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HEAVY METAL VEGETATION IN THE OLKUSZ REGION (SOUTHERN POLAND) – PRELIMINARY STUDIES

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Abstract. Grassland communities of areas with high levels of zinc and lead in the Olkusz region (southern Poland) were studied. They developed spontaneously on mine waste deposited at the beginning of the 20th century. Twenty phytosociological relevés in two areas are presented, along with pH and the zinc and lead concentrations in the upper soil layer. The soils were shallow, pH-neutral or slightly alkaline, and with very high heavy metal content (Zn 3.3–10.4%, Pb 0.32–1.66%). The grasslands were generally short and rather dense, and floristically similar to the *Armerietum halleri* Libbert 1930 association described by many authors from metalliferous areas of Germany; they differed from German ones by the presence of *Biscutella laevigata* and by the constant and often abundant occurrence of some vascular plants and lichen species (e.g., *Rumex thyrsiflorus*, *Cardaminopsis arenosa*, *Diploschistes muscorum*, *Verrucaria muralis*). Difficulties in comparing phytosociological materials from various areas are discussed. The paper points to the need to conserve grassland islands in the monotonous, seriously degraded landscape of the area.

Keywords: heavy metal plant communities, grasslands, phytosociology, *Armerietum halleri, Violetea calaminariae*

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INTRODUCTION

Zinc and lead ores occur on almost all continents (Ernst 1974). In Europe the richest deposits have been found in France, Belgium, the Netherlands and Germany (Ernst 1974; Ellenberg 1978). In Poland they occur only in the southern part of the country (Liszka & Świć 2004).

Metalliferous sites are overgrown with specific vegetation (Ernst 1974). Natural patches of this vegetation are associated with rock outcrops rich in zinc and lead, while secondary patches occur in mining areas, on post-mining waste and dumps. Natural patches, which have been repeatedly ravaged by opencast mining since prehistoric times, now occupy areas smaller than secondary patches.

The vegetation of zinc and lead areas in Central and Western Europe has been the subject of many syntaxonomic studies. The first publications date to the 1920s and 1930s (Libbert 1930; Schwickerath 1931; Koch 1932). They were followed by work done mainly by German botanists (e.g., Tüxen 1937, 1955; Schubert 1954a, b, 1974; Ernst 1974, 1976; Daniels & Geringhoff 1994; Brown 2001; Becker & Dierschke 2007; Pott & Hellwig 2007; Dierschke & Becker 2008). However, detailed information about the plant communities of zinc-lead areas in Poland is lacking. There are only brief mentions of them in the literature, with no phytosociological materials attached. Quoting floristic papers from the environs of Olkusz by Dobrzańska (1955), Ernst (1974) classified grasslands occurring in the metalliferous areas of Poland as an impoverished association of *Armerietum halleri* Libbert 1930. Later, Brown (2001) stated that the grasslands of Polish metalliferous areas represent the *Silene vulgaris-Armeria maritima* community, though he had no phytosociological relevés from the Olkusz region. Relying on Ernst (1974), Matuszkiewicz (2002) recognized grasslands of the Olkusz region as an impoverished *Armerietum halleri* association.

The present paper describes the grassland communities of the zinc-lead areas of the Olkusz region

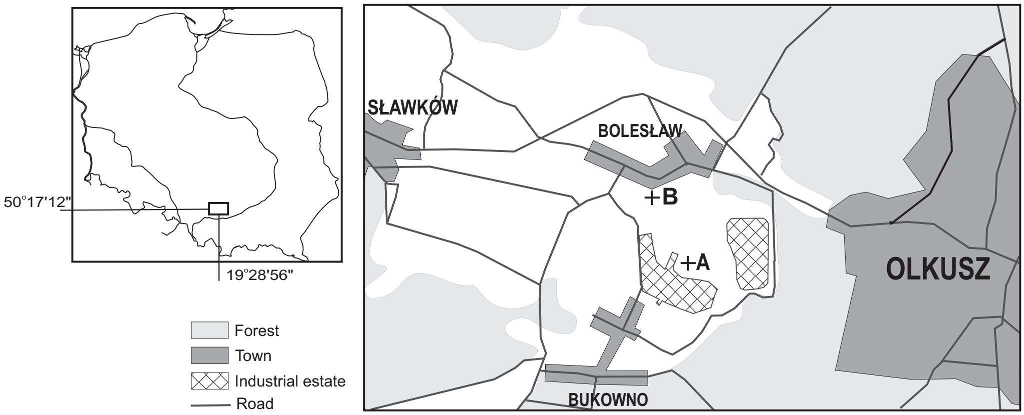

Fig 1. Location of study areas (A, B).

and compares them with grasslands of other metalliferous areas in Europe, mainly Germany.

Study area

Deposits of zinc and lead ores occur in southern Poland in the Silesian Upland (Fig. 1). The richest deposits are in the Olkusz region (environs of Olkusz, Bukowno, Bolesław). They occur in Triassic formations, mainly in ore-bearing dolomite and rarely in limestone. They contain over a dozen minerals. The basic minerals are sulphides of zinc (sphalerite, ZnS), lead (galena, PbS) and iron (marcasite, FeS_2). They are accompanied by secondary minerals (calamine) originating as the result of oxidation and carbonization processes, and minerals containing other elements (Liszka & Świć 2004). The ores contain different amounts of zinc and lead. The average content of zinc is 3.2–4.6%, and that of lead 0.3–1.9%. The ores also bear trace amounts of about 40 other elements such as cadmium (Cd), chromium (Cr), silver (Ag), selenium (Se), thallium (Tl) and uranium (U).

The latest archaeological research locates the beginnings of metal ore exploitation in the Olkusz region in antiquity, in the Hallstatt period (700–400 B.C.). According to historical sources, extraction and smelting of lead and silver ores started at the turn of the 11th/12th centuries, and zinc mining and smelting somewhat later on. These deposits were exploited almost continuously until the 1990s.

Many years of mining and smelting have completely changed the landscape of the Olkusz region, altering the hydrological regime, creating exploitation hollows and excavations, and producing huge accumulations of different waste materials in dumps. Mine waste accumulated during several periods in the environs of Bukowno and Bolesław. The oldest waste originates from the late 19th and early 20th centuries. Until the end of the 1980s the Olkusz region received high amounts of industrial emissions of sulphur and dust with heavy metals. Dust emissions from smelting plants alone amounted to *ca* 500 tons/year in that period, and SO_2 emissions more than 5000 tons/year. Currently these plants are emitting *ca* 1.5 tons of dust/year and *ca* 400 tons of SO_2/year.

Post-mining areas in the Olkusz region have been reclaimed mostly through tree planting (afforestation). It is also possible to find vegetation patches that have been developing spontaneously on metalliferous waste for 80–100 years and more. This vegetation is represented by open grassland with sparse trees and shrubs. This type of grassland is the subject of the present work.

Materials and methods

We studied grasslands developed on mine waste deposited at the beginning of the 20th century. That waste has never been reclaimed; the vegetation has been developing spontaneously for a long time (80–100 years).

Two areas (A, B) of a few hectares each were selected in the environs of Bukowno and Bolesław; in each area, 10 circular sample plots (25 m^2 each) were established. The sample plots were distributed systematically, but places with untypical surface features (depression sinks, deep ditches originating after recultivation work, paths, lanes) were omitted. Phytosociological relevés were made according to the standard Braun-Blanquet method (1964) in all sample plots (n = 20). Coverage of particular vascular plant, moss and lichen species was determined on a six-grade scale (+ to 5). All relevés are presented in a standard phytosociological table. Species constancy was determined according to Braun-Blanquet's five-grade scale (I–V). Nomenclature follows Mirek *et al.* (2002) for vascular plant species, Ochyra *et al.* (2003) for mosses, and Bielczyk (2003) for lichens. Vascular plant species were classified according to their syntaxonomic affinity on the basis of Matuszkiewicz (2002) and Zarzycki *et al.* (2002).

Around each sample plot in areas A and B, 5 samples were taken from the upper soil layer (10 cm depth), combined into one mixed sample per plot, and analyzed for pH and zinc and lead concentrations. The pH was determined potentiometrically, and heavy metal concentrations spectrophotometrically (AAS Varian 220 FS).

Results

The Olkusz region grasslands cover flat ground or slightly inclined south-facing slopes. The soils were shallow and largely skeletal. The pH of the upper soil layer was neutral or slightly alkaline (Table 1). The concentration of heavy metals (Zn, Pb) originating from mine waste was very high. The soils of area A contained twice as much heavy metal as area B (Table 1).

The studied grasslands were generally short and dense, and 78 species were found in the two studied areas (Table 1). Vascular plants were represented by 44 species, ranging from 7 to 27 species in particular relevés. The lichen group comprised 30 species, from 5 to 13 per relevé. There were only 4 moss species. The common species, most frequently noted, were *Festuca ovina* agg. (always dominating), *Silene vulgaris*, *Armeria maritima*, *Dianthus carthusianorum*, *Carex caryophyllea*, *Pimpinella saxifraga*, *Rumex thyrsiflorus*, *Cladonia pyxidata*, *C. glauca* and *C. pocillum.*

In Table 1, relevés 1–10 represent area A, and relevés 11–20 represent area B. Area A hosted 41 species (19 vascular plants, 19 lichens, 3 mosses), and area B hosted 65 species (40 vascular plants, 24 lichens, 1 moss). Area B was floristically much richer than area A. In area A there were 6 species characteristic of the class *Festuco-Brometea* Br. Bl. et R. Tx. 1943, 5 of *Molinio-Arrhenatheretea* R. Tx. 1937, and 1 of *Koelerio glaucae-Corynophoretea canescentis* Klika in Klika et Novak 1941/*Sedo-Scleranthetea* Br.-Bl. 1955 em. Müller 1961 species; in area B the corresponding numbers were 12, 12, and 3 (Table 1). *Cardaminopsis arenosa* was a differential species for area A. Area B was distinguished by *Anthyllis vulneraria*, *Scabiosa ochroleuca*, *Euphrasia stricta*, *Potentilla arenaria*, *Lotus corniculatus*, *Rhinanthus minor*, *Leontodon hispidus*, *Linum catharticum* and seedlings of *Pinus sylvestris* among the vascular plants, and the moss *Tortella tortuosa* and lichen *Verrucaria muralis* (Table 1). In area A more than a third were sporadic species, and less than a fifth occurred in most of the phytosociological relevés. The floristic composition of area B grassland was more homogenous. Almost half of the species occurred in most patches, and less than a third were sporadic species (Table 1).

Discussion

The floristic composition of the grasslands of the Olkusz region most resembles that of the *Armerietum halleri* association described by Libbert (1930) and later mentioned by Schubert (1954a, b, 1974), Ernst (1974, 1976), Brown (2001) and Dierschke and Becker (2008) from metalliferous areas of Germany. Of the species considered characteristic of *Armerietum halleri*, *Armeria maritima* and *Silene vulgaris* occur in the Olkusz region. Here we refer to these two species as species *sensu lato*, though features distinguishing them as *Armeria maritima* subsp. *halleri* and *Silene vulgaris* var. *humilis* are visible (Abratowska 2006). Molecular work is needed to verify their precise taxonomy. A constant element of the Olkusz grasslands is *Biscutella laevigata*. It should be considered locally

Table 1. Heavy metal vegetation of the Olkusz region (S Poland)

Relevé number in the table	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
Relevé number in the field	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	10.10	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	12.10			
Date					06.2004										07.2004						Constancy		
Aspect (degrees)	.	.	.	.	.	.	.	.	.	.	180	.	.	180	.	.	.	.	.	.			
Slope (degrees)	.	.	.	.	.	.	.	.	.	.	5	.	.	12	.	.	.	.	.	.			
Cover herb layer (%)	80	80	80	80	90	80	80	70	80	70	90	90	80	90	90	70	80	70	90	90			
Cover moss and lichen layer (%)	10	5	30	10	5	15	20	15	15	5	10	10	5	5	10	40	40	40	20	20			
Relevé area (m^2)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	1–10	11–20	1–20
Soil pH $_{H_2O}$	6.71	7.11	7.22	7.04	6.93	6.78	6.92	6.92	6.97	7.09	6.81	7.31	6.94	7.41	7.18	7.16	7.25	7.20	7.20	7.04			
Soil concentration Zn %	6.93	6.93	10.41	10.41	8.26	5.22	7.35	7.35	6.12	8.82	4.45	5.01	3.35	3.30	4.22	5.31	7.78	4.65	4.84	4.41			
Soil concentration Pb %	1.11	1.11	1.20	1.20	1.16	0.61	0.90	0.90	1.66	1.21	0.40	0.39	0.37	0.32	0.47	0.50	0.65	0.37	0.32	0.36			
Ch. *Armerietum halleri*																							
Armeria maritima (Mill.) Willd.	3	3	3	3	3	2	3	3	2	3	+	+	+	.	+	+	+	.	.	.	V	III	IV
Silene vulgaris (Moench) Garcke	2	1	+	1	2	1	1	1	1	1	+	+	+	+	+	+	+	+	.	1	V	V	V
Biscutella laevigata L.	.	+	+	.	.	.	+	+	.	.	+	+	+	.	+	+	1	1	1	+	II	V	IV
Ch. *Violetea calaminariae*																							
Festuca ovina L.	4	4	4	4	5	4	4	3	5	3	3	3	3	3	3	3	3	3	3	3	V	V	V
Cladonia foliacea (Huds.) Willd.	.	2	1	.	1	1	.	+	.	.	1	+	.	+	.	1	.	.	.	.	III	II	III
Ch. *Festuco-Brometea*																							
Dianthus carthusianorum L.	+	+	+	+	+	+	.	+	+	+	1	2	2	1	1	+	+	2	2	2	V	V	V
Carex caryophyllea Latourr.	+	1	.	+	1	1	1	.	+	+	3	3	1	2	1	2	+	+	.	.	IV	IV	IV
Galium album Mill.	.	.	.	.	+	+	+	.	.	.	2	2	1	2	2	.	+	+	1	2	II	V	III
Pimpinella saxifraga L.	.	.	.	+	+	+	+	.	.	.	1	1	2	1	2	1	1	2	2	2	II	V	IV
Thymus pulegioides L.	.	.	.	.	.	.	+	.	.	.	2	2	2	2	2	1	2	2	1	1	I	V	III
Anthyllis vulneraria L.	.	.	.	.	.	.	.	.	.	.	2	+	2	1	2	1	2	1	+	.	.	V	III
Scabiosa ochroleuca L.	.	.	.	.	.	.	.	.	.	.	1	+	1	2	1	+	+	+	1	2	.	V	III
Euphrasia stricta D.Wolff *ex* J.F.Lehm.	.	.	.	.	.	.	.	.	.	.	1	+	1	+	+	+	1	+	2	1	.	V	III
Potentilla arenaria Borkh.	.	.	.	.	.	.	.	.	.	.	2	2	2	3	3	3	2	2	.	2	.	V	III
Carlina vulgaris L. s.l.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	1	1	+	.	III	II
Carlina acaulis L.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	+	+	I	II	I
Gentianella germanica (Wild.) Borner	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	II	I
Ch. *Molinio-Arrhenatheretea*																							
Rumex thyrsiflorus Fingerh.	+	+	.	+	.	+	+	+	.	+	+	+	+	+	+	.	+	+	+	+	IV	V	IV
Carex hirta L.	1	+	+	.	+	+	+	+	.	+	.	+	+	+	.	.	.	.	.	.	IV	II	III
Plantago lanceolata L.	.	.	.	.	+	.	+	.	.	.	2	1	2	2	1	.	+	.	+	.	I	IV	III
Ranunculus acris L.	+	.	.	.	.	.	.	.	.	+	.	1	1	2	+	.	.	.	2	1	I	III	II
Lotus corniculatus L.	.	.	.	.	.	.	.	.	.	.	+	+	2	1	1	1	1	1	1	1	.	V	III
Rhinanthus minor L.	.	.	.	.	.	.	.	.	.	.	1	+	+	.	+	+	1	+	+	1	.	V	III

Leontodon hispidus L. subsp. *hispidus*	.	.	.	.	.	.	.	.	.	.	+	1	+	+	1	+	+	+	+	+	.	V	III
Leontodon hispidus L. subsp. *hastilis* (L.) Rchb.	.	.	.	.	.	.	.	.	.	.	+	2	2	2	3	1	1	+	2	1	.	V	III
Linum catharticum L.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	1	+	+	+	.	IV	II
Achillea millefolium L.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	+	.	+	.	+	.	.	III	II
Veronica chamaedrys L.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	II	I
Agrostis gigantea Roth	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	+	.	+	.	II	I
Galium boreale L.	.	+	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	II	.	I
Ch. *Koelerio-Corynophoretea*, *Sedo-Scleranthetea*																							
Cardaminopsis arenosa (L.) Hayek	2	1	2	2	2	2	2	1	2	2	.	.	.	.	.	.	.	+	.	.	V	I	III
Gypsophila fastigiata L.	.	.	.	.	.	.	.	.	.	.	2	2	2	3	3	3	2	2	.	2	.	IV	III
Campanula rotundifolia L.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	2	2	1	1	1	.	IV	II
Other																							
Pinus sylvestris L.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	+	+	+	+	+	.	V	III
Mosses																							
Tortella tortuosa (Hedw.) Limpr.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	3	3	3	1	1	.	V	III
Bryum caespiticium Hedw.	.	.	.	+	+	1	1	.	1	.	.	.	.	.	.	.	.	.	.	.	III	.	II
Weissia controversa Hedw.	+	+	2	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	III	.	II
Ceratodon purpureus (Hedw.) Brid.	+	+	.	.	.	.	.	1	.	+	.	.	.	.	.	.	.	.	.	.	II	.	I
Lichens																							
Cladonia pyxidata (L.) Hoffm.	2	1	1	1	2	2	2	1	+	1	1	1	2	2	1	2	2	2	1	1	V	V	V
Cladonia glauca Florke	+	1	+	1	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	V	V	V
Cladonia pocillum (Ach.) Grognot	+	.	.	+	+	+	+	.	+	+	+	+	+	.	+	1	1	1	1	+	IV	V	IV
Bacidia bagliettoana (A. Massal. & De Not.) Jatta	.	.	+	+	+	.	.	.	.	.	+	+	+	.	+	+	+	+	+	+	II	V	III
Diploschistes muscorum (Scop.) R. Sant	.	+	+	+	.	.	.	+	.	.	.	+	1	+	+	+	+	+	+	1	II	V	IV
Cladonia furcata (Huds.) Schrad.	.	.	.	1	.	.	.	.	.	.	+	+	1	1	2	+	1	1	1	+	I	V	III
Vezdaea stipitata Poelt & Dobbeler	1	1	1	+	1	1	2	2	1	2	+	.	.	+	.	+	.	.	.	.	V	II	IV
Mycobilimbia sabuletorum (Schreb.) Hafellner	.	.	+	.	+	+	.	.	.	.	.	.	+	.	.	+	+	+	+	+	II	III	III
Lecanora muralis (Schreb.) Rabenh	.	+	+	.	.	+	.	+	+	+	+	.	.	.	.	.	.	.	.	.	III	I	II
Verrucaria nigrescens Pers.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	+	.	1	I	II	I
Verrucaria aethiobola Wahlenb.	.	.	+	.	.	.	.	.	.	.	.	+	.	+	+	+	.	.	+	.	I	II	I
Verrucaria muralis Ach.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	+	+	1	+	1	.	V	III
Lecanora dispersa (Pers.) Sommerf.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	.	+	+	.	+	.	III	II
Candelariella aurella (Hoffm.) Zahlbr.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	+	.	II	I
Baeomyces rufus (Huds.) Rebent.	.	.	+	+	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	III	.	II
Cladonia subulata (L.) Weber *ex* F. H. Wigg	+	+	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	II	.	I

(cont.)

Table 1. *Continued.*

Relevé number in the table	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
Placynthiella icmalea (Ach.) Coppins & P. James	.	.	.	.	+	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	II	.	I
Steinia geophana (Nyl.) Stein	+	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	II	.	I
Number of vascular plant species	10	10	8	8	11	10	16	8	7	9	27	27	27	26	27	21	26	27	22	24			
Number of moss species	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Number of lichen species	6	7	11	8	11	9	5	9	7	7	12	11	9	12	9	12	10	13	10	11			
Total number of species	18	19	20	18	24	20	22	18	15	17	40	39	37	39	37	34	37	41	33	36			

SPORADIC SPECIES. Vascular plants: *Alyssum montanum* L. (FB) 11:1; 12; *Erysimum odoratum* Ehrh (FB) 11:1; 12:1; *Euphorbia cyparissias* L. (FB) 7; *Helianthemum nummularium* (L.) Mill. subsp. *obscurum* (FB) 5, 7; *Viola rupestris* F. W. Schmidt (FB) 18; *Daucus carota* L. (MA) 20; *Molinia caerulea* (L.) Moench (MA) 18; *Rumex acetosa* L. (MA) 1, 3; OTHERS: *Genista tinctoria* L. 15; *Malaxis monophyllos* (L.) Sw. 17; *Verbascum thapsus* L. 12, 14; Lichens: *Agonimia tristicula* (Nyl.) Zahlbr. 12; *Bacidia phacodes* (A. Massal & De Not.) Jatta 9, 10; *Cetraria aculeata* (Schreb.) Fr. 6, 16, 17; *Cladonia fimbriata* (L.) Fr. 18; *Lecanora albescens* (Hoffm.) Branth & Rostr. 14, 18; *Lecidella stigmatea* (Ach.) Hertel & Leuckert 13; *Mycobilimbia tetramera* (De Not.) Vitik., Ahti, Kuusinen, Lommi & T. Ulvinen 19; *Peltigera rufescens* (Weiss) Humb.15; *Trapeliopsis flexuosa* (Fr.) Coppins & P. James 9; *Verrucaria bracteatat* (Th. Fr.) Orange 11; *Verrucaria obfuscans* (Nyl.) Nyl. 14

characteristic of metalliferous habitats. The occurrence of this species is limited to two areas in Poland: the zinc and lead Olkusz region and the limestone West Tatras (Zając & Zając 2001). The populations of the Olkusz region differ from those of the Tatras in many morphological and physiological features (Wierzbicka & Pielichowska 2004); their taxonomic rank has not been determined as yet.

Ernst (1974) distinguished three subassociations within *Armerietum halleri*, among them the *Plantago* subassociation represented by 33 relevés and with differential species including *Plantago lanceolata*, *P. media*, *Achillea millefolium*, *Scabiosa ochroleuca* and *Ranunculus bulbosus*. Accompanying species constantly associated with this subassociation are *Euphrasia stricta*, *Dianthus carthusianorum*, *Leontodon hispidus*, *Lotus corniculatus*, *Carex caryophyllea*, *Gentianella germanica* and *Tortella tortuosa*. Dierschke and Becker (2008) also distinguished three subassociations of *Armerietum halleri*, including *A.h. achilletosum millefoliae* Ernst 1965 (34 relevés) with the following differential species: *Plantago lanceolata*, *Galium album*, *Pimpinella saxifraga*, *Thymus pulegioides*, *Achillea millefolium*, *Cerastium holeostoides*, *Hieracium pilosella*, *Viola tricolor*, *Sedum acre* and *Scleropodium purum*. These subassociations of *Armerietum halleri* are associated with metalliferous and slightly alkaline substrate (pH 7.1–7.4). Floristically the Olkusz grasslands are very similar to both of those subassociations from Germany. They also occur on slightly alkaline soils with high concentrations of heavy metals.

Brown (2001) gave a community without syntaxonomic rank from metalliferous areas of Germany, named *Silene vulgaris-Armeria maritima*, and distinguished two geographical races, western and eastern. According to him the zinc-lead grasslands of Poland represent the eastern race of *Silene vulgaris-Armeria maritima*. That last assertion was not supported by phytosociological material from Poland. Brown characterized the soil chemistry of the studied areas. The community *Silene vulgaris-Armeria maritima* occurs in Germany on sandy soils containing large amounts of lead, and locally also zinc. These soils are very nutrient-poor and acidic (pH 5.1–6.8). The soils of the Olkusz grasslands, originated on dolomites, are slightly alkaline and contain high amounts of zinc and lead. Floristically they are richer than the patches of *Silene vulgaris-Armeria maritima* from Germany. In view of the habitat and floristic differences, the Olkusz grasslands cannot be assigned to *Silene vulgaris-Armeria maritima* as described by Brown (2001).

According to Brown (2001), grasslands occurring on soils that are acidic or highly contaminated by heavy metals (mainly lead) are floristically poorer than grasslands on slightly alkaline soils. Such is the case in the Olkusz region. The area A grassland on soil with high lead content contained fewer species than the area B grassland on less polluted soil.

Poland's zinc-lead grasslands differ from the German ones by the presence of *Biscutella laevigata* and the constant and often abundant occurrence of *Rumex thyrsiflorus*, *Cardaminopsis arenosa*, *Carex hirta*, *Gypsophila fastigiata*, *Potentilla arenaria* and *Anthyllis vulneraria*. Among the lichens, the differential species of the Olkusz grasslands are *Cladonia pocillum*, *C. glauca*, *Bacidia bagliettoana*, *Diploschistes muscorum*, *Vezdaea stipitata* and *Verrucaria muralis.*

The syntaxonomic position of the European grasslands of metalliferous areas has been discussed and changed many times (e.g., Schubert 1954; Ernst 1974; Ellenberg 1978; Brown 2001). Here we adopted Dierschke and Becker's (2008) syntaxonomic approach. On the basis of a wealth of phytosociological material, they placed associations of metalliferous sites in the alliance *Armerion halleri* Ernst 1965, order *Violetalia calaminariae* Br.-Bl. et Tx 1943, and class *Violetea calaminariae* Tx. in Lohmeyer *et al*. 1962.

Unfortunately the phytosociological materials published by different authors are not uniform. Comparing such materials is problematic. Phytosociological relevés have been made from plots varying in area from 1 to 100 m^2 (Libbert 1930; Schubert 1954; Ernst 1974; Brown 2001; Dierchke & Becker 2008). Obviously this affects the number of plants recorded from particular relevés. The number of relevés representing *Armerietum halleri* has also varied greatly, from a few to more than a hundred (Libbert 1930; Schubert 1954; Ernst 1974; Dierschke & Becker 2008). The species constancy calculated from different numbers of relevés is open to question. Some phytosociological tables comprise only vascular plants, with no information on lichens and mosses. Comparisons of such heterogeneous material cannot be sound.

In the Olkusz region all the relevés were made from patches covering 25 m^2, but only 20 relevés were made. Because there is so little data on the grasslands of metalliferous substrates in Poland, we decided to present all materials collected so far.

Grasslands on zinc and lead post-mining waste are islands in a heavily degraded, monotonous landscape. They enrich the landscape and add to the biotic diversity of the area. It is easy to justify the need for conservation of grasslands in the Olkusz region. Many plant species that are legally protected or known from only a few localities in Poland are found in such grasslands. For this reason, the area B grassland has been placed under legal protection as a site of ecological interest. As a consequence of decreased emissions of metallic dust and earlier cessation of grazing, pine (*Pinus sylvestris*) has been overgrowing the grassland in the past few years. Active protection, that is, the removal of trees, is needed for the grassland vegetation to be maintained.

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