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Bryophytes of spoil heaps rich in toxic metals in Central Slovakia

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Abstract: In recent years environmental burdens such as spoil heaps left after mining industry have started to lose their negative reputation as scars in the modern landscape as they often hold a significant ecological value and can host many vanishing species of various organisms. In this paper we present a total of 13 bryophyte species recorded at two spoil heaps near the city of Banská Bystrica in Central Slovakia with notes on their ecology, distribution and conservation status. The evaluated species include: *Bryum algovicum*, *Campylidium calcareum*, *Campylopus introflexus*, *Coscinodon cribrosus*, *Drepanocladus polygamus*, *Helodium blandowii*, *Leucobryum juniperoideum*, *Orthotrichum stramineum*, *Plagiomnium ellipticum*, *Pohlia annotina*, *P. bulbifera*, *P. camptotrachela* and *Trichostomum crispulum*. Our study provides knowledge that some rare and valuable bryophyte species can occur in post-mining areas such as spoil heaps. Special attention should be paid to these sites in terms of biodiversity protection.

Keywords: endangered bryophytes, spoil heaps, Veľká studňa, Podlipa.

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Introduction

Post-mining sites are an unavoidable consequence of the mining industry and represent important land forms in many regions (WALKER 1992). Because mineral resources are underground and cannot usually be got at without removing the soils and vegetation that overlay them, and nearly always generate wastes which have to be disposed of on the surface, mining causes major damage to whole ecosystems. In both surface and deep mining the natural vegetation is inevitably destroyed, and the soils usually lost or buried by wastes (BRADSHAW 1997). As a result, post-mining sites such as spoil heaps, represent a specific habitat type for both plants and animals. Besides usually having coarse grain size, poor moisture retention properties, lack of major nutrients and elevated contents of heavy metals in the soil substrate (BANÁSOVÁ 1976, BINI 2011), spoil heaps also have a different microclimate than surrounding habitats.

Despite the enormous impacts of mining activities on landscapes, current restoration ecology gives preference to utilizing the conservation potential of various post-mining sites over their quick effacement after the mining cessation (YOUNG 2000). Recently, increasing evidence that post-mining sites constitute biodiversity refuges hosting large numbers of vanishing species of various organisms (e.g. BENEŠ et al. 2003, HOLEC & FROUZ 2005, BAUMBACH 2012, DOLNÝ & HARABIŠ 2012, TROPEK et al. 2012) has changed the traditionally negative view of these post-industrial barrens (YOUNG 2000). Such secondary habitats should not necessarily be regarded as ecological traps as they often are the available habitats with highest quality. Natural (primary) metalliferous soil sites are relatively rare in Central Europe, thus the conservation potential of these specific secondary habitats lies in the fact that they can substitute for very rare natural habitats. These anthropogenic surrogates host valuable communities not only of terrestrial but also freshwater groups containing numerous endangered species (DOLNÝ & HARABIŠ 2012). However, selection of the restoration approach affects the conservation potential of every post-mining site (TROPEK et al. 2012).

Habitats with particular edaphic conditions such as post-mining sites usually require special morphological, anatomical, and physiological adaptations of colonizing plants. Therefore, they often present specialized flora and vegetation and belong to one of the ecologically most interesting habitat types of Central Europe. Specific abiotic factors and the isolated geographic occurrence of metalliferous sites facilitate the evolution of specially adapted and genetically differentiated plant populations and can lead to the evolution of neo-endemic species. Apart from flowering plants which have for a long time been in scientific focus, adapted and genetically differentiated populations also have to be expected in lichens, fungi, bacteria, soil fauna, as well as bryophytes (BAUMBACH 2012). Among bryophytes, metal-tolerant ecotypes were demonstrated in two liverworts – *Marchantia polymorpha* (BRIGGS 1972) and *Solenostoma crenulata* (BROWN & HOUSE 1978) and in moss *Funaria hygrometrica* (SHAW 1988). JULES & SHAW (1994) described a tolerant ecotype in *Ceratodon purpureus* from a zinc smelter in Palmerton (Pennsylvania, USA) and BAUMBACH (2012) reports *Ceratodon purpureus*, as well as *Bryum caespiticium* as characteristic species for metallicolous vegetation of association *Armerietum halleri* Libb. 1930 in the eastern part of the Harz Mts. (Germany). In Slovakia, tolerant bryophyte ecotypes were also reported in species *Ceratodon purpureus*, as well as *Pohlia drummondii* and *Pleurozium schreberi* from spoil heaps in Staré Hory, Gelnica and Smolník (BANÁSOVÁ 2006, BANÁSOVÁ et al. 2007) or *Brachythecium albicans* from Banská Štiavnica (BANÁSOVÁ et al. 2012). It has also been known for a long time that some bryophytes are most common on, and even completely restricted to, substrates enriched with heavy metals. Such bryophytes showing an affinity for metalliferous substrates have been referred to as "copper mosses" (LIMPRICHT 1895, MORTON & GAMS 1925, PERSSON 1948, 1956, SCHATZ 1955, BRASSARD 1969, SHAW 1987, HOLYOAK & LOCKHART 2009), even though some are constrained to other metals than copper and some are liverworts (e.g. *Cephaloziella massalongi*, *C. nicholsonii*, *Mielichhoferia* spp. *Scopelophila cataractae*, *S. ligulata*, *Pohlia andalusica*). Nonetheless, most of the copper mosses have extraordinarily broad geographic ranges that span several continents, yet are extremely rare throughout their ranges (SHAW 1993). Moreover, bryophytes represent a significant group of organisms that are able to form small communities which can give precise insight into ecological conditions of microhabitats (SABOVLJEVIĆ 2008).

Knowledge on biodiversity of post-mining sites is still insufficient and requires further scientific research. In this paper, we give insight into some rare, endangered or otherwise noteworthy bryophyte species recorded at two spoil heaps in Central Slovakia with different age, restoration approach and mineralogical composition of the substrate. Ecology, distribution and conservation issues of these species are discussed.

Material and methods

Study area

Two spoil heaps near the city of Banská Bystrica (Central Slovakia) were examined: Hg-spoil heap Veľká studňa near Malachov village and Cu-spoil heap Podlipa in Ľubietová village (Fig. 1).

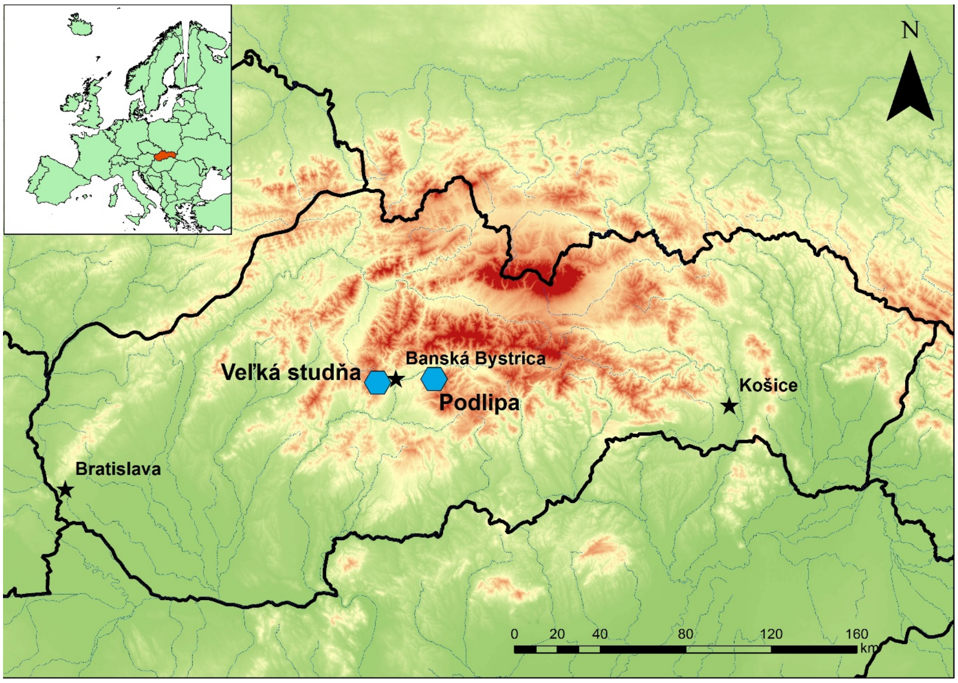

Fig. 1. Spoil heaps Veľká studňa and Podlipa within Slovakia.

Spoil heap Veľká studňa lies on the border of cadasters Malachov and Badín, about 3 km to the west from the center of the village Malachov near the city of Banská Bystrica in the Kremnické vrchy Mts. (ca 800–830 m a.s.l.). The Malachov – Veľká studňa geological bed is made up of carbonate rocks of the Chočian pit, represented by tectonically broken and gray dolomitic limestones with a rich net of crystalline calcite veins and numerous positions of varied fissile slivers (KNÉSL et al. 1981). The area of the spoil heap has a cold and very humid climate with average annual temperatures from 2 to 5 °C (LAPIN et al. 2002) and annual precipitation of ca 950 mm (AUXT et al. 1997). Mercury mines in the Malachov region are considered the second most exploited deposit of mercury in Europe. During almost a six-century history (beginning in the 14th century) there were periods with intense mining and operational standstill (BERNÁTH & BADÍK 1967). Veľká studňa deposit was discovered in the 1950s and here the exploitation of mercury took place from 1980–1991. After the mining cessation the processing area and the area of the spoil heap were partially reclaimed by applanation and soil deposition (MAŤOVÁ et al. 2008, FERENC et al. 2013). The mining activities at this deposit had a significant impact on all components of the environment. Extreme content of Hg in the waste rock material was found by DADOVÁ et al. (2015) (up to 44.24 ppm) as well as MIDULA et al. (2017) (from 16 up to astonishing 910 ppm, with an average of 332 ppm). Contents of other metals such as Pb (6.9–117 ppm), Sr (78–227 ppm), Ba (51–426 ppm) or Zr

(9.7–125.4 ppm) were also quite high (DADOVÁ et al. 2015). At present, a mozaic of habitat types are developed across the whole spoil heap, from open stands on fine-grained waste rock material, through various grasslands and shrublands to closed tree stands with deep soil layer, as well as from dry to wet communities.

Spoil heap Podlipa is located 1 km to the east of the center of the village Ľubietová between the cities Banská Bystrica and Brezno in the Veporské vrchy Mts. at an altitude from ca 550 to 800 m a.s.l. The cadaster area of Ľubietová is characterised by a complicated geological and structural-tectonic composition. The area of the spoil heap is situated in the terrigenous Permian of the Ľubietová crystalline, which consists of period and arkose slates and conglomerates close to the junction with granitoid porphyry and porphyroids of the lower Permian. The rocks around the deposit are intensely dynamically metamorphosed and crushed (POLÁK et al. 2003, ANDRÁŠ et al. 2006). The cadastral area of Ľubietová belongs to a slightly warm climatic region, a slightly warm and slightly humid highlands with a cold mountain climate (LAPIN et al. 2002). Annual temperatures reach from 6 to 7 °C and annual precipitation is ca 800 mm (SUPUKA et al. 2012). The Ľubietová ore region belongs to one of the historically most important Cu-Fe deposits of the Slovak Republic. Here exploitation of copper (but also gold) is known from the 14th century (KODĚRA et al. 1990). The last mining activities were aborted in April 1915 during the First World War (ANDRÁŠ et al. 2009). The dump-field mining sediments are influenced by heavy metals from the hydrothermal Cu-mineralization. The main contaminants: Cu (up to 20 360 ppm), As (up to 457 ppm), Sb (up to 79.3 ppm) and Zn (up to 80 ppm) are accompanied also by U (up to 10 ppm) and Th (up to 35 ppm) (ANDRÁŠ et al. 2008). The spoil heap is characterized by a steep relief with a high proportion of coarse-grained waste rock and it is being drained by a mountain brooklet which collects the water from the hills as well as the water percolating in the spoil heap sediments into a flood pool at the base of the heap. The central spoil heap body is covered by sparse islet-like grasslands or bryophytes and crust lichens. Only in flat and more humid places with deeper soil layer the vegetation has a denser cover where islands of pioneer woody species are created. Around the central spoil heap body the vegetation developed into a closed tree stand with spruce, pine and oak.

Data collection and moss determination

During the floristic and vegetation research in the growing seasons of 2015 and 2016 both examined spoil heaps were differentiated into physiognomic vegetation types according to plant communites or dominance of certain plant species. Within each physiognomic vegetation type all present vascular plants and bryophytes were recorded with their cover-abundance (in percentage). Uncertain and diagnostically difficult taxa of bryophytes were collected for microscope determination. The nomenclature of recorded bryophytes follows HILL et al. (2006). Threat categories follow KUBINSKÁ et al. (2001). Specimens are stored in personal herbarium of Pavel Širka and herbarium of the Moravian Museum (BRNM).

Results and discussion

At both studied sites we recorded a total of 118 taxa of bryophytes (13 liverworts and 105 mosses) (ŠIRKA et al. 2018). For the purpose of this paper, 13 species of mosses with significant or poorly known chorology and those deserving special attention regarding conservation in Slovakia are listed and discussed. Ecological and collection details of the recorded species are also given. Of the 13 evaluated taxa, 11 qualified for The Red List of Bryophytes of Slovakia (KUBINSKÁ et al. 2001) and included 7 Data Deficient (DD) taxa, 1 Vulnerable (VU) taxon, 2 Endangered (EN) taxa and 1 Critically Endangered (CR) taxon, while 1 taxon is regarded as invasive in Slovakia according to KUBINSKÁ & JANOVICOVÁ (2001).

Bryum algovicum Sendtn. ex Müll. Hal. Central Slovakia, the Kremnické vrchy Mts., the Veľká studňa spoil heap, on moist skeletal soil in a stand dominated by *Campylium stellatum* and *Equisetum palustre*, slope: 3°, exposition: SE, altitude: 819 m a.s.l., N48°42'53.90" E19°01'34.70", leg. P. Širka, 4 July 2016 (Herb. P. Širka). The species grows scaterredly on moist sandy soils, in wall and rock crevices, in dunes, on cliff-ledges, by roadsides, on walls, on soil-covered rocks and in quarries. It has a cosmopolitan distribution and is a European ubiquist (PILOUS & DUDA 1960 – syn. *B. pendulum*, DIERSSEN 2001). Unpublished studies by Holyoak suggest that autoicous plants of *B. algovicum* appear to occur mainly if not entirely on high ground in the Alps, whereas synoicous plants occur throughout the lowlands, from Central Europe north to Svalbard (HILL et al. 2006). In the updated checklist and Red List of bryophytes of the Czech Republic (KUČERA et al. 2012) it is recognized as "Vanished", as a subcategory within DD taxa (DD-va), meaning it is a taxon not recorded for a long period of time (more than ≈30 years) but with a realistic chance of being refound. According to The Red List of Bryophytes of Slovakia (KUBINSKÁ et al. 2001) this taxon belongs to category DD, however it is known for example from the Tatra Mts. (CHAŁUBIŃSKI 1886, ŠMARDA 1948, PILOUS 1961), the Muránska planina National Park (ŠMARDA 1940, HERBEN & SOLDÁN 1987), the Veľká Fatra Mts. (ŠOLTÉS et al. 2008) and other regions of the country. It is probably not under threat.

Campylidium calcareum (Crundw. & Nyholm) Ochyra. Central Slovakia, the Kremnické vrchy Mts., the Veľká studňa spoil heap, on dry skeletal soil in a sparse *Calamagrostis epigejos*-dominated grassland, slope: 0°, exposition: -, altitude: 817 m a.s.l., N48°42'53.17" E19°01'34.66", leg. P. Širka, 23 August 2016 (Herb. P. Širka). According to DIERSSEN (2001) this moss occurs on chalk and limestone rocks, in quarries, on roots and stumps, on dry earth and walls. It is distributed in Western and Central Europe north to Fennoscandia, in Caucasus, Turkey and Kenya (SMITH 2004). In the new European Red List of bryophytes (HODGETTS 2015) occurrence of this species is confirmed (either LC – Least Concern or no information about status) in all neighbouring countries of Slovakia and on the whole-European level it is only EN in Romania and VU in the Netherlands. In the Czech Republic this taxon is registered in the 'attention list' as a subcategory of LC taxa (LC-att), which is used for less well known taxa for which there is limited information on their current distribution and the potential threat to them. Such taxa need to be closely monitored in the future as they might either qualify for inclusion in the Red List in future versions of the checklist or might prove not to be threatened. In addition, this taxon was confused or merged with *C. sommerfeltii* and the North American *C. hispidulum* by previous authors and therefore a revision of this complex is needed (KUČERA et al. 2012). In Slovakia, according to KUBINSKÁ et al. (2001) *C. calcareum* is DD, however there are some published records of this species from Bratislava (KORNHUBER 1866, BÄUMLER 1884), the Biele Karpaty Mts. (MATOUSCHEK & HOLUBY 1901), the Malá Fatra Mts. (ŠMARDA 1952, PILOUS 1981), the Slovenský raj National Park (PILOUS 1979, HERBEN et al. 1982), the Pieniny National Park (PUJMANOVÁ et al. 1989), the Slovenský kras National Park (PECIAR 1995), the Belianske Tatry Mts. (BLACKBURN et al. 1997), the Slanské vrchy Mts. (PUJMANOVÁ 1990) and the Bukovské vrchy Mts. (PECIAR 1987, ŠOLTÉS & BURAĽ 2012). This moss is most likely not under threat.

Drepanocladus polygamus (Schimp.) Hedenäs. Central Slovakia, the Kremnické vrchy Mts., the Veľká studňa spoil heap, on skeletal soil in a sparse *Calamagrostis epigejos*-dominated grassland, slope: 0°, exposition: -, altitude: 813 m a.s.l., N48°42'55.20" E19°01'41.19", leg. P. Širka, 16 June 2016 (Herb. P. Širka). *D. polygamus* is found on moist grassland and marshy turf, in dune slacks, in flushes of sea-cliffs, in shallow, seasonally wet fens (DIERSSEN 2001) and has a circumpolar distribution with a disjunction in New Zealand (PILOUS & DUDA 1960). It is listed in many national red lists in Europe (CR in Luxembourg, Highly Endangered in Austria, EN in Switzerland, VU in Bosnia and Herzegovina, Czech Republic, Germany, Montenegro, Romania, Serbia, Slovenia and Spain, at risk in Sicily, NT – Nearly Threatened in Hungary and DD but recently recorded in Albania) and therefore is considered to be in threat at a whole-European level (HODGETTS 2015). However, it should be noted that a detailed distribution of this species is insuficiently known, as reported for example from Czech Republic (ŠTECHOVÁ et al. 2011). In Slovakia, *D. polygamus* is known for example from the Borská nížina Lowland (MIŠÍKOVÁ & DOBIÁŠOVÁ 2014) and even though it is listed as EN in the red list (KUBINSKÁ et al. 2001), it was most likely ommited in the past and could be more common than currently thought.

Orthotrichum stramineum Hornsch. ex Brid. Central Slovakia, the Kremnické vrchy Mts., the Veľká studňa spoil heap, on the bark of *Corylus avellana*, slope: 0°, exposition: -, altitude: 810 m a.s.l., N48°42'55.40" E19°01'39.74", leg. P. Širka, 1 July 2015 (Herb. P. Širka). The taxon grows preferably on the base-rich bark of ash, alder, sycamore, field maple and hazel, sometimes persisting on fallen trunks in the early stages of decay, most frequently in sheltered wooded valleys. It has a mediteranean, montane hemiboreal, suboceanic, subcontinental, circumpolar (DIERSSEN 2001), European-Oriental (PILOUS & DUDA 1960) distribution. According to HODGETTS (2015) this taxon is Endangered in Austria, Threatened in Belgium, VU in Estonia, Finland, Ireland, Northern Ireland and Poland but is not considered as threatened in Europe. Even though this moss is in the category DD in the Slovak red list (KUBINSKÁ et al. 2001), besides some old records from Bratislava (FÖRSTER 1881), the Tatra Mts. (CHAŁUBIŃSKI 1886), the Biele Karpáty Mts. (MATOUSCHEK & HOLUBY 1901) and other regions, it was also recently well-documented in the Borská nížina Lowland (MIŠÍKOVÁ & DOBIÁŠOVÁ 2014), the Poloniny National Park (PLÁŠEK 2007, ŠOLTÉS & BURAĽ 2012) and the Muránska planina National Park (PLÁŠEK et al. 2016) and most likely is not under threat.

Plagiomnium ellipticum (Brid.) T. J. Kop. Central Slovakia, the Kremnické vrchy Mts., the Veľká studňa spoil heap, in mixed grasslands in various places within the spoil heap area, leg. P. Širka, 16 June 2016 (Herb. P. Širka). The moss occurs in fen margins, around springs, in swamp forests and wet alluvial meadows flooded in spring and in ditches (DIERSSEN 2001). It has a wide area and it was recorded throughout Europe north to Svalbard and Iceland, in Caucasus, Turkey, Central and Northern Asia, Japan, Greenland, North America, Chile and Patagonia (SMITH 2004). *P. ellipticum* is Endangered in Austria, VU in Luxembourg, the Netherlands and Romania, NT in Hungary and DD (recently recorded) in Bulgaria but is not a candidate for the European Red List (HODGETTS 2015). According to HRIVNÁK et al. (2004) the exact distribution of the moss in Slovakia is poorly known (DD according to KUBINSKÁ et al. 2001) because it was confused with other species of the genus *Plagiomnium*, especially *P. medium*, *P. elatum* and *P. affine*. This species was not included in the commonly used keys, therefore it was not distinguished for a long time. However, it is certainly present in the Muránska planina National Park (HERBEN & SOLDÁN 1987), the Pieniny National Park (PUJMANOVÁ et al. 1989), the Tatra Mts. (BLACKBURN et al., 1997), the Poloniny National Park (ŠOLTÉS & BURAĽ 2012), the Veľká Fatra Mts. (ŠOLTÉS et al. 2008), the Slovenský raj National Park (ŠOLTÉS 1998), the Liptovská and Popradská kotlina Basins, the Veporské vrchy Mts., the Volovské vrchy Mts., the Revúcka vrchovina Highlands and other regions (HRIVNÁK et al. 2004). Most likely it does not represent a threatened species in the Slovak bryoflora.

Trichostomum crispulum Bruch. Central Slovakia, the Kremnické vrchy Mts., the Veľká studňa spoil heap, on bare skeletal soil in various places within the spoil heap area, leg. P. Širka, 16 June 2016 (Herb. P. Širka). This taxon occurs in crevices of limestone outcrops, on exposed crags, in chalk grasslands, on rocky banks, rarely on clay (DIERSSEN 2001). It can be found throughout Europe north to Svalbard, in Turkey, Cyprus, Caucasus, Asia Minor, Siberia, Eastern Asia, New Guinea, Macaronesia, Northern and Central Africa, Newfoundland and New Mexico (SMITH 2004). *T. crispulum* is not a canditate for the European Red List (HODGETTS 2015) as it is only EN in the Netherlands, NT in Estonia and DD in Norway and San Marino. Even though it is listed as VU in the Slovak Red List (KUBINSKÁ et al. 2001), there are many known localities of the species' occurrence in limestone mountain ranges such as the Belianske Tatry Mts. (e.g. ŠMARDA 1948, 1958a,b, PILOUS 1992), the Slovenský raj National Park (ŠMARDA 1961, PILOUS 1979, HERBEN et al. 1982, BLACKBURN et al. 1997), the Muranská planina National Park (e.g. SUZA 1930, ŠMARDA 1948, 1961, HERBEN & SOLDÁN

1987) or the Veľká Fatra Mts. (e.g. ŠMARDA 1948, ŠOLTÉS et al. 2008). The species should not be considered as threatened in Slovakia.

Campylopus introflexus (Hedw.) Brid. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, on bare soil in an islet of pioneer woody species in a flat part of the spoil heap body, slope: 0°, exposition: -, altitude: 669 m a.s.l., N48°44'52.40" E19°23'07.92", leg. P. Širka, 11 July 2016 (Herb. P. Širka). *C. introflexus* occupies acid sandy and gritty soils, decaying logs and stumps, bare peat following burning or peat cutting, occasionally acid rocks (DIERSSEN 2001) and is also able to colonize mine waste (CORLEY 1992). It is an alien species in Europe (HILL et al. 2006) native in the southern hemisphere. *C. introflexus* was first recorded in 1941 in Britain (CORLEY 1992), from where it is spreading rapidly towards the east. The eastern-most border of its expansion in Europe is currently roughly in the area of Lviv region in Western Ukraine (LOBACHEVSKA & SOKHANCHAK 2010). In the Czech Republic this species was first recorded in 1988 (NOVOTNÝ 1990) and currently is known from more than 80 localities across the whole country (MIKULÁŠKOVÁ et al. 2012). Occurrence of this species in the territory of the Slovak Republic was first published by HOLOTOVÁ & ŠOLTÉS (1997) and it is known from the Borská nížina Lowlands (MIŠÍKOVÁ & DOBIÁŠOVÁ 2014) as well as a Cu-spoil heap in Špania dolina village in Central Slovakia (ŠIRKA et al. 2016). The number of localities will probably increase in the future. *C. introflexus* is a species with a high reproduction potential and therefore can cause strong impacts on the natural flora (ESSL et al. 2009) and should be given increased attention.

Coscinodon cribrosus (Hedw.) Spruce. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, in a sparse tree stand with *Pinus sylvestris* on the steep spoil heap body with coarse-grained waste rock, slope: 45°, exposition: SE, altitude: 674 m a.s.l., N48°44'52.07" E19°23'06.11", leg. P. Širka, 11 July 2016 (Herb. P. Širka). *C. cribrosus* can be found on dry sun-exposed rock mostly in lower altitudes (PILOUS & DUDA 1960), on granite, gneiss, mica and andesite, in rock crevices, it is toxitolerant with a preference to heavy-metal containing rock (DIERSSEN 2001). It is rare in Europe from Sicily and Sardinia north to Scandinavia, in Northern Cyprus, Turkey, Caucasus, Siberia, Himalayas, Japan, Tenerife, Northern Africa, Northern America, Greenland and Patagonia (SMITH 2004). This moss is listed in many national red lists (Vanished in Luxembourg, CR in Slovakia and Greece, EN in Finland, Rare in Poland, VU in Canary Islands and Bulgaria, NT in Sicily, Romania and Slovenia and DD in Albania) and is a candidate for the European Red List (HODGETTS 2015). Although recently two new localities of *C. cribrosus* have been discovered in Poland (in the Silesian Beskids in Western Carpathians by BEDNAREK-OCHYRA & STEBEL 2014 and Góry Opawskie range in the Eastern Sudetes by STEBEL & BEDNAREK-OCHYRA 2015) it is difficult to explain why this moss is so rare in the Polish part of the Sudetes, while in the Czech part of these mountains it occurs frequently (KUČERA et al. 2004, 2009), hence the status LC in the Czech Red List according to KUČERA et al. (2012). According to STEBEL & BEDNAREK-OCHYRA (2015) it is possible that its occurrence is affected by the different climatic and habitat conditions. A similar situation prevails in the Carpathians, where the species is rare and scattered in the Southern and Eastern Carpathians, but it is extremely rare in the Western Carpathians (BLOCKEEL et al. 2009, BEDNAREK-OCHYRA & STEBEL 2014). It was discovered in the Vihorlat range (BAUER 1941, ŠMARDA 1948, HERBEN et al. 1980) as well as the Bukovské vrchy Mts. (PECIAR 1987) in the Slovak part of the Eastern Carpathians. In the Western Carpathians the species was discovered only recently in the Medves range in Hungary (BLOCKEEL et al. 2009) but so far not from the Slovak and Polish part of these mountains.

Helodium blandowii (F. Weber & D. Mohr) Warnst. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, in a small wetland at the bottom of the spoil heap body, slope: 0°, exposition: -, altitude: 593 m a.s.l., N48°44'41.92" E19°23'03.48", leg. P. Širka, 7 July 2016 (Herb. P. Širka, BRNM 795111 (20/2017)). This species grows in oligotrophic, basic fens and their margins (DIERSSEN 2001). It is a glacial relict and is scatteredly distributed in Northern, Western and Central Europe, North Asia, Japan, Greenland and North America (SMITH 2004), predominantly at lower altitudes (PILOUS & DUDA 1960). This taxon is a candidate for the European Red List (HODGETTS 2015) since it is present in many national red lists and considered to be in threat at European level. It is RE (Regionally Extinct) in Great Britain, Belgium and Switzerland, CR in Germany and Bulgaria, seriously threatened with high extinction risk in Austria, Highly Endangered in the Netherlands, EN in the Czech Republic, Slovakia and Poland, VU in Romania and Ukraine, at risk in France and DD in Hungary. Up to date, *Helodium blandowii* was published from a total of 17 sites in Slovakia, while recently 3 new localities have been discovered (ŠIRKA et al., in press).

Leucobryum juniperoideum (Brid.) Müll. Hal. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, near a small wetland at the bottom of the spoil heap body at the edge of *Picea abies* forest, slope: 0°, exposition: -, altitude: 592 m a.s.l., N48°44'41.48" E19°23'03.23", leg. P. Širka, 7 July 2016 (Herb. P. Širka).This taxon can be found most often on sandstone rocks and sandy soil, often on a thin layer of humus through silicate rocks (KUČERA 2007) and in drier sites than *L. glaucum* (DIERSSEN 2001) across Europe, Macaronesia, Turkey, Caucasus, east African islands (Mauritius, Réunion), South and East Asia, Northern America and Brazil (SMITH 2004). According to HODGETTS (2015) *L. juniperoideum* is not a candidate for the European Red List of bryophytes. In the Czech Republic distribution of *L. juniperoideum* is insuficiently known, where most of the records are from the northern and eastern Bohemian sandstones, but it is also scatteredly distributed in other parts of the territory together with *L. glaucum* (KUČERA 2007). In Slovakia *L. juniperoideum* is DD (KUBINSKÁ et al. 2001) and it was only published from the Malá Fatra Mts. (PECIAR 1985). This taxon was probably treated as the common *L. glaucum* in most cases and therefore its exact distribution at present is poorly known.

Pohlia annotina (Hedw.) Lindb. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, on waste rock material with thin soil in various places within the spoil heap area, leg. P. Širka, 7 July 2016 (Herb. P. Širka). The moss grows on open habitats on seasonally moist sandy, loamy or gravelly soils, on the banks of streams, at the margins of reservoirs, by ditchbanks, tracks, roadsides and in disused quarries (DIERSSEN 2001). It is distributed throughout Europe, in Turkey, Asia Minor, Siberia, Azores, Madeira, North America and Greenland (SMITH 2004). It is not threatened at the whole-European level according to HODGETTS (2015), altough it is EN in Estonia, VU in the Canary Islands, NT in Luxembourg and Romania, DD in Bulgaria (recently recorded), Portugal, Sicily and Hungary. Within the territory of Slovakia *P. annotina* was in the past ranked to at the time widely understood taxon *P. proligera*. Since the latest Slovak Red List of bryophytes (KUBINSKÁ et al. 2001) is also outdated, *P. annotina* is not incorporated in it. There are some data about *P. proligera* from Bratislava (BÄUMLER 1884), the Tatra Mts. (e.g. ŠMARDA 1952, 1954, 1958a, 1961) or the Bukovské vrchy Mts. (ŠOLTÉS & BURAĽ 2012) but it was not recognized and collected in the past and therefore it needs further revision.

Pohlia bulbifera (Warnst.) Warnst. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, on waste rock material with thin soil in various places within the spoil heap area, leg. P. Širka, 7 July 2016 (Herb. P. Širka). Similarly as the previous species it grows on damp, open, loamy or sandy soils on alluvium by streams, at the margins of lakes and reservoirs, on river banks, ditches, disused quarries and on cliff ledges (DIERSSEN 2001) and has distribution in montane and Northern Europe north to Fennoscandia, in Faeroes, Iceland, Turkey, Northern Asia, Azores, Northern America and Greenland (SMITH 2004). It is CR in Luxembourg and Romania, EN in Slovenia, Vulnerable in Estonia and Switzerland, with a risk assumed in Austria and DD in Portugal and Sardinia but it is not a candidate for the European Red List (HODGETTS 2015). In Slovakia this moss is listed as DD in the red list (KUBINSKÁ et al. 2001) and generally it is an overlooked species with poorly known distribution with published records only from the Vysoké Tatry Mts. (ŠMARDA 1958).

Pohlia camptotrachela (Renauld & Cardot) Broth. Central Slovakia, the Veporské vrchy Mts., the Podlipa spoil heap, on waste rock material with thin soil in a sparse grassland of *Agrostis capillaris*, slope: 40°, exposition: E, altitude: 660 m a.s.l., N48°44'49.03" E19°23'02.52", leg. P. Širka, 7 July 2016 (Herb. P. Širka). The taxon has a very similar ecology as *P. annotina* and *P. bulbifera* and can be found on sandy, loamy and peaty soils, in road cuttings, besides paths and ditches and in sandpits (DIERSSEN 2001), often together with the two species. It is distributed in Europe north to Fennoscandia, Azores, Madeira and Western North America (SMITH 2004). Likewise the previous two species it is not a candidate for the European Red List (HODGETTS 2015) and is only VU in Switzerland, at risk in Latvia, NT in Luxembourg and DD in Hungary and Serbia. There are published records about the species only from the Veľká Fatra Mts. (PILOUS 1980, ŠOLTÉS et al. 2008), hence the status DD in the Slovak red list (KUBINSKÁ et al. 2001). It is an omitted species in the Slovak bryoflora with poorly known distribution.

Some of the post-mining areas can develop a vegetation cover of significant ecological value and this value has been recognised in some instances in England and France, where reclamation proposals were orientated towards exclusive use of the sites for nature conservation and related activities, including habitat conservation, paths and observation points (RICHARDS et al. 1993). Generally, in post-mining areas natural development of vegetation is quite rare as the mining companies are often obligated to reclaim them. The aim of the reclamation works is basically to introduce any plant cover that can protect the waste material against surface erosion. Even though planting of selected trees and grasses leads to an acceleration of soil cover formation, it can also disrupt the specific composition of local flora (SZAREK-ŁUKASZEWSKA 2009). According to PRACH (2003) in a variety of man-made habitats in Central Europe it usually takes approximately 25 years of succession to reach (semi)-natural vegetation, usually woodland, which subsequently changes little in species composition and thus, the establishment of woodland does not necessarily need to be aided by planting trees. Compared to technical reclamation, spontaneous succession results in the development of more diverse plant communities with species composition closer to that of (semi)-natural vegetation (HODAČOVÁ & PRACH 2003).

However, in some cases modern mines are of no interest for conservation of metallophyte bryophytes (but also lichens, HUMPHRIES 2012), the survival of which will depend on persistence and suitable management of relict patches of habitat that resulted from the older mining work, in many cases from the nineteenth century. These areas are often under pressure as potential development land, as untidy and potentially dangerous places that need 'landscaping' or they are merely lost under scrub and saplings after generations of neglect. It is therefore important to ensure statutory protection and appropriate management of the most important metalliferous mine sites with rare bryophytes and the distinctive habitat types on which they depend (HOLYOAK & LOCKHART 2011). The importance of such habitat types was recognised for instance with the designation of The West Cornwall Bryophytes Site of Special Scientific Interest in 1999, providing statutory protection to six old mine sites specifically for the conservation of rare metallophytic bryophytes such as *Cephaloziella massalongi* and *C. nicholsonii*. With regard to practical conservation management for these plants, habitat restoration or creation should be coupled with soil analysis to help judge substrate suitability (CALLAGHAN & BOWYER 2011). Spontaneous development of local vegetation therefore seems an appropriate way to rehabilitate at least part of post-mining areas with regard to the maintenance of the vegetation typical for the metalliferous soils and islands of such vegetation increase the biodiversity of degraded areas (SZAREK-ŁUKASZEWSKA 2009).

Although most of the so called “copper mosses” or metallophytes are rare plants, they occur at additional localities, where they can be easily overlooked (HOLYOAK & LOCKHART 2011). For that purpose, for example, a wide-ranging survey of bryophytes was recently undertaken at metalliferous mine sites in Ireland which produced numerous new finds, such as lead-tolerant *Ditrichum plumbicola* new to Ireland and *Cephaloziella nicholsonii*, *C. massalongi*, *C. integerrima* and

Scopelophila cataractae at additional sites in Ireland (HOLYOAK & LOCKHART 2009). MIDDLETON & LUNN (2001) describe the bryophyte and lichen flora of colliery spoil heaps in Yorkshire (United Kingdom) and indicate that such sites can be of interest for these groups of organisms, in terms of species diversity and abundance, as well as rarity. The very rare lichen *Cladonia cyathomorpha*, as well as the invasive moss *Campylopus introflexus* was a remarkable discovery made by these authors. Furthermore, they show that through being primary colonisers of such land, sometimes in abundance, bryophytes and lichens can make a contribution to its ecological development. Among metal-contaminated anthropogenic habitat types in Slovakia, BLANÁR & PETRÁŠOVÁ (2007) recently found moss *Desmatodon cernuus* (reported from the territory of Slovakia for the first time) in an air-polluted region of the magnesite factories in Lubeník, Jelšava (Teplá voda) and Hačava in the Slovenské rudohorie Mts.

The questions regarding the distribution of bryophytes over metal-contaminated areas have perhaps not yet been fully explained as there is a lot of controversy as to whether copper itself (or other heavy metal) is indeed the controlling factor. SCHATZ (1955) argues that copper mosses are frequently associated with sulfur compounds of copper, lead, zinc, and iron, as well as with sulfur deposits at mineral springs and therefore should be more promptly termed “sulfur mosses”. PERSSON (1956) proposed that the controlling factor for the distribution of copper mosses is the low pH, while HARTMAN (1969) showed that the occurrence of *Mielichhoferia mielichhoferiana* reflects a combination of all three factors, high copper and sulfate concentrations and low pH. According to SCHACKLETTE (1967) the tendency of these bryophytes to grow on mineralized substrates might be a species characteristic, not a generic one. BROOKS et al. (1985) state that it is possible that the “preference” shown by these species for sites contaminated by heavy metals is a result of an acquired resistance to toxic ions, and a low tolerance to competition from other species outside contaminated sites.

Our botanical survey supplements the knowledge that post-mining areas such as spoil heaps, where different microhabitat types are developed, can harbour some rare and valuable bryophyte species. In addition, given the fact that they occur at heavy metal-contaminated sites, these species may also exhibit a rather atypical ecology as well as some significant physiological features in regard to heavy metal tolerance. Unless post-mining sites represent immediate danger for human health, they should be given increased attention regarding conservation prior to any reclamation activities as some reclamation schemes may have a detrimental impact on the local wildlife and conservation potential of these secondary sites.

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