10

The lichen biota of the Olkusz Ore-bearing Region

Urszula Bielczyk

Institute of Biology, Pedagogical University of Cracow, 2 Podchorążych St., 30-084 Kraków, e-mail: bielczyk@up.krakow.pl

Introduction

The compound structure and resulting biology of lichens enables them to colonise extremely hostile environments. They occur in different, often extreme climatic conditions, and grow on almost any type of substrate. Importantly, they can tolerate toxic substances present in the environment and accumulate them in amounts that significantly exceed their metabolic needs and that can be lethal to plants and animals. These are properties of lichens which permit their use as pollution biomarkers (Conti and Cecchetti 2001) and indicators of the presence of heavy metals in substrate (e.g. Aznar *et al*. 2008). They can be used in biogeochemical searches for metals such as Cu, Fe, Pb and Zn (Purvis and Halls 1996).

In a metal-enriched environment, lichens are often the dominant component of biodiversity; they accompany plant groups or together with bryophytes create independent communities (e.g. Wirth 1972; Purvis and Halls 1996; Paus 1997; Cuny *et al*., 2004). That is why habitats such as these are of great interest to the world's lichenologists, who carry out fieldwork and laboratory research on their species diversity, taxonomy, biogeography, ecology, physiology, and especially their tolerance to high concentrations of metals and their adaptation to environmental conditions (Purvis and Halls 1996; Purvis and Pawlik-Skowrońska 2008; Bačkor and Loppi 2009). Substrates containing zinc and lead are particularly favourable for lichen vegetation; some species of the genera *Gyalideopsis*, *Sarcosagium*, *Steinia* and *Vezdaea* seem to be restricted to such habitats. Their original localities, associated with natural outcrops of zinc and lead ore, occur on all continents; in Europe they can be found in Belgium, France, Germany, the Netherlands, Poland and the United Kingdom. Nowadays those natural sites are rare. Most localities are created artificially as a result of metal ore mining and processing.

So far over 300 species of lichens that grow on natural rock and on mining waste in the vicinity of mines and smelters have been reported occurring on substrates rich in metal compounds (Cuny *et al*. 2004; Rajakaruna *et al*. 2011). Some of them occupy anthropogenic habitats unrelated to mining and metallurgy, such as impregnated wood, iron bars, old railroad tracks, lead inscriptions on monuments, and walls next to garages contaminated with lead from gasoline (Purvis and Halls 1996). Species new to science, such as *Micarea confusa* (Coppins and van den Boom 1995), *Pyrenocollema chlorococcum* (Aptroot and van den Boom 1998) and *Coppinsia minutissima* (Lumbsch and Heibel 1998), were described after their discovery in post-mining areas containing soil enriched with zinc and cadmium.

In Poland the localities of lichens associated with metalliferous substrates are located in the southern part of the country, mainly in Lower Silesia, the Sudety Mts and parts of the Silesia-Cracow Upland (Bielczyk and Kossowska 2015). The latter localities are related to centuries of mining and metallurgy; the Olkusz Ore-bearing Region (OOR) is the most valuable of these areas for study of the lichen biota. Ore extraction and processing in the vicinity of Olkusz degraded the soil, the natural vegetation and the landscape. There are many outcrops, old mine pits and waste heaps remaining from early and modern technological processes. The soil that formed on them contains large amounts of heavy metals (mainly zinc and lead) and is nutrient-poor and dry; high air pollution contributed sulphur dioxide, dust and heavy metals (Grodzińska and Szarek-Łukaszewska 2009; Grodzińska *et al.* 2010).

It is an area of natural contrasts. Some parts have been completely altered by man, and other less altered areas have preserved semi-natural plant communities. Calamine communities of plants that tolerate or prefer high levels of metals in the soil developed here; they are the only communities of this kind found in Poland (Szarek-Łukaszewska and Grodzińska 2011). The area is also a refuge for valuable, sometimes endangered species of plants and fungi (Mleczko *et al.* 2009; Kapusta *et al.* 2010; Nowak *et al.* 2011). A few lichenological works treating the OOR point to the species-richness of the lichens on these unique sites (Kiszka 2003, 2009; Kiszka and Kościelniak 2006; Bielczyk *et al.* 2009). A feature of this biota is the presence of species able to tolerate and/or accumulate heavy metals in their thalli (Pawlik-Skowrońska *et al.* 2008; Pawlik-Skowrońska and Bačkor 2011).

Recent lichenological studies made under the interdisciplinary project "Vegetation of calamine soils and its importance for biodiversity and landscape conservation in post-mining areas" (EEA FM PL0265), realised in 2008–2011, yielded important data on the lichens of the OOR, presented here. This paper gives a list of species of lichens and lichenicolous fungi occurring in the area, together with their distribution; characterises the lichen biota and indicates its particular association with post-mining areas; and suggests the factors that may threaten the lichens, as well as ways of protecting them.

Material and methods

Field studies were carried out in 2008–2009 in the post-mining Olkusz Ore-bearing Region. The area covers 48 km^2 and is located in the southeastern part of the Silesia-Cracow Upland (50°17′N, 19°29′E) (Godzik – Chapter 2, this volume), in squares DF36 and DF46 of the ATPOL system. The study area is described in detail by Stefanowicz *et al.* (2010) and Nowak *et al.* (2011), and also in this volume (Godzik – Chapter 2, Kapusta and Godzik – Chapter 6).

Detailed lichenological studies were carried out at 49 homogeneous sites (1–30, 32–34, 36–51) representing six habitat types, following methodology specified in project EEA FM PL0265 (Kapusta and Godzik – Chapter 6, this volume).

The material consisted of lichens (lichenised fungi) occurring on all substrates within the designated area, including soil, stones, pieces of wood, and plants. In forests the bark of stumps, fallen branches and the lowest portion of tree trunks were also examined. Clearly identifiable taxa were listed in the field and the others were determined in the laboratory from collected samples. Secondary metabolite composition was analysed by thin-layer chromatography (Orange *et al*. 2001; Kubiak and Kukwa 2011). This work produced more than 1490 records (collected specimens and field records). Lichen specimens collected during the study are deposited in the herbarium of the Department of Botany of the Pedagogical University of Cracow (KRAP).

Lichen taxa nomenclature follows Diederich *et al*. (2012) and Smith *et al*. (2009), except for *Viollela* (Spribille *et al*. 2011), *Verrucaria* (Krzewicka 2012), *Cladonia conista* (Pino-Bodas *et al*. 2012) and *Lecanora saxicola* (Laundon 2010); lichenicolous fungi are described following Czyżewska and Kukwa (2009).

The Results section gives an alphabetical list of species, with substrate type, total number of sites, and site number codes.

Abbreviations and symbols: OOR – Olkusz Ore-bearing Region; * – lichenicolous fungus; St. – number of sites, followed by site number codes; EN – endangered species; VU – vulnerable species; NT – near-threatened species; DD – data-deficient species (based on Cieśliński *et al*. 2006).

Habitat types, with site number codes (Kapusta and Godzik – Chapter 6, this volume):

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 dominated by *Festuca ovina* 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.

Results

Overall, 94 species of lichens and 3 species of lichenicolous fungi were found in the Olkusz Ore-bearing Region. Four problematic specimens were classified only to genus (*Bacidina* sp., *Epigloea* sp., *Macentina* sp., *Stigmidium* sp.), as their identification requires further work. The list also contains *Cladonia* and *Verrucaria* species that could not be determined due to poor development or degeneration of the thalli.

Two lichen species found in the OOR, *Agonimia vouauxii* and *Vezdaea leprosa*, are first records for Poland. Thirteen other taxa were not previously known from the Silesia-Cracow Upland: *Bacidina saxenii*, *B. chloroticula*, *Cladonia conista*, *C. monomorpha*, *Cladoniicola staurospora*, *Lichenoconium erodens*, *L. lecanorae*, *Micarea nigella*, *Placynthiella dasaea*, *Ropalospora viridis*, *Scoliciosporum sarothamni*, *Thelidium fumidum* and *Violella fucatus*. Eighteen taxa are first records for the OOR: *Absconditella lignicola*, *Buellia punctata*, *Caloplaca cerina* var. *muscorum*, *Cladonia chlorophaea*, *C. digitata*, *C. floerkeana*, *C. rei*, *C. scabriuscula*, *Lecanora pulicaris*, *Lepraria incana*, *Micarea nitschkeana*, *Placynthiella oligotropha*, *P. uliginosa*, *Pseudevernia furfuracea*, *Trapeliopsis granulosa*, *Verrucaria fuscella*, *V. viridula* and *V. xyloxena*.

The largest group comprised representatives of *Cladonia* (19 species) and *Verrucaria* (8).

The most common species were *Vezdaea leprosa* (26 sites), *Lecanora conizaeoides* (24), *Cladonia monomorpha* (23), *C. pyxidata* (20) (Fig. 1), *Cladonia rei*, *Sarcosagium campestre*, *Scoliciosporum chlorococcum* (18), *Agonimia vouauxii*, *Cladonia coniocraea*, *Micarea micrococca*, *Verrucaria bryoctona* and *V. muralis* (15 each). Lichen species were recorded in all of the studied areas. Their number varied considerably, ranging from one (site 38) to 38 species (site 14). Thermophilous grassland was the richest in lichens, especially at sites 1, 3, 8, 14, 15, 17, 20, 34, 46 and 51, where 14–38 species occurred. Among the morphological forms, crustose lichens were dominant (70 species). Less species-rich were fruticose lichens (23 species) but they were frequent and occurred in large populations. Only 8 species having foliose form were found.

The lichen biota of the OOR developed under the strong impact of a variety of anthropogenic factors. This is seen in the effects and in the types of taxa found:

- pioneer and ephemeral species able to rapidly and efficiently colonise exposed rock and soil, such as *Sarcosagium campestre* (Fig. 2), *Vezdaea leprosa*, *V. aestivalis*, *Steinia geophana*, *Bacidina saxenii*, *Leptogium biatorinum* and *Verrucaria bryoctona*);
- species with a documented ability to tolerate and/or accumulate heavy metals in thalli, such as *Hypocenomyce scalaris*, *Lepraria incana*, *L. elobata*, *L. jackii*, *Cladonia furcata*, *C. pocillum*, *C. fimbriata*, *Peltigera didactyla*, *Hypogymnia physodes*, *Stereocaulon incrustatum* and *Diploschistes muscorum* (Fig. 3);
- species dependent on the presence of zinc and lead in substrate, such as *Vezdaea*

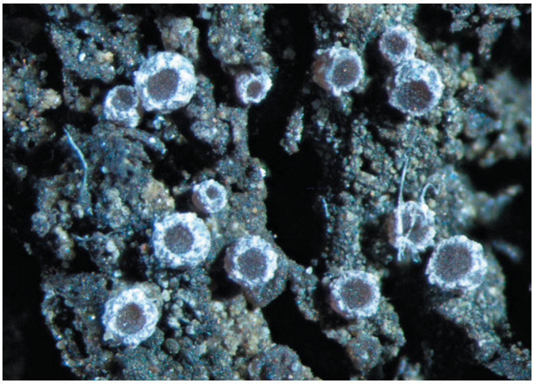

Fig. 2. *Sarcosagium campestre* – an ephemeral species (photo A. Flakus)

Ryc. 2. *Sarcosagium campestre* – gatunek efemeryczny (fot. A. Flakus)

Fig. 1. *Cladonia pyxidata* – a common terricolous lichen in calamine areas (photo R. Kościelniak)

Ryc. 1. *Cladonia pyxidata* – częsty porost naziemny w obszarach galmanowych (fot. R. Kościelniak)

Fig. 3. *Diploschistes muscorum* – a hyperaccumulator of zinc and lead (photo R. Kościelniak)

Ryc. 3. *Diploschistes muscorum* – hiperakumulator cynku i ołowiu (fot. R. Kościelniak)

Fig. 4. *Vezdaea leprosa* – a common microlichen in post-mining areas (photo A. Flakus)

Ryc. 4. *Vezdaea leprosa* – częsty mikroporost w terenach pogórniczych (fot. A. Flakus)

leprosa (Fig. 4), *V. aestivalis* and *Bacidina saxenii*);

- dominance of species that form part of epigeic communities and epibryophytes; some colonise thalli of other lichens and inhabit small rocks and pieces of wood in the soil;
- conspicuous predominance of crustose forms;
- visible morphological changes in multi-thallus lichens (deformation, dwarfing, crumbling of thallus fragments, discolouration spots);
- scarcity of epiphytes, with the exception of the most toxin-tolerant ones such as *Scoliciosporum chlorococcum* and *Lecanora conizaeoides*;
- small share of epixyliths.

The occurrence of rare and endangered species is another feature that distinguishes the lichen biota of the OOR from the other lichen biotas of Poland. Three species have their only localities in Poland there (*Vezdaea leprosa*, *Agonimia vouauxii*, *Thelocarpon imperceptum*). Also found are some very rare species which have only single localities in Poland (e.g. *Bacidina saxenii*, *B. chloroticula*, *Cladonia conista*, *Verrucaria xyloxena*, the lichenicolous fungus *Cladoniicola staurospora*), taxa under legal protection in Poland (*Caloplaca cerina* var. *muscorum*, *Cetraria aculeata*, *C. islandica*, *Cladonia mitis*, *Peltigera didactyla*, *P. rufescens*, *Pseudevernia furfuracea*, *Stereocaulon incrus-*

Fig. 5. *Stereocaulon incrustatum* – a fruticose lichen of the OOR (photo R. Kościelniak)

Ryc. 5. *Stereocaulon incrustatum* – przedstawiciel porostów krzaczkowatych na terenie OOR (fot. R. Kościelniak)

tatum) (Fig. 5), and taxa endangered on the national scale (*Stereocaulon incrustatum* EN, *Caloplaca cerina* var. *muscorum* VU, *Cetraria islandica* VU, *Arthonia fusca* NT, *Vezdaea aestivalis* DD) (Cieśliński *et al.* 2006).

List of species

Absconditella lignicola Vězda & Pišút – pine stumps in forest. St. 3 – FW: 29; FS: 39, 43.

Acarospora moenium (Vain.) Räsänen [syn. *Aspicilia moenium* (Vain.) G. Thor & Timdal] – scraps of asbestos-based roofing material. St. 1 – GW: 14.

Agonimia vouauxii (B. de Lasd.) M.Brand & Diederich – parts of plants, especially bryophytes. St. 15 – GS: 3; P: 5, 7, 10, 11, 18, 19; GS: 8, 9; MW: 13, 50; GW: 14, 15, 17, 34.

Amandinea punctata (Hoffm.) Coppins & Scheid.] – pine bark. St. 1 – GW: 14.

Arthonia fusca (A. Massal.) Hepp [syn. *Arthonia lapidicola* (Tayl.) Branth & Rostr.] – small stones. St. 3 – GW: 1, 15, 51.

Bacidia bagliettoana (A. Massal. & De Not.) Jatta – parts of plants, especially bryophytes. St. 9 – P: 6; GW: 14, 15, 16, 17, 34; FW: 23; MW: 30, 50.

Bacidina chloroticula (Nyl.) Vězda & Poelt – parts of plants, stones, in damp places. St. 9 – MW: 2, 30, 50; P: 10, 18, 19; GS: 12; GW: 14; FW: 23.

Bacidina phacodes (Körb.) Vězda – damp wood, fragments of bryophytes. St. 5 – MW: 13; GW: 15; P: 19; FW: 24, 29.

Bacidina saxenii (Erichsen) combined. [syn. *Bacidia saxenii* Erichsen] – remains of plants. St. 1 – GW: 14.

Bacidina sp. – parts of plants. St. 1 – GW: 14.

Baeomyces rufus (Huds.) Rebent. – soil. St. 2 – GW: 1, 14.

Bilimbia sabuletorum (Schreb.) Arnold – remains of plants, stones. St. 5 – GW: 14, 15; FW: 23, 25; MW: 50.

Caloplaca cerina var. ***muscorum*** A. Massal. – remains of plants. St. 1 – next to site GW: 14.

Candelariella aurella (Hoffm.) Zahlbr. – stones. St. 3 – GW: 14, 15, 51.

Cetraria aculeata (Schreb.) Fr. – soil. St. 3 – GW: 14, 15, 51.

Cetraria islandica (L.) Ach. – soil. St. 1 – GW: 14. Species common outside of the studied sites.

Cladonia cariosa (Ach.) Spreng. – soil, stones. St. 13 – GS: 3, 4, 8, 9, 46; P: 6, 7, 10; GW: 14, 15; FW: 27; MW: 30, 49.

Cladonia chlorophaea (Sommerf.) Spreng. – humus. St. 4 – GS: 8; MW: 13; GW: 14; FS: 44.

Cladonia coniocraea (Flörke) Spreng. – tree bark, stumps, pieces of wood. St. 15 – P: 18; FS: 22, 28, 33, 37, 41, 42, 44, 45, 47; FW: 24, 27, 29; GS: 46; GW: 51.

Cladonia conista (Ach.) Robbins – soil with pebbles. St. 4 – GS: 8, 12, 46; MW: 30.

Cladonia digitata (L.) Hoffm. – soil, wood. St. 2 – FS: 43, 44.

Cladonia fimbriata (L.) Fr. – soil, humus, pine bark. St. 4 – FW: 23, 27; FS: 37; GS: 46.

Cladonia floerkeana (Fr.) Flörke – soil. St. 1 – GS: 46.

Cladonia foliacea (Huds.) Willd. – soil. St. 4 – GW: 1, 14, 15; FW: 24. Species quite common outside of the studied sites.

Cladonia furcata (Huds.) Schrad. – soil. St. 9 – GS: 8, 20; MW: 21, 30; FS: 37, 43, 45, 47; GS: 46.

Cladonia glauca Flörke – soil, humus, wood, pine bark. St. 12 – GW: 1, 15, 16, 17, 34; P: 6; GS: 8, 46; FW: 23; MW: 30, 49; FS: 41.

Cladonia mitis Sandst. – soil, humus. St. 3 – P: 7; FS: 41; GS: 46.

Cladonia monomorpha Aptroot, Sipman & van Herk – soil. St. 23 – GW: 1, 14, 15, 16, 17, 51; GS: 3, 4, 8, 9, 20, 46; P: 6, 7, 19, 48; MW: 13, 21, 30, 49, 50; FW: 24, 29.

Cladonia pocillum (Ach.) Grognot – soil, humus, bryophytes. St. 9 – GW: 14, 15, 34, 51; P: 18, 19; FW: 23; MW: 30, 50.

Cladonia pyxidata (L.) Hoffm. – soil, humus, bryophytes. St. 20 – GW: 1, 14, 15, 16, 17; GS: 3, 4, 8, 9, 12, 20, 46; P: 19; MW: 21, 30, 49; FW: 23, 27; FS: 37, 41.

Cladonia rangiformis Hoffm. – sandy soil. St. 3 – GW: 14, 15; FW: 24.

Cladonia rei Schaer. – soil, humus. St. 18 – GW: 1, 34, 51; GS: 3, 4, 8, 9, 12, 20, 46; P: 6, 7, 18, 19; MW: 13, 21, 30; FS: 45.

Cladonia scabriuscula (Delise) Leight. – soil. St. 4 – GS: 3, 4; P: 7; GW: 14.

Cladonia subulata (L.) F.H. Wigg. – soil. St. 10 – GS: 3, 4, 8, 12, 20, 46; P: 7, 48; MW: 13, 21.

Cladonia symphycarpia (Flörke) Fr. – soil. St. 5 – GW: 14, 15, 16; FS: 37; MW: 49.

Cladonia spp. – soil, humus. St. 8 – GS: 3; P: 5, 18, 19; MW: 21; FS: 22, 42; GW: 51.

****Cladoniicola staurospora*** Diederich, Van den Boom & Aptroot – *Cladonia* scales. St. 1 – GS: 3.

Coenogonium pineti (Schrad. ex Ach.) Lücking & Lumbsch [syn. *Dimerella pineti* (Ach.) Vězda] – pine bark. St. 2 – FS: 37, 44.

Collema limosum (Ach.) Ach. – soil. St. 6 – GW: 1, 15, 17, 34, 51; FW: 23.

Collema tenax (Sw.) Ach. – soil. St. 1 – GW: 14.

Diploschistes muscorum (Scop.) R. Sant. – *Cladonia* sp. thalli, bryophytes, soil, pebbles. St. 6 – GW: 1, 14, 16; P: 7; FS: 41; MW: 49. Species common outside of the studied sites.

Diploschistes scruposus (Schreb.) Norman – stones. St. 1 – GW: 14.

Epigloea sp. – soil. St. 1 – GS: 8.

Hypocenomyce scalaris (Ach.) M. Choisy – pine bark, wood. St. 8 – FS: 22, 41, 42, 43, 44, 47; FW: 38; GS: 46.

Hypogymnia physodes (L.) Nyl. – pine bark. St. 5 – GS: 8; FS: 26, 37, 42; FW: 27.

Lecanora conizaeoides Nyl. ex Cromb. – pine bark, wood. St. 24 – P: 11; GW: 16; FS: 22, 26, 28, 32, 33, 36, 37, 39, 40, 41, 42, 43, 44, 45, 47; FW: 23, 24, 25, 27, 29, 38; GS: 46.

Lecanora dispersa (Pers.) Sommerf. – stones. St. 4 – GW: 1, 14, 15; FW: 27.

Lecanora pulicaris (Pers.) Ach. – pine bark. St. 1 – FW: 24.

Lecanora saligna (Schrad.) Zahlbr – pine wood. St. 2 – FW: 27, 29.

Lecanora saxicola (Pollich) Ach. [syn. *Lecanora muralis* (Schreb.) Rabenh., *Protoparmeliopsis muralis* (Schreb.) M. Choisy] – concrete. St. 1 – GW: 14.

Lepraria elobata Tønsberg – pine bark, wood. St. 12 – FS: 22, 32, 33, 36, 37, 39, 41, 42, 43, 44, 47; FW: 38.

Lepraria incana (L.) Ach. – pine bark, wood. St. 3 – FS: 39, 43, 44.

Lepraria jackii Tønsberg – pine bark. St. 1 – FS: 44.

Leptogium biatorinum (Nyl.) Leight. – stones. St. 3 – FW: 24; FS: 26, 37.

****Lichenoconium erodens*** M.S. Christ. & D. Hawksw. – *Lecanora conizaeoides* thallus and fruiting bodies. St. 3 – GW: 14, 15, 51.

****Lichenoconium lecanorae*** (Jaap) D. Hawksw. – *Lecanora conizaeoides* fruiting bodies. St. 11 – FS: 22, 26, 32, 33, 39, 41, 43, 45; FW: 24, 25, 27.

Macentina sp. – parts of plants, especially bryophytes. St. 10 – GS: 3, 12, 30; P: 6, 7, 10, 11, 18; MW: 13; GW: 17.

Micarea botryoides (Nyl.) Coppins – pine bark and wood. St. 2 – FS: 22, 39.

Micarea denigrata (Fr.) Hedl. – pine bark and wood. St. 11 – GS: 3, 20, 46; GW: 14, 51; FW: 23, 24; FS: 26, 41, 43, 45.

Micarea micrococca (Körb.) Gams ex Coppins – pine bark. St. 15 – FS: 22, 26, 28, 33, 36, 37, 39, 40, 42, 43, 44, 45; FW: 24, 27; GS: 46.

Micarea nigella Coppins – pine wood. St. 1 – FS: 33.

Micarea nitschkeana (J. Lahm ex Rabenh.) Harm. – pine bark. St. 2 – FW: 24; FS: 43.

Mycobilimbia tetramera (De Not.) Vitik., Ahti, Kuusinen, Lommi. & T. Ulvinen ex Hafellner & Türk. – bryophytes. St. 1 – GW: 14.

Parmelia sulcata Taylor – pine bark. St. 1 – FS: 26.

Peltigera didactyla (With.) JR Laundon – soil. St. 1 – MW: 30. Species quite common outside of the studied sites.

Peltigera rufescens (Weiss) Humb. – soil. St. 1 – FS: 37. Species common outside of the studied sites.

Phaeophyscia orbicularis (Neck.) Moberg – stones. St. 2 – GW: 14, 15.

Physcia caesia (Hoffm.) Fürnr. – concrete. St. 1 – GW: 14.

Placopyrenium fuscellum (Turner) Gueidan & Cl. Roux [syn. *Verrucaria fuscella* (Turner) Winch.] – stones. St. 2 – GW: 14, 15.

Placynthiella dasaea (Stirt.) Tønsberg – wood, humus. St. 9 – FW: 24, 29; FS: 28, 39, 40, 42, 43, 44; GS: 46.

Placynthiella icmalea (Ach.) Coppins & P. James – wood, humus. St. 11 – P: 18; FW: 24; FS: 28, 33, 36, 40, 42, 43, 44, 45; GS: 46.

Placynthiella oligotropha (J.R. Laundon) Coppins & P. James – soil, humus. St. 4 – GS: 4, 8; MW: 21; GS: 46.

Placynthiella uliginosa (Schrad.) Coppins & P. James – soil, humus. St. 1 – FS: 43.

Porpidia crustulata (Ach.) Hertel & Knoph – wood, stone. St. 2 – GW: 14; P: 18.

Protoblastenia rupestris (Scop.) J. Steiner – stone. St. 1 – GW: 51.

Pseudevernia furfuracea (L.) Zopf – spruce twig on ground. St. 1 – FS: 26.

Ropalospora viridis (Tønsberg) Tønsberg – pine bark. St. 1 – FW: 27.

Sarcosagium campestre (Fr.) Poetsch & Schied. – soil, humus, bryophytes. St. 18 – GW: 1, 14, 15, 17, 34; MW: 2, 13, 21, 30, 50; GS: 3, 20, 46; P: 10, 19; FW: 23; FS: 37, 47.

Scoliciosporum chlorococcum (Graewe ex Stenh.) Vězda – pine bark. St. 18 – P: 10; FS: 22, 26, 32, 33, 36, 37, 39, 40, 41, 42, 43, 45, 47; FW: 24, 27, 29; GS: 46.

Scoliciosporum sarothamni (Vain.) Vězda – birch bark and wood. St. 4 – P: 10; FW: 24, 27; FS: 37.

Scoliciosporum umbrinum (Ach.) Arnold – stones. St. 2 – GW: 14; FW: 25.

Steinia geophana (Nyl.) Stein – humus, soil. St. 7 – GW: 1, 14, 16, 34; MW: 2; P: 7; GS: 9.

Stereocaulon incrustatum Flörke – soil. St. 2 – GW: 14; FS: 41. Species very common outside of the studied sites.

****Stigmidium*** sp. – thalli of *Agonimia vouauxii* and *Vezdaea* spp. St. 6 – GS: 3, 4, 8, 9, 20; MW: 13.

Strangospora moriformis (Ach.) – stone, wood. St. 1 – GW: 14.

Thelidium fumidum (Nyl.) Hazsl. – stone. St. 1 – FW: 27.

Thelocarpon imperceptum (Nyl.) Mig. – soil. St. 1 – GW: 34.

Trapelia coarctata (Turner ex Sm.) M. Choisy – pebble. St. 1 – P: 6.

Trapeliopsis flexuosa (Fr.) Coppins & P. James – humus, soil. St. 7 – FW: 24, 29; FS: 33, 39, 41, 43, 44.

Trapeliopsis granulosa (Hoffm.) Lumbsch – soil, humus. St. 3 – FS: 22, 40; GS: 46.

Verrucaria bryoctona (Th. Fr.) Orange – soil, bryophytes. St. 15 – GW: 1, 15, 16, 17, 34; MW: 2, 30, 50; GS: 4, 12, 20; P: 6, 7, 19; FW: 23.

Verrucaria dolosa Hepp – pebbles. St. 3 – MW: 2; GW: 15; FW: 23.

Verrucaria muralis Ach. – pebbles. St: 18 – GW: 1, 14, 15, 16, 17, 34, 51; MW: 2, 13, 30, 50; P: 6, 7, 19; GS:20; FW: 23, 25; FS: 26.

Verrucaria nigrescens Pers. – pebbles. St. 10 – MW: 2, 50; P: 6, 18; GW: 14, 15, 17, 34; FW: 27, 29.

Verrucaria obfuscans (Nyl.) Nyl. – pebbles. St. 3 – GW: 14, 15, 17.

Verrucaria procopii Servite – pebbles. St. 3 – GW: 15, 34; MW: 50.

Verrucaria viridula (Schrad.) Ach. [syn. *Verrucaria silvatica* Zschacke] – pebbles. St. 1 – GW: 15.

Verrucaria xyloxena Norman – soil. St. 1 – GS: 12.

Verrucaria spp. – pebbles. St. 2 – P: 6; FW: 27.

Vezdaea aestivalis (Ohlert) Tscherm.-Woess & Poelt – soil, bryophytes. St. 13 – GW: 1, 14, 17, 51; MW: 2, 13, 21, 49; P: 6, 11; GS: 12, 20; FW: 23.

Vezdaea leprosa (P. James) Vězda – parts of plants, especially bryophytes, soil, humus. St. 26 – GW: 1, 14, 15, 16, 17, 34, 51; MW: 2, 13, 21, 30, 50; GS: 3, 4, 9, 12, 20, 46; P: 10, 11, 18; FW: 23, 25, 27, 29; FS: 47.

Vezdaea rheocarpa Poelt & Döbbeler –fragments of bryophytes. St. 7 – MW: 2; P: 7, 18; GW: 14, 15, 17; FW: 27.

Violella fucatus (Stirt.) Zahlbr. [syn. *Mycoblastus fucatus* (Stirt.) Zahlbr. – pine bark, wood. St. 2 – P: 10; FW: 24.

Discussion

The Olkusz Ore-bearing Region (OOR) is characterised by considerable diversity of lichen species, reflecting the variety of habitats in the mining area, which includes sand, calamine waste, and substrates of various pH, humidity and insolation. The number of taxa identified here is comparable with the number on lists of lichens from similar European areas such as in Belgium, the Netherlands, France, Germany and the United Kingdom (Purvis and Halls 1996; Heibel 1999). The lichen species composition at different sites is not uniform. It is determined by local edaphic, microclimatic and biotic factors. The prevalence of particular species varies as well.

Metallophytes – species that tolerate or prefer high concentrations of heavy metals in the soil – are indicators of plant communities growing on soil naturally and/or secondarily enriched with heavy metals. Due to their structure and biology, lichens generally are adapted to living in hostile environments, including those contaminated with heavy metals. It is difficult to say which of the species growing in calamine areas are obligate metallophytes, but clearly they all tolerate high content of heavy metals in the soil and air. Sixty of them (50%) have been recorded from other areas containing zinc and/or lead in the substrate (Purvis and Halls 1996; Heibel 1999; Cuny *et al.* 2004; Baňasová 2006; Smith *et al.* 2009; Rajakaruna *et al.* 2011; Bielczyk and Kossowska 2015). Many of them have the ability to tolerate and/or accumulate these elements in their thalli (Pawlik-Skowrońska *et al.* 2008; Pawlik-Skowrońska and Bačkor 2011). *Stereocaulon* species, especially *S. nanodes*, are mentioned as fruticose lichens and as characteristic of environments with zinc and lead. From that genus only *Stereocaulon incrustatum* was found in the OOR; it is not reported from similar areas in Europe but occurs frequently in the study area. It forms large populations there. Research by Pawlik-Skowrońska *et al.* (2008) showed that it accumulates considerable amounts of heavy metals in its thalli. *Diploschistes muscorum*, recognised as a zinc hyperaccumulator, is also a very common species (Sarret *et al.* 1998). A number of other species with crustose thalli not shown to accumulate heavy metals appear to be dependent on them. They include *Vezdaea leprosa* and *V. aestivalis*, which outside of metal-bearing areas are also found around galvanised metal barriers on roads in Germany and the UK (Ernst 1995; Gilbert 2000). Similarly, *Bacidina saxenii* grows below metal power-line poles and on zinc cans and oil tanks (Gilbert 1990).

From the ecological point of view it is worth mentioning the presence in the OOR of lichens whose main component is autotrophic blue-green algae (cyanobacteria). Their ability to bind free nitrogen makes them an important link in the trophic chain, especially on nutrient-poor calamine soil. In calamine areas this group is represented by *Peltigera rufescens*, *P. didactyla*, *Stereocaulon incrustatum*, *Collema limosum*, *C. tenax* and *Leptogium biatorinum*.

A characteristic feature of the OOR's lichen biota is the presence of a group of pioneering lichens able to rapidly colonise exposed rock and soil. They play a very important role in the ecosystem because they stabilise the substrate in the initial stage of plant succession. Short-lived stress-tolerant ruderal lichens are among the most typical lichens occurring on unstable heavy-metal-contaminated substrates around mines and smelters. They are difficult to find due to the very small size of their thalli. Some of them have a short life cycle and produce fruiting bodies only in wet seasons (Gilbert 2004). The following species found in the OOR belong to this group: *Sarcosagium campestre*, *Vezdaea leprosa*, *V. aestivalis*, *Steinia geophana*, *Bacidina saxenii* and *Leptogium biatorinum*.

Further research may turn up more ephemeral species with small thalli that occur in similarly disturbed habitats in various parts of Europe. Species such as *Epigloea soleiformis*, *Gregorella humida*, *Bacidia viridescens* and *Gyalidea lecideopsis* fit this type. They are tolerant of heavy metals in soil; in the UK they grow near lead and zinc mines (Smith *et al.* 2009). Such species have also been recorded in Poland at single localities in the Carpathians and the northwestern part of the country (Ceynowa-Giełdon 2002; Czarnota 2003; Czarnota and Coppins 2007; Flakus 2007).

Rare and very rare species are valuable components of the lichen biota in the OOR. Three of them – *Vezdaea leprosa*, *Agonimia vouauxii* and *Thelocarpon imperceptum* – have their only Polish localities there. *V. leprosa* is an ephemeral lichen with a very short life cycle, which reaches full development during late fall and winter. In the studied area it occurs abundantly at many stations. It grows on living and dying ground bryophytes, less frequently on parts of flowering plants and soil in thermophilous grassland, wet grassland and pine forest on mining waste, and more rarely among the vegetation of fallows. This species, associated with substrate abundant in zinc and lead, is a common component of the lichen biota in heavy-metal-contaminated environments. It is known from Europe, Madeira, North and South America and Asia, where it occurs in natural and anthropogenic habitats (Chambers and Purvis 2009). *Agonimia vouauxii* was found at 15 stations in the OOR, where it grows on plant remains in thermophilous grassland and wet grassland on mining waste, and less frequently on sand and in fallows. In Europe it is a rare species (Pykälä 2007), recorded in anthropogenic habitats (Sérasiaux *et al.* 1999; Vondrák *et al.* 2010). *Thelocarpon imperceptum* is a terricolous lichen found at one location on a reclaimed mining excavation in the vicinity of Bolesław (Kiszka 2009). It is a very rare species in Europe, reported from Switzerland and Russia, and more recently found in the Netherlands (van den Boom 2000) and Ukraine (Khodosovtsevet *et al.* 2010).

In the analysed lichen biota, species previously known from only single localities in Poland deserve special attention. Some of these species have been described only in recent years and their general distribution is still unknown. Confirmation of their occurrence in the studied area adds new localities to the lichen biota of the country and raises the conservation value of the area. These include *Bacidina saxenii* (Czarnota and Coppins 2007), *Bacidina chloroticula*, *Cladonia conista* (Fałtynowicz 2003), *Verrucaria xyloxena* (Krzewicka 2012) and the lichenicolous fungus *Cladoniicola staurospora* (Czyżewska and Kukwa 2009). Also worth mentioning are two microlichens very common in the studied area, which are characteristic of post-mining sites in Europe (Gilbert and Purvis 2009; Orange *et al.* 2009). One is *Sarcosagium campestre*, an ephemeral species that forms fruiting bodies in wet, cold periods during autumn and winter, usually from August to February (Gilbert 2004). In the OOR it grows on soil, mosses and vascular plant remains, usually in thermophilous grassland on mining waste, and occasionally in forests, fallows and wet grassland. In Poland it is distributed in lowlands and mountains (Faltynowicz 2003). The second microlichen is *Verrucaria bryoctona*, often encountered on remains of bryophytes and flowering plants, usually in thermophilous grassland on mining waste and sand, and rarely among the vegetation in fallows. It is known in Poland from single localities in mountains (Tatra Mts, Bieszczady Mts, Gorce Mts, Sudety Mts), in the Chęciny region and in lowlands (Pomerania, Kujawy) (Fałtynowicz 2003; Krzewicka 2012).

The demonstrably unique character of the lichen biota in the OOR calls for measures to protect it (Bielczyk 2012). The most valuable elements of the lichen biota of Olkusz are species found in ecologically specialised calamine grassland communities of the *Violetea calaminariae* class (Szarek-Łukaszewska and Grodzińska 2011). Like the vascular plant species, they are heliophilous and thermophilous, preferring alkaline soil and tolerating heavy metals. Macrolichens have proper insolation there; the herbaceous plants no longer constitute an eliminating factor for them. The microlichens are characterised by a particular phenology: they develop and produce fruiting bodies when the vegetation cycle is over, in autumn and early spring or even winter. Misguided remediation measures threaten this group of species and whole communities of calamine grassland (Kapusta *et al.* 2010). These measures include afforestation of pits and dumps, mainly with pine, which, together with natural processes of overgrowing, shades habitats and eliminates xerothermic species, including terricolous lichens. Lichenological studies in the Pleszczotka ecological area (currently a part of Natura 2000) give an example of this. Pleszczotka, an area of turf more than a century old, legally protected since 1997, began to be rapidly overgrown by pine. Żegleń (2010) showed that terricolous lichens occur there mainly in unshaded parts of the grasslands. Accumulations of needles under the trees are another factor that limits the lichen vegetation, which requires active protection involving removal of trees and shrubs. All rare lichen species require protection and constant monitoring of their localities, as proposed by Kiszka (2009) for protection of *Thelocarpon imperceptum*.

Acknowledgments

I thank Dr. hab. Paweł Czarnota, Dr. Adam Flakus and Dr. Ryszard Kozik for their help in labelling and verifying critical taxa, and Dr. hab. Grażyna Szarek-Łukaszewska, Dr. Paweł Kapusta, Dr. Laura Betleja and Dr. Robert Kościelniak for valuable assistance with the field research.

References

Aznar J.C., Richer-Lafléche M., Cluis D. 2008. Metal contamination in the lichen *Alectoria sarmentosa* near the copper smelter of Murdochville, Québec. *Environmental Pollution* **156**: 76–81.

Aptroot A., van den Boom P.P.G. 1998. *Pyrenocollema chlorococcum*, a new species with a chlorococcoid photobiont from zinc-contaminated soils and wood. *Cryptogamie*, *Bryologie-Lichénologie* **19**: 193–196.

Bačkor M., Loppi S. 2009. Interactions of lichens with heavy metals. *Biologia Plantarum* **53**(2): 214–222.

Banásová V. 2006. The participation of lichens in species diversity of mine waste vegetation, pp. 205–218. In: A. Lackovičova, A. Guttová, E. Lisická, P. Lizoň (Eds.). *Central European lichens – diversity and threat*. Mycotaxon, Ithaca.

Bielczyk U. 2012. Lichens of zinc-lead post-mining areas in the Olkusz region – state of preservation, threats and needs for protection, pp. 119–128. In: L. Lipnicki (Ed.). *Lichen protection – Protected lichen species*. Sonar Literacki, Gorzów Wlkp.

Bielczyk U., Kossowska M. 2015. Porosty podłoży wzbogaconych w związki metali. In: M. Wierzbicka (Ed.). *Ekotoksykologia – rośliny, gleby, metale*. Wydawnictwo Uniwersytetu Warszawskiego, Warszawa. (in press)

Bielczyk U., Jędrzejczyk-Korycińska M., Kiszka J. 2009. Lichens of abandoned zinc-lead mines. *Acta Mycologica* **44**(2): 139–149.

Boom van den P.P.G. 2000. Some interesting records of lichens and lichenicolous fungi from The Netherlands IV. *Österreichische Zeitschrift für Pilzkunde* **9**: 141–145.

Ceynowa-Giełdon M. 2002. The genus *Epigloea* in Poland. *Acta Mycologica* **37**(1/2): 3–11.

Chambers S.P., Purvis O.W. 2009. Vezdaea Tscherm.-Woess & Poelt (1976), pp. 958–961. In: C.W. Smith., A. Aptroot, B.J. Coppins, A. Fletcher, O.L. Gilbert, P.W. James, P.A. Wolseley (Eds.). *The lichens of Great Britain and Ireland*. The British Lichen Society, London.

Cieśliński S., Czyżewska K., Fabiszewski J. 2006. *Red list of the lichens in Poland*, pp. 71–89. In: Z. Mirek, K. Zarzycki, W. Wojewoda, Z. Szeląg (Eds.). Red list of plants and fungi in Poland:. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Conti M.E., Cecchetti G. 2001. Biological monitoring: lichens as bioindicators of air pollution assessment – a review. *Environmental Pollution* **114**: 471–492.

Coppins B.J., van den Boom P.P.G. 1995. *Micarea confusa*, a new species from zinc- and cadmium-contaminated soils in Belgium and The Netherlands. *Lichenologist* **27**: 81–90.

Cuny D., Denayer F.O., de Foucault B., Schumacker R., Colein P., van Haluwyn C. 2004. Patterns of metal soil contamination and changes in terrestrial cryptogamic communities. *Environmental Pollution* **129**: 289–297.

Czarnota P. 2003. Notes on some new and noteworthy lichens from southern Poland. *Graphis Scripta* **14**: 18–26.

Czarnota P., Coppins B.J. 2007. Contribution to the knowledge of rare *Bacidia* s.lat. (Lecanorales, lichenized Ascomycetes) from Central Europe including a new, pallid forma of *Bacidia hemipolia. Nova Hedwigia* **85**: 503–513.

Czyżewska K., Kukwa M. 2009. *Lichenicolous fungi of Poland. A catalogue and key to species*. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Diederich, P., Ertz D., Stapper N., Sérusiaux E., van den Broeck D., van den Boom P., Ries C. 2012. *The lichens and lichenicolous fungi of Belgium, Luxembourg and northern France*. – URL: http://www.lichenology.info

Ernst G. 1995. *Vezdaea leprosa* – Spezialist am Strassenrand. *Herzogia* **11**: 175–188.

Fałtynowicz W. 2003. *T*he lichens, lichenicolous and allied fungi of Poland. An annotated checklist. In: Z. Mirek (Ed.). *Biodiversity of Poland 6*. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Flakus A. 2007. Lichenized and lichenicolous fungi from the mylonitized areas of the subnival belt in the Tatra Mountains (Western Carpathians). *Annales Botanici Fennici* **44**: 427–449.

Gilbert O.L. 1990. The lichen flora of urban wasteland. *Lichenologist* **22**: 87–101.

Gilbert O.L. 2000. *Lichens*. New Naturalist Library. Harper Collins, London.

Gilbert O.L. 2004. The phenology of *Sarcosagium campestre* observed over three years. *Lichenologist* **36**(2): 159–161.

Gilbert O.L., Purvis O.W. 2009. *Sarcosagium* A. Massal. (1856), p. 832. In: C.W. Smith., A. Aptroot, B.J. Coppins, A. Fletcher, O.L. Gilbert, P.W. James, P.A. Wolseley (Eds.). *The lichens of Great Britain and Ireland*. The British Lichen Society, London.

Grodzińska K., Szarek-Łukaszewska G. 2009. Heavy metal vegetation in the Olkusz Region (southern Poland) – preliminary studies. *Polish Botanical Journal* **54**: 105–112.

Grodzińska K., Szarek-Łukaszewska G., Godzik B. 2010. Pine forests of Zn-Pb post-mining areas of southern Poland. *Polish Botanical Journal* **55**(1): 229–237.

Heibel E. 1999. Flechtenvegatation auf Schwermetallstandorten in Nordrhein-Westfalen. In: A. Pardey (Ed.). Naturschutz-Rahmenkonzeption Galmeifluren NRW. *LÖBF- Schriftenreihe* **16**: 49–72.

Kapusta P., Szarek-Łukaszewska G., Grodzińska K., Godzik B. 2010. Murawy galmanowe okolic Olkusza (południowa Polska) i problemy ich ochrony. *Chrońmy Przyrodę Ojczystą* **66**(1): 27–24.

Khodosovtsevet A.Y., Naumovich A.O., Vondráková O.S., Vondrák J. 2010. *Athelium imperceptum* Nyl. (Thelocarpaceae, Ascomycota) a scarcely known ephemeral lichen of biological soil crust, new to Ukraine. *Chornomorski Botanical Journal* **6**(3): 385–389.

Kiszka J. 2003. Porosty hałd cynkowo-ołowiowych w Bolesławiu koło Olkusza, pp. 193–199. In: J. Lach (Ed.). *Dynamika zmian środowiska geograficznego pod wpływem antropopresji*. Instytut Geografii, Zakład Ochrony i Kształtowania Środowiska Przyrodniczego Akademia Pedagogiczna im. KEN, Kraków.

Kiszka J. 2009. Thelocarpon imperceptum (Nyl.) Mig. – a new lichen species from central Europe, pp. 245–246. In: Z. Mirek, A. Nikel (Eds.). *Rare, relict and endangered plant species in Poland*. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Kiszka J., Kościelniak R. 2006. Localities of the high-mountain species Leucocarpia biatorella in the Silesian Upland (southern Poland), pp. 325–329. In: A. Lackovičova, A. Guttová, E. Lisická, P. Lizoň (Eds.). *Central European lichens. Diversity and threat*. Mycotaxon, Ithaca.

Krzewicka B. 2012. A revision of *Verrucaria* s.l. (Verrucariaceae) in Poland. *Polish Botanical Studies* **27**: 3–143.

Kubiak D., Kukwa M. 2011. Chromatografia cienkowarstwowa (TLC) w lichenologii, pp. 176–190. In: M. Dynowska, E. Ejdys (Eds.). *Mikologia laboratoryjna. Przygotowanie materiału* *badawczego i diagnostyka*. Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego w Olsztynie, Olsztyn.

Laundon J.R. 2010. *Lecanora antiqua*, a new saxicolous species from Great Britain, and the nomenclature and authorship of *L. albescens*, *L. conferta* and *L. muralis*. *Lichenologist* **42**(6): 631–636.

Lumbsch H.T., Heibel E. 1998. *Coppinsia minutissima*, a new genus and species in the Agyriaceae from the British Isles. *Lichenologist* **30**: 95–101.

Mleczko P., Gawroński S., Kapusta P. 2009. New inland localities of a rare gasteroid Basidiomycete *Scleroderma septentrionale* in natural and anthropogenic habitats in Central Europe. *Polish Botanical Journal* **54**(1): 99–104.

Nowak T., Kapusta P., Jędrzejczyk-Korycińska M., Szarek-Łukaszewska G., Godzik B. 2011. *The vascular plants of the Olkusz Ore-bearing Region* [Rośliny naczyniowe Olkuskiego Okręgu Rudnego]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Orange A., James P.W., White F.J. 2001. *Microchemical methods for the identification of lichens*. British Lichen Society, London.

Orange A., Hawksworth D.L., McCarthy P.M., Flether A. 2009. *Verrucaria* Schrad. (1794), pp. 931–957. In: C.W. Smith., A. Aptroot, B.J. Coppins, A. Fletcher, O.L. Gilbert, P.W. James, P.A. Wolseley (Eds.). *The lichens of Great Britain and Ireland*. The British Lichen Society, London.

Paus S.M. 1997. Die Erdflechtenvegetation nordwestdeutschlands und einiger Randgebiete. *Bibliotheca Lichenologica* **66**: 1–222.

Pawlik-Skowrońska B., Bačkor M. 2011. Zn/Pb-tolerant lichens with higher content of secondary metabolites produce less phytochelatins than specimens living in unpolluted habitats. *Environmental and Experimental Botany* **72**: 64–70.

Pawlik-Skowrońska B., Wójciak H., Skowroński T. 2008. Heavy metal accumulation, resistance and physiological status epigeic and epiphytic lichens inhabiting Zn and Pb polluted areas. *Polish Journal of Ecology* **56**(2): 195–207.

Pino-Bodas R., Ahti T., Stenroos S., Martín M.P., Burgaz A.R. 2012. *Cladonia conista* and *C. humilis* (Cladoniaceae) are different species. *Bibliotheca Lichenologica* **108**: 161–176.

Purvis O.W., Halls C. 1996. A review of lichens in metal-enriched environments. *Lichenologist* **28**: 571–601.

Purvis O.W., Pawlik-Skowrońska B. 2008. Lichens and metals, pp. 175–200. In: S.V. Avery, M. Stratford, P. van West (Eds.). *Stress in Yeasts and Filamentous Fungi. British Mycological Society Symposium Series*. Elsevier & Academic Press, Amsterdam.

Pykälä J. 2007. Additions to the lichen flora of Finland. II. Calcareous rock and associated in Lohja. *Graphis scripta* **19**: 17–32.

Rajakaruna N., Harris T.B., Clayden S.R., Dibble A.C., Olday F.C. 2011. Lichens of the Callahan Mine, a copper- and zinc-enriched Superfund site in Brooksville, Maine, U.S.S. *Rhodora* **113**: 1–33.

Sarret G., Manceau A., Cuny D., van Haluwyn C., Deruelle S., Hazemann J.L., Soldo Y., Eybert-Berard L., Menthonnex J.J. 1998. Mechanisms of lichen resistance to metallic pollution. *Environmental Science Technology* **32**: 3325–3330.

Sérasiaux E., Diederich P., Brand A.M., van den Boom P. 1999. New or interesting lichens and lichenicolous fungi from Belgium and Luxembourg. VIII. *Lejeunia* N.S. 162: 1–95.

Smith C.W., Aptroot A., Coppins B.J., Fletcher A., Gilbert O.L., James P.W., Wolseley P.A. (Eds.). 2009. *The lichens of Great Britain and Ireland*. The British Lichen Society, London.

Spribille T., Goffinet B., Klug B., Muggia L., Obermayer W., Mayrhofer H. 2011. Molecular support for the recognition of the *Mycoblastus fucatus* group as the new genus *Violella* (Tephromelataceae, Lecanorales). *Lichenologist* **43**(5): 445–466.

Stefanowicz A.M., Niklińska M., Kapusta P., Szarek-Łukaszewska G. 2010. Pine forest and grassland differently influence the response of soil microbial communities to metal contamination. *Science of the Total Environment* **408**: 6134–6141.

Szarek-Łukaszewska G., Grodzińska K. 2011. Grasslands of a Zn-Pb post-mining area (Olkusz Ore-bearing Region, S Poland). *Polish Botanical Journal* **56**(2): 245–260.

Vondrák J., Merkulova O., Redchenko O. 2010. Several noteworthy lichen found in the foothills of the Šumava Mts, South Bohemia, Czech Republic. *Bryonora* **45**: 31–35.

Wirth V. 1972. Die Silikatflechten-Gemeinschaften in ausseralpinen Zentraleuropa. Dissertationes Botanicae **17**: 1–306.

Żegleń A. 2010. *Wpływ czynników siedliskowych na zróżnicowanie lichenobioty użytku ekologicznego* "*Pleszczotka górska*" *w gminie Bolesław* (*Wyżyna Śląsko-Krakowska*). Praca magisterska, Uniwersytet Pedagogiczny im. KEN w Krakowie, Kraków.