of the mining area is formed by a narrow ridge dividing the valley of Richtársky potok from Veľká Zelená valley, with Zelený potok crossing through it (Mazúrek, 1989). Area of Špania Dolina ore field represents one of the historically most distinguished copper mining deposits in Europe. The mineralization forms a 4 km long and 1.5 km wide vein stretching between Panský diel (1100 m a.s.l.) on the south and Staré Hory on the north to the east of Starohorský potok (Michňová, Ozdín, 2010). The first written reports of ore mining in the area of Staré Hory and Špania Dolina are from the 11th century (from the year 1006), although on the deposit Piesky copper is proven to be mined already in the Late Stone Age (Točík, Bublová, 1985). At first, copper and silver ore was mined in Staré Hory (historical deposit Haliar). Later, the mining expanded further south in Richtárová and Špania Dolina (Koděra et al., 1990). After depleting the surface portions the mining was gradually transferred to underground mining from the mid-14th century. Maximum development of copper ore mining with an extremely valuable silver content was in the years 1496–1546. Since the 17th century, mining gradually declined until it completely disappeared in the early 20th century (Jeleň et al., 2009). During the years 1963–1964, old mine heaps (originating from the 16th – 19th century) in the area of village Richtárová were re-mined by surface mining, which significantly changed the original configuration (Mazúrek, 1989).

Mine heaps in Staré Hory – Richtárová part (Fig. 4) fill the Richtársky potok valley lenghtwise and they are mine heaps in a natural valley, unlike the mine heap in Špania Dolina which represents a sloping mine heap (Dobríková, 2011). Turisová et al. (2014) recorded a total of 147 taxa of vascular plants and 13 taxa of lichens from the mine heap Richtárová and 83 taxa from Maximilián. The representation of higher plants in waste dump-field Richtárová is relatively low and they cover about 30% of the area. Vegetation is concentrated mainly in field depressions, on even surfaces or in the areas with fine substrate. Vegetation is incoherent and forms a mosaic pattern. On considerably exposed parts of the heap grow only lichens and mosses. Dominant plant species on this mine heap are *Agrostis capillaris* (sometimes forming a relatively continuous cover), *Silene dioica*, *Acetosella vulgaris* and *Arabidopsis arenosa*. Dominant trees are *Picea abies* and *Pinus sylvestris* (Štrba et al., 2014). Similarly, on the mine heap Maximilián (Fig. 5) vegetation is present individually and in islets and a total vegetation

Fig. 3. Mine heap Podlipa (Photo. P. Širka)

Fig. 4. Mine heap Richtárová (Photo. I. Turisová)

cover reaches 30%–40%. On a relatively flat top part of the mine heap a forest habitat is established in which the highest plant diversity was recorded. On surfaces without humus and fine earth grow only lichens – the most dominant group of organisms on the mine heap, represented mostly by genera *Rhizocarpon*, *Cladonia*, *Cetraria*, *Lecanora* and *Peltigera*.

Fig. 5. Mine heap Maximilián (Photo. I. Turisová)

The most wide-spread grass is also *Agrostis capillaris* which often forms monocultural overgrowth among lichens. Among herbs the most frequent species are *Arabidopsis arenosa*, *Acetosella vulgaris* and *Silene dioica*. Pioneer tree species such as *Betula pendula*, *Salix caprea*, *Picea abies*, *Pinus sylvestris* and *Abies alba* are present sporadically. They often have a dwarfish appearance, deformed shape or weakened vitality (Aschenbrenner et al., 2011).

Methods

The field survey of chosen mine heaps was conducted in November and December of 2013, using the method of the Zürich-Montpellier school (Braun-Blanquet, 1964) adjusted to bryophytes. A total of 54 relevés were made. A standard surface size of 1 m^2 was chosen for all relevés. The sites were chosen randomly. Bryophytes were determined according to Pilous, Duda (1960) and Smith (2004). Nomenclature follows Hill et al. (2006) and Ros et al. (2007). Species cover-abundance was recorded using the extended nine-grade Braun-Blanquet scale (Westhoff, van der Maarel, 1973): r – 1–2 individuals with insignificant cover-abundance; + – cover-abundance not higher than 1%; 1 – 1%–5% cover-abundance; 2 m – cover-abundance about 5%; 2a – 5%–15% cover-abundance; 2b – 15%–25% cover-abundance; 3 – 25%–50% cover-abundance; 4 – 50%–75% cover-abundance; 5 – 75%–100% cover-abundance. The list of all relevés is presented in Appendix 1, the information contains respectively: relevé number, short habitat description, geographical coordinates, altitude, slope, terrain exposure (using a GPS device Garmin – Oregon 600), tree layer cover (E_3), shrub layer cover (E_2), herb layer cover (E_1), moss layer cover (E_0), total number of recorded bryophyte species and date of collection.

Results and discussion

A total of 45 bryophytes species were identified in 54 relevés in the invesigeted areas (Tab. 1).

Tab. 1. The list of recorded bryophyte species; P – mine heap Podlipa, R – mine heap Richtárová, M – mine heap Maximilián; number of relevés and cover (shown in brackets)

Name of species	Localities
Abietinella abietina (Hedw.) M. Fleisch.	P: 3(1), 4(2a), 5(1), 8(1); R: 28(2a)
Amblystegium serpens (Hedw.) Schimp.	P: 4(1); R: 24(1), 25(1), 3w1(1)
Aulacomnium palustre (Hedw.) Schwägr.	P: 20(1)
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	P: 5(1)
Barbula unguiculata Hedw.	R: 22(2m), 26(2a), 30(1)
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen	R: 30(2a); M: 39(1), 47(1)
Brachythecium albicans (Hedw.) Schimp.	P: 2(2a), 4(1), 8(1), 18(2m); R: 34(r), 36(1); M: 53(+)
B. rivulare Schimp.	R: 23(2a)
B. rutabulum (Hedw.) Schimp.	P: 11(1), 14(2a), 15(2b)
B. salebrosum (Hoffm. ex F. Weber & D. Mohr) Schimp., nom. cons.	P: 2(1), 11(2a); R: 24(2a), 25(2m), 26(1), 29(1), 30(1); M: 43(2a), 51(1)
Bryum caespiticium Hedw.	P: 3(2m), 6(1); R: 25(1), 26(1); M: 49(1)
B. capillare Hedw.	P: 20(2a); R: 21(2b), 23(2b), 30(2a)
B. moravicum Podp.	P: 4(+), 18(1); R: 32(1); M: 39(1), 47(1)
Calliergonella cuspidata (Hedw.) Loeske	P: 20(+)
Campylopus introflexus (Hedw.) Brid.	M: 48(3), 49(1), 50(2a)
Ceratodon purpureus (Hedw.) Brid.	P: 4(r), 6(1), 12(2a); R: 24(1), 26(2a), 27(2a), 28(2a), 29(2a), 31(2a), 33(2a), 34(2m), 36(1); M: 38(2a), 39(2a), 40(+), 41(1), 43(3), 45(1), 47(2a), 48(1), 49(1), 51(2m), 52(2a), 54(2a)
Cirriphyllum piliferum (Hedw.) Grout	R: 35(1)
Climacium dendroides (Hedw.) F. Weber & D. Mohr	P: 2(1), 5(2m), 7(1), 8(2a); R: 28(1)
Dicranella heteromalla (Hedw.) Schimp.	P: 20(1)
Dicranum montanum Hedw.	P: 13(1); M: 38(+)
D. scoparium Hedw.	P: 6(2m), 7(1), 9(1); R: 30(3), 31(2m); M: 40(2a), 50(2a), 51(1), 52(2a), 53(2a), 54(2a)
Didymodon fallax (Hedw.) R.H. Zander	R: 32(1)
Drepanocladus aduncus (Hedw.) Warnst.	R: 24(2a)
Grimmia pulvinata (Hedw.) Sm.	M: 37(+)
Hylocomium splendens (Hedw.) Schimp.	P: 6(1), 7(2m), 17(1); R: 30(1), 31(1), 34(2m), 36(1); M: 53(2m)

Hypnum cupressiforme Hedw.	P: 4(2m), 5(1), 6(2a), 9(1); M: 39(2a), 40(2a), 44(3), 47(+), 51(2m), 53(3), 54(2a)
Lophocolea bidentata (L.) Dumort.	P: 11(1)
Oxyrrhynchium hians (Hedw.) Loeske	R: 29(1)
Plagiomnium affine (Blandow ex Funck) T.J. Kop.	P: 7(2a), 11(1), 19(r); R: 30(1), 33(1), 35(2a); M: 53(2a)
P. cuspidatum (Hedw.) T.J. Kop.	P: 4(1), 5(1), 6(r), 8(2b), 14(r)
Pleurozium schreberi (Willd. ex Brid.) Mitt.	P: 2(2a), 4(2a), 6(2a), 7(1), 9(1), 17(2a), 18(2m); R: 30(2m), 31(1), 34(2a), 36(2m)
Pohlia cruda (Hedw.) Lindb.	P: 9(1), 10(2b), 13(1), 19(2a); R: 21(1), 23(1), 24(1), 25(1), 28(2m), 30(2a), 31(2m), 36(2a); M: 39(1), 41(2a), 42(1), 46(2b), 49(1)
P. drummondii (Müll. Hal.) A.L. Andrews	P: 1(3), 2(1), 16(2a), 20(1)
Polytrichastrum formosum (Hedw.) G.L. Sm.	P: 2(2m), 9(1), 17(1); R: 28(2a), 31(1), 36(2m); M: 51(1), 53(2m), 54(2a)
Pterigynandrum filiforme Hedw.	M: 40(1)
Racomitrium canescens (Hedw.) Brid.	P: 8(2m), 19(1); R: 24(1), 25(1), 26(1), 27(1); M: 38(2a), 41(1), 43(1)
R. lanuginosum (Hedw.) Brid.	P: 5(1); M: 39(1)
Rhytidiadelphus squarrosus (Hedw.) Warnst.	P: 5(2a), 17(2a), 20(1); R: 30(1), 34(2a), 35(r), 36(2m)
R. triquetrus (Hedw.) Warnst.	R: 34(2a)
Sciuro-hypnum populeum (Hedw.) Ignatov & Huttunen	R: 33(1)
S. reflexum (Starke) Ignatov & Huttunen	P: 5(2a)
Schistidium apocarpum (Hedw.) Bruch & Schimp.	R: 26(1); M: 51(1)
Syntrichia ruralis (Hedw.) F. Weber & D. Mohr	P: 5(2a), 8(1); R: 27(1), 28(+)
Thuidium delicatulum (Hedw.) Schimp.	P: 6(1), 8(+); R: 26(1)
Tortella tortuosa (Hedw.) Limpr.	M: 38(1), 39(1), 45(3), 47(1)

On the mine heap Ľubietová – Podlipa a total of 31 bryophyte species were recorded (29 mosses and 2 liverworts). This area is the species-richest among studied. The highest number of species (10) was noticed in one relevé (No. 5), while only one species was recorded in 5 relevés. The highest frequency on this mine heap had species *Pleurozium schreberi* (present in 7 relevés) and *Plagiomnium cuspidatum* (5). *Ceratodon purpureus* as a characteristic species for this type of habitat was present in 3 relevés. Species with the highest cover (25%) was *Pohlia drummondii* in relevé No. 1, followed by *Pohlia cruda* (20% – relevé No. 10) and *Brachythecium rutabulum* (20% – relevé No. 15).

On the mine heap Staré Hory – Richtárová a total of 29 species of mosses were recorded. The highest number of species (10) was present in one relevé (No. 30), one species was recorded only in one relevé. To the most frequently occured species belong *Ceratodon purpureus* (9) and *Pohlia cruda* (8). The species with the highest cover are: *Dicranum scoparium* (30% – relevé No. 30) and *Bryum capillare* (25% – relevé No. 21 and 20% – relevé No. 23).

Species-poorest mine heap was Maximilián in Špania Dolina where we found only 20 species of mosses. The highest number of species present in a relevé was 7 (relevé No. 39) and one species was recorded in 4 relevés. Few species had the highest cover compared to other studied areas: *Hypnum cupressiforme* (40% – relevé No. 53 and 30% – relevé No. 44), *Ceratodon purpureus* (35% – relevé No. 43), *Tortella tortuosa* (30% – relevé No. 45) and *Campylopus introflexus* (30% – relevé No. 48). The most frequent species was *Ceratodon purpureus* (present in 12 relevés) and *Hypnum cupressiforme* (7).

A total of 11 moss species were present on all three mine heaps: *Brachythecium albicans*, *B. salebrosum*, *Bryum caespiticium*, *B. moravicum*, *Ceratodon purpureus*, *Dicranum scoparium*, *Hylocomium splendens*, *Plagiomnium affine*, *Pohlia cruda*, *Polytrichastrum formosum* and *Racomitrium canescens*, while 9 bryophyte species were found only on Podlipa (*Aulacomnium palustre*, *Barbilophozia barbata*, *Brachythecium rutabulum*, *Calliergonella cuspidata*, *Dicranella heteromalla*, *Lophocolea bidentata*, *Plagiomnium cuspidatum*, *Pohlia drummondii* and *Sciuro-hypnum reflexum*), 8 on Richtárová (*Barbula unguiculata*, *Brachythecium rivulare*, *Cirriphyllum piliferum*, *Didymodon fallax*, *Drepanocladus aduncus*, *Oxyrrhynchium hians*, *Rhytidiadelphus triquetrus* and *Sciuro-hypnum populeum*) and 4 on Maximilián (*Campylopus introflexus*, *Grimmia pulvinata*, *Pterigynandrum filiforme* and *Tortella tortuosa*). The most frequent species on all studied sites was *Ceratodon purpureus*, recorded in 24 relevés altogether, followed by *Pohlia cruda* (17) and *Dicranum scoparium*, *Hypnnum cupressiforme* and *Pleurozium schreberi* (all present in 11 relevés). The genus with the highest number of species was *Brachythecium* (*B. albicans*, *B. rivulare*, *B. rutabulum* and *B. salebrosum*). *Hypnum cupressiforme* was the species with the highest overall cover (40% – relevé No. 53), but was not recorded on mine heap Richtárová. Species with the highest cover that were present on all three studied sites (at least 2a – 5%–15% cover-abundance) were *Brachythecium salebrosum*, *Ceratodon purpureus*, *Plagiomnium affine* and *Pohlia cruda*. According to Kubinská et al. (2001) none of the species recorded in our survey belongs to the "Red list of bryophytes of Slovakia". According to Kubinská, Janovicová (2001) species *Campylopus introflexus* (found in our field survey only on Maximilián) belongs to invasive species in Slovakia.

As a general rule in our studied areas, relevés with the highest number of species were situated in sites with deeper soil layer such as the ecotone between the mine heap and forest habitat or on sites with lower inclination. This is evident by the presence of species typical for humid and shady habitats such as *Climacium dendroides*, *Dicranum scoparium*, *Hylocomium splendens*, *Rhytidiadelphus squarrosus* etc. (Pilous, Duda, 1960). On the contrary, relevés with often only one species present lie more or less on bare rocky sites with species such as *Ceratodon purpureus*, *Pohlia cruda*, *P. drummondii*, *Racomitrium canescens*, *Tortella tortuosa*, or species from genus *Bryum*.

Štrba et al. (2014) but also Dobríková (2011) reported several bryophyte species from mine heap Richtárová in Staré Hory: *Abietinella abietina*, *Ceratodon purpureus*, *Dicranum scoparium*, *Hylocomium splendens*, *Plagiomnium affine*, *P. undulatum*, *Pleurozium schreberi*, *Pohlia cruda*, *Polytrichastrum commune*, *P. formosum*, *Racomitrium canescens*, *R. lanuginosum*, *Rhytidiadelphus squarrosus*, *R. triquetrus* and *Thuidium tamariscinum*. On the mine heap Maximilián in Špania Dolina genera such as *Dicranum*, *Hylocomium*, *Plagiomnium*, *Pleurozium*, *Polytrichastrum*, *Rhytidiadelphus* and *Thuidium* had the highest abundance (Aschenbrenner et al., 2011). Data on bryophytes from the mine heap Podlipa in Ľubietová have not been published yet.

A high heavy metal content in soil has a strong selection pressure on vegetation. Most plant species are not capable of adapting. There is, however, a small group of plants – specialists, that could tolerate these soils (Ernst, 1974; Ernst et al., 1992). Studies have shown that tolerant ecotypes are formed within a certain species that are adapted to these habitats. In recents years it has been discovered that some species of grasses, herbs and also lichens form tolerant ecotypes (Bačkor et al., 1998; Bačkor, Váczi, 2002). Among bryophytes such tolerant ecotypes were reported in *Ceratodon purpureus*, *Pohlia drummondii* and *Pleurozium schreberi* from mine heaps in Staré Hory, Gelnica and Smolník (Banásová, 2006; Banásová et al., 2007) or *Brachythecium albicans* in Banská Štiavnica (Banásová et al., 2012). All these species were noted in the investigated areas. A tolerant ecotype was also reported in *Ceratodon purpureus* (Jules, Shaw, 1994), *Funaria hygrometrica* Hedw. (Shaw, 1988) and in two liverworts, *Marchantia polymorpha* L. (Briggs, 1972) and *Solenostoma crenulata* (Sm.) Mitt. (Brown, House, 1978). Shaw (1990) stated that *Funaria hygrometrica* forms copper-tolerant ecotypes, although tolerance to other metals (e.g. zinc and cadmium) appears to be due mostly to cross-tolerance and generally vigorous growth.

Shacklette (1967) stated that some bryophyte species have been known to occupy substrates with greater than the normal content of copper or other metals. These species are commonly known in literature as copper mosses (Limpricht, 1895; Morton, Gams, 1925; Persson, 1956; Schatz, 1955; Brooks et al., 1985), although some are associated with metals other than copper and some are liverworts, not mosses. Schatz (1955) considered copper mosses to be more properly termed "sulfur mosses" because of their frequent linkage with sulfur compounds of copper, lead, zinc, and iron, as well as with sulfur deposits at mineral springs. Persson (1956) proposed that the controlling factor for the distribution of the copper mosses was the low pH (3.4–4.3) and observed that copper mosses were never found over ultramafic substrates (high pH) despite the high concentrations of heavy metals in these rocks and soils. Johnson-Groh (1987) also pointed out the importance of microclimate.

Širka (2014) reported a significant amount of Cu accumulated in the species *Pohlia drummondii* from the mine heap Podlipa in Ľubietová (4010.3 mg/kg) compared to

Thuidium delicatulum (8.5 mg/kg), and the mean value of Cu concentration in the substrate (3253 mg/kg). Since bryophytes do not have a well developed cuticle and root system like vascular plants and rely mostly on atmospheric deposition for nourishment, there is much controversy as to whether copper itself (or other heavy metal for that matter) is indeed the controlling factor for the distribution of bryophytes on metal-contaminated sites. Fernández (2013) and Brown (1995) concluded that mosses remain in a state of unstable equilibrium between inputs and outputs of contaminants and do not integrate metals from deposition and that this equilibrium of the concentrations of elements in moss cannot be studied by only considering the total concentrations of contaminants in the tissues as it is known that contaminants may be located in different cell compartments. According to Brooks et al. (1985) it is possible that the "preference" shown by some mosses for sites contaminated by heavy metals is a result of two factors: an acquired resistance to toxic ions, and a low tolerance to competition from other species outside contaminated sites. Results by Jules, Shaw (1994) give some indication that there might be a biological cost associated with metal-tolerance in *Ceratodon purpureus*. In their study smelter plants produced fewer stems and fewer gametangia on the control treatment than on the contaminated treatment and although this result may be, in fact, due to other differences between the studied sites (e.g. nutrient content), their evidence is suggestive of a cost. Similarly, Shaw (1990) demonstrated that metal-tolerant *Funaria hygrometrica* individuals form stems more slowly on normal (uncontaminated) treatments than non-tolerant individuals. The tendency of these mosses to grow on mineralized substrates might be a species characteristic, not a generic one (Shacklette, 1967). According to Jules, Shaw (1994) bryophytes can better adapt to heterogeneous environments than angiosperms as they have higher levels of phenotypic plasticity, rather than small-scale genetic responses. Strong conclusions cannot be made as to lack of evidence at present.

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Conclusions

A total of 45 species of bryophytes (43 mosses and 2 liverworts) in 54 releves were found in three mine heaps with copper-rich substrate in central Slovakia that had a similar bryophyte species composition. Species-richest mine heap was Podlipa (31 recorded species), while species-poorest mine heap was Maximilián (20 recorded species). Most frequent species were *Ceratodon purpureus*, *Pohlia cruda*, *Dicranum scoparium*, *Hypnum cupressiforme* and *Pleurozium schreberi*. *Hypnum cupressiforme* was the species with the highest overall cover. We confirmed that bryophytes play an important role in the initial stages of the succession process on anthropogenically created habitat types, as with lichens they formed a major component of the vegetation cover on mine heaps where any kind of mining activity was ended centuries ago. Their detailed study in relation to phytoextraction or phytostabilization of heavy metals may be used in succession management process aimed at restoring the environment, particularly the soil and air.

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Appendix 1

The list of all relevés (explanation in the "Methods").

Ľubietová – Podlipa (P)
1. bare coarse scree; 48°44'45.63" N, 19°23'4.04" E; 611 m; 0°; -; E_0 25%; 1; 8.11.2013
2. shrubland with pioneer tree species and moderately developed soil; 48°44'45.84" N, 19°23'2.94" E; 617 m; 5°; NE; E_2 35%; E_1 15%; E_0 25%; 6; 8.11.2013
3. dry fine scree with slightly developed soil; 48°44'45.54" N, 19°23'3.48" E; 611 m; 0°; -; E_1 5%; E_0 7%; 2; 8.11.2013
4. sparse vegetation on medium-sized scree with moderately developed soil; 48°44'47.90" N, 19°23'5.69" E; 628 m; 15°; NE; E_3 25%; E_1 15%; E_0 35%; 8; 8.11.2013
5. shrubland vegetation with developed soil; 48°44'48.06" N, 19°23'5.34" E; 625 m; 15°; E; E_2 60%; E_1 35%; E_0 40%; 10; 8.11.2013
6. shrubland vegetation with moderately developed soil; 48°44'47.64" N, 19°23'5.04" E; 624 m; 0°; -; E_2 50%; E_1 25%; E_0 30%; 7; 8.11.2013
7. sparse shrubland vegetation with moderately developed soil; 48°44'47.28" N, 19°23'4.38" E; 624 m; 0°; -; E_2 20%; E_1 40%; E_0 20%; 6; 8.11.2013
8. sparse shrubland with moderately developed soil; 48°44'47.04" N, 19°23'3.84" E; 624 m; 0°; -; E_2 35%; E_1 5%; E_0 35%; 6; 8.11.2013
9. tree cover with *Picea abies* on coarse scree but developed soil; 48°44'47.34" N, 19°23'2.94" E; 629 m; 20°; NE; E_3 85%; E_1 5%; E_0 13%; 5; 8.11.2013
10. bare coarse scree; 48°44'48.36" N, 19°23'4.92" E; 631 m; 20°; SW; E_0 15%; 1; 8.11.2013
11. grassland on coarse scree but moderately developed soil; 48°44'51.96" N, 19°23'10.14" E; 657 m; 10°; E; E_1 90%; E_0 15%; 4; 8.11.2013
12. bare coarse scree; 48°44'51.24" N, 19°23'9.60" E; 653 m; 10°; S; E_0 10%; 1; 8.11.2013
13. bare medium-sized scree on steep slope; 48°44'53.77" N, 19°23'9.81" E; 676 m; 50°; SW; E_0 3%; 2; 8.11.2013
14. grassland on coarse scree but moderately developed soil; 48°44'50.10" N, 19°23'8.94" E; 643 m; 5°; S; E_1 95%; E_0 10%; 2; 8.11.2013
15. grassland on coarse scree but moderately developed soil; 48°44'49.74" N, 19°23'8.28" E; 640 m; 0°; -; E_1 97%; E_0 15%; 1; 8.11.2013
16. shady sparse grassland on medium-sized scree with slightly developed soil; 48°44'48.60" N, 19°23'7.20" E; 633 m; 5°; SW; E_1 10%; E_0 8%; 1; 8.11.2013
17. tree cover with Picea abies on developed soil; 48°44'43.80" N, 19°23'5.34" E; 613 m; 7°; NW; E_3 90%; E_1 20%; E_0 30%; 4; 8.11.2013
18. sparse tree cover with *Picea abies* on developed soil; 48°44'42.42" N, 19°23'3.00" E; 595 m; 0°; -; E_3 70%; E^1 5%; E_0 12%; 3; 8.11.2013
19. sparse vegetation cover on fine scree and slightly developed soil; 48°44'42.84" N, 19°23'2.76" E; 596 m; 0°; -; E_1 15%; E_0 7%; 3; 8.11.2013
20. shady and wet vegetation cover with moderately developed soil; 48°44'42.06" N, 19°23'3.18" E; 595 m; 0°; -; E_3 65%; E_2 8%; E_1 35%; E_0 17%; 6; 8.11.2013
Staré Hory – Richtárová (R)
21. bare scree on steep slope; 48°49'40.20" N, 19°8'0.12" E; 580 m; 60°; NW; E_0 25%; 2; 23.11.2013
22. bare scree on steep slope; 48°49'40.08" N, 19°7'59.70" E; 583 m; 60°; N; E_0 5%; 1; 23.11.2013
23. wet grassland vegetation cover on skeletal soil; 48°49'39.84" N, 19°8'0.18" E; 581 m; 20°; NE; E_1 60%; E_0 30%; 3; 23.11.2013

24. sparse vegetation cover on coarse scree; 48°49'39.72" N, 19°8'0.42" E; 582 m; 10°; W; E_1 10%; E_0 20%; 6; 23.11.2013
25. sparse shrubland vegetation cover with high portion of forest litter and slightly developed soil; 48°49'38.34" N, 19°7'59.58" E; 589 m; 15°; N; E_2 25%; E_1 7%; E_0 35%; 5; 23.11.2013
26. flat surface with sparse herbaceous cover on skeletal soil; 48°49'38.88" N, 19°7'59.04" E; 588 m; 0°; -; E_1 25%; E_0 30%; 7; 23.11.2013
27. sparse moss cover on coarse scree; 48°49'38.94" N, 19°7'58.86" E; 591 m; 15°; E; E_1 5%; E_0 15%; 3; 23.11.2013
28. moss cover on steep slope with coarse scree; 48°49'38.46" N, 19°7'58.80" E; 592 m; 50°; E; E_1 3%; E_0 50%; 6; 23.11.2013
29. herbaceous and moss cover on coarse scree; 48°49'38.04" N, 19°7'58.32" E; 595 m; 30°; NW; E_1 20%; E_0 15%; 3; 23.11.2013
30. dense moss cover in a tree overgrowth with *Picea abies* on skeletal soil; 48°49'36.90" N, 19°7'58.27" E; 601 m; 10°; NW; E_3 75%; E_1 30%; E_0 85%; 10; 23.11.2013
31. overgrown coarse scree slope with pioneer tree species; 48°49'35.29" N, 19°7'57.40" E; 613 m; 30°; E_1 25%; E_0 65%; NW; 7; 23.11.2013
32. bare fine scree in the center of the mine heap; 48°49'31.08" N, 19°7'53.58" E; 651 m; 5°; N; E_0 6%; 2; 23.11.2013
33. sparse vegetation cover on fine scree; 48°49'31.97" N, 19°7'52.40" E; 656 m; 7°; NE; E_1 15%; E_0 10%; 3; 23.11.2013
34. tree cover with *Picea abies* on a steep slope with developed soil and dense moss cover; 48°49'29.46" N, 19°7'53.40" E; 663 m; 20°; NE; E_3 99%; E_1 2%; E_0 55%; 6; 23.11.2013
35. dense grassland vegetation; 48°49'28.44" N, 19°7'54.30" E; 664 m; 0°; -; E_1 95%; E_0 10%; 3; 23.11.2013
36. dense moss cover on coarse scree; 48°49'26.99" N, 19°7'55.71" E; 669 m; 20°; NE; E_0 40%; 7; 23.11.2013

Špania Dolina – Maximilián (M)

37. bare coarse scree; 48°48'31.04" N, 19°8'8.61" E; 764 m; 45°; SW; E_0 1%; 1; 19.12.2013
38. bare coarse scree; 48°48'31.74" N, 19°8'8.40" E; 773 m; 45°; W; E_0 15%; 4; 19.12.2013
39. coarse scree with slightly developed soil; 48°48'32.04" N, 19°8'8.46" E; 775 m; 10°; S; E_1 10%; E_0 25%; 7; 19.12.2013
40. coarse scree with slightly developed soil; 48°48'32.64" N, 19°8'9.18" E; 784 m; 0°; -; E_1 5%; E_0 20%; 4; 19.12.2013
41. coarse scree with slightly developed soil; 48°48'31.74" N, 19°8'11.70" E; 777 m; 5°; SW; E_0 15%; 3; 19.12.2013
42. bare coarse scree; 48°48'31.43" N, 19°8'13.26" E; 775 m; 5°; S; E_0 1%; 1; 19.12.2013
43. moss cover on coarse scree with slightly developed soil; 48°48'31.50" N, 19°8'15.00" E; 776 m; 5°; S; E_0 40%; 3; 19.12.2013
44. coarse scree with high portion of forest litter; 48°48'31.86" N, 19°8'12.96" E; 780 m; 5°; NW; E_1 3%; E_0 30%; 1; 19.12.2013
45. bare coarse scree; 48°48'31.20" N, 19°8'9.18" E; 766 m; 40°; S; E_0 30%; 2; 19.12.2013
46. bare coarse scree; 48°48'31.86" 19°8'8.64" E; 774 m; 30°; N; E_1 2%; E_0 15%; 1; 19.12.2013
47. coarse scree with slightly developed soil; 48°48'32.10" N, 19°8'8.46" E; 775 m; 30°; N; E_1 5%; E_0 12%; 5; 19.12.2013
48. coarse scree with slightly developed soil and higher portion of forest litter; 48°48'33.12" N, 19°8'8.58" E; 789 m; 0°; -; E_1 7%; E_0 30% 2; 19.12.2013
49. coarse scree with slightly developed soil; 48°48'33.18" N, 19°8'8.40" E; 789 m; 0°; -; E_1 3%; E_0 10%; 4; 19.12.2013
50. coarse scree with slightly developed soil and high portion of forest litter; 48°48'33.30" N, 19°8'7.74" E; 788 m; 0°; -; E_0 25%; 2; 19.12.2013

51. vegetation cover with *Picea abies* on coarse scree and moderately developed soil; 48°48'33.42" N, 19°8'7.62" E; 788 m; 0°; -; E_3 20%; E_2 40%; E_1 15%; E_0 30%; 6; 19.12.2013
52. coarse scree with moderately developed soil and high portion of forest litter; 48°48'33.48" N, 19°8'7.20" E; 787 m; 0°; -; E_0 25%; 2; 19.12.2013
53. tree cover with *Picea abies* and dense moss cover on developed soil; 48°48'34.20" N, 19°8'7.14" E; 794 m; 15°; W; E_3 90%; E_1 10%; E_0 70%; 6; 19.12.2013
54. tree cover with *Picea abies* and dense moss cover on developed soil; 48°48'34.02" N, 19°8'4.50" E; 780 m; 10°; S; E_3 75%; E_2 7%; E_1 5%; E_0 45%; 4; 19.12.2013

Abstract

The knowledge of bryophytes growing on metal-contaminated sites is still insufficient in Slovakia. This study deals with bryophyte flora of three mine heaps (Podlipa, Richtárová and Maximilián) with copper-rich substrate. A total of 54 relevés was made, in which a total of 45 bryophyte species (43 mosses and 2 liverworts) was recorded. Species-richest mine heap was Podlipa with 31 bryophyte species (29 mosses and 2 liverworts) and species-poorest was Maximilián with 20 species of mosses. 11 species were mutual for all three mine heaps, while 9 species where present only on Podlipa, 8 on Richtárová and 4 on Maximilián. The most representative bryophytes, in terms of their occurrence and cover, are *Ceratodon purpureus*, *Pohlia cruda*, *Dicranum scoparium*, *Hypnum cupressiforme*, *Pleurozium schreberi*, *Brachythecium salebrosum* and *Plagiomnium affine*. Occurence of bryophytes on metal-contaminated sites was discussed.

Key words: bryophytes, mine heaps, Ľubietová, Staré Hory, Špania Dolina, central Slovakia

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Mszaki z hałd kopalni miedzi w okolicach Bańskiej Bystrzycy (centralna Słowacja)

Streszczenie

Na Słowacji nadal niewystarczająca jest znajomość mszaków rosnących na terenach zanieczyszczonych metalami, takimi jak miedź. Niniejsze badania dotyczą flory mszaków trzech hałd kopalnianych (Podlipa, Richtárová i Maximilián), o podłożu bogatym w ten metal. Na analizowanym terenie wykonano 54 zdjęcia fitosocjologiczne, w których łącznie stwierdzono 45 gatunków mszaków (43 mchy i 2 wątrobowce). Najbogatsza gatunkowo okazała się być hałda kopalniana z Podlipa, na której odnotowano 31 gatunków mszaków (29 mchów i 2 wątrobowce), a najuboższa hałda Maximilián z 20 gatunkami mchów. Jedynie 11 gatunków było wspólnych dla wszystkich trzech hałd kopalnianych, natomiast tylko 9 gatunków występowało wyłącznie na hałdzie Podlipa, 8 na Richtárovej i 4 na Maximilián. Najczęstszymi mszakami, zarówno pod względem występowania, jak i pokrycia w płatach były: *Ceratodon purpureus*, *Pohlia cruda*, *Dicranum scoparium*, *Hypnum cupressiforme*, *Pleurozium schreberi*, *Brachythecium salebrosum* i *Plagiomnium affine*.

Słowa kluczowe: mszaki, hałdy kopalniane, Ľubietová, Staré Hory, Spania Dolina, centralna Słowacja

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