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GRASSLANDS OF A Zn-Pb POST-MINING AREA (OLKUSZ ORE-BEARING REGION, S POLAND)

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Abstract. We studied the diversity of grasslands in the Olkusz Ore-bearing Region (OOR). The OOR area has been severely degraded by Zn-Pb mining and polluted with heavy metals originating from mine and industrial waste and from industrial emissions. We assessed the species composition and cover of vascular plants, mosses and lichens in 9 plots at each of 28 study sites on two types of substrate (sands and dolomite mining waste). In the 252 study plots we recorded 260 species. Only one species was common (*Festuca ovina*) and four were noted frequently (*Rumex thyrsiflorus*, *Leontodon hispidus* subsp. *hastilis*, *Ceratodon purpureus*, *Bryum pallescens*). Most numerous were species typical of calcareous, warm, dry habitats and mesophilous meadows; species characteristic of poor sandy habitats and fields were rarer. Metallophytes were also fairly often noted (e.g., *Cardaminopsis halleri*, *Biscutella laevigata*, *Brachythecium albicans*, *Diploschistes muscorum*). Grassland diversity depended on substrate type and land use history. Grassland of abandoned fields developed on fertile sandy soil was richest in species, with numerous meadow and weed species (*Crepis biennis*, *Melandrium album*). Grassland on poor sandy soil was poor in vascular plants but rich in lichens (*Cladonia rei*, *C. monomorpha*). Grassland on mining ore-bearing waste was rich in thermophilous and meadow species (*Thymus pulegioides*, *Lotus corniculatus*). Grassland on mining waste was floristically similar to the *Armerietum halleri* association of metalliferous areas of Western and Central Europe. It differed by the presence of *Biscutella laevigata* and the frequent occurrence of *Rumex thyrsiflorus*, *Cardaminopsis arenosa*, *Gypsophila fastigiata*, *Potentilla arenaria* and *Anthyllis vulneraria*. The OOR grasslands, especially those developed on mining waste, should be placed under legal protection, as they contain species that are rare and unique for Poland. These grasslands increase the biotic diversity of this post-mining region and form colorful islands on its landscape.

Key words: mining waste, sands, heavy metals, vascular plants, bryophytes, lichens, phytosociology

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INTRODUCTION

Open-cast mining damages the soil and leaves vast areas bare of plant cover. The vegetation developing spontaneously on such land is a very interesting subject for botanical and ecological studies (e.g., Prach & Pyšek 2001; Prach & Hobbs 2008). Post-mining areas typically have a mosaic of different habitats which host rare and protected species (Tischew & Kirmer 2007; Tropek *et al.* 2010). Studies on the vegetation there are of great value for environmental restoration projects aimed at reestablishing self-sustaining ecosystems in those degraded areas (Tischew & Kirmer 2007).

Once metalliferous ore quarrying is done, the terrain is entirely altered, degraded and highly polluted. Abandoned mining waste consists largely of remnant ore, so the soil developing on it contains heavy metals in amounts far exceeding any requirements of the vegetation (Baker *et al.* 2010). It is also polluted by emissions from nearby smelters. Studies in ore-mining areas of Germany, Belgium and England showed that the vegetation spontaneously growing on metalliferous soils differs significantly in physiognomy and composition from the surrounding vegetation (Ernst 1974; Brown 2001; Dierschke & Becker 2008). The vegetation consists of unique species assemblages not seen anywhere else. In areas where Zn-Pb ores were extracted, specific communities – calamine grasslands – are composed of plants adapted to various extents to high concentration of metals in the soils. According to Ernst (1974), calamine grasslands reach the eastern edge of their distribution in the vicinity of Olkusz in southern Poland, the country's oldest zinc and lead mining region. However, detailed studies of these grasslands are still lacking.

The Olkusz Ore-bearing Region (OOR) is formed of shallow-dipping ore-bearing dolomite rich in Zn-Pb ore, alternating with areas of fluvioglacial sands. Metal ores have been exploited in the OOR since the 12th century, and most intensively from the 19th to the late 20th centuries. Mining waste was left in the form of heaps of various sizes, mainly around the mine pits or between cultivated fields. As exploitation of ore deposits has ceased, mine pits and mining waste heaps have been reclaimed or left untouched. This post-mining area consists of various types of substrates (dolomites, sands), highly or moderately polluted with heavy metals. Plant cover developed there spontaneously now represents grasslands varying in age, structure and composition. The composition of grasslands on the oldest metalliferous mining waste is similar to that of calamine grasslands in Western Europe (Grodzińska & Szarek-Łukaszewska 2009). Little is known about the other types of grassland in the post-mining area. Insufficient knowledge of those habitats and their natural value is one reason why they are treated as worthless wasteland and are reforested, built over or otherwise destroyed.

The aim of this study was (*i*) to characterize the grasslands of the OOR post-mining area, incorporating substrate type (sand, mining waste), (*ii*) to compare them with communities of other metalliferous mining areas across Europe and (*iii*) to assess their conservation value.

Study area

The Olkusz Ore-bearing Region (OOR) (southeastern part of the Wyżyna Śląsko-Krakowska upland 50°17′N, 19°29′E; Fig. 1) has been very intensively exploited by open-cast mining. It is one of the most heavily polluted regions in Poland (Pasieczna & Lis 2008).

The OOR is situated in the climatic zone of Wyżyna Śląsko-Krakowska upland (Romer 1949). It has characterized by shorter transition seasons and shows some typical features of continentality. Average annual temperature is 8°C, with average annual precipitation of 750 mm. Light and moderate westerly winds predominate. The vegetation season lasts 200–210 days (*Program ochrony środowiska dla powiatu olkuskiego* 2004).

The OOR is built of Triassic formations composed of ore-bearing dolomites (Zn-Pb ores), and Pleistocene fluvioglacial and eolic sands (Cabała 2009). Extraction and processing of Zn-Pb ores produced various kinds of waste made of dolomite rock and rarely limestone, crushed to sizes ranging from very coarse to very fine, polluted with remnant ore minerals (sulphides, carbonates, sulphates mainly of Zn and Pb). Initial rendzinas or degraded soils have developed on that waste, or soil cover is absent (Cabała 2009). Away from the mine pits and waste heaps are mainly brown soils developed on sand and rarely on dolomite, which were cultivated or managed as pasture until the early 1980s (*Program ochrony środowiska dla powiatu olkuskiego* 2004). The OOR soils show extremely high concentrations of heavy metals as compared with soils in other regions in Poland (Pasieczna & Lis 2008).

Until the 1980s the OOR was exposed to high emissions of SO_2 and metallic dusts from industry. Dustfall from ZGH Bolesław, the largest zinc smelter in Poland, situated in the center of the mining area (Fig. 1), was among the highest in the country, reaching 500 tons/year, and SO_2 reached 5000 tons/year (Szarek-Łukaszewska 2009). Currently dustfall is low at 1.5 tons/year, and SO_2 emission is 400 tons/year.

OOR areas damaged by industry have been reclaimed, mainly by reforestation, since the 1970s. Vegetation has developed spontaneously in places outside the reclamation programs, and in some areas since the late 19th century (Grodzińska & Szarek-Łukaszewska 2009). At present about half of the post-mining area has various types of grassland, and the other half is woodland (Fig. 1).

Material and methods

We studied 28 sites scattered over 48 km² of the Olkusz Ore-bearing Region (Fig. 1, Table 1). They represent the most frequent open vegetation types in the OOR

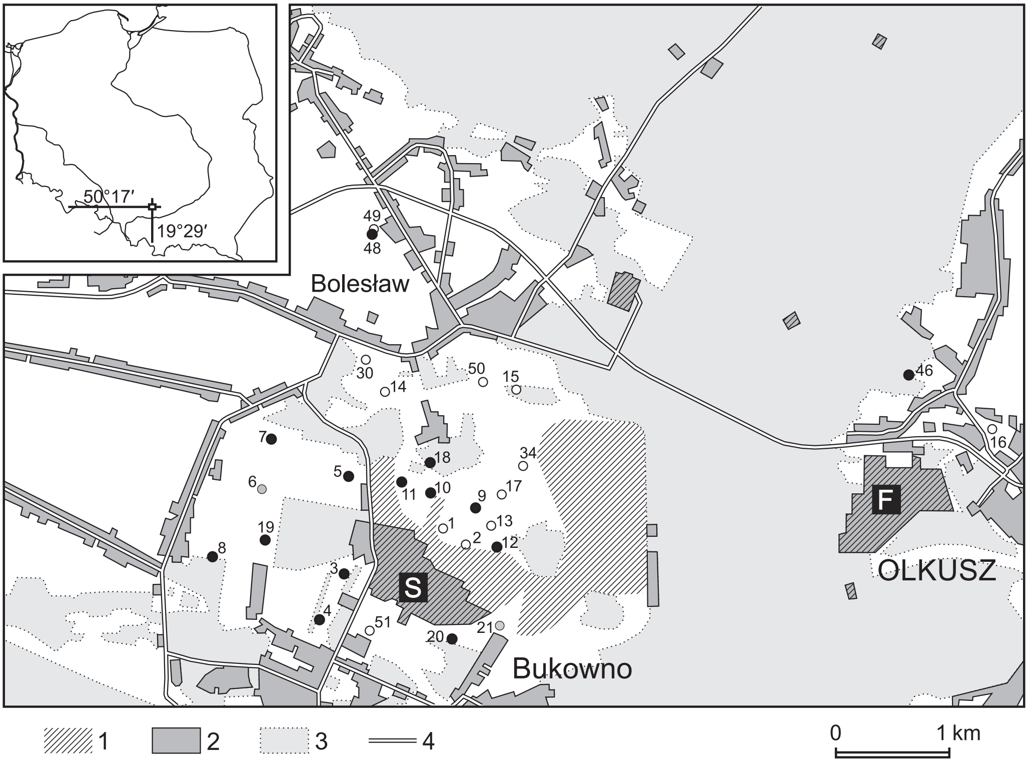

Fig. 1. Location of 28 study sites in the Olkusz Ore-bearing Region (OOR). ● – grassland on sand; ○ – grassland on mining waste; ● – grassland on other substrates; 1 – industrial area including tailings ponds, smelting heaps and ore processing plant (F), smelting plant (S); 2 – built-up area, 3 – forest, 4 – roads.

on the main substrate types: metal-rich dolomite mining waste typical for mining wasteland, and various types of sand, from poor to fertile, mostly cultivated until the early 1980s.

Table 1 gives detailed information on particular study sites. Land use types are according to unpublished reports on the buffer zone around ZGH Boleslaw and the registry of reclaimed post-mining areas (Rodek & Bielas 1976; *Rejestr terenów przekształconych przez Zakłady Górniczo-Hutnicze 'Bolesław'* 2004). We use data from Kapusta *et al.* (2011) for content of zinc (Zn%), the main metal of the ores, and the reaction (pH_{KCl}) of the top mineral horizon at the study sites.

At each study site, 9 circular plots (4 m^2 each) were demarcated on a 10 × 10 m grid. In 2008 and 2009 we inventoried the plants (vascular, mosses, liverworts) and lichens in each of the 252 plots. Abundance was estimated on the Braun-Blanquet cover-abundance scale (Medwecka-Kornaś *et al.* 1972). Nomenclature follows Mirek *et al.* (2002) for vascular plants, Ochyra *et al.* (2003) for mosses and liverworts, and Bielczyk (2003) for lichens. The syntaxonomic position of particular vascular species follows Matuszkiewicz (2002) and Zarzycki *et al.* (2002). Ecological classification is based on Kuc (1964) for mosses, and Purvis *et al.* (1992) and Cuny *et al.* (2004) for lichens.

Classification of plots and species (plants, lichens) was done with MULVA 5 software, as described in detail by Grodzińska *et al*. (2010). Ordination of species was prepared with the use of detrended correspondence analysis (DCA) detrended by segments, with root square transformation and down-weighting by rare species, using CANOCO 4.5 software. All taxonomic groups (plants, lichens) were ordinated together.

Results

We recorded 260 species in the 252 studied plots (Tables 2 & 3). Most of them (235 species) were sporadic, with up to 20% frequency (I^{st} degree of constancy). Vascular plants represented 148 of

Table 1. Characteristics of study sites in the Olkusz Ore-bearing Region. Site type: PS – thermophilous grassland on fertile sand, GS – thermophilous grassland on poor sand, GW – thermophilous grassland on mining waste, MW – moist grassland on mining waste, P – thermophilous grassland on other substrates, M – moist grassland on other substrates, Zn % – concentration of Zn in upper soil layer, pH_{KCl} – pH of upper soil layer.

Study site		Land use	Upper soil layer	
Type	No.		Zn %	pH_{KCl}
PS	5	Abandoned field – arable field cultivated until early 1980s	0.2	6.73
	7	Abandoned field – arable field cultivated until early 1980s	0.7	6.34
	10	Abandoned field – arable field cultivated until early 1980s	0.2	6.64
	11	Abandoned field – arable field cultivated until early 1980s	0.2	6.54
	18	Abandoned field – arable field cultivated until early 1980s	0.2	6.71
	19	Abandoned field – arable field cultivated until early 1980s	0.1	6.83
	48	Abandoned field	0.1	5.36
GS	3	Abandoned field – arable field cultivated until early 1980s	0.3	6.18
	4	Abandoned field – arable field cultivated until early 1980s	0.7	6.33
	8	Abandoned field – arable field cultivated until early 1980s	0.1	6.26
	9	Mining wasteland – arable field polluted by mining waste and abandoned in 1970s	1.3	6.49
	12	Mining wasteland – arable field polluted by mining waste and abandoned in 1970s	0.6	6.52
	20	Abandoned field – arable field cultivated until early 1980s	0.2	6.12
	46	Mining wasteland – a site has polluted by washery tailings since the beginning of the 20th century	1.3	6.84
GW	1	Mining wasteland, *ca* 80 years old	7.5	6.74
	14	Mining wasteland, *ca* 100 years old	1.9	6.99
	15	Mining wasteland – an area of mining waste dumping until 1990s	3.2	7.44
	16	Mining wasteland – mining waste heap, *ca* 80–100 years old	0.8	6.84
	17	Mining wasteland – mining waste heap, *ca* 50 years old	2.0	6.67
	34	Mining wasteland – mining waste heap, *ca* 20 years old	0.1	7.77
	51	Mining wasteland, *ca* 30 years old	1.8	6.73
MW	2	Mining wasteland – an area of mining waste dumping until 1990s	1.5	7.42
	13	Mining wasteland – mining waste heap reclaimed by covering of fertile soil layer and sowing of grasses mixture in late 1990s	0.2	6.28
	30	Mining wasteland – mining waste heap reclaimed by covering of fertile soil layer and sowing of grasses mixture in 1990s	0.04	5.85
	49	Mining wasteland – an area of mining waste dumping reclaimed by covering of fertile soil layer and a sowing of grasses mixture in 1990s	6.5	6.86
	50	Mining wasteland – an area of mining waste dumping reclaimed by planting trees in 1990s	3.1	6.98
P	6	Abandoned field – arable field cultivated until early 1980s	0.7	7.00
M	21	Abandoned field – a pasture until 1980s	0.3	5.21

the species (with 129 sporadic), mosses 32 (with 30 sporadic), liverworts 1 and lichens 79 (with 76 sporadic). Only one vascular plant species (*Festuca ovina*) was present in more than 60% of the plots (IVth degree of constancy) (Table 2). Two vascular plant species (*Rumex thyrsiflorus*, *Leontodon hispidus* subsp. *hastilis*) and two moss species (*Ceratodon purpureus*, *Bryum pallescens*) were recorded in 41–60% of the plots (IIIrd degree of constancy). Sixteen vascular plant species (e.g., *Achillea millefolium*, *Viola tricolor*, *Cardaminopsis arenosa*, *Silene vulgaris*), 1 moss species (*Amblystegium serpens*) and 3 lichen species (*Vezdaea leprosa*, *Cladonia monomorpha*, *C. rei*) occurred in 21–40% of the plots (IInd degree of constancy).

Vascular plants represented several habitat groups (Table 2). The most numerous was the group of meadow species of the class *Molinio-Arrhenatheretea* (34% of all species) and the group of species typical for grassland on alkaline substrate (24%), mainly of the class *Festuco-Brometea*. We noted a few species typical for dry, poor grassland on sandy substrate (classes *Koelerio glaucae-Corynephoretea* and *Nardo-Callunetea*), weeds (class *Stellarietea mediae*), ruderal, forest and clearcut habitats (8–11%).

Mosses represented mainly dry and warm alkaline habitats (e.g., *Tortella tortuosa*, *Tortula muralis*, *Bryum pallescens*, *Weissia controversa*). Only a few species were associated with slightly acid and sandy habitats (e.g., *Pohlia nutans*, *Brachythecium velutinum*, *B. albicans*). Most moss species occurred on bare soil or on humus between small stones.

Among the lichens, species occupying bare ground formed the most numerous group (e.g., *Cladonia rei*, *C. scabriuscula*, *Placynthiella oligotropha*). Less numerous were lichens on plant debris (e.g., *Bacidia bagliettoana*, *Diploschistes muscorum*, *Sarcosagium campestre*) and on stony mining waste (e.g., *Verrucaria muralis*, *V. nigrescens*, *Lecanora muralis*). Very occasionally we noted lichens on dead wood (e.g., *Lecanora conizaeoides*, *Hypocynomyce scalaris*, *Scoliciosporum chlorococcum*). Most of the lichens were species typical for alkaline substrate (e.g., *Agonimia gelatinosa*, *A. vouauxii*, *Bacidia saxenii*, *Phaeophyscia orbicularis*), and only a few for acidic substrate (*Cladonia subulata*, *Baeomyces rufus*, *Placynthiella icmalea*).

We distinguished 7 groups of plots based on floristic similarity (Table 3, Appendix). Group A comprised plots on abandoned fields on sand, least polluted with metals (Table 1). This group clearly differed from the others. It was the most rich in species, mainly vascular plants (113 species) and mosses (19 species) (Table 2). Among vascular plants the most numerous were meadow species (41). Weeds (16 species) and ruderal plants (8 species) were noted only in group A. The group was distinguished by *Crepis biennis*, *Melandrium album*, *Valeriana*

Table 2. Distribution of species by habitat group in seven distinguished grassland types (A–G, Table 3) in the Olkusz Ore-bearing Region. Syntaxonomic classes: MA – *Molinio-Arrhenatheretea*, FB – *Festuco-Brometea*, TG – *Trifolio-Geranietea*, KC – *Koelerio glaucae-Corynephoretea canescentis*, NC – *Nardo-Callunetea*, Ar – *Asplenietea rupestris*, Sm – *Stellarietea mediae*, A – *Artemisietea*, Agr – *Agropyretea intermedio-repentis*, Aln – *Alnetea glutinosea*, E – *Epilobietea angustifolii*, QF – *Querco-Fagetea*, Qr – *Quercetea robori-petraeae*, RP – *Rhamno-Prunetea*, SC – *Scheuchzerio-Caricetea nigrae*, VP – *Vaccinio-Piceetea*.

Type of grassland	A		B		C		D		E		F		G		A–G	
Habitat group (Syntax.)	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Thermophilous calcareous grasslands (FB, TG, RP, Ar)	29	*26*	1	*10*	0	*0*	12	*22*	16	*34*	14	*33*	22	*31*	36	*24*
Psammophilous grasslands (KC, NC)	9	*8*	3	*30*	3	*75*	8	*15*	8	*17*	7	*17*	11	*15*	17	*11*
Meadows (MA, SC)	41	*36*	1	*10*	1	*25*	24	*44*	15	*32*	17	*40*	30	*42*	51	*34*
Arable weed communites (Sm)	16	*14*	3	*30*	0	*0*	4	*7*	3	*6*	1	*2*	4	*6*	17	*11*
Ruderal vegetation (A, E, Agr)	8	*7*	0	*0*	0	*0*	3	*5*	1	*2*	2	*5*	1	*1*	12	*8*
Forests (QF, Qr, Aln, VP)	11	*10*	0	*0*	0	*0*	4	*7*	2	*4*	3	*7*	2	*3*	16	*11*
Vascular plants	113	*100*	10	*100*	4	*100*	55	*100*	47	*100*	42	*100*	71	*100*	148	*100*
Bryophytes	19	*12*	3	*8*	1	*7*	13	*13*	10	*10*	11	*11*	14	*13*	33	*13*
Lichens	33	*20*	24	*65*	9	*64*	33	*33*	44	*44*	50	*49*	20	*19*	79	*30*
Total	165	*100*	37	*100*	14	*100*	101	*100*	101	*100*	103	*100*	105	*100*	260	*100*

Table 3. Species composition of seven distinguished grassland types (A–G) in the Olkusz Ore-bearing Region. Constancy classes: V–I. Syntaxonomic classes: MA, FB, TG, KC, NC, Ar, Sm, A, Agr, Aln, E, QF, Qr, RP, SC, VP (abbreviations explained in Table 2).

Type of vegetation Site type No. of plot			A PS, P 71	B GS 35	C GS 9	D MW, M 55	E GS, GW 46	F GW 18	G GW 18	A–G 252	
Species	Species abbrev.	Taxonomic group	Constancy class								Syntax.
Diploschistes muscorum (Scop.) R. Sant.	*Dipl mus*	Lich	I	.	.	I	I	II	.	I	
Cladonia scabriuscula (Delise) Leight.	*Clad sca*	Lich	I	I	.	.	.	II	.	I	
Bacidia bagliettoana (A. Massal. & De Not.) Jatta	*Baci bag*	Lich	I	.	.	I	I	III	II	I	
Verrucaria nigrescens Pers.	*Verr nig*	Lich	I	.	.	I	I	IV	I	I	
Campylidium calcareum (Crundwell & Nyholm) Ochyra	*Camp cal*	Bry	.	.	.	.	I	III	.	I	
Didymodon rigidulus Hedw.	*Didy rig*	Bry	.	.	.	.	.	II	.	I	
Sarcosagium campestre (Fr.) Poetsch & Schied.	*Sarc cam*	Lich	I	I	.	II	I	I	I	I	
Molinia caerulea (L.) Moench. s.str.	*Moli cae*	Vasc	.	.	.	V	I	I	.	II	MA
Potentilla erecta (L.) Rausch.	*Pote ere*	Vasc	.	.	.	II	.	I	.	I	NC
Calamagrostis epigejos (L.) Roth.	*Cala epi*	Vasc	.	.	.	I	.	.	.	I	E
Festuca ovina L. s.str.	*Fest ovi*	Vasc	II	V	V	IV	V	V	V	IV	KC
Dianthus carthusianorum L.	*Dian car*	Vasc	I	.	.	I	V	V	III	II	FB
Bryum pallescens Schleich. *ex* Schwägr.	*Bryu pal*	Bry	I	II	.	III	V	III	IV	III	
Silene vulgaris (Moench) Garcke	*Sile vul*	Vasc	I	.	.	III	IV	V	I	II	FB
Cardaminopsis arenosa (L.) Hayek	*Card are*	Vasc	I	II	II	II	V	II	II	II	KC
Carex hirta L.	*Care hir*	Vasc	I	.	III	I	III	II	III	I	MA
Vezdaea leprosa (P. James) Vězda	*Vezd lep*	Lich	I	I	V	III	III	II	II	II	
Armeria maritima (Mill.) Willd.	*Arme mar*	Vasc	.	.	III	II	V	I	II	II	KC
Pimpinella saxifraga L.	*Pimp sax*	Vasc	I	.	.	.	II	III	II	I	FB
Rhinanthus serotinus (Schönh.) Oborný subsp. *serotinus*	*Rhin ser*	Vasc	I	.	.	.	.	IV	I	I	MA
Tortilla tortuosa (Hedw.) Limpr.	*Torl tor*	Bry	.	.	.	I	I	IV	I	I	
Linum catharticum L.	*Linu cat*	Vasc	.	.	.	I	.	II	IV	I	MA
Biscutella laevigata L.	*Bisc lae*	Vasc	.	.	.	I	I	IV	.	I	Ar
Pinus sylvestris L.	*PinusylB*	Vasc	I	.	.	.	.	II	.	I	VP
Thymus pulegioides L.	*Thym pul*	Vasc	I	.	.	III	I	V	IV	II	FB
Lotus corniculatus L.	*Lotu cor*	Vasc	II	.	.	III	II	IV	V	II	MA
Anthyllis vulneraria L.	*Anth vul*	Vasc	I	.	.	II	II	IV	IV	II	FB

Plantago lanceolata L.	*Plan lan*	Vasc	I	.	.	II	II	II	V	II	MA
Potentilla arenaria Borkh.	*Pote are*	Vasc	I	.	.	I	I	III	V	I	FB
Ranunculus acris L. s.str.	*Ranu acr*	Vasc	I	.	.	II	I	II	III	I	MA
Gypsophila fastigiata L.	*Gyps fas*	Vasc	.	.	.	II	I	IV	III	I	KC
Campanula rotundifolia L.	*Camp rot*	Vasc	I	.	.	II	I	IV	I	I	KC
Scabiosa ochroleuca L.	*Scab och*	Vasc	I	.	.	.	I	II	III	I	FB
Euphrasia stricta D. Wolff *ex* J. F. Lehm.	*Eupr str*	Vasc	I	.	.	.	I	IV	III	I	FB
Carlina acaulis L.	*Carl aca*	Vasc	I	.	.	.	I	.	III	I	FB
Carex caryophyllea Latourr.	*Care car*	Vasc	.	.	.	I	I	II	III	I	FB
Ranunculus bulbosus L.	*Ranu bul*	Vasc	I	.	.	I	I	I	II	I	FB
Cladonia pyxidata (L.) Hoffm.	*Clad pyx*	Lich	.	I	III	I	II	III	II	I	
Plagiomnium cuspidatum (Hedw.) T. J. Kop.	*Plag cus*	Bry	I	.	.	I	.	.	II	I	
Erysimum odoratum Ehrh.	*Erys odo*	Vasc	.	.	.	I	.	.	II	I	FB
Cladonia symphycarpia (Flörke) Fr.	*Clad sym*	Lich	.	.	.	I	.	I	I	I	
Eurhynchium hians (Hedw.) Sande Lac.	*Eurh hia*	Bry	I	.	.	.	.	.	I	I	
Cladonia monomorpha Aptroot, Sipman & van Herk	*Clad mon*	Lich	I	III	.	II	IV	III	.	II	
Cladonia rei Schaer.	*Clad rei*	Lich	I	V	II	II	II	.	I	II	
Cladonia subulata (L.) F. H. Wigg.	*Clad sub*	Lich	I	II	I	I	I	.	.	I	
**Stigmidium* sp.	*Stig sp.*	Lich	.	III	.	I	I	.	.	I	
Silene nutans L.	*Sile nut*	Vasc	.	.	.	.	I	I	IV	I	TG
Hieracium pilosella L.	*Hier pil*	Vasc	I	.	.	.	.	.	III	I	KC
Trifolium pratense L.	*Trif pra*	Vasc	I	.	.	I	.	.	IV	I	MA
Cerastium arvense L. s.str.	*Cera arv*	Vasc	.	.	.	.	.	.	III	I	KC
Abietinella abietina (Hedw.) M. Fleisch.	*Abie abi*	Bry	.	.	.	.	.	.	III	I	
Anthoxanthum odoratum L. s.str.	*Antx odo*	Vasc	.	.	.	.	.	.	II	I	MA
Sedum acre L.	*Sedu acr*	Vasc	.	.	.	.	.	.	II	I	KC
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	*Eurs pul*	Bry	.	.	.	.	.	.	II	I	
Plantago media L.	*Plan med*	Vasc	.	.	.	.	.	.	I	I	FB
Verrucaria muralis Ach.	*Verr mur*	Lich	I	I	.	II	I	II	III	I	
Vicia cracca L.	*Vici cra*	Vasc	I	.	.	I	I	.	III	I	MA
Barbula unguiculata Hedw.	*Barb ung*	Bry	I	.	.	I	.	I	II	I	
Agrostis capillaris L.	*Agro cap*	Vasc	I	.	.	I	.	I	III	I	MA
Erigeron acris L.	*Erig acr*	Vasc	I	.	.	.	.	.	II	I	FB
Coronilla varia L.	*Coro var*	Vasc	I	I	.	.	.	.	II	I	TG
Festuca pratensis Huds.	*Fest pra*	Vasc	I	.	.	.	.	.	II	I	MA
Cerastium holosteoides Fr. *emend.* Hyl.	*Cera hol*	Vasc	I	.	.	I	.	I	I	I	MA
Rumex acetosella L.	*Rume acl*	Vasc	I	I	.	I	.	.	I	I	KC
Convolvulus arvensis L.	*Conv arv*	Vasc	II	II	.	I	I	.	.	I	Sm

Table 3. *Continued.*

Species	Sp. abbrev.	Tg	A	B	C	D	E	F	G	A–G	Syntax.
Leontodon hispidus L. subsp. *hastilis* (L.) Rchb.	*Leon has*	Vasc	V	.	.	II	I	IV	V	III	MA
Leontodon hispidus L. subsp. *hispidus*	*Leon his*	Vasc	IV	.	.	I	I	III	V	II	MA
Achillea millefolium L. s.str.	*Achi mil*	Vasc	V	.	.	I	I	I	V	II	MA
Galium album Mill.	*Gali alb*	Vasc	III	.	.	II	II	IV	III	II	TG
Ceratodon purpureus (Hedw.) Brid.	*Cera pur*	Bry	V	III	.	III	I	II	III	III	
Rumex thyrsiflorus Fingerh.	*Rume thy*	Vasc	IV	IV	.	III	III	III	II	III	MA
Daucus carota L.	*Dauc car*	Vasc	III	.	.	I	I	II	II	II	MA
Crepis biennis L.	*Crep bie*	Vasc	V	.	.	I	.	.	II	II	MA
Amblystegium serpens Schimp.	*Ambl ser*	Bry	III	.	.	I	.	I	III	II	
Viola tricolor L. s.str.	*Viol tri*	Vasc	IV	III	.	II	I	I	I	II	Sm
Melandrium album (Mill.) Garcke	*Mela alb*	Vasc	V	II	.	I	I	.	.	II	A
Valeriana officinalis L.	*Vale off*	Vasc	III	.	.	.	.	.	.	I	MA
Arrhenatherum elatius (L.) P. Beauv. *ex* J. Presl & C. Presl	*Arrh ela*	Vasc	I	.	.	.	.	.	.	I	MA
Vicia hirsuta (L.) Gray	*Vici hir*	Vasc	II	.	.	I	.	.	.	I	Sm
Trifolium repens L.	*Trif rep*	Vasc	I	.	.	.	.	.	II	I	MA
Poa angustifolia L.	*Poa ang*	Vasc	I	.	.	.	.	.	I	I	TG
Veronica chamaedrys L. s.str.	*Vero cha*	Vasc	II	.	.	I	I	.	III	I	MA
Avenula pubescens (Huds.) Dumort.	*Aven pub*	Vasc	III	.	.	.	.	.	III	I	MA
Brachythecium albicans (Hedw.) Schimp.	*Brac alb*	Bry	I	.	.	.	.	.	III	I	
Poa pratensis L. s.str.	*Poa pra*	Vasc	I	.	.	.	.	I	.	I	MA
Cardaminopsis halleri (L.) Hayek subsp. *halleri*	*Card hal*	Vasc	I	.	.	I	.	.	.	I	QF
Festuca rubra L. s.str.	*Fest rub*	Vasc	I	.	.	.	.	.	.	I	MA
Brachythecium mildeanum Schimp.	*Brac mil*	Bry	I	.	.	I	.	.	.	I	
Heracleum sphondylium L. s.str.	*Hera sph*	Vasc	I	.	.	.	.	.	.	I	MA
Senecio jacobaea L.	*Sene jac*	Vasc	II	.	.	.	.	.	.	I	MA
Picris hieracioides L.	*Picr hie*	Vasc	I	.	.	.	.	.	.	I	FB
Angelica sylvestris L.	*Ange syl*	Vasc	I	.	.	I	.	.	.	I	MA

Sporadic species, not exceeding 20% frequency in all of the distinguished grassland types (A–G, Table 3) in the OOR. Species arranged by syntaxonomic class: MA, FB, TG, KC, NC, Sm, Agr, Aln, QF, Qr, RP, SC, VP (abbreviations explained in Table 2).

VASCULAR PLANTS: **FB**: *Arenaria serpyllifolia* L. (A), *Carlina vulgaris* L. (A), *Centaurea scabiosa* L. (A, G), *Euphorbia cyparissias* L. (A, D, E, G), *Galium verum* L. (D, G), *Gentianella germanica* (Willd.) Börner (F), *Helianthemum nummularium* (L.) Mill. (A), *Hypericum perforatum* L. (A), *Medicago falcata* L. (A), *Peucedanum oreoselinum* (L.) Moench (A, F), *Phleum phleoides* (L.) H. Karst. (A, G), *Poa compressa* L. (A); **TG**: *Anthericum ramosum* L. (E), *Astragalus glycyphyllos* L. (A), *Verbascum lychnitis* L. (A); **MA**: *Agrostis gigantea* Roth (A, D–G), *Anthriscus sylvestris* (L.) Hoffm. (A), *Campanula patula* L. (A), *Centaurea jacea* L. (A), *Dactylis glomerata* L. (A), *Deschampsia caespitosa* (L.) P. Beauv. (D, G), *Filipendula ulmaria* (L.) Maxim. (D), *Galium boreale* L. (E), *Geum rivale* L. (D), *Holcus lanatus* L. (A), *Hypochoeris radicata* L. (A), *Lathyrus pratensis* L. (D), *Knautia arvensis* (L.) J. M. Coult. (A, B), *Leucanthemum vulgare* Lam. (A), *Lysimachia vulgaris* L. (G), *Medicago lupulina* L. (G), *Ranunculus repens* L. (A), *Rumex acetosa* L. (A, F, G), *Taraxacum officinale* F. H. Wigg. (A, G), *Tragopogon orientalis* L. (A, G), *Trifolium dubium* Sibth. (A), *Viccia sepium* L. (A); **KC**: *Alyssum montanum* L. (E–G), *Cerastium semidecandrum* L. (A), *Herniaria glabra* L. (D, G), *Thymus serpyllum* L. *emend.* Fr. (E), *Trifolium arvense* L. (A); **NC**: *Botrychium lunaria* (L.) Sw. (A), *Luzula campestris* (L.) DC. (A, E); **Sm**: *Apera spica-venti* (L.) P. Beauv. (A), *Arabidopsis thaliana* (L.) Heynh. (G), *Cirisium arvense* (L.) Scop. (A), *Conyza canadensis* (L.) Cronquist (A), *Equisetum arvense* L. (A, B, D, E, G), *Euphorbia esula* L. (A), *Fallopia convolvulus* (L.) Á. Löve (A), *Galeopsis bifida* Boenn. (A), *Lathyrus tuberosus* L. (A), *Tussilago farfara* L. (A, G), *Veronica arvensis* L. (A), *Vicia angustifolia* L. (A), *Vicia tetrasperma* (L.) Schreb. (A); **A**: *Artemisia vulgaris* L. (A, G), *Carduus acanthoides* L. (A), *Cirisium vulgare* (Savi) Ten. (A), *Robinia pseudoacacia* L. (D), *Rubus caesius* L. (A, E), *Solidago gigantea* Aiton (A), *Verbascum densiflorum* Bertol. (A); **Agr**: *Elymus repens* (L.) Gould (A); **Aln**: *Salix cinerea* L. (E); **E**: *Carex spicata* Huds. (A, B), *Verbascum nigrum* L. (G); **QF**: *Acer pseudoplatanus* L. (A), *Elymus caninus* (L.) L. (A), *Epilobium montanum* L. (A, D), *Frangula alnus* Mill. (A), *Fraxinus excelsior* L. (A), *Hieracium lachenalii* C. C. Gmel. (A, G); **Qr**: *Hieracium umbellatum* L. (A), *Quercus robur* L. (F); **RP**: *Ligustrum vulgare* L. (A), *Rhamnus cathartica* L. (A); **SC**: *Carex nigra* Reichard (D); **VP**: *Betula pendula* Roth (D, E, E), *Juniperus communis* L. (E), *Solidago virgaurea* L. (A).

BRYOPHYTES: *Amblystegium juradskanum* Schimp. (A), *Brachythecium rutabulum* (Hedw.) Schimp. (A), *B. salebrosum* (Hoffm. *ex* F. Weber & D. Mohr) Schimp. (A), *B. velutinum* (Hedw.) Ignatov & Huttunen (A, E), *Bryum argenteum* Hedw. (A, G), *B. caespiticium* (D), *B. dichotomum* Hedw. (A, G), *Calliergonella cuspidata* (Hedw.) Loeske (F), *Cephaloziella divericata* (Sm.) Schiffn. (D, E), *Dicranella rufescens* (Dicks.) Schimp. (D, G), *D. staphylina* H. Whitehouse (D, E, F), *D. varia* (Hedw.) Schimp. (D, E), *Didymodon fallax* (Hedw.) R. H. Zander (F, G), *Oxyrrhynchium hians* (Hedw.) Loeske (A), *Plagiomnium rostratum* (Schrad.) T. J. Kop. (A), *Pohlia nutans* (Hedw.) Lindb. (A, E), *Rhynhostegium murale* (Hedw.) Schimp. (A), *Schistidium apocarpum* (Hedw.) Bruch & Schimp. (F), *Tortula muralis* Hedw. (A), *Weissia controversa* Hedw. (B, C–E).

LICHENS: *Agonimia* cf. *gelatinosa* (Ach.) M. Brand & Diederich (A, B, D–G), *A. vouauxii* (B. de Lasd.) Brand & Diederich (A, B, D–G), *Agonimia/Leucocarpia* (A–E, G), *Arthonia lapidicola* (Tayl.) Branth & Rostr. (E, F), *Amandinea punctata* (Hoffm.) Coppins & Scheid. (F), *Bacidia saxenii* Erichsen (F), *Bacidina chloroticula* (Nyl.) Vězda & Poelt (A, C, D, F), *B. phacodes* (Körb.) Vězda (A, D, F), *Bacidina* sp. (F), *Baeomyces rufus* (Huds.) Rebent. (E, F), *Bilimbia sabuletorum* (Schreb.) Arnold (D, F), *Candelariella aurella* (Hoffm.) Zahlbr. (E, F), *Cetraria aculeata* (Schreb.) Fr. (E, F), *C. islandica* (L.) Ach. (F), *Cladoniicola staurospora* Diederich, P. Boom & Aptroot (B), *Cladonia cariosa* (Ach.) Spreng. (A, B, D–G), *C. chlorophaea* (Flörke *ex* Sommerf.) Spreng. (B, D), *C. coniocraea* (Flörke) Spreng. (A), *C. conista* Robbins *ex* A. Evans (B–E), *C. fimbriata* (L.) Fr. (E), *C. foliacea* (Huds.) Willd. (E, F), *C. furcata* (Huds.) Schrad. (B, D, E), *C. glauca* Flörke (A, B, D–G), *C. mitis* Sandst. (A), *C. pocillum* (Ach.) Grognot (A, D, E), *Collema limosum* (Ach.) Ach. (E–G), *C. tenax* (Sw.) Ach. (F), *Diploschistes scruposus* (Schreb.) Norman (F), *Epigloea* sp. (B), *Hypocenomyce scalaris* (Ach. *ex* Lilj.) M. Choisy (E), *Lecanora conizaeoides* Nyl. *ex* Cromb. (A, E, G), *L. dispersa* (Pers.) Sommerf. (E, F), *L. muralis* (Schreb.) Rabenh. (F), *Leptogium biatorinum* (Nyl.) Leight. (F, G), *Micarea denigrate* (Fr.) Hedl. (B, E, F), *M. micrococca* (Körb.) Gams *ex* Coppins (E), *Mycoblastus fucatus* (Stirt.) Zahlbr. (A), *Mycobilimbia tetramera* (De Not.) Vitik. (F), *Peltigera didactyla* (With.) J. R. Laundon (D), *Phaeophyscia orbicularis* (Neck.) Moberg (F), *Physcia caesia* (Hoffm.) Fürnr. (F), *Placynthiella dasaea* (Stirt.) Tonsberg (E), *P. icmaela* (Ach.) Coppins & P. James (A, E), *P. ologotropha* (J. R. Laundon) Coppins & P. James (B, D, E), *Porpidia crustulata* (Ach.) Hertel & Knoph (A, F), *Protoblastenia rupestris* (Scop.) J. Steiner (F), *Scoliciosporum chlorococcum* (Graewe *ex* Stenh.) Vězda (A), *S. sarothamni* (Vain.) Vězda (A), *S. umbrinum* (Ach.) Arnold (F), *Steinia geophana* (Nyl.) Stein (A, D–G), *Strangospora moriformis* (Ach.) Stein (F), *Thelidium fumidum* (Nyl.) Hazsl. (G), *Trapelia coarctata* (Turner *ex* Sm.) M. Choisy (A), *Trapeliopsis granulosa* (Hoffm.) Lumbsch (E), *Verrucaria bryoctona* (Th. Fr.) Orange (A, B, D–G), *V. dolosa* Hepp (D, F), *V. fuscella* (Turner) Winch & Thornhill (F), *V. obfuscans* Nyl. (E, F), *V. procopii* Servit (D, F, G), *V. sylvatica* Zschacke (F), *V. xyloxena* Norman (C), *Verrucaria* sp. (A), *Vezdaea aestrivalis* (Ohlert) Tscherm.-Woess & Poelt (A, F), *V*. cf. *rheocarpa* Poelt & Döbbeler (A, D–F).

Fig. 2. DCA biplot of plots and species against first two axes of variation. Each symbol represents one plot; different symbols indicate the seven groups of grasslands (A–G) distinguished in Table 3. Species abbreviations given in Table 3.

officinalis and the moss *Amblystegium serpens*. It was somewhat related to groups D, F and G on mining waste by the presence of *Leontodon hispidus* and *Achillea millefolium*, and to group B on poor sandy soil by *Rumex thyrsiflorus* and *Ceratodon purpureus*.

Groups B to G were linked by the presence of species typical for thermophilous grassland (*Festuca ovina*, *Cardaminopsis arenosa*, *Vezdaea leprosa*, *Cladonia pyxidata*) (Table 3), but they differed in species richness and the shares of taxonomic groups. We recorded 37 species in group B and 14 in C, but more than 100 in each of groups D to G (Table 2). Lichens played the main role in groups B and C, comprising *ca* 70% of all species; vascular plants formed more than 50% of all species in group D; vascular plants and lichens each accounted for *ca* 40% in groups E and F; and *ca* 70% of all species were vascular plants in group G.

Among groups B to G, groups F and G on mining waste polluted by heavy metals (Table 1) were clearly distinguished floristically by the presence of, for example, *Thymus pulegioides*, *Lotus corniculatus*, *Anthyllis vulneraria*, *Potentilla arenaria* and *Gypsophila fastigiata* (Table 3). Group F was distinguished from group G by a few vascular species (*Rhinanthus serotinus*, *Biscutella laevigata*, *Pimpinella saxifraga*), mosses (*Tortella tortuosa*, *Campylidium calcareum*) and lichens (*Verrucaria nigrescens*, *Bacidia bagliettoana*). Group G was distinguished from group F by a few vascular species (*Silene nutans*, *Trifolium pratense*, *Hieracium pilosella*, *Cerastium arvense*), and by the moss *Abietinella abietina* and the lichen *Verrucaria muralis*.

Group D on fertile foreign soil spread during reclamation on mining and processing waste (washery and flotation tailings) differed from other grasslands on non-reclaimed mining waste (groups F, G) only by the presence of *Molinia caerulea*. Group B (grassland on sand) was distinguished from them only by the presence of several lichens (e.g., *Cladonia rei*, *C. monomorpha*, *Stigmidium* sp.) (Table 3). Groups C and E did not possess any significant individual characters.

We used DCA analysis to determine the direction and range of vegetation variability in the studied area. Figure 2 diagrams the ordination of species and plots in the space of the first two DCA axes. Axis I explains 14% of the variability (eigenvalue 0.49), and axis II 8% (eigenvalue 0.27). Groups of plots were clearly separated by land use type (axis I) as well as substrate type (axis II). The group representing grassland developed on abandoned fields is on the left side of axis I. It corresponds with group A of the MULVA classification (Table 3). It was distinguished by numerous tall herbs of mesophilous habitats. On the right side of axis I are plots on mining wasteland (groups C to G, Table 3). They were distinguished by vascular plants and lichens of open and dry habitats. In the lower part of axis II are plots on sand, mainly acid and nutrient-poor, and in the upper part of the axis II are those on old dolomite mining waste, with more fertile soil. They represented respectively group B, the most species-poor, and groups F and G, rich in species of various types of habitats (Table 3). Between them are plots on sand polluted with metalliferous waste, and on mining waste (groups C, E, Table 3), as well as those on reclaimed mining waste (group D, Table 3).

Discussion

The grasslands of the Olkusz Ore Region (OOR) composed of vascular plant species, mainly those that are common regionally (Nowak 1999; Nowak *et al.* 2011) or throughout Poland (Zając & Zając 2001). Rare species are sparse (e.g., *Biscutella laevigata*, *Gentianella germanica*, *Erysimum odoratum*). We draw particular attention to *B. laevigata*, a species known in Poland from only two areas: mountainous terrain in the West Tatras, and lowland near Olkusz (Wóycicki 1913; Zając & Zając 2001). In the OOR it is found mainly in grassland on rocky metalliferous mining waste, and more rarely in open pine forest on the same substrate (Grodzińska *et al.* 2010). *Biscutella laevigata* is a montane species; its presence in lowland OOR may suggest a glacial origin (Dobrzańska 1955; Szafer 1959). *Biscutella laevigata* occurs in many European mountain ranges, where it occupies shallow, calcareous soil and scree (Tremetsberger *et al.* 2002; Guinea & Heywood 2010), as well as in mining areas of the Southern Alps in Slovenia on shallow dolomite soil highly polluted with heavy metals (Vidic *et al.* 2006).

The metal-tolerant plants of the grasslands we studied deserve serious attention. We found no obligatory metallophytes (as defined by Baker *et al.* 2010), only facultative ones. An important species was *Cardaminopsis* (*Arabidopsis*) *halleri*, Poland's only Zn hyperaccumulator (Kostecka 2009). It was recorded rarely in OOR grasslands, and frequently in forests and moist meadows (Grodzińska *et al*. 2010; Nowak *et al*. 2011). *Cardaminopsis halleri* occurs in southern Poland in the Sudetes and Carpathians, as well as on the Wyżyna Małopolska upland and Wyżyna Lubelska upland (Zając & Zając 2001). Species classified as metallophytes which often occur in OOR grasslands are *Cardaminopsis arenosa*, *Dianthus carthusianorum*, *Silene vulgaris*, *Viola tricolor* and *Biscutella laevigata*

(Wierzbicka & Panufnik 1998; Wierzbicka 2002; Załęcka & Wierzbicka 2002; Wierzbicka & Pielichowska 2004; Grodzińska & Szarek-Łukaszewska 2009; Słomka *et al.* 2011).

The bryophytes noted in the OOR are mainly common species, easily spreading and often connected with anthropogenic habitats. Among them are species typical for metalliferous substrates (e.g., *Brachythecium albicans*, *Ceratodon purpureus*, *Pohlia nutans*) (Cuny *et al.* 2004; Holyoak 2008). The small number of bryophytes in the OOR grasslands may be due to their suppression by lichens in dry grassland, and by grasses (e.g., *Molinia caerulea*) in moister grassland.

Unlike the vascular plants and bryophytes, the lichen species we recorded in grasslands are rare and also new for the OOR (e.g., *Amadinea punctata*, *Cladonia rei*, *Verrucaria fuscella*), as well as for the Wyżyna Śląska upland (e.g., *Agonimia glutinosa*, *Bacidina chloroticula*) or for Poland (e.g., *Agonimia vouauxii*, *Vezdaea leprosa*, *V. rheocarpa*) (Bielczyk *et al.* 2009; U. Bielczyk, pers. comm.). Among the lichens is a large group of metallophytes such as *Bacidia bagliettoana*, *Cladonia pocillum*, *C. monomorpha*, *Diploschistes muscorum* and *Vezdaea leprosa* (Purvis *et al*. 1992; Bielczyk *et al*. 2009; Farkas 2010).

The OOR grasslands vary in respect to species composition and richness. This diversity is connected with substrate type (sands, mining waste), land use type (arable fields, mining wastelands) and land use history (abandoned, reclaimed area). The differences are greatest between grassland on fertile sandy soil and those on poor sandy soil and on metalliferous waste. Grassland of the first type developed on arable fields abandoned about 30 years ago. It is characterized by luxuriant vegetation and high species richness. Common weeds are sparse, as elsewhere observed on land not cultivated for a long period (Critchley & Fowbert 2000; Prach *et al.* 2001). A feature those grasslands share with the oldest grasslands on mining waste is the presence of mesophilous species. At present there are shrub/tree plantations and forests in the vicinity; those shrubs and trees can be expected to encroach if the grasslands' dense cover of herbaceous plants does not prevent it.

Festuca ovina is common and dominant in other OOR grasslands. It is resistant both to high concentrations of heavy metals in soil and to strong insolation and drought (Pawlus 1983; Brown & Brinkmann 1992; Kanapeckas *et al.* 2008). *Festuca ovina* is recognized as a species typical for grasslands of metalliferous areas in Europe (Becker & Dierschke 2008; Dierschke & Becker 2008), where it dominates, as in the OOR, on soils rich in Zn and Pb, both dry, poor and acid as well moister, more fertile and alkaline. This species probably comprises several distinct taxa colonizing heavy metal grasslands, but more detailed studies are required (Brown 2001). In the OOR, *F. ovina* represented the typical form (*F. ovina* s.str.) (Pawlus 1983; Nowak *et al.* 2011).

Along with the lichens, *Festuca ovina* and only a few other vascular plants form the grasslands on poor sandy soil in the OOR. The small number of plants on those habitats seems attributable to the adverse edaphic conditions of sandy soils (dry, acid, nutrient-poor) and the persisting effects of atmospheric pollution. From the 1950s to the mid-1990s, the ZGH Boleslaw smelter emitted enormous amounts of metallic dusts and sulphur compounds (Szarek-Łukaszewska 2009); atmospheric deposition of those pollutants in the OOR area was the highest in the country (Klich & Szarek-Łukaszewska 2001). The soil near the smelting plant has been heavily polluted for many years. Sulphur from the atmosphere acidifies poor sandy soil much more readily than it does to other soil types. Heavy metals are readily available to plants growing in polluted and acid soil. Only species resistant to excess metal can survive in such conditions (mainly species of Poaceae, Caryophyllaceae, Brassicaceae) (Baker *et al.* 2010). Monocultures of grasses (Poaceae) are commonly found in the vicinity of smelting plants, along with a few dicotyledonous species of the families mentioned above (Vidic *et al.* 2006). They survive long after pollutant emissions decrease.

The numerous occurrence of terricolous lichens in OOR grasslands dominated by *F. ovina* may be related to the life cycle of this species (Krebs 1994). The vitality of the grass declines with age. In the mature stage its tussock degrades, allowing lichens to encroach. Lichens are also frequent on mining calamine waste where *F. ovina* is dominant.

The OOR mining waste forms substrates of highly diverse texture and relief. They are a mosaic of stones and deeper soil heavily or slightly polluted with metals. Growing together are plants of various types of habitats: dry and warm (class *Festuco-Brometea*), fertile, weakly and moderately humid (class *Molinio-Arrhenatheretea*), and dry and nutrient-poor (class *Koelerio-Corynephoretea*). Found in the same place are calcicolous plants (*Gypsophilla fastigiata*), calcifugous plants (*Campanula rotundifolia*), highly metal-tolerant plants (*Armeria maritima* s.l., *Silene vulgaris* s.l.) and less tolerant ones (*Ranunculus acris*, *Achillea millefolium*). On the oldest waste they form dense sward. Numerously occurring terricolous and epilithic lichens take advantage of the free space (bare soil, stones) that opens up in dense sward when the shallow soil typical for mining waste erodes. The mosaic of habitats developing on waste ensures species diversity, important from the viewpoint of plant conservation and landscape values.

Grasslands with *Molinia caerulea* are typical for OOR wasteland reclaimed with fertile and foreign topsoil. *Molinia caerulea* has a persistent soil seed bank. It produces many small seeds (>20,000 seeds per plant) which readily spread on bare substrate and colonize it (Taylor *et al.* 2001). This grass may have entered reclaimed areas of the OOR from the seed bank of soil used for reclamation and/or from resources of the regional species pool, in which it was continuously present (Dobrzańska 1955; Nowak *et al.* 2011). *Molinia caerulea* is a species of mainly humid habitats, both natural and degraded. On old (>150 years old) metalliferous mining areas in Western Europe it accompanies metallophytes in humid patches (Brown 1994). It also encroaches on younger and dry substrates rich in metals (Ryszka & Turnau 2007).

Molinia caerulea is a strong competitor, but the OOR grasslands where it dominates are floristically rich. This was the result of temporal and spatial variation of habitat conditions. *Molinia caerulea* did not create a dense, continuous layer; species of humid and fertile habitats could find a place around its tussocks, and species of drier habitats could grow between them on shallow soil. This grass reaches its maximum height in late summer, so plants that bloom and fruit earlier can coexist with it.

Usually the material used for reclamation of degraded areas is a mixture of grasses giving quick growth but needing artificial fertilization (Turnau *et al.* 2001). *Molinia caerulea* is not in that mixture. In view of how rapidly it encroaches on post-mining areas in the OOR, it might be useful to include it in the mixtures used in reclamation programs, especially for metalliferous waste and flotation tailings (Ryszka & Turnau 2007).

The syntaxonomy of OOR grasslands on abandoned fields and on reclaimed mining waste is difficult to determine. To some extent the other grasslands on mining waste resemble thermophilous grasslands in the uplands of southern Poland, by the presence of some species of the classes *Festuco-Brometea* (e.g., *Dianthus carthusianorum*, *Potentilla arenaria*, *Anthyllis vulneraria*) and *Koelerio-Corynephoretea* (*Festuca ovina*, *Agrostis capillaris*). However, they are closer to the calamine grasslands of Central Europe represented by *Armerietum halleri*, an association of the order *Violetalia calaminariae* (Ernst 1974, 1976; Dierschke & Becker 2008; Baker *et al.* 2010). We pointed this out in previous work on the grasslands of the oldest fragments (80–100 years old) of the OOR mining area (Grodzińska & Szarek-Łukaszewska 2009). Among the few subassociations distinguished within *Armerietum halleri* calamine grasslands of the OOR, those on rocky mining waste are related to a subassociation with *Plantago lanceolata* (Ernst 1974) and its corresponding subassociation with *Achillea millefolium* (*A. h. achilletosum*) (Dierschke & Becker 2008). Grasslands on sands have weaker connections with the subassociation *A. h. achilletosum*, but closer to the subassociation with lichens *A. h. cladonietosum* (Dierschke & Becker 2008). The OOR calamine grasslands differ from Central European ones by the presence of *Biscutella laevigata* and frequent shares of *Rumex thyrsiflorus*, *Cardaminopsis arenosa*, *Carex hirta*, *Gypsophila fastigiata*, *Potentilla arenaria* and *Anthyllis vulneraria* (Grodzińska & Szarek-Łukaszewska 2009).

Floristically the OOR grasslands on mining waste show similarities to those of zinc-lead areas in Banska Stiavnica in Slovakia (Banásová *et al.* 2006), to the *Silene vulgaris*, *Armeria maritima* community of Northwestern Europe (Eifel Mts) (Brown 2001), and to a community on metalliferous substrate in central Germany (Becker & Brändel 2007).

The syntaxonomic classification of grasslands of metalliferous areas is interpreted variously by different authors (Brown 2001; Becker & Brändel 2007; Dierschke & Becker 2008; Baker *et al.* 2010). The differences of opinion are related in part to questions about the taxonomy of characteristic species of polyphyletic origin (*Armeria maritima*, *Silene vulgaris*, *Minuartia verna*) (Becker & Brändel 2007). In our study, as for Brown (2001), those species are described as species *sensu lato* even though morphological characteristics given for *A. maritima* subsp. *halleri* and *S. vulgaris* var. *humilis* are seen (Wierzbicka & Panufnik 1998; Abratowska 2006). Molecular studies should clarify their taxonomic position.

The grasslands of the Olkusz Ore-bearing Region supply a wealth of interesting material for the botanist and ecologist. Their species composition is specific to this metalliferous area. The grasslands are floristically rich. They contain species of vascular plants and lichens known from only a few sites in Poland. They boost the biotic diversity of the whole region and form colorful islands on its landscape. These grasslands, especially those developed on mining waste, need to be placed under legal protection and preserved through the implementation of active conservation measures.

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