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Bryophytes of selected habitat types in the Olkusz Ore-bearing Region

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Introduction

Bryophytes are ubiquitous green plants which, despite their small size and simple structure, occupy virtually all the ecosystems on Earth, including the most inhospitable, with the notable exception of the marine environment. Quite often they provide one of the first links in the vegetation succession, and for that reason, along with lichens, they are labelled pioneers of life. They grow successfully in polar regions, reaching the highest possible latitudes in the Antarctic near the South Pole, as well as in deserts, and in the mountains they sometimes occur at elevations above 5000 metres. Bryophytes are an essential component of forests in all climatic zones. The exceptional adaptability of these plants is a consequence of their special physiological abilities, especially their ectohydricity. The vast majority of them do not possess special organs for conducting water and they absorb it from external capillary spaces as needed (Proctor 2000).

Some bryophytes exhibit a special ability to accumulate pollutants, especially heavy metals, and therefore for several decades they have been used in environmental monitoring (Maschke 1981; Muhle 1985; Markert *et al.* 2003). The first investigations of this type were carried out in Scandinavian countries in the 1970s (Tyler 1970; Rühling and Tyler 1973; Steinnes 1987; Poikolainen *et al*. 2004). Since 1990, most European countries have participated in five-yearly monitoring of heavy metal deposits in a few bioindicator moss species, including *Pleurozium schreberi* (Brid.) Mitt., *Hylocomium splendens* (Hedw.) Schimp., *Hypnum cupressiforme* Hedw. and *Pseudoscleropodium purum* (Hedw.) Broth. (Rühling 1994; Rühling *et al*. 1997; Suchara *et al*. 2007a,b; Harmens *et al*. 2008, 2013).

A number of bryophyte species are associated with a specific substrate containing high concentrations of metals, for example copper, zinc, nickel, iron or aluminium (Persson 1948, 1956; Mårtensson and Berggren 1954; Canon 1960; Shacklette 1967; Shaw and Owens 1995). There is considerable evidence indicating that some taxa evolved in such habitats, while their close relatives or ancestral species grow in areas in which metal-bearing ores are absent or scarce. Such pairs of closely related

taxa include *Ditrichum plumbicola* Crundwell and *D. lineare* (Sw.) Lindb. among the mosses, and *Gymnocolea acutiloba* (Schiffn.) Müll.Frib. and *G. inflata* (Huds.) Dumort. as well as *Cephaloziella massalongi* (Spruce) Müll.Frib. and *C. compacta* (Jörg.) Müll.Frib. among the hepatics, although the latter pairs are sometimes considered merely ecological modifications of the parent species (Persson 1948).

The best-known moss accumulators of heavy metals, often called copper mosses, include *Streptocolea atrata* (Hornsch.) Ochyra & Żarnowiec (Ochyra and Bednarek-Ochyra 2004), *Mielichhoferia elongata* (Hoppe & Hornsch.) Nees & Hornsch., *M. mielichhoferiana* (Funck) Loeske and *Scopelophila ligulata* (Spruce) Spruce, which are native European species, as well as *S. cataractae* (Mitt.) Broth., a species introduced to Europe several decades ago (Corley and Perry 1985). Due to their unusual abilities, these species are often used as bioindicators helpful in detecting metal-bearing ore deposits (Shacklette 1961, 1965a, b, 1967; Brooks 1968, 1971; Brooks *et al*. 1973).

Unfortunately, none of those metal accumulating moss species has been discovered in Poland so far, despite the existence of areas with deposits of zinc- and lead-bearing ores in the vicinity of Bytom, Trzebinia and Olkusz (Godzik – Chapter 2, this volume). The present-day anthropogenic landscape in this region is associated with mining and processing of metal-bearing ores, resulting in total transformation of its surface and the occurrence of artificial elements. There are numerous remains of mining activity in this area, such as post-mining outcrops, sand pits and waste dumps. Natural outcrops of zinc and lead ores are absent but the whole area is strongly polluted with heavy metals originating from settling of dust from ore processing and smelting. In some places heavy metal pollution of the soil exceeds the permitted levels. This is especially true of the dumps left after exploratory mining and surface mining of outcrops, and these contain exceptionally high concentrations of heavy metals (Pasieczna and Lis 2008). Such sites are of special botanical interest since they are occupied by a specific type of xerothermic grassland containing species that tolerate high levels of metals, such as *Biscutella laevigata* L., *Silene vulgaris* L., *Dianthus carthusianorum* L. and *Armeria maritima* (Mill.) Willd. In species composition they are similar to the calamine grasslands of Western Europe (Szarek-Łukaszewska and Grodzińska 2008, 2011).

Metal-bearing land in the vicinity of Olkusz has not hitherto been studied bryologically, although the first information on bryophytes in this region dates from the end of the 19th century (Steingauz 1887; Błoński 1889, 1890a, b). The moss flora of the western part of the area, situated in the Silesian Upland, was described by Kuc (1956). Some bryological data are scattered in various publications devoted to the Kraków-Częstochowa Upland (e.g. Kuc 1959; Jędrzejko and Wika 1989, 1992). All these incidental records of bryophytes have been summarised by Stebel (1998) in his bryoflora of Katowice Province (in its pre-1998 boundaries).

Previous information on the bryophytes of the Olkusz Ore-bearing Region (OOR) is scattered and disregards the specific features of the terrain. From 2008 to 2012, studies on the bryophytes of the OOR were carried out within the interdisciplinary project "Vegetation of calamine soils and its importance for biodiversity and landscape conservation in post-mining areas" (EEA FM PL0265). They focused mainly on describing the species richness and variety of the bryophyte flora of the study area, and determining the main factors shaping the contemporary bryoflora and the distribution of particular species. These issues

are discussed in detail in a separate treatment (Stebel *et al*. 2014). The present chapter discusses the bryophyte species occurring in selected habitat types occupied by uniform vegetation stands in the OOR.

Material and methods

The fieldwork in the post-mining Olkusz Ore-bearing Region was carried out in 2008–2009 and focused primarily on the composition and frequency of bryophyte species in selected sampling plots. In 2012, composite field studies were performed in all types of habitat throughout the OOR with the aim of forming a complete list of liverwort and moss species (Stebel *et al*. 2015). Some additional fieldwork on the bryoflora carried out in 2014 was aimed primarily at obtaining supplementary distributional records, especially for frequent and common species that may have been overlooked during the earlier survey.

The OOR study area covers 48 sq. km and is situated in the southeastern part of the Silesia-Cracow Upland (50°15′–50°19′N, 19°25′–19°32′E) (Godzik – Chapter 2, this volume). It lies in ATPOL grid squares DF36 and DF46 (Zając 1978), Fd63 and Fd64 in the ATMOS system (Ochyra and Szmajda 1981). A detailed description of the study area is in Nowak *et al*. (2011) and in this volume (Godzik – Chapter 2).

Bryophytes were recorded at sites representing six homogeneous habitat types, using the methods specified in project EEA MF PL0265 (Kapusta and Godzik – Chapter 6, this volume). In total, 49 sites (400 m^2 each) were studied, bearing numbers 1–30, 32–34 and 36–51, and within each site the species and their frequency and abundance were recorded from nine plots (4 m^2 each). Sites (and plots) were investigated in the following vegetation and habitat types:

FS – pine forest on sand: 22, 26, 28, 32, 33, 36, 37, 39, 40, 41, 42, 43, 44, 45, 47;

FW – pine forest on mining waste: 23, 24, 25, 27, 29, 38;

GS – thermophilous grassland on sand: 3, 4, 8, 9, 12, 20, 46;

GW – thermophilous grassland on mining waste: 1, 14, 15, 16, 17, 34; 51;

MW – grassland dominated by *Molinia caerulea* on mining waste: 2, 13, 21, 30, 49, 50;

P – mesophilous grassland on old fields: 5, 6, 7, 10, 11, 18, 19, 48.

Bryophytes were collected on all substrates occurring in a given sampling plot, including soil, stones, fallen branches, rotten stumps, litter, humus, tree bark and exposed roots. In total, 931 bryophyte records were made, 342 of which were collected. Voucher specimens are deposited in the bryological herbarium of the Institute of Botany of the Polish Academy of Sciences (KRAM).

Below are listed all the recorded hepatic and moss species, arranged systematically. Unless otherwise stated, the data for each species refer to the investigated sampling plots and include (*a*) the substrate on which it was recorded, (*b*) its frequency, (*c*) the total number of records at the sites (ST), and (*d*) the number of sampling plots in each habitat type, designated by the abbreviations given above. Some species collected outside but very near the sampling plots are listed; for these the relevant numbers are given in parentheses. They are exceptional cases which do not affect the general characterisation of the bryoflora of the sites: a single record of the epilithic moss *Schistidium apocarpum* (Hedw.) Bruch & Schimp., and the majority of the records of *Schistidium crassipilum* H.H.Blom. The abundance of each species was evaluated using the 6-degree combined Braun-Blanquet scale, commonly accepted in phytosociology. The results were

used for assessment of the abundance of the species in particular types of vegetation stand.

The frequency of each species in the OOR is also given, because quite often it differed from that in the sampling plots. Information on its occurrence in the coterminous Silesian and Kraków-Częstochowa Uplands is also given.

List of taxa

MARCHANTIOPHYTA

Aneuraceae

Riccardia palmata (Hedw.) Carruth. – On a rotten stump in pine forest. Exceedingly rare, recorded only once in the OOR. So far the species has not been recorded in the Olkusz Upland, and in the Kraków-Częstochowa Upland was found only twice in the 19th century (Szweykowski and Koźlicka 1980). It was reported once in the 19th century from the Silesian Upland (Uechtritz 1864). ST: 1 – FS: 43.

Lophocoleaceae

Lophocolea heterophylla (Schrad.) Dumort. – On decaying stumps and logs in pine forest. Infrequent in the sampling plots but relatively frequent in the OOR and in coterminous areas of the Silesian Upland (Stebel 1998). ST: 2 – FS: 38, 43.

Cephaloziellaceae

Cephaloziella rubella (Nees) Warnst. – On dry soil in tufts of mosses. A very rare species, known from only two localities in the OOR, one of which was situated in a sampling plot. In addition, it occurs occasionally in the Silesian Upland (Stebel 1998). ST: 1 – FW: 27.

Cephaloziella divaricata (Sm.) Schiff. – On dry soil. Very rare in the sampling plots and in the whole OOR, scattered in the Silesian Upland (Stebel 1998). ST: 2 – GS: 46; MW: 49.

Lophoziaceae

Barbilophozia barbata (Schreb.) Loeske – On soil, pine needles and bark. Very rare in pine forest on the eastern and northern outskirts of the OOR. It is also exceedingly rare in the Silesian Upland (Stebel 1998). ST: 4 – FS: 22, 37, 43, 45.

Lophozia ventricosa (Dicks.) Dumort. – On soil in a moss patch in pine forest. A very rare species, known only from a single site in the OOR, sporadically recorded in the Olkusz and Katowice Uplands (Stebel 1998). ST: 1 – FS: 39.

BRYOPHYTA

Ditrichaceae

Ceratodon purpureus (Hedw.) Brid. (Fig. 1) – On denuded sandy and clayey soil, on stones and in strongly disturbed habitats, common in the sampling plots. A ubiquitous species in the OOR, one of the commonest moss species in the whole country. ST: 28(29) – FS: 22, 26, (28), 42, 43, 44, 47; FW: 23, 24, 27; GS: 3, 4, 8, 46; GW: 15, 16, 34; MW: 2, 13, 30, 49; P: 5, 6, 7, 10, 11, 18, 19, 48.

Dicranaceae

Dicranella heteromalla (Hedw.) Schimp. – On a decaying stump. In the sampling plots it was recorded only once, but it is relatively frequent in the OOR, and common in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 1 – FS: 43.

Dicranella rufescens (Dicks.) Schimp. – On dry or slightly moist soil and dolomite pebbles, very rare. The species is relatively frequent in the Silesian Upland (Stebel 1998) but very rare

Fig. 1. *Ceratodon purpureus* (Hedw.) Brid. (photo V. Plášek)
Ryc. 1. *Ceratodon purpureus* (Hedw.) Brid. (fot. V. Plášek)

in the neighbouring Olkusz Upland (Fojcik 2011). ST: 2 – GW: 34; MW: 2.

Dicranella staphylina H.Whitehouse – Gregarious or in small tufts on dry, clayey soil. The species is infrequent in the OOR and so far has not been recorded in the Pagóry Jaworznickie hills (Stebel 1998). It is relatively frequent in the Olkusz Upland but not in the part constituting the OOR (Fojcik 2011). ST: 5 – FW: 23; GW: 1, 14, 15; MW: 30.

Dicranella varia (Hedw.) Schimp. – On dry or slightly moist clayey or sandy soil. The species is fairly frequent in the central part of the OOR, and widespread in the Silesian Upland (Stebel 1998) and Olkusz Upland (Fojcik 2011). ST: 2 – GS: 46; MW: 50.

Pottiaceae

Barbula unguiculata Hedw. – On clayey and stony ground. The species was infrequent in the sampling plots but generally is widespread and locally common in the OOR, as it is throughout the Silesian Upland (Stebel 1998) and the adjacent Kraków-Częstochowa Upland (Fojcik 2011). ST: 7 – GW: 15, 16, 34; MW: 30; P: 6, 7, 11.

Didymodon fallax (Hedw.) R.H.Zander – On dry, stony soil. The species was only recorded once in the sampling plots but generally is relatively frequent in the central and western parts of the OOR. Frequent in the Silesian Upland (Stebel 1998) and Olkusz Upland (Fojcik 2011). ST: 1 – GW: 15.

Didymodon rigidulus Hedw. – On stony soil on mining waste. The species was very rare in the sampling plots but is widely distributed in the southwestern and northeastern parts of the OOR. It is also frequent in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 2 – GW: 15, 34.

Tortella tortuosa (Hedw.) Limpr. – On stony ground with dolomite. It is widespread and common in places in the central and western parts of the OOR. The species is common on limestone rocks in the Kraków-Częstochowa Upland (Fojcik 2011) and less frequent in the Silesian Upland (Stebel 1998). ST: 12(13) – FS: 37; FW: 23, 24, (25), 27, 29; GW: 1, 14, 15, 16, 17; MW: 2, 50.

Tortula muralis Hedw. – On boulders, mining waste and concrete walls. It was very seldom recorded in the sampling plots but is relatively frequent throughout the whole OOR. Common in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 2 – P: 6, 19.

Weissia controversa Hedw. – On basic stony substrate, on soil with dolomite stones and pebbles. The species is rare in the OOR, though locally very abundant. It is generally rare in the Silesian Upland (Stebel 1998) and

widely scattered in the Kraków-Częstochowa Upland (Fojcik 2011). ST: 10 – GS: 3, 9, 12, 20; GW: 1, 51; MW: 2, 13, 21, 49.

Grimmiaceae

Niphotrichum canescens (Hedw.) Bednarek-Ochyra & Ochyra – On stony soil in mining waste. The species is relatively rare in the OOR, usually forming small populations, but is widely distributed though scattered in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 1 – FW: 28.

Schistidium apocarpum (Hedw.) Bruch & Schimp. – On stony soil, recorded only once in the OOR. Its distribution in the study area as well as in the country as a whole is poorly known, since until recently it had not been distinguished from several species of this complex (Blom 1996). ST: 1 – GW: 15.

Schistidium crassipilum H.H.Blom (Fig. 2) – On dolomite stones at dry, sunny, exposed sites. It was not recorded in the sampling plots but occurred close by. So far the species has not been separated from *S. apocarpum* but it seems to occur commonly in the OOR, on stones, stone and concrete walls. Its distribution in the country remains to be determined, but it is certainly one of the commonest species in the Kraków-Częstochowa Upland (Fojcik 2011) and most probably throughout the Polish lowlands. ST: (2) – FS: (37); MW: (50).

Fig. 2. *Schistidium crassipilum* H.H.Blom (photo V. Plášek)
Ryc. 2. *Schistidium crassipilum* H.H.Blom (fot. V. Plášek)

Schistidium dupretii (Thér.) W.A.Weber – An epilithic moss, growing on dry stones, boulders, stony soil and walls. In the sampling plots it was found only once but it was observed in the vicinity more often. It is the commonest species of the genus in the OOR, growing exclusively on stony substrate. ST: 1(7) – FS: (37); FW: (23), 25; GW: (14); MW: (49), (50); P: (18).

Bryaceae

Bryum argenteum Hedw. (Fig. 3) – A ubiquitous species, growing on all types of soil at anthropogenic sites, most often in dry and exposed sites. It was rarely found in the sampling plots but is one of the commonest moss species in the OOR and in Poland as a whole. ST: 2 – GW: 16; P: 6, 11.

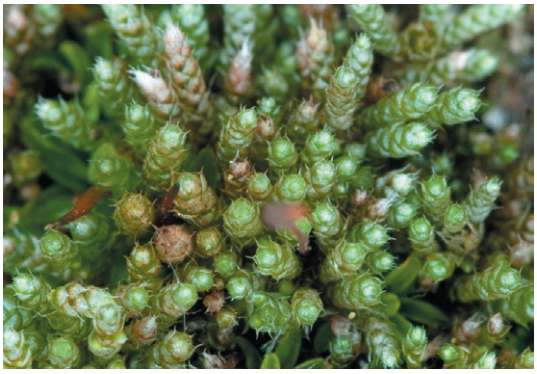

Fig. 3. *Bryum argenteum* Hedw. (photo V. Plášek)
Ryc. 3. *Bryum argenteum* Hedw. (fot. V. Plášek)

Bryum caespiticium Hedw. – On clayey soil. It was found only once in the sampling plots but is scattered throughout the OOR. It is

one of the commonest species in the country, occurring on dry anthropogenic sites. ST: 1 – MW: 50.

Bryum dichotomum Hedw. – An epigean moss growing on dry or somewhat moist soil, commonly with axillary gemmae. In the sampling plots it was an occasional species of grassland and fallows. It is scattered in the OOR and in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 3 – GW: 16, 34; P: 6.

Bryum pallescens Schwägr. – On stony basic ground, on soil with dolomite pebbles, on clay, sand and humus. Frequent and locally common and abundant in all the sampling plots on anthropogenic sites and in the entire OOR. Along with *Bryum argenteum* and *B. pseudotriquetrum* (Hedw.) P.Gaertn., B.Mey. & Scherb. (which was not recorded in any sampling plot) it is one of the commonest species of the genus. Interestingly, it is rather infrequent in the Silesian Upland (Stebel 1998) and in the Kraków-Częstochowa Upland (Fojcik 2011). ST: 26(28) – FS: 26, 47; FW: (24), 23, 27; GS: 3, 4, 9, (12), 20, 46; GW: 1, 14, 15, 16, 17, 34, 51; MW: 2, 13, 21, 30, 50; P: 6, 7, 10, 11, 18.

Pohlia nutans (Hedw.) Lindb. – On soil, pine needles and rotten wood. The species was frequent in the sampling plots. In the OOR it is one of the commonest species, especially in pine forest. Common throughout the country. ST: 14(15) – FS: 22, 26, 32, 33, 36, 39, 40, 41, 43, 44, 45; FW: (27), 38; GS: 46; P: 6.

Rosulabryum capillare (Hedw.) J.R.Spence – Most often found on dry sandy soil and humus in pine forest. It was rather rare in the sampling plots but is more frequent and abundant throughout the OOR in pine forest. It is common in the Silesian Upland (Stebel 1998) and the Kraków-Częstochowa Upland (Fojcik 2011). ST: 3 – FS: 22, 37, 42.

Mniaceae

Plagiomnium affine (Funck) T.J.Kop. – On pine needles in dry situations in pine forest. The species was only recorded once in the sampling plots but in the OOR it is relatively frequent, especially in the southern part of the area. It is common in the Silesian Upland (Stebel 1998), the Kraków-Częstochowa Upland (Fojcik 2011) and throughout the country. ST: 1 – FW: 27.

Plagiomnium cuspidatum (Hedw.) T.J.Kop. – On sandy, clayey and stony soil in pine forest, less often in grassland and fallows. The species was rather infrequent in the sampling plots but in general is one of the commonest moss species in the OOR, as it is in the Silesian Upland (Stebel 1998) and the Kraków-Częstochowa Upland (Fojcik 2011). ST: 10 – FS: 37; FW: 24, 27, 38; GW: 16; MW: 30; P: 11, 18, 19, 48.

Plagiomnium rostratum (Hedw.) T.J.Kop. – On basic stony and clayey soil in fallow fields, rarely in pine forest. The species is very rare, recorded from only three sampling plots and generally sporadically observed in the OOR. Unlike in the study area, it is very frequent in the Silesian Upland (Stebel 1998) and the Kraków-Częstochowa Upland (Fojcik 2011). ST: 3 – FS: 37; P: 6, 48.

Thuidiaceae

Abietinella abietina (Hedw.) M.Fleisch. (Fig. 4) – On dry soil on insolated and open sites in grassland and pine forest on mining waste. Rare in the sampling plots and in the OOR, common in xerothermic grassland in the Kraków-Częstochowa Upland (Fojcik 2011), and less frequent in the Silesian Upland (Stebel 1998). ST: 2 – FW: 38. GW: 16.

Fig. 4. *Abietinella abietina* (Hedw.) M.Fleisch. (photo V. Plášek)

Ryc. 4. *Abietinella abietina* (Hedw.) M.Fleisch. (fot. V. Plášek)

Thuidium delicatulum (Hedw.) Schimp. – On dry soil, usually at shady sites in pine forest. Very rare in the sampling plots and in the OOR. In Poland the species is common but locally infrequent, as for example in the Kraków-Częstochowa Upland (Fojcik 2011), and less frequent in the Silesian Upland (Stebel 1998). ST: 3 – FS: 42; FW: 24, 38.

Hylocomiaceae

Pleurozium schreberi (Brid.) Mitt. (Fig. 5) – On the ground, primarily in pine forest, at shady and sunny sites. A relatively frequent species in the sampling plots and in the whole OOR. It is widespread in Poland in coniferous forest. ST: 12(13) – FS: 22, 36, 39, 41, 42, 43, 44, 45, 47; FW: 24, (27), 29, 38.

Fig. 5. *Pleurozium schreberi* (Brid.) Mitt. (photo A. Stebel)

Ryc. 5. *Pleurozium schreberi* (Brid.) Mitt. (fot. A. Stebel)

Brachytheciaceae

Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen – On soil, pine needles, humus, at tree bases and on stumps and rotten wood. One of the commonest species in the study area and in Poland. ST: 21 – FS: 22, 26, 28, 32, 33, 36, 37, 39, 40, 41, 42, 43, 44, 45, 47; FW: 24, 27, 29, 38; GS: 46; P: 11.

Brachythecium albicans (Hedw.) Schimp. – On dry sandy and clayey soil in grassland and forest. A rare species in the sampling plots, but common in the OOR and in the country as a whole. ST: 4 – FW: 24; GW: 16, 18; P: 48.

Brachythecium mildeanum (Schimp.) Schimp. – On fairly moist soil. A very rare species, found only once in the sampling plots on fallow ground and once outside them. It is also rare in the OOR as well as in adjacent areas of the Kraków-Częstochowa Upland (Fojcik 2011) and Silesian Upland (Stebel 1998). ST: 1(2) – FW: (25); P: 48.

Brachythecium rutabulum (Hedw.) Schimp. – On the ground in pine forest and fallow fields. The species was frequently recorded in the sampling plots and is generally common in the OOR and throughout the country. ST: 10(11) – FS: 26, 40, 41, 42; FW: (24), 25, 27, 38; P: 5, 19, 48.

Brachythecium salebrosum (F.Weber & D. Mohr) Schimp. (Fig. 6) – On soil, pine needles, stumps, fallen tree branches, exposed roots and stony ground. A fairly frequent species in the sampling plots. One of the commonest species in the OOR and throughout the country. ST: 10 – FS: 22, 37, 40, 47; FW: 24, 25, 27, 29, 38; P: 5.

Fig. 6. *Brachythecium salebrosum* (F.Weber & D.Mohr) Schimp. (photo A. Stebel)

Ryc. 6. *Brachythecium salebrosum* (F.Weber & D.Mohr) Schimp. (fot. A. Stebel)

Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen – On soil in forest and grassland. A relatively rare species, recorded in a few sampling plots and scattered throughout the OOR. It is also widely distributed but scattered in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 5(6) – FS: 40; FW: (23), 24, 25, 29; GW: 16.

Kindbergia praelonga (Hedw.) Ochyra – On the ground in pine forest. A very rare species, found in only one sampling plot, additionally recorded at only one more station in the OOR. It is rare and scattered in the Kraków-Częstochowa Upland (Fojcik 2011) and Silesian Upland (Stebel 1998). ST: 1 – FW: 38.

Oxyrrhynchium hians (Hedw.) Loeske – On soil in fallow fields and grassland. An infrequent species, both in the sampling plots and in the whole OOR, although in Poland it is ubiquitous. ST: 4 – GW: 16; P: 11, 19, 48.

Rhynchostegium murale (Hedw.) Schimp. – On stones. It was recorded only once in the sampling plots but is fairly common in the OOR as well as in neighbouring areas of the Kraków-Częstochowa Upland (Fojcik 2011) and Silesian Upland (Stebel 1998). ST: 1 – P: 6.

Sciuro-hypnum oedipodium (Mitt.) Ignatov & Huttunen – On the ground in pine forest. A rather frequent species in the OOR and Silesian Upland (Stebel 1998) and more common still in the Kraków-Częstochowa Upland (Fojcik 2011). ST: 15 – FS: 26, 28, 36, 37, 39, 42, 43, 44, 45, 47; FW: 24, 25, 27, 29, 38.

Plagiotheciaceae

Plagiothecium denticulatum (Hedw.) Schimp. – On the ground in pine forest. An infrequent species, scattered throughout the OOR but common in coterminous areas of the Kraków-Częstochowa (Fojcik 2011) and Silesian Uplands (Stebel 1998), as well as throughout the country. ST: 7 – FS: 26, 39, 41, 44, 45, 47; FW: 38.

Plagiothecium laetum Schimp. – On soil and humus in pine forest. It was found in only one sampling plot, occurs occasionally in the OOR, but is elsewhere common in Poland. ST: 1 – FS: 39.

Amblystegiaceae

Amblystegium juratzkanum Schimp. – On soil. It was found only once in the sampling plots and is equally very rare in the OOR. It is scattered in neighbouring areas of the Kraków-Częstochowa (Fojcik 2011) and Silesian Uplands (Stebel 1998). ST: 1 – P: 7.

Amblystegium serpens (Hedw.) Schimp. – On dry or somewhat moist soil in open or sheltered sites. It was rather infrequent in the sampling plots but is frequent in the OOR. It is a ubiquitous species throughout the country. ST: 13 – FW: 24; GW: 15, 16, 34; MW: 30, 49; P: 5, 6, 10, 11, 18, 19, 48.

Campylophyllopsis calcarea (Crundwell & Nyholm) Ochyra – On stony ground and on rich basic mining waste (dolomite). The species is fairly widespread in the OOR and in some places frequent and abundant, as it is in most of the neighbouring Kraków-Częstochowa Upland (Fojcik 2011) and Silesian Upland (Stebel 1998). ST: 8 – FW: 23, 24, 25, 27, 29; GW: 14, 15, 17.

Sanionia uncinata (Hedw.) Loeske – On the ground in pine forest. It was found in only one sampling plot but is more frequent elsewhere in the OOR and common in the Kraków-Częstochowa Upland (Fojcik 2011) and Silesian Upland (Stebel 1998). ST: 1 – FS: 44.

Hypnaceae

Calliergonella cuspidata (Hedw.) Loeske – On humus and slightly moist stony ground in pine forest on mining waste. In the sampling plots it was recorded only twice but it is generally more frequent in the OOR. It is very frequent in the Kraków-Częstochowa Upland (Fojcik 2011) and Silesian Upland (Stebel 1998). ST: 2(3) – FS: 47; FW: (24); GW: 14.

Herzogiella seligeri (Brid.) Z.Iwats. – An epixylic species growing on decaying wood. It was found in a single sampling plot and is rare in the OOR. Fairly common in the Silesian Upland (Stebel 1998) and Kraków-Częstochowa Upland (Fojcik 2011). ST: 1 – FW: 38.

Discussion

Species richness

The bryophyte flora of the research sites studied in the Olkusz Ore-bearing Region (OOR) was exceptionally poor and monotypic even for an area strongly disturbed by human impacts, but we should point out that the sampling plots represent specific habitat types that dominate this area, with particular reference to sites polluted with heavy metals above permitted levels, and their associated calamine grasslands. Only 51 species were found in the sampling plots: 6 species of hepatics and 45 species of mosses. These numbers are glaringly less than the total bryoflora of the OOR: 19 species and one variety of liverwort, and 171 species and two varieties of moss (Stebel *et al*. 2014).

All the species found in the study area represent a relatively narrow spectrum of supraspecific taxa. The hepatics were within four families and five genera, while the mosses constituted 12 families and 29 genera. The vast majority of genera, as many as 25, were represented by a single species, 4 genera (*Cephaloziella*, *Didymodon*, *Plagiothecium* and *Amblystegium*) by 2 species, 2 genera (*Schistidium* and *Plagiomnium*) by 3 species, and 3 genera (*Dicranella*, *Bryum* and *Brachythecium*) by 4 species.

The poverty of the bryoflora of the sampling plots is particularly clear when viewed in terms of species frequency. Well over half of the 51 species were very rare, found in the sampling plots three times or less:

(*a*) species recorded in a single sampling plot – 15 (29.4%): *Riccardia palmata*, *Cephaloziella rubella*, *Lophozia ventricosa*, *Dicranella heteromalla*, *Didymodon fallax*, *Niphotrichum canescens*, *Schistidium apocarpum*, *Bryum caespiticium*, *Plagiomnium affine*, *Kindbergia praelonga*, *Rhynchostegium murale*, *Plagiothecium laetum*, *Amblystegium juratzkanum*, *Sanionia uncinata* and *Herzogiella seligeri*;

(*b*) species recorded in two sampling plots – 10 (19.6%): *Lophocolea heterophylla*, *Cephaloziella divaricata*, *Dicranella rufescens*, *D. varia*, *Didymodon rigidulus*, *Tortula muralis*, *Schistidium crassipilum*, *Bryum argenteum*, *Abietinella abietina* and *Brachythecium mildeanum*;

(*c*) species recorded in three sampling plots – 5 (9.8%): *Bryum dichotomum*, *Rosulabryum capillare*, *Plagiomnium rostratum*, *Thuidium delicatulum* and *Calliergonella cuspidata*.

The 30 species listed above constitute 58.8% of the bryophyte flora of the study sites. They were not abundant and were not important biocoenotic constituents of the plant communities in the sampling plots. All the liverworts were of the group of the rarest bryophytes. These are particularly sensitive to any disturbance of the natural environment and vegetation.

Only two species can be designated as common, recorded in over half the sampling plots. These were the ubiquitous *Ceratodon purpureus*, recorded in 29 sampling plots, and *Bryum pallescens*, found in 28. It is interesting to note that the latter is not one of the commonest or ubiquitous species in Poland, but it happens to be very widespread and abundant in the OOR, where sometimes it is found with sporophytes.

Another widespread species was *Brachytheciastrum velutinum*, found in 21 sampling plots and growing in great abundance, primarily in pine forest. Two species, *Pohlia nutans* and *Sciuro-hypnum oedipodium*, also occurred almost exclusively in pine forest and were recorded in 15 sampling plots each. They are common species in the Polish lowlands.

Only seven species can be designated as frequent, recorded in ten or more sampling plots. These are *Tortella tortuosa*, *Pleurozium schreberi* and *Amblystegium serpens*, recorded in 13 plots; *Brachythecium rutabulum,* found in 11; and *Weissia controversa*, *Plagiomnium cuspidatum* and *Brachythecium salebrosum*, found in 10. All of them except for *Tortella tortuosa* and *Weissia controversa* are common in Poland. The latter two basiphilous species are locally abundant in plant communities on mining waste composed of dolomite.

Habitat analysis

The species impoverishment of the studied plots should be attributed mainly to the habitat uniformity of the plots selected for this work on the bryoflora. The majority of them had plant communities developed on dry, most often sandy soils, which create favourable conditions only for epigean bryophytes. This habitat group gave 75% of the species and represented the core of the bryoflora.

Species of other habitat types were poorly represented in the sampling plots. This was particularly true for epiphytic species, which are very rare throughout the OOR. Typical epiphytes were not recorded in the sampling plots. *Brachytheciastrum velutinum* was found on bark at the base of tree trunks or on exposed roots, but this species grows on a variety of substrates, especially on soil. The absence of old trees in the study area is the main reason for the lack of epiphytic bryophytes. In addition, the relatively high air pollution inhibits the growth of epiphytes, due to toxic emissions from the adjacent Upper Silesia industrial belt as well as from the local company ZGH Bolesław in Bukowno, whose basic activity is producing electrolytic zinc and also zinc and lead concentrates.

The lack of old trees and the predominance of young pine tree stands resulted in the great rarity of epixylic bryophytes, which typically grow on decaying and rotten logs and stumps. The only typical epixylic bryophytes in the study area were *Riccardia palmata*, *Lophocolea heterophylla* and *Herzogiella seligeri*. In such habitats there were species that also grow on other substrates, including *Dicranella heteromalla*, *Pohlia nutans* and *Brachythecium salebrosum*, typical terrestrial mosses that usually grow on soil or humus.

One of the most important habitats occupied by bryophytes is rock. Natural rock outcrops occur very rarely in the OOR, but

anthropogenic rock-like habitats, including stone and brick walls, concrete structures, bridges, roofing tiles, foundations and ruined or abandoned buildings are widespread. Epilithic bryophytes were found only occasionally in the sampling plots, on occasional field stones. Only three species (*Tortula muralis*, *Schistidium apocarpum*, *S. dupretii*) were found in such habitats, but *S. crassipilum* was discovered outside the sampling plots at the study sites or nearby. A special type of rocky substrate is mining waste composed of dolomite stones and pebbles. In some sampling plots these were commonly and abundantly overgrown with *Tortella tortuosa* and *Campylophyllopsis calcarea*.

Aquatic and paludicolous bryophytes were not recorded at the research sites. In the OOR they occur quite often in numerous artificial canals, drains and streams, as well as in small fens and swamps, wet meadows and fragmentary stands of carr and bog pinewood on the northern and southern outskirts of the area (Stebel *et al*. 2014).

The poor diversity of the bryoflora affected the floristic composition and abundance of species in the types of vegetation examined (Table 1). Only two of the commonest species, *Ceratodon purpureus* and *Bryum pallescens*, were recorded in all habitat types. Of these, only the former occurred with more or less equal frequency in each habitat. *B. pallescens* evidently avoided forest communities but was common and abundant in grassland and fallow fields.

Two species, *Plagiomnium cuspidatum* and *Schistidium dupretii*, were recorded in five habitat types and were absent only from xerothermic grassland on sand. The first of these occurred rather sporadically in 1–4 sampling plots, whilst *S. dupretii* was only found in a single sampling plot in pine forest on mining waste. In other habitat types it was recorded outside the sampling plots.

Only four species were found in four habitat types, reaching optimum occurrence in different types of vegetation. *Tortella tortuosa* occurred in vegetation stands on dolomite mining waste, including pine forest and thermophilous and humid grassland, while *Pohlia nutans* and *Brachytheciastrum velutinum* occurred en masse in pine forest on sand, and *Amblystegium serpens* in fallows.

Because of the great rarity and incidental occurrence of most species, it is impossible to associate them with definite types of vegetation. All liverwort species except for *Cephaloziella bicuspidata* occurred exclusively in pine forest on sand or mining waste. Such species as *Dicranella heteromalla*, *Rosulabryum capillare* and *Sanionia uncinata* were found only in pine forest on sand. *Niphotrichum canescens*, *Kindbergia praelonga* and *Herzogiella seligeria* occurred in pine forest on mining waste. *Thuidium delicatulum*, *Plagiothecium denticulatum* and *Sciuro-hypnum oedipodium* were found in both types of pine forest. It is difficult to find any correlations in species occurrence in non-forest types of vegetation, because most species were discovered there only sporadically, and such species as *Rhynchostegium murale* and *Amblystegium juratzkanum* were found only occasionally in fallows.

Measures of species richness differed little between most vegetation stands (Table 1). The two kinds of pine forest, on sand (FS) and mining waste (FW), had the richest bryoflora, containing 25 and 26 species respectively. In thermophilous grassland on mining waste (GW) there were 21 species, and 19 in fallows (P). In contrast to these vegetation types, the other two (MW and GS) had poorer species diversity: in humid grassland with *Molinia caerulea* (L.) Moench. (MW) only 14 species were found, and only 7 in thermophilous grassland on sand (GS) dominated by *Armeria maritima*.

Table 1. Occurrence of bryophyte species in the different habitat types. Dots and numbers in parentheses indicate records outside the sampling plots. For abbreviations of the habitat types see p. 175

Tabela 1. Występowanie mszaków w poszczególnych powierzchniach reprezentujących sześć typów siedlisk. Punkty i cyfry w nawiasach oznaczają notowania poza poletkami. Oznaczenia typów powierzchni, jak na str. 191

No. Nr	Species Gatunek	FS	FW	GS	GW	MW	P
	MARCHANTIOPHYTA						
1.	*Riccardia palmata*	•					
2.	*Lophocolea heterophylla*	•					
3.	*Cephaloziella rubella*		•				
4.	*C. divaricata*			•		•	
5.	*Barbilophozia barbata*	•					
6.	*Lophozia ventricosa*	•					
	BRYOPHYTA						
7.	*Ceratodon purpureus*	•	•	•	•	•	•
8.	*Dicranella heteromalla*	•					
9.	*D. rufescens*				•	•	
10.	*D. staphylina*		•		•	•	
11.	*D. varia*			•		•	
12.	*Barbula unguiculata*				•	•	•
13.	*Didymodon fallax*				•		
14.	*D. rigidulus*				•		
15.	*Tortella tortuosa*	•	•		•	•	
16.	*Tortula muralis*						•
17.	*Weissia controversa*			•	•	•	
18.	*Niphotrichum canescens*		•				
19.	*Schistidium apocarpum*				•		
20.	*S. crassipilum*	(•)				(•)	
21.	*S. dupretii*	(•)	•		(•)	(•)	(•)
22.	*Bryum argenteum*				•		•
23.	*B. caespiticium*					•	
24.	*B. dichotomum*				•		•
25.	*B. pallescens*	•	•	•	•	•	•
26.	*Pohlia nutans*	•	•	•			•
27.	*Rosulabryum capillare*	•					
28.	*Plagiomnium affine*		•				
29.	*P. cuspidatum*	•	•		•	•	•
30.	*P. rostratum*	•					•
31.	*Abietinella abietina*		•		•		
32.	*Thuidium delicatulum*	•	•				
33.	*Pleurozium schreberi*	•	•				
34.	*Brachytheciastrum velutinum*	•	•	•			•
35.	*Brachythecium albicans*		•		•		•
36.	*B. mildeanum*		(•)				•
37.	*B. rutabulum*	•	•				•

Table 1. Continued – Tabela 1. Kontynuacja

No. Nr	Species Gatunek	FS	FW	GS	GW	MW	P
38.	*B. salebrosum*	•	•				•
39.	*Eurhynchiastrum pulchellum*	•	•		•		
40.	*Kindbergia praelonga*		•				
41.	*Oxyrrhynchium hians*				•		•
42.	*Rhynchostegium murale*						•
43.	*Sciuro-hypnum oedipodium*	•	•				
44.	*Plagiothecium denticulatum*	•	•				
45.	*P. laetum*	•					
46.	*Amblystegium juratzkanum*						•
47.	*A. serpens*		•		•	•	•
48.	*Campylophyllopsis calcarea*		•		•		
49.	*Sanionia uncinata*	•					
50.	*Calliergonella cuspidata*	•	(•)		•		
51.	*Herzogiella seligeri*		•				
Total Ogółem		23 + (2)	24 + (2)	7	20 + (1)	12 + (2)	18 + (1)

Conclusion

The bryoflora of the Olkusz Ore-bearing Region as a whole exhibits marked diversity. Research included all habitats in the whole area of the OOR (48 km^2), resulting in the discovery of 192 bryophyte taxa consisting of 19 species and one variety of liverwort and 170 species and two varieties of moss. On the permanent plots, established mainly in places with high concentrations of heavy metals (zinc, lead, cadmium) and on sand, the recorded bryoflora is exceptionally poor in terms of species number, frequency and abundance. Only 51 bryophyte species were recorded: 6 hepatics and 45 mosses.

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