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VASCULAR FLORA OF SITES CONTAMINATED WITH HEAVY METALS ON THE EXAMPLE OF TWO POST-INDUSTRIAL SPOIL HEAPS CONNECTED WITH MANUFACTURING OF ZINC AND LEAD PRODUCTS IN UPPER SILESIA

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Abstract: The paper presents results of floristic investigation conducted within the territory of post-industrial spoil heaps connected with zinc and lead products manufacturing. The flora of specific technogenic habitats was analyzed with regard to geographical-historical groups and syntaxonomic classification. For each species, the following characteristics were determined: a life form according to the classification of Raunkiaer, means of seed spreading and types of mycorrhiza for each species based on the literature. On the two heaps, a total of 257 species of vascular plants belonging to 59 families were found. Only 92 species occurred on both sites, which is 36% of all plants recorded. The most numerous families are: *Asteraceae* (45 species) and *Poaceae* (28 species). Apophytes dominate in the flora of spoil heaps (70.9%). Hemicryptophytes are the most numerous group and therophytes are also abundant. Ruderal (belonging to *Artemisietea vulgaris* and *Stelarietea mediae*) and meadow species (belonging to *Molino-Arrhenatheretea*) dominate on both post-industrial dumps. Xerothermal species (belonging to *Festuco-Brometea*) are also fairly numerous (6.7%). Their presence is related to the specific habitat conditions. The anemochoric species dominate in the flora of dumps. The high proportion of mycorrhizal plants was recorded. Finally, reclamation interventions which were carried out on the H2 spoil heap are discussed.

INTRODUCTION

Zinc and lead ores have been extracted in Poland since the twelfth century [1, 19]. The exploitation of these ores from the numerous mines in Upper Silesia and a primitive metal smelting technology have resulted in large quantities of waste. Moreover, it caused not only the transformation of the landscape but also the increase of heavy metals content in soil in the vicinity of processing plants and smelting works. Therefore, large amounts of waste were deposited in post-industrial areas as spoil heaps (dumps).

The issues concerning vascular flora and vegetation on post-industrial wastelands have become an interesting issue due to the industrial development in different parts of Poland. Each spoil heap, which was created as a result of various technological processes, represents unique chemical and physical properties. Because of that, these anthropogenic habitats have become interesting opportunities for biological and ecological investigations. There are many publications on spontaneous development of vegetation on different kinds of post-industrial dumps [25, 26, 27, 28, 35, 40, 41]. The stages of plant succession [25, 29, 30, 46] as well as the associated soil formation processes [6, 23, 32, 33] were considered. Furthermore, the reclamation interventions and bioremediation have become an interesting issue [5, 7, 9, 14, 29, 39]. The rich wildlife and the presence of rare and protected species in such places have attracted the attention of researchers [2, 3, 11, 25, 29, 36, 37].

Post-industrial dumps contaminated with heavy metals, due to the high toxicity of the substrate and a negative impact on human health, are a current problem that requires solutions in Upper Silesia. Despite many adverse effects that limit colonization by plants (for example, unstable ground, landslides, steep slopes, toxicity of waste, high pH, poor moisture conditions, temporary lack of water, introduction of alien species during reclamation interventions), we can observe a process of spontaneous succession on these dumps. Consequently, in spite of the unfavourable habitat conditions, many plant species are able to colonize these spoil heaps [29].

This paper presents a detailed qualitative and quantitative analysis of vascular flora of the two post-industrial spoil heaps associated with zinc and lead products manufacturing by the "Orzeł Biały" plant. The main purpose of this study was to demonstrate how diverse the vegetation on spoil heaps can be and to describe a high level of species diversity on these technogenic areas. In addition, the role of individual species in the formation of plant cover was defined. The author also indicates the plant species that may be the most important for the gradual colonization of spoil heaps and, thus, their alternative reclamation. Moreover, the effect of planting alien species during reclamation on biodiversity has been discussed.

METHODS

The floristic investigations were carried out during the two growing seasons of 2008 and 2009 on two kinds of spoil heaps, which are located in the central part of Upper Silesian Industrial Region (Fig. 1).

The research area includes the plateau and slopes of each heap and their surroundings (the 10 meter wide sections around the heaps). The floristic data were collected by means of multiple lists of vascular plants for each spoil heap. The qualitative and quantitative composition of vascular flora was analyzed, including the occurrence of individual species. Vascular plant nomenclature follows Mirek *et al.* [18].

The following characteristics were taken into account:

- The average species abundance in the following scale: 1 – single individuals; 2 – several individuals; 3 – over a dozen individuals; 4 – several dozen individuals; 5 – several hundred and more individuals; 6 – several hundred and more individuals (species clearly dominates)
- Geographical-historical groups [18, 38, 48]
- Life form according to the classification of Raunkiaer [50]
- Syntaxonomic classification [17, 50]
- Means of seed spreading [20]
- Mycorrhizal preferences of species [10, 45]

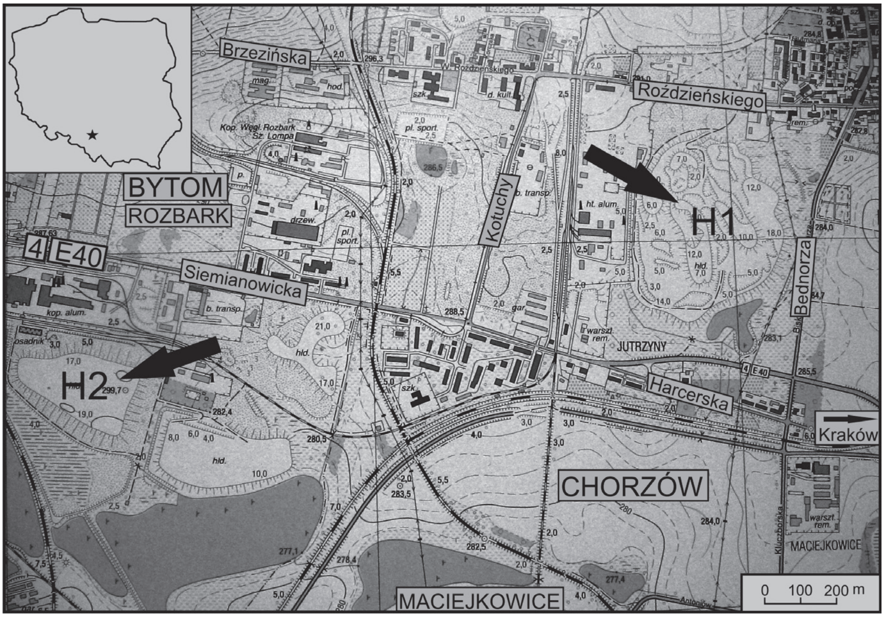

Fig. 1. Localisation of the investigated spoil heaps (H1, H2)

SITE DESCRIPTION

The location of the examined objects is presented on the topographical map (Fig. 1). The first spoil heap (H1) is located in Piekary Śląskie (Brzeziny Śląskie district). The second (H2) in Bytom (Rozbark district). The objects differ in size and, thus, the number of tones of dry matter of wastes accumulated on the dumps. The shapes of the heaps are also different. These facts are related to the deposition of different types of wastes, which are generated as a result of different treatment processes. Therefore, these wastes are characterized by various physical and chemical properties, as well as different grain sizes. The age of examined spoil heaps should also be taken into account. This fact is associated with the plant cover stage and diversity of plant species. Equally important feature that affects the composition of vascular flora is the reclamation interventions, which were carried out on one of the spoil heaps (H2). The comparison of the two spoil heaps is presented in Table 1.

RESULTS AND DISCUSSION

Vascular flora

A total number of 257 vascular plant species, representing 59 families, was recorded on the investigated objects (Tab. 2).

The study site is rich in species considering its small area. It is important to emphasize the differences in biodiversity between the two heaps. There were 227 species of vascular plants on the heap H1, while on the heap H2 only 122. Only 92 species occurred on both sites, which is 36% of the total number of plant species recorded. The most numer-

Table 1. Basic data on the investigated spoil heaps [44]

No	Characteristics	H1 spoil heap		H2 spoil heap	
1	Location	Piekary Śląskie (Brzeziny Śląskie district); surrounded by streets: Bednorza on the east, Harcerska on the south, Roździeńskiego on the north		Bytom (Rozbark district); on the south of Siemianowicka street	
2	Surroundings of the heaps	Lead smelter - Mining and Smelting Works „Orzeł Biały", post-industrial wastelands, cemetery, allotments, industrial water tank overgrown by cane rushes, deciduous forest, field under cultivation, ruderal communities		Battery scrap processing plant „Orzeł Biały". The heap adjacent to the „Żabie Doły" (a form of nature conservation called nature and landscape complex), ruderal communities	
3	Area (ha)	18		11.5	
5	Elevation (m)	286 – 303		293 – 307	
6	Shape	Irregular shape with numerous elevations and depressions		Truncated cone shape with average height 12–14 m	
7	Form of waste deposited	The slag from the blast furnaces – a mixture of fragments of dolomite, sinter slag and coke residue		Flotation sludge mixed with finely ground dolomite with vestigial amounts of zinc and lead	
8	Formation time	1926–1979		1969–1970	
9	Reclamation interventions	no action		In the years 1983–1990: grasses were sown, trees were planted, specific "soil like" material was deposited – probably the waste rock from the nearby coal mines	
10	pH	~ 8.2		6.1 – 7.2	
11	Fraction (grain size) (mm)	1.5 – 20		0 – 1	
12	The content of Zn and Pb (%)	Zn	2.1	Zn	2.4
		Pb	0.2	Pb	0.6

ous families were *Asteraceae* (45 species), *Poaceae* (28 species), *Fabaceae* (19 species) and *Rosaceae* (19 species). In addition to this, *Hieracium*, *Oenothera*, *Populus* and *Salix* genera were represented by the greatest number of species.

The analysis of the average species abundance showed that species, which are represented by medium-sized populations (belonging to the group 3 and 4) dominate on the both sites (72.8% of species recorded). On the other hand, there are not many common species, which are represented by numerous populations within the dumps (belonging to the group 6 and 5) (8.3%). However, these species are undoubtedly successful in colonization of the post-industrial dumps. They are primarily representatives of the *Poaceae* family, e.g., *Deschampsia cespitosa*, *Calamagrostis epigeios, Festuca tenuifolia*. In addition, they often form dense turfs. These groups also include some trees and shrubs. It is noteworthy that they constitute the largest biomass on the heaps. *Betula pendula*, *Populus tremula*, *Pinus sylvestris* are the species that spontaneously colonized unfavourable habi-

Table 2. List of vascular flora species of the investigated spoil heaps (H1 and H2) including species abundance Ghg – geographical-historical groups (Ap – apophytes, Ar – archeophytes, Eph – ephemerophytes and cultivated taxa, Kn – kenophytes); Rlf – Raunkiaer's life forms (C – woody chamaephytes, Ch – herbaceous chamaephytes, G – geophytes, H – hemicryptophytes, Hy – hydrophytes, M – megaphanerophytes, N – nanophanerophytes, T – therophytes, cr – creepers, hp – halfparasites; Mss – means of seed spreading (a – anemochory, an – anthropochory, au – autochory, hy – hydrochory, z – zoochory)

No.	Name of species	H1	H2	Ghg	Rlf	Mss
1	*Acer negundo* L.	+2	-	Kn	M	a, (z)
2	*Acer platanoides* L.	+2	+2	Ap	M	a, (z)
3	*Acer pseudoplatanus* L.	+2	-	Ap	M	a, (z)
4	*Achillea millefolium* L.	+4	-	Ap	H	a, (z)
5	*Aegopodium podagraria* L.	+3	-	Ap	G, H	an, (au)
6	*Agropyron caninum* (L.) P.Beauv.	+3	+3	Ap	H	a
7	*Agropyron repens* (L.) P.Beauv.	-	+3	Ap	G	a, (z)
8	*Agrostis capillaris* L.	+4	+4	Ap	H	a, (z)
9	*Agrostis stolonifera* L.	+3	-	Ap	H	a, (z)
10	*Allium vineale* L.	+2	-	Ap	G	an
11	*Alnus glutinosa* (L.) Gaertn.	+2	+2	Ap	M	a, (hy), (z)
12	*Alopecurus pratensis* L.	+3	+4	Ap	H	a
13	*Anagallis arvensis* L.	+3	-	Ar	T	au, (z)
14	*Anthoxanthum odoratum* L.	-	+4	Ap	H	a, (z)
15	*Anthylis vulneraria L.*	-	+3	Ap	H	a, (z)
16	*Apera spica-venti* (L.) P. Beauv.	+3	-	Ar	T, H	a, (z)
17	*Arabidopsis thaliana* (L.) Heynh.	+4	+2	Ap	T	a
18	*Arctium lappa* L.	+3	-	Ap	H	z
19	*Arenaria serpyllifolia* L.	+4	-	Ap	T	a, (z)
20	*Arrhenatherum elatius* (L.) P.Beauv. *ex* J. Presl &C. Presl	+2	+3	Ap	H	a
21	*Artemisia vulgaris* L.	+3	+3	Ap	H	a, (z)
22	*Asperula cynanchica* L.	+4	-	Ap	H	z
23	*Aster novi-belgii* L.	+3	-	Kn	H	a, (an), (z)
24	*Aster tradescantii* L.	+3	-	Kn	H	a, (an)
25	*Astragalus glycyphyllos* L.	+3	+2	Ap	H	a
26	*Barbarea vulgaris* R. Br.	+3	-	Ap	H	a, (z)
27	*Bellis perennis* L.	+4	+4	Ap	H	a, (z)
28	*Betula pendula* Roth	+6	+5	Ap	M	a, (z)
29	*Betula pubescens* Ehrh.	+1	-	Ap	M	a
30	*Bidens frondosa* L.	+2	-	Kn	T	z
31	*Bromus hordeaceus* L.	-	+3	Ap	T	a, (z)
32	*Bromus inermis* Leyss.	+3	-	Ap	H	a
33	*Calamagrostis epigejos* (L.) Roth	+6	+6	Ap	G, H	a, (hy)
34	*Calystegia sepium* (L.) R. Br.	+3	-	Ap	G, H, cr	hy, (an), (au)
35	*Camelina sativa* (L.) Crantz	+3	-	Ar	T	a, (an)
36	*Campanula rapunculoides* L.	+4	+3	Ap	H	a
37	*Capsella bursa-pastoris* (L.) Medik.	+3	+3	Ar	H, T	hy, (z)
38	*Caragana arborescens* Lam.	+1	-	Eph	N	au, (an)
39	*Cardaminospis arenosa* (L.) Hayek	+6	+5	Ap	H	a
40	*Carduus crispus* L.	+2	-	Ap	H	a
41	*Carex hirta* L.	+4	+4	Ap	G	a, (hy)

42	*Carex pairae* F. W. Schultz	-	+4	Ap	H	z
43	*Carlina vulgaris* L.	+4	+3	Ap	H, T	a
44	*Carpinus betulus* L.	-	+2	Ap	M	a, (z)
45	*Centaurea cyanus* L.	+2	-	Ar	T	a, (z), (an)
46	*Centaurea jacea* L.	+4	+3	Ap	H	a, (z)
47	*Centaurea scabiosa* L.	+3	-	Ap	H	a, (z)
48	*Centaurea stoebe* L.	+3	+4	Ap	H	a
49	*Centaurium erythraea* Rafn	+4	+4	Ap	T, H	a
50	*Centaurium pulchellum* (Sw.) Druce	+3	-	Ap	T	a
51	*Cerastium holosteoides* Fr. Em. Hyl.	+3	-	Ap	C, H	a
52	*Cerastium semidecandrum* L.	+3	-	Ap	H, T	a
53	*Cerastium tomentosum* L.	+3	-	Eph	C	a
54	*Cerasus mahaleb* (L.) Mill.	+2	-	Eph	M	z
55	*Cerasus vulgaris* Mill.	+2	-	Eph	M, N	z
56	*Chaenorhinum minus* (L.) Lange	+2	+2	Ap	T	a, (z)
57	*Chamaenerion angustifolium* (L.) Scop.	+3	+3	Ap	H	a
58	*Chamaenerion palustre* Scop.	+4	-	Ap	Ch	a
59	*Chamomilla suaveolens* (Pursh) Rydb.	+2	-	Kn	T	a
60	*Chelidonium majus* L.	+4	-	Ap	H	z
61	*Chenopodium album* L.	+3	+4	Ap	T	z
62	*Chenopodium glaucum* L.	-	+4	Ap	T	z
63	*Cirsium arvense* (L.) Scop.	+3	+3	Ap	G	a, (z)
64	*Cirsium oleraceum* (L.) Scop.	+3	-	Ap	H	a, (z)
65	*Cirsium vulgare* (Savi) Ten.	+3	+3	Ap	H	a, (z)
66	*Convolvulus arvensis* L.	+4	-	Ap	G, H, cr	z, (an), (au)
67	*Conyza canadensis* (L.) Cronquist	+4	-	Kn	T, H	z
68	*Cornus alba* L.	-	+3	Eph	N	z
69	*Cornus sanguinea* L.	+3	-	Ap	N	a
70	*Coronilla varia* L.	+4	-	Ap	H	au, (z), (an)
71	*Corylus avellana* L.	+2	+2	Ap	N	a
72	*Corynephorus canescens* (L.) P. Beauv.	+4	-	Ap	H	z
73	*Cotoneaster horizontalis* Decne.	+2	-	Eph	N	z
74	*Crataegus monogyna* Jacq.	-	+2	Ap	N	z
75	*Crataegus x subsphaerica* Gand.	+3	-	Ap	N	a, (z)
76	*Crepis biennis* L.	+3	-	Ap	H	a, (z)
77	*Dactylis glomerata* L.	+3	+3	Ap	H	an
78	*Danthonia decumbens* DC.	+3	-	Ap	H	a, (an)
79	*Datura stramonium* L.	+3	-	Kn	T	a, (z)
80	*Daucus carota* L.	+5	+4	Ap	H	a, (z), (an)
81	*Dechampsia caespitosa* (L.) P.Beauv.	+6	+5	Ap	H	a
82	*Dryopteris filix-mas* (L.) Schott	+3	+3	Ap	H	au, (an)
83	*Echinocystis lobata* (F. Michx.) Torr & A. Gray	+3	-	Kn	T, cr	a, (z)
84	*Echium vulgare* L.	+5	+3	Ap	H	z, (an)
85	*Elaeagnus angustifolia* L.	-	+1	Eph	N	a
86	*Epilobium hirsutum* L.	+3	-	Ap	H	a
87	*Epipactis atrorubens* (Hoffm.) Besser	+4	-	Ap	G	a
88	*Epipactis helleborine* (L.) Crantz	+3	+4	Ap	G	a
89	*Epipactis x schmalhausenii* Richter	+2	-	Ap	G	a

90	*Equisetum arvense* L.	+3	+3	Ap	G	a
91	*Erigeron acris* L.	+3	-	Ap	H, T	a
92	*Erigeron annuus* (L.) Pers.	+3	-	Kn	H, T	a, (z)
93	*Erysimum cheiranthoides* L.	+3	-	Ap	T	a
94	*Eupatorium cannabinum* L.	+4	+3	Ap	H	a, (z)
95	*Euphorbia cyparissias* L.	+4	-	Ap	G, H	au, (z)
96	*Euphorbia exigua* L.	+3	-	Ar	T	au, (z)
97	*Euphrasia stricta* D. Wolff ex J. F. Lehm.	+5	+5	Ap	T, hp	a
98	*Fagus sylvatica* L.	+1	+2	Ap	M	z, (an)
99	*Festuca rubra* L. s. s.	+4	-	Ap	H	a, (z), (hy)
100	*Festuca tenuifolia* Sibth.	+3	+5	Ap	H	a
101	*Filago arvensis* L.	+2	-	Ap	T	a
102	*Fragaria x ananassa* Duch.	+3	-	Eph	H	z, (an)
103	*Frangula alnus* Mill.	+3	+3	Ap	N	z
104	*Fraxinus excelsior* L.	+2	-	Ap	M	a, (z)
105	*Galeopsis pubescens* Besser	+3	-	Ap	T	z
106	*Galinsoga parviflora* Cav.	+3	-	Kn	T	a, (an)
107	*Galium mollugo* L.	+3	+3	Ap	H	z
108	*Galium verum* L.	-	+3	Ap	H	z
109	*Geranium pusillum* Burm. F. ex L.	+3	-	Ar	T	au, (z)
110	*Glechoma hederacea* L.	+3	-	Ap	G, H	au, (z)
111	*Helianthus tuberosus* L.	+3	-	Kn	G	a, (z)
112	*Herniaria glabra* L.	+4	-	Ap	H	a
113	*Hieracium bauhinii* Schult.	-	+5	Ap	H	a
114	*Hieracium pilosella* L.	+3	+6	Ap	H	a
115	*Hieracium piloselloides* Vill.	-	+5	Ap	H	a
116	*Hieracium sabaudum* L.	+3	+3	Ap	H	a
117	*Hieracium umbellatum* L.	+2	-	Ap	H	a
118	*Holcus lanatus* L.	+5	+4	Ap	H	a, (z)
119	*Hordeum distichon* L.	+2	-	Eph	T	z, (an)
120	*Hordeum murinum* L.	+2	-	Ar	T	a, (z)
121	*Humulus lupulus* L.	+3	-	Ap	H, cr	a, (an)
122	*Hypericum perforatum* L.	+4	+4	Ap	H	a, (z)
123	*Hypochaeris radicata* L.	-	+3	Ap	H	a
124	*Impatiens parviflora* DC.	+2	-	Kn	T	au
125	*Inula conyza* DC.	+4	-	Ap	H	a
126	*Iris sibirica* L.	+2	-	Ap	G	a
127	*Iris* sp. kultywar	+3	-	Eph	G	a, (an)
128	*Jasione montana* L.	+4	-	Ap	H	a, (z)
129	*Juncus compressus* Jacq.	+3	-	Ap	G	a, (z)
130	*Juncus tenuis* Willd.	+3	-	Kn	H	z
131	*Juniperus communis* L.	+2	-	Ap	N	z
132	*Lactuca serriola* L.	+3	-	Ar	H	a
133	*Lamium purpureum* L.	+3	-	Ar	T, H	z
134	*Lapsana communis* L. s. s.	+3	-	Ap	H, T	a
135	*Larix decidua* Mill.	+2	-	Ap	M	a, (z)
136	*Lathyrus tuberosus* L.	-	+3	Ar	H	au
137	*Leontodon hispidus* L.	+3	+4	Ap	H	a

138	*Lepidium densiflorum* Schrad.	+3	-	Kn	T	an
139	*Leucanthemum vulgare* Lam.	-	+3	Ap	H	a, (z), (an)
140	*Ligustrum vulgare* L.	-	+1	Kn	H	z
141	*Linum catharticum* L.	+3	+3	Ap	T	a, (z)
142	*Lolium multiflorum* Lam.	+4	+3	Kn	H, T	a, (z)
143	*Lolium perenne* L.	+2	+2	Ap	H	a, (z)
144	*Lonicera xylosteum* L.	+3	-	Ap	N	z
145	*Lotus corniculatus* L.	+5	+5	Ap	H	au, (z)
146	*Lunaria annua* L.	+2	-	Eph	T, H	a, (an)
147	*Lychnis flos-cuculi* L.	-	+3	Ap	H	a
148	*Lysimachia vulgaris* L.	+3	-	Ap	H	a, (hy), (z)
149	*Malus domestica* Borkh.	+3	-	Eph	M	z, (an)
150	*Malva sylvestris* L.	+3	-	Ar	H	a, (an)
151	*Matricaria maritima*, L. *subsp. inodora* (L.) Dostál	+3	+3	Ar	H, T	a
152	*Medicago lupulina* L.	+4	+3	Ap	H, T	z
153	*Medicago sativa* L.	+3	-	Kn	H	z
154	*Melandrium album* (Mill.) Garcke	+2	+4	Ar	T, H	a
155	*Melilotus alba* Medik.	+3	+3	Ap	T, H	au, (an)
156	*Melilotus officinalis* (L.) Pall.	+2	+3	Ap	T, H	au, (an)
157	*Myosotis arvensis* (L.) Hill	+4	+3	Ar	T, H	z
158	*Myosotis sylvatica* kultywar	+3	-	Eph	H	z, (an)
159	*Odontites verna* (Bellardi) Dumort.	+3	-	Ar	T, hp	a, (z)
160	*Oenothera biennis* L. s. s.	+4	+3	Ap	H	a, (au)
161	*Oenothera flaemingina* Hudziok	+3	-	Kn	H	a, (au)
162	*Oenothera paradoxa* Hudziok	-	+3	Kn	H	a, (au)
163	*Oenothera subterminalis* Gates	+3	-	Kn	H	a, (au)
164	*Oenothera subterminalis x Oenothera biennis*	+2	-	Kn	H	a, (au)
165	*Padus serotina* (Ehrh.) Borkh.	+3	-	Kn	N, M	z, (an)
166	*Papaver rhoeas* L.	+3	-	Ar	T	a, (an)
167	*Pastinaca sativa* L.	+3	-	Ar	H	a, (an)
168	*Philadelphus coronarius* L.	+3	-	Eph	N	an
169	*Philadelphus tomentosus* Wall.	-	+4	Eph	N	an
170	*Phragmites autralis* (Cav.) Trin. *ex* Steud.	+4	+4	Ap	G, Hy	a, (z)
171	*Physocarpus opulifolius* (L.) Maxim.	+2	+5	Eph	N	an
172	*Picris hieracioides* L.	+3	+3	Ap	H	a, (z)
173	*Pimpinella saxifraga* L.	+4	-	Ap	H	a, (an)
174	*Pinus sylvestris* L.	+6	+6	Ap	M	a, (z)
175	*Plantago lanceolata* L.	+3	+3	Ap	H	z
176	*Plantago major* L.	+3	-	Ap	H	z
177	*Poa angustifolia* L.	+4	-	Ap	H	a
178	*Poa compressa* L.	+4	-	Ap	H	a
179	*Poa pratensis* L.	+4	+4	Ap	H	a
180	*Poa trivialis* L.	+3	+3	Ap	H	a
181	*Polygonum aviculare* L.	+4	+4	Ap	T	z
182	*Polygonum mite* Schrank	+3	-	Ap	T	hy
183	*Polygonum persicaria* L.	+3	-	Ap	T	z
184	*Populus alba* L.	+4	+3	Ap	M	a

185	*Populus nigra* L.	+3	+3	Ap	M	a, (an)
186	*Populus tremula* L.	+6	+4	Ap	M	a
187	*Populus x canadensis* Moench	+4	+3	Eph	M	a, (an)
188	*Populus x canescens* (Aiton) Sm.	+3	-	Ap	M	a
189	*Potentilla anserina* L.	+3	-	Ap	H	a
190	*Prunella vulgaris* L.	-	+3	Ap	H	hy, (z)
191	*Quercus robur* L.	+2	+2	Ap	M	z
192	*Quercus rubra* L.	+2	+3	Kn	M	z, (an)
193	*Ranunculus acris* L. s. s.	+3	+3	Ap	H	a, (z)
194	*Ranunculus repens* L.	+3	+3	Ap	H	a
195	*Reseda lutea* L.	+5	+3	Ap	H	a, (z)
196	*Reynoutria japonica* Houtt.	+3	-	Kn	G	a, (an)
197	*Reynoutria sachalinensis* (F. Schmidt) Nakai	+4	-	Kn	G	a, (an)
198	*Rhus typhina* L.	-	+5	Eph	N, M	an
199	*Ribes uva-crispa* L.	+2	-	Ap	N	z, (an)
200	*Robinia pseudacacia* L.	+4	+4	Kn	M	a, (an)
201	*Rorippa palustris* (L.) Besser	-	+3	Ap	T, H	a, (z), (hy)
202	*Rorippa sylvestris* (L.) Besser	+3	+3	Ap	G, H	a, (z)
203	*Rosa* sp.	+1	-	-	N	z
204	*Rubus caesius* L.	+3	-	Ap	N	z
205	*Rubus idaeus* L.	+2	-	Ap	N	z
206	*Rubus plicatus* Weihe & Nees	+4	-	Ap	N	z
207	*Rumex acetosa* L.	+3	+3	Ap	H	a, (z)
208	*Rumex acetosella* L.	+4	-	Ap	G, H, T	a, (z)
209	*Rumex obtusifolius* L.	-	+3	Ap	H	a, (z)
210	*Rumex thyrsiflorus* Fingerh.	+3	-	Ap	H	a
211	*Sagina procumbens* L.	+3	-	Ap	C, T	a, (z)
212	*Salix aurita* L.	+3	-	Ap	N	a
213	*Salix caprea* L.	+4	-	Ap	M, N	a
214	*Salix fragilis* L.	+2	-	Ap	M	a
215	*Salix repens* L.	+4	-	Ap	Ch, N	a
216	*Salix x rubens* Schrank	-	+3	Ap	M	a
217	*Sambucus nigra* L.	+3	-	Ap	N	z
218	*Scabiosa ochroleuca* L.	+3	-	Ap	H	a
219	*Sedum acre* L.	+4	-	Ap	C	hy, (an)
220	*Senecio jacobaea* L.	+3	+3	Ap	H	a
221	*Silene nutans* L.	-	+4	Ap	H	a, (z)
222	*Silene vulgaris* (Moench) Garcke	+3	+3	Ap	C, H	a, (z)
223	*Sisymbrium loeselii* L.	+3	-	Kn	H, T	a
224	*Solanum dulcamara* L.	-	+2	Ap	N, cr	z
225	*Solidago canadensis* L.	+3	+3	Kn	G, H	a, (an)
226	*Solidago gigantea* Aiton	+3	+2	Kn	G, H	a, (an)
227	*Solidago virgaurea* L. s. s.	+3	+4	Ap	H	a
228	*Sorbus aucuparia* L. em. Hedl.	+4	+3	Ap	M, N	z
229	*Sorbus intermedia* (Ehrh.) Pers.	+3	+5	Kn	M, N	z, (an)
230	*Sorbus mougeotii* Soy.-Willm. Et Godron	+2	-	Eph	M, N	z, (an)
231	*Spiraea menziesii* Hooker	-	+3	Eph	N	an
232	*Stellaria graminea* L.	+3	+3	Ap	H	au

233	*Stellaria media* (L.) Vill.	+3	-	Ap	T, H	a, (z)
234	*Symphoricarpos albus* (L.) S. F. Blake	+2	-	Eph	N	z, (an)
235	*Syringa vulgaris* L.	+2	-	Eph	N, M	a, (z), (an)
236	*Tanacetum vulgare* L.	+3	+2	Ap	H	a
237	*Taraxacum officinale* F. H. Wigg.	+4	-	Ap	H	a, (z)
238	*Thymus pulegioides* L.	+3	+6	Ap	C	a, (z)
239	*Tilia cordata* Mill.	+2	+2	Ap	M	a
240	*Trifolium arvense* L.	+4	+3	Ap	T	a
241	*Trifolium campestre* Schreb.	+3	-	Ap	T	a
242	*Trifolium pratense* L.	+3	+3	Ap	H	a, (z)
243	*Trifolium repens* L.	+3	+3	Ap	C, H	z
244	*Triticum aestivum* L.	+2	-	Eph	T	a, (an)
245	*Tussilago farfara* L.	+5	+4	Ap	G	a, (z)
246	*Urtica dioica* L.	+3	-	Ap	H	a, (z)
247	*Verbascum densiflorum* Bertol.	+4	-	Ap	H	a
248	*Verbascum thapsus* L.	-	+4	Ap	H	a
249	*Veronica arvensis* L.	-	+3	Ar	T	hy, (z)
250	*Veronica chamaedrys* L.	+3	+3	Ap	C	a
251	*Vicia angustifolia* L.	+2	-	Ar	T	au
252	*Vicia cracca* L.	+3	+3	Ap	H	au, (z)
253	*Vicia hirsuta* (L.) S. F. Gray	+3	-	Ar	T	au, (z)
254	*Vicia sepium* L.	+2	-	Ap	H	au, (z)
255	*Viola arvensis* Murray	+3	-	Ar	T	z
256	*Viola tricolor* L.	+3	-	Ap	T	z, (au)
257	*Viscum album* L.	+2	-	Ap	N	z

tat. The species belonging to group 1 and 2, which are represented by a few individuals, often spread from the surrounding of the heaps. Their number is relatively high (18.9%), which may suggest a low stability of the habitat.

The analysis of geographical-historical groups revealed an overwhelming dominance of native species in the flora of the spoil heaps (71.1%) despite the anthropogenic origin of the sites (Fig. 2).

Apophytes form a group that has the greatest ability to spread into new, anthropogenic habitats. The dominance of apophytes on the post-industrial dumps was confirmed by previous studies [2, 3, 13, 15, 25, 26, 27, 28, 29]. The incidence of anthropophytes is much lower (kenophytes – 12.1% and archaeophytes – 8.2%). It should be noted that majority of alien species occur mainly in the surrounding of the heaps (e.g., *Acer negundo*, *Aster tradescanti*, *Datura stramonium*, *Echinocystis lobata*, *Reynoutria japonica*, *Reynoutria sachalinensis*). They are connected with the ruderal habitats, which are very common in the area of post-industrial wastelands. Therefore, kenophytes are not successful in dumps colonization. However, a few of them are able to spread within the dumps (*Conyza canadensis*, *Lolium multiflorum*, *Oenothera flaemingina*, *Oenothera subterminalis*). The remaining 8.6% are ephemerophytes, i.e. species not appearing spontaneously and cultivated taxa.

The analysis of life forms revealed that hemicryptophytes are the dominant group (45.9% of the flora, Fig. 3).

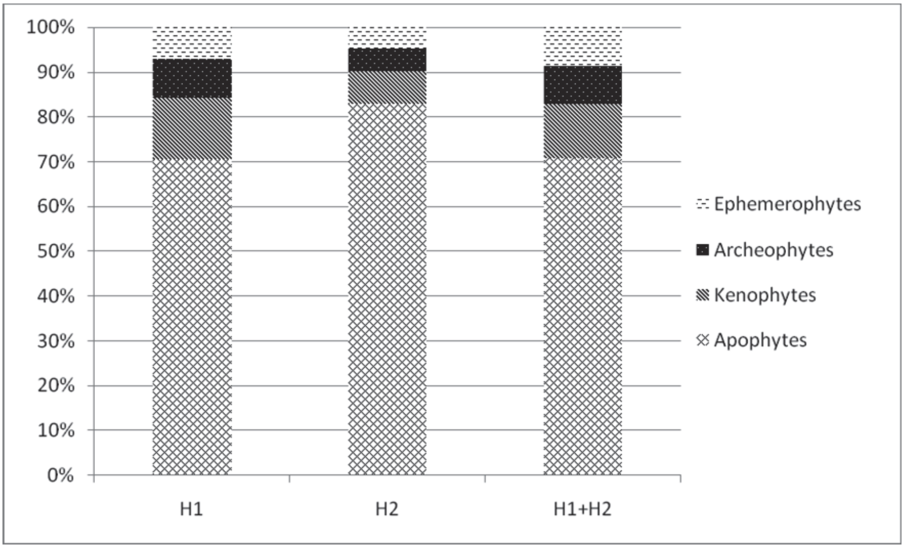

Fig. 2. Proportion of the geographical-historical groups on investigated dumps

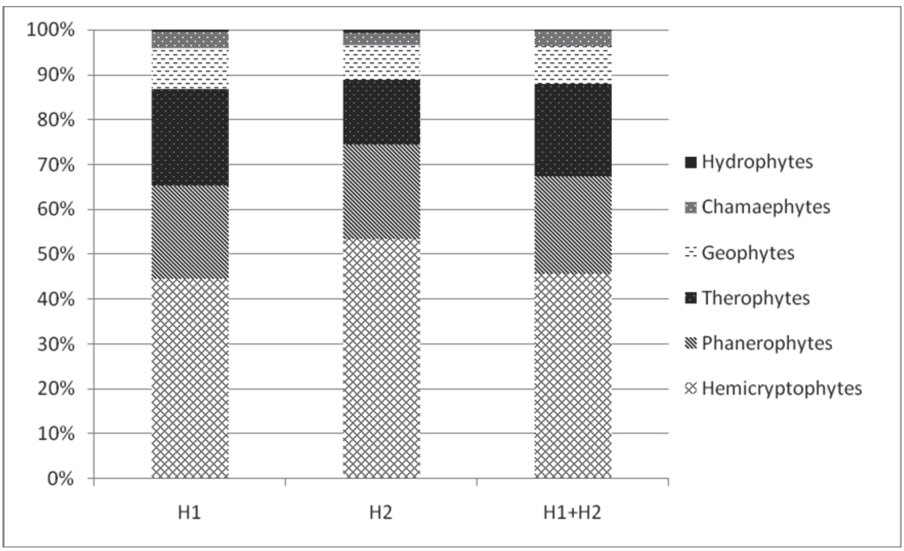

Fig. 3. Proportion of Raunkiaer's life form groups on H1 and H2 dumps

A similar phenomenon was observed on colliery spoil heaps in Upper Silesia [29] and also in the flora of Upper Silesian Industrial Region [31]. It is important to note that phanerophytes are represented by 21.3% of flora. It is also associated with the presence of planted taxa being a result of reclamation interventions. The proportion of annual plant species (therophytes) is also relatively high (20.6%). This fact is connected with a low stability of the habitat. Therophytes form a group of pioneer species which colonize exposed and anthropogenic areas. The participation of therophytes is noticeably bigger on the H1 heap. This fact is related to the lack of soil substrate on the heap H1 (the substrate is a steel slag), which is beneficial to therophytes. In addition, the weathering processes are also much slower there.

Ruderal (belonging to *Artemisietea vulgaris* and *Stelarietea mediae*) and meadow species (belonging to *Molino-Arrhenatheretea*) dominate on both post-industrial dumps (Fig. 4).

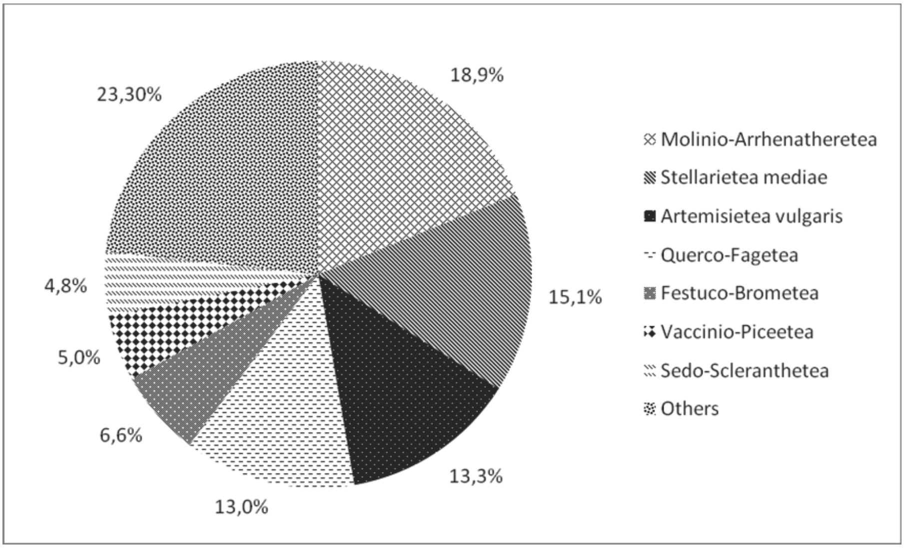

Fig. 4. Percentage of syntaxonomic gropus on the studied area

The most numerous among meadow species are grasses (*Poaceae*), which play an important role in the colonization of the spoil heaps (e.g. *Agrostis vulgaris*, *Calamagrostis epigeios*, *Deschampsia caespitosa*, *Festuca rubra*, *Festuca tenuifolia*, *Holcus lanatus*, *Poa pratensis*). Other authors reported the same species to be significant in the development of plant communities in post-industrial waste sites [22, 30]. The proportion of forest species (belonging to *Querco-Fagetea*), whose presence is associated with the proximity of forest communities, is remarkable. It is also important to note that xerothermal species (belonging to *Festuco-Brometea*) are quite numerous (6.7%). Their presence is related to the specific habitat conditions, such as strong insolation, poor water availability, and dark colour of the substrate accumulating heat.

Anemochorous species dominate in the flora of spoil heaps (52.7%, Fig. 5).

It is connected with the shape and complicated morphology of the heaps, which is favourable for the retention of seeds. The colonization processes of the dumps by plants were essential in the past, when the succession process began, but also today. There is also a high proportion of zoochorous species (28.9%).

The analysis of plant species preferences in relation to the type of mycorrhiza based on the literature data [10, 45] revealed the dominance of species which form arbuscular mycorrhiza (61.9%, Fig. 6).

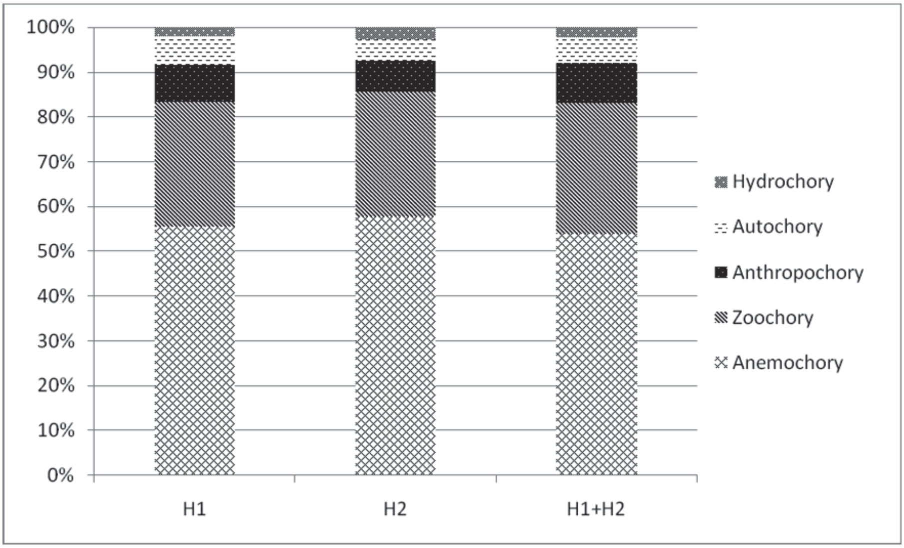

Fig. 5. Proportion of groups of individual means of seed spreading on both dumps

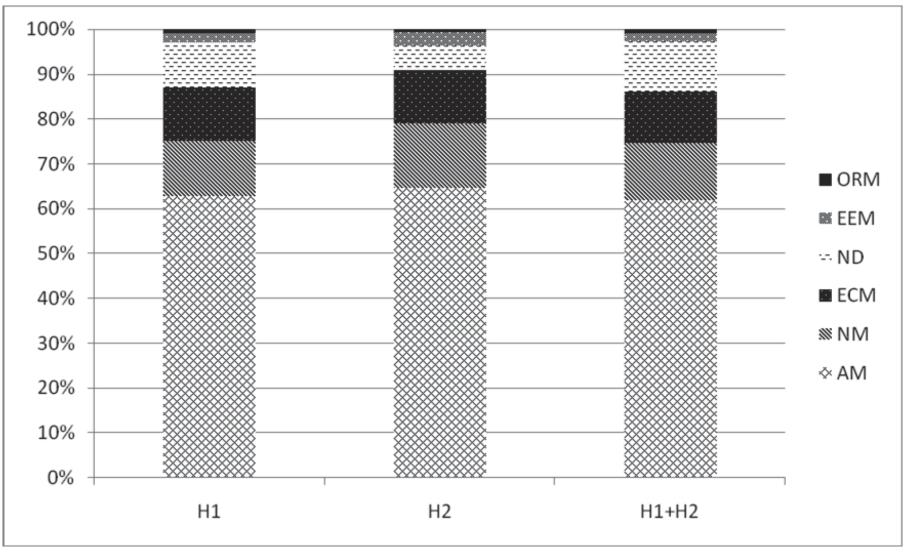

Fig. 6. Proportion of species due to the type of mycorrhiza on the investigated sites based on literature data [10, 45]. AM – arbuscular mycorrhiza, NM – nonmycorrhiza, ECM – ectomycorrhiza, ND – no data available, EEM – ectendomycorrhiza, ORM – orchid mycorrhiza

This is certainly associated with the fact that arbuscular mycorrhiza is the predominant and ancestral type of mycorrhiza in land plants [34, 45]. There are only 12.8% nonmycorrhizal species. The presence of tree species that form ectomycorrhiza is also notewothy (11.3%). On the other hand, the proportion of species characterized by ectendomycorrhiza and orchid mycorrhiza is relatively low (1.9% and 0.8%, respectively). In addition, it should be noted that the presence or absence of mycorrhiza may be seasonal, environmental, a phase of root development, sporadic or absolute [10]. The occurrence of mycorrhiza was previously observed on post-industrial sites contaminated with heavy metals [8, 12, 24, 42, 49]. In such habitats mycorrhiza is considered to be beneficial for plant growth [34, 42, 43]. Furthermore, mycorrhizal fungi are known to be able to accelerate the revegetation of industrial areas, such as coal mines or waste sites containing high levels of heavy metals [16]. The high proportion of mycorrhizal plants may suggest that mycorrhiza is an important factor in the plant growth and, therefore, in the colonization of examined post-industrial dumps.

The composition of the flora is dominated by common species, which have many localities in Poland [50]. These plants are characterized by a wide range of tolerance to unfavourable environmental conditions. They have adapted to growth in these unusual, anthropogenic habitats. However, rare species, with a relatively few localities in the country, e.g. *Camelina sativa*, *Euphorbia exigua*, *Iris sibirica*, which can be called regressing species, were also observed on the dumps. Furthermore, many species rare in the local scale [21] were noted in the study, for example, *Asperula cynanchica*, *Carex pairae*, *Centaurium pulchellum*, *Epipactis atrorubens*, *Epipactis helleborine*, *Inula conyza*, which should be considered as an interesting case. The presence of rare and endangered species on the post-industrial dumps was also reported in some previous studies [11, 36, 37, 47].

The evaluation of reclamation interventions carried out on H2 spoil heap.

The reclamation interventions included two stages [4]:

1. Biological protection of the plateau and slopes of the dumps against dusting to provide favourable habitat and soil conditions.
2. The introduction of different species of grasses and trees.

The weakened condition of the majority of introduced species of trees was recorded. Substrate toxicity, adverse water conditions, and thermal fluctuations in the substrate resulted in growth inhibition of trees and leaf damage. Only a few of the introduced species have a fairly good condition and have the ability to spontaneous spreading by seeds or vegetative reproduction. They are mostly native species (*Betula pendula*, *Pinus sylvestris*, *Populus tremula*). Besides them, there are also alien species (e.g. *Robinia pseudacacia*) which can threaten our native flora, because they have a great potential of expansion, often spreading to semi-natural and natural plant communities. The consequences caused by biological invasions should be taken into account in a proper selection of plant material used in reclamation [39]. Unfortunately, the reclamation interventions of the studied dump do not take into account the possible expansion of black locust and its ability to enter the nearby forests and scrub communities. The third group of species consists of hybrids and cultivars mainly of the genus *Populus*. Their relatively good condition can be explained by a high resistance to heavy metals content in soil [9]. A similar relationship was observed for the spoil heaps of Carboniferous waste material [29]. With regard to grass species, native species were used primarily (e.g. *Dactylis glomerata*, *Festuca tenuifolia*), which can be considered as a positive aspect. After almost 20 years, there is quite a dense plant cover on the top of the dump, but relatively sparse on the slopes, which probably could be the result of landslides and wind erosion.

The reclamation interventions, which were carried out on this dump, should be considered as unsuccessful, because there are only a few individuals of tree species previously planted there. Many of these species have weakened condition and no possibilities to spread effectively within the dump. Most of the introduced species do not correspond to soil conditions (e.g. *Eleagnus angustifolia*, *Cornus alba, Rhus typhina*). As a result, these species gradually disappear, while the native species spontaneously spread within the heap. Finally, the species diversity is much lower on the H2 spoil heap compared to H1, although the heap H2 is 9 years older.

CONCLUSIONS

1. The composition of the vascular flora on the investigated dumps is quite rich despite unfavourable habitat conditions. A total of 257 species was recorded.
2. Different habitat conditions and reclamation interventions (carried out on the H2 dump) have decided that only 36% of the species are common to both sites.
3. Post-industrial dumps have specific habitat conditions resulting in a unique composition of species. The most frequent species which can be found on the investigated post-industrial dumps are: *Betula pendula*, *Calamagrostis epigeios*, *Cardaminopsis arenosa*, *Deschampsia caespitosa*, *Lotus corniculatus*, *Pinus sylvestris*, *Populus tremula*, *Reseda lutea*. Therefore, some species can be considered as specific for various kinds of post-industrial dumps.
4. The native species are the dominant group (71.1%). Apophytes should be considered as a group that has the greatest ability to spread into anthropogenic habitats, such as post-industrial spoil heaps. The proportion of anthropophytes is much lower.
5. Hemicryptophytes are the dominant group. The proportion of therophytes is also noticeable – this confirms their role as a pioneer species in anthropogenic habitats.
6. Plant communities in the vicinity of the dumps have a major impact on the composition of flora. Consequently, ruderal and meadow species dominate on both sites. It is also noteworthy that there are many grassland species. This is due to the fact that the examined heaps are open and well insolated habitats, which is favourable for the development of thermophilic vegetation.
7. The reclamation interventions have a significant impact on the rate of the plant cover formation and species diversity. Poorly planned reclamation and inappropriate selection of plant species can lead to a slower development of plant cover.

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FLORA NACZYNIOWA TERENÓW SKAŻONYCH METALAMI CIĘŻKIMI NA PRZYKŁADZIE DWÓCH ZWAŁÓW POPRZEMYSŁOWYCH PO PRZERÓBCE RUD CYNKU I OŁOWIU NA GÓRNYM ŚLĄSKU

Praca prezentuje wyniki badań florystycznych prowadzonych na obszarze zwałowisk poprzemysłowych związanych z przeróbką rud cynku i ołowiu Zakładów Górniczo-Hutniczych „Orzeł Biały”. W trakcie badań, obejmujących dwa sezony wegetacyjne (2008 i 2009), na każdym z obiektów odnotowywano występowanie gatunków roślin, uwzględniając przeciętną liczebność osobników danego gatunku. Florę badanych obiektów analizowano pod kątem grup geograficzno-historycznych oraz przynależności syntaksonomicznej gatunków. Dla każdego gatunku określono formę życiową wg klasyfikacji Raunkiaera, sposób dyspersji nasion oraz

preferencje mikoryzowe gatunków na podstawie literatury. Na obydwu zwałowiskach stwierdzono łączne występowanie 257 gatunków roślin naczyniowych, należących do 59 rodzin. Gatunków wspólnych dla obydwu zwałów odnotowano 92, co stanowi tylko 36% łącznej flory badanych obiektów. Najliczniej reprezentowanymi rodzinami są *Asteraceae* (45 gat.) i *Poaceae* (28 gat.). Dominującą grupą we florze zwałowisk są gatunki rodzime (apofity) (70,9%). Największy udział mają hemikryptofity. Zaznacza się także wyraźny udział terofitów. Najliczniej reprezentowane są gatunki ruderalne (z klas *Artemisietea vulgaris* i *Stelarietea mediae*) oraz łąkowe (z klasy *Molinio-Arrhenatheretea*). Godny uwagi jest również duży udział gatunków ciepłolubnych (z klasy *Festuco-Brometea*), który wiąże się ze specyficznymi warunkami siedliskowymi. W składzie flory zwałowisk dominują gatunki anemochoryczne. Udział roślin mikoryzowych jest wysoki. Praca zawiera również ocenę zabiegów rekultywacyjnych prowadzonych na jednym ze zwałowisk (H2).