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ECOLOGICAL FEATURES OF SPONTANEOUS VASCULAR FLORA OF SERPENTINE POST-MINING SITES IN LOWER SILESIA

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Abstract: The aim of this study was to determine the ecological characteristics of vascular plants colonizing serpentine mining waste dumps and quarries in Lower Silesia. The investigated flora was analyzed with regard to species composition, geographical-historical status, life forms, as well as selected ecological factors, such as light and trophic preferences, soil moisture and reaction, value of resistance to increased heavy metals content in the soil, seed dispersal modes and occurrence of mycorrhiza. There were 113 species of vascular plants, belonging to 28 families, found on seven sites in the study. The most numerous families were Asteraceae, Poaceae, Fabaceae and Caryophyllaceae. Only 13% of all plants recorded occurred on at least five of the study sites. The most numerous were species related to dry grassland communities, particularly of the Festuco-Brometea class, which included taxa endangered in the region of Lower Silesia: *Avenula pratensis*, *Salvia pratensis*, *Festuca valesiaca*. Apophytes dominated in the flora of the investigated communities. Hemicryptophytes were the most numerous group and therophytes were also abundant. The serpentine mining waste dumps and querries hosted heliophilous species which prefer mesic or dry habitats moderately poor in nutrients, featuring neutral soil reaction. On two study sites 30% of the flora composition consisted of species that tolerate an increased content of heavy metals in the soil. Anemochoric species were the most numerous with regard to types of seed dispersal. Species with an arbuscular type of mycorrhiza were definitely dominant in the flora of all the study sites, however, the number of nonmycorrhizal species was also relatively high. It was suggested that both the specific characteristics of the habitats from serpentine mining and the vegetation of adjacent areas had a major impact on the flora composition of the communities in the investigated sites.

INTRODUCTION

The Sudetes, the Sudetes Foothills and Foreland, due to their varied geological formation and history, are one of richer in mineral resources regions of Poland – there can be found, among others, the largest occurrence of igneous rocks in our country, which have been mined for centuries. Some of the most interesting types of rock formations are the serpentines, which are present only in this region of Poland. These rocks form the southern part of the Ślęża Massif, a range of hills that extends from Gogołów in the west to Jordanów Śląski in the east. There are also lesser areas with serpentine rock outcrops in the Owl Mountains and in the region of Ząbkowice Śląskie. Plant communities occurring on serpentines feature distinct flora and, therefore, serpentine soils and their natural vegetation were the subject of ecological and floristic studies [7, 36, 42, 53, 58, 59].

Mining rock material has a profound impact on the surrounding environment. It creates transformational changes in the habitats and leads to the creation of waste dumps, mining pits or quarries. These areas often have high conservation potential, enabling documentation of geological facts and phenomena, or serving as a refuge for rare or protected species of flora and valuable phytocenoses [24, 44, 45]. As man-transformed sites, they provide habitats for the development of synantropic vegetation, as well as become secondary habitats for the species migrating from endangered natural and semi-natural communities. Dumps and pits from mining are excellent sites for studying the processes occurring in the course of spontaneous succession, connected with, for example, the establishment of species with specific adaptations or the development of phytocenoses [15, 20, 21, 22, 44, 51].

As habitats for plants development, waste dumps and quarries from serpentine mining feature a combination of unfavorable properties known as the serpentine complex resulting from specific traits of serpentine weathered rocks [14, 21, 40, 52, 59, 60]. Both weathered bedrocks and serpentine soils are characterized by: plate thickness, xerism, low richness in basic nutrients along with a high concentration of magnesium, often exceeding the optimal level for plants, and high concentrations of heavy metals, mainly nickel, chromium and cobalt, as well as a high pH value [3, 8, 9, 10, 22, 26, 42, 60]. The properties of serpentine bedrocks can govern the process of spontaneous succession and reduce the pool of plant species that are able to colonize them.

The aim of this study was to provide the ecological characteristics of vascular flora, spontaneously colonizing in the early stages of succession, the waste dumps and quarries from serpentine mining in Lower Silesia.

MATERIAL AND METHODS

Study sites

The investigation was conducted on seven sites associated with the mining of serpentine deposits in the area of Lower Silesia; distribution of the sites presents Fig. 1.

The serpentine open-pit mine in Nasławice is located in the Gogołów-Jordanów serpentine massif, in the north-western part of the Kamienny Grzbiet Ridge, east of Sobótka. Serpentine rock is deposited there under a series of the Quaternary rocks, formed as clay, partly mixed with rock rubble and weathered rocks [5, 23]. The research was conducted at the excavation site, on the southwest and west slopes of the quarry and the adjacent serpentine waste dumping ground. Here, the spontaneously establishing vegetation develops on weathered rock and rock debris. Large angle of inclination causes the fact that the slopes of the mining pit are susceptible to erosion, which hinders natural succession.

The magnesite mine in Wiry is situated south–west of Sobótka. There were mined magnesite deposits, located in the western part of the Gogołów-Jordanów serpentine massif. In direct vicinity of the underground mine a serpentine-magnesite waste dump was accumulated with steep slopes and a flat, leveled top surface. The research plots were located on the slopes of east exposition and a part of the plateau covered with herbaceous vegetation. The substrate was characterized by a gravel-sandy texture.

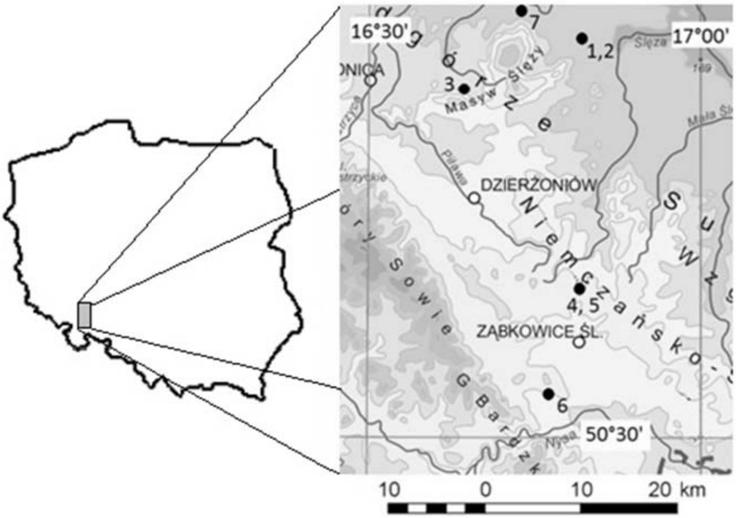

Fig. 1. Distribution of the study sites. 1, 2 – Nasławice quarry and dumps; 3 – Wiry dumps; 4 – Szklary dumps and quarry; 6 – Grochowa dumps; 7 – Sobótka dump

The surface mine of nickel ores in Szklary is located on an uplift of land, called Szklana Góra Mountain, north of Ząbkowice Śląskie. Here, deposits were mined belonging to the Szklary serpentine massif. On the mined area there are numerous steep dumps, formed to accumulate mine overburden and waste rock poor in nickel ore. The investigation was carried out on the south-expose slopes of the serpentine waste dumps, characterized by a slightly accentuated process of soil formation and poor vegetation covering.

A small quarry is situated near the nickel ore mine in Szklary, on the northwest side of Szklana Góra Mountain. The research plots were on the southern and western slopes of the stone pit where spontaneous vegetation colonized small ledges, weathered rock and rock rubble.

The serpentine waste dump in Grochowa was accumulated as a result of the magnesite mining from deposits in the region of the Grochowa Massif. The dump covers an area of approximately 36 hectares and is situated near the magnesite mining operation. The spontaneously succeeding vegetation develops there on weathered rock and rock debris. The investigation was conducted on the dump slopes of southern exposition and on the plateau area.

The serpentine waste dump in Sobótka is a small dump localized by worked out magnesite deposits, in the region of Gogołów-Jordanów serpentine massif. Weathered rock and rock rubble constitute the substrate for plants development. The research plots were situated on the slopes of southern exposition and the plateau part of the serpentine waste dump.

All the study sites were characterized by a low rate of spontaneous succession and after several dozen years of overgrowing the succession represents the colonization stage with vegetation not completely covering the site area.

Features of flora

The study was conducted during two growing seasons in 2009 and 2010. At each of the study sites fragments of ground was chosen for examination, uniform in shape and surface area as well as visible soil properties and covered with sward vegetation representing the early stages of succession. The areas of the research plots ranged from approximately 15 to 100 m^2. Within each of the plot there were sampled 3 to 5 randomly selected relevés of 1 m^2 area. The number of the plots at each study sites depended on its size and diversity of phytocenoses. The species recorded in all the relevés were presented in a table form in alphabetical order using the same nomenclature as in the list of Mirek et al. [28]. Flora was analyzed in the view of division into geographical–historical groups, following the classification by Kornaś [19], on the basis of works by Zając and Zając [54], Zając and Zając [55], Zając et al. [56]. To each species Raunkiaer's life form was assigned as well as the values of the following indicators: light, moisture, trophism, soil acidity and resistance to heavy metals according to Zarzycki et al. [57]. Species were analyzed as belonging to the ecological-habitat groups and classes of plant communities based on Matuszkiewicz [27]. According to data available in the literature, classification of species was done regarding the seed dispersal types [4, 29, 38].

At each site, apart from floristic studies, investigations of the mycorrhizal status of plants were carried out and 52 plant species in total were analyzed for mycorrhizal colonization. In the case of the remaining species, their mycorrhizal status was determined on the basis of literature data [12, 16, 50]. For the mycorrhizal investigation, samples of roots were collected from the rhizosphere (usually from the depth 5–15 cm). The samples were collected from at least 5 individuals of the surveyed species. The roots were prepared according to the modified Philips and Hayman method [33] using 0.1% trypan blue in lactoglycerol.

RESULTS

The list of vascular plans species recorded on the serpentine mining dumps and quarries together with the ecological characteristics of the taxa are presented in Table 1.

The flora colonizing the study sites amounted, in total, to 113 species of vascular plants representing 28 families. The highest number of species was recorded on the slopes of the Nasławice mine pit (67 species), while the floristically poorest areas were the waste dumps of the nickel mine in Szklary, which were inhabited merely by 28 species. The most numerous families were Asteraceae (20%), Fabaceae (15%), Poaceae (14%) and Caryophyllaceae (8%).

Only 15 species (approximately 13%) of the analyzed flora were present at a total of five or more of the study sites: *Arrhenatherum elatius*, *Calamagrostis epigejos*, *Festuca ovina*, *Koeleria macrantha*, *Poa compressa*, *Lotus corniculatus*, *Trifolium arvense*, *Achillea millefolium*, *Artemisia vulgaris*, *Scabiosa ochroleuca*, *Silene vulgaris*, *Daucus carota*, *Galium verum*, *Thymus pulegioides* and *Hypericum perforatum*. There were also species that were found at only one site. The largest number of that type of taxa with very low frequency was recorded on the slopes of the Nasławice mine pit and on the dumping site in Sobótka.

In the composition of the flora, the most numerously represented were species of dry grasslands communities (26%) from the *Festuco-Brometea* class (Fig. 1). A large group

Table 1. List of vascular flora species of the study sites with their ecological characteristics

Ghg – historical-geographical status: Ap – apophyte, Ar – archeophyte, Kn – kenophyte; Rlf – Raunkiaer's life form: C – chamaephyte, G – geophyte, H – hemicryptophyte, M – Megaphanerophyte, N – nanophanerophyte, li – liana, T – therophyte; Cl – phytosociological class; a – anemochory, z – zoochory, an – anthropochory, au – autochory, hy – hydrochory; M – value of resistance to heavy metal content in the soil: 1 – species tolerating an increased content; (Zarzycki et al. 2002)

No.	Species	Ghg	Rlf	Cl	Nasławice quarry [1]	Nasławice dumps [2]	Wiry dumps [3]	Szklary dumps [4]	Szklary quarry [5]	Grochowa dumps [6]	Sobótka dump [7]	Disperrsal type	M
1	*Achillea millefolium* L.	Ap	H	*Mol-Arr*	+	+	+		+	+	+	a(z)	
2	*Agrostis capillaris* L.	Ap	H	*Mol-Arr*			+				+	a(z)	
3	*Agrostis stolonifera* L.	Ap	H	*Mol-Arr*							+	a(z)	1
4	*Alyssum alyssoides* (L.) L.	Ap	T	*Fest-Brom*				+				z	
5	*Amaranthus retroflexus* L.	Kn	T	*Stel med*							+	a(z)	
6	*Anthyllis vulneraria* L.	Ap	H	*Fest-Brom*	+	+			+	+		a(z)	
7	*Apera spica-venti* (L) P.Beauv.	Ar	T, H	*Stel med*						+		a(z)	
8	*Arabidopsis thaliana* (L.) Heynh.	Ap	T	*Stel med*	+			+	+			a	
9	*Arenaria serpyllifolia* L.	Ap	T	*Fest-Brom*	+	+		+			+	a(z)	
10	*Arrhenatherum elatius* (L.) P.Beauv. ex. J.Presl & C. Presl	Ap	H	*Mol-Arr*	+	+	+	+	+		+	a	1
11	*Artemisia vulgaris* L.	Ap	H	*Artemi*	+	+	+		+		+	a(z)	
12	*Avenula pratensis* (L.) Dumort.	Ap	H	*Fest-Brom*	+	+			+			a	
13	*Barbarea vulgaris* R. Br.	Ap	H	*Artemi*	+	+		+				a(z)	
14	*Betula pendula* Roth seedlings	Ap	M	*Que rob*			+	+		+		a(z)	
15	*Bromus erectus* Huds.	Ap	H	*Fest-Brom*						+		a	
16	*Calamagrostis epigejos* (L.) Roth	Ap	G, H	*Epilob*	+	+	+	+		+	+	a	1
17	*Camelina microcarpa* subsp. *sylvestris* (Wallr.) Hiitonen	Ap	H	*Fest-Brom*	+							an	

Table 1. List of vascular flora species of the study sites with their ecological characteristics – cont.

Ghg – historical-geographical status: Ap – apophyte, Ar – archeophyte, Kn – kenophyte; Rlf – Raunkiaer's life form: C – chamaephyte, G – geophyte, H – hemicryptophyte, M – Megaphanerophyte, N – nanophanerophyte, li – liana, T – therophyte; Cl – phytosociological class; a – anemochory, z – zoochory, an – anthropochory, au – autochory, hy – hydrochory; M – value of resistance to heavy metal content in the soil: 1 – species tolerating an increased content; (Zarzycki et al. 2002)

No.	Species	Ghg	Rlf	Cl	Nasławice quarry [1]	Nasławice dumps [2]	Wiry dumps [3]	Szklary dumps [4]	Szklary quarry [5]	Grochowa dumps [6]	Sobótka dump [7]	Disperrsal type	M
18	*Campanula patula* L.	Ap	H	*Mol-Arr*							+	a	
19	*Campanula rotundifolia* L.	Ap	H	*Fest-Brom*	+	+				+		a	1
20	*Capsella bursa pastoris* (L.) Medik	Ar	H, T	*Stel med*							+	a(an)	
21	*Cardaminopsis arenosa* (L.) Hayek	Ap	H	*Koel-Coryn*				+				a	1
22	*Carlina vulgaris* L.	Ap	H, T	*Fest-Brom*	+		+		+	+		a	1
23	*Centaurea scabiosa* L.	Ap	H	*Fest-Brom*	+	+						a(z)	
24	*Centaurea stoebe* L.	Ap	H	*Fest-Brom*	+		+	+		+		a	
25	*Cerastium arvense* L.	Ap	C	*Koel-Coryn*	+	+					+	a	1
26	*Chenopodium album* L.	Ap	T	*Stel med*	+	+						z	
27	*Cichorium intybus* L.	Ar	H	*Artemi*							+	a(z)	1
28	*Cirsium arvense* (L.) Scop.	Ap	G	*Stel med*						+	+	a(z)	
29	*Convolvulus arvensis* L.	Ap	G, H, li	*Fest-Brom*	+	+		+				z(an)	
30	*Daucus carota* L.	Ap	H	*Mol-Arr*	+	+	+	+	+	+	+	a(z)	
31	*Dianthus carthusianorum* L.	Ap	C	*Fest-Brom*	+	+			+		+	a	
32	*Echium vulgare* L.	Ap	H	*Artemi*	+	+				+		z(an)	
33	*Euphorbia cyparissias* L.	Ap	G, H	*Fest-Brom*	+	+					+	au(z)	
34	*Euphrasia rostkoviana* Hayne	Ap	T	*Mol-Arr*						+		a	

35	*Fallopia convolvulus* (L.) Á. Löve	Ar	T, H	*Stel med*	+							a(z)	
36	*Festuca ovina* L.	Ap	H	*Koel-Coryn*	+		+	+	+	+	+	a	1
37	*Festuca valesiaca* Schleich. ex Gaudin	Ap	H	*Fest-Brom*		+						a	
38	*Filago arvensis* L.	Ap	T	*Koel-Coryn*	+	+						a	
39	*Filipendula vulgaris* Moench	Ap	H	*Fest-Brom*	+	+						a	
40	*Galium aparine* L.	Ap	T, H	*Stel med*	+							z	
41	*Galium mollugo* L.	Ap	H	*Mol-Arr*			+					z	
42	*Galium verum* L.	Ap	H	*Fest-Brom*	+	+	+	+	+	+	+	z	
43	*Genista tinctoria* L.	Ap	C	*Nard-Cal*						+		au	
44	*Geranium pratense* L.	Ap	H	*Mol-Arr*							+	a	
45	*Hieracium caespitosum* Dumort.	Ap	H	*Mol-Arr*	+	+	+					a	
46	*Hieracium echioides* Lumn.	Ap	H	*Fest-Brom*				+	+			a	
47	*Hieracium pilosella* L.	Ap	H	*Koel-Coryn*	+	+					+	a	
48	*Hieracium piloselloides* Vill	Ap	H	*Fest-Brom*			+					a	
49	*Hieracium sabaudum* L.	Ap	H	*Que rob*	+		+					a	
50	*Holosteum umbellatum* L.	Ap	H	*Koel-Coryn*					+			a	
51	*Hypericum perforatum* L.	Ap	H	*Fest-Brom*	+	+	+	+	+	+		a(z)	
52	*Koeleria macrantha* (Ledeb.) Schult.	Ap	H	*Fest-Brom*	+	+		+	+	+		a	
53	*Lathyrus sylvestris* L.	Ap	H	*Trif-Ger*						+		au(an)	
54	*Leontodon hispidus* L	Ap	H	*Mol-arr*						+		a	1
55	*Lepidium campestre* (L.) R.Br.	Ap	T	*Artemi*				+				an	
56	*Linaria vulgaris* Mill.	Ap	G	*Artemi*	+	+	+					a(z,an)	
57	*Lotus corniculatus* L.	Ap	H	*Mol-Arr*	+	+	+	+	+	+	+	au(z)	1
58	*Medicago lupulina* L.	Ap	H, T	*Artemi*	+							z	

Table 1. List of vascular flora species of the study sites with their ecological characteristics – cont.

Ghg – historical-geographical status: Ap – apophyte, Ar – archeophyte, Kn – kenophyte; Rlf – Raunkiaer's life form: C – chamaephyte, G – geophyte, H – hemicryptophyte, M – Megaphanerophyte, N – nanophanerophyte, li – liana, T – therophyte; Cl – phytosociological class; a – anemochory, z – zoochory, an – anthropochory, au – autochory, hy – hydrochory; M – value of resistance to heavy metal content in the soil: 1 – species tolerating an increased content; (Zarzycki et al. 2002)

No.	Species	Ghg	Rlf	Cl	Nasławice quarry [1]	Nasławice dumps [2]	Wiry dumps [3]	Szklary dumps [4]	Szklary quarry [5]	Grochowa dumps [6]	Sobótka dump [7]	Disperrsal type	M
59	*Medicago sativa* L.	Kn	H	*Artemi*							+	z	
60	*Melandrium album* (Mill.) Garcke	Ap	T, H	*Artemi*	+						+	a	
61	*Melilotus alba* Medik.	Ap	T, H	*Artemi*	+		+			+	+	au(an)	
62	*Melilotus officinalis* (L.) Pall.	Ap	T, H	*Artemi*			+				+	au(an)	
63	*Papaver dubium* L.	Ar	T	*Stel med*	+							a(an)	
64	*Papaver rhoeas* L.	Ar	T	*Stel med*	+							a(an)	
65	*Pastinaca sativa* L.	Ap	H	*Mol-Arr*	+	+	+					a(an)	
66	*Phleum phleoides* (L.) H. Karst.	Ap	H	*Fest-Brom*	+				+			a	
67	*Phleum pratense* L.	Ap	H	*Mol-Arr*						+		a	
68	*Pimpinella saxifraga* L.	Ap	H	*Fest-Brom*					+			a(an)	
69	*Pinus sylvestris* L. seedlings	Ap	M	*Vac-Pic*			+	+		+		a(z)	
70	*Plantago lanceolata* L.	Ap	H	*Mol-Arr*					+		+	z	
71	*Plantago media* L.	Ap	H	*Fest-Brom*						+		z	
72	*Poa compressa* L.	Ap	H	*Fest-Brom*	+	+	+	+	+		+	a	
73	*Poa palustris* L.	Ap	H	*Mol-Arr*	+							a	
74	*Poa pratensis* L.	Ap	H	*Mol-Arr*	+	+	+					a	
75	*Polygonum aviculare* L.	Ap	T	*Stel med*	+	+						z	
76	*Potentilla argentea* L.	Ap	H	*Koel-Coryn*	+	+					+	a	

77	*Potentilla heptaphylla* L.	Ap	H	*Fest-Brom*	+				+			a	
78	*Potentilla erecta* L.	Ap	H	*Nard-Cal*						+		a	
79	*Ranunculus polyanthemos* L.	Ap	H	*Mol-Arr*	+							a	
80	*Reseda lutea* L.	Ap	H	*Artemi*			+					a(z)	
81	*Rosa arvensis* L.	Ap	N	*Rha-Prun*							+	z	
82	*Rumex acetosella* L.	Ap	G, H, T	*Mol-Arr*	+						+	a(z)	
83	*Rumex crispus* L.	Ap	H	*Mol-Arr*	+	+						a(z)	
84	*Salvia pratensis* L.	Ap	H	*Koel-Coryn*	+	+					+	a(z)	
85	*Saxifraga granulata* L.	Ap	H	*Mol-Arr*				+	+			a	
86	*Scabiosa ochroleuca* L.	Ap	H	*Fest-Brom*	+	+		+	+	+		a	1
87	*Scleranthus perennis* L.	Ap	C, H	*Koel-Coryn*	+	+						z	
88	*Sedum acre* L.	Ap	C	*Koel-Coryn*				+	+		+	hy(an)	
89	*Sedum maximum* (L.) Hoffm.	Ap	G, H	*Fest-Brom*	+							hy(an)	
90	*Senecio vernalis* Waldst.& Kit	Kn	H, T	*Koel-Coryn*			+					a	
91	*Senecio viscosus* L.	Ap	T	*Stel med*	+						+	a	
92	*Silene nutans* L.	Ap	H	*Trif-Ger*				+	+			a(z)	
93	*Silene vulgaris* (Moench) Garcke	Ap	C, H	*Stel med*			+	+	+	+	+	a(z)	1
94	*Solidago canadenis* L.	Kn	G, H	*Artemi*			+					a	
95	*Sonchus oleraceus* L.	Ar	H, T	*Stel med*			+					a(an)	
96	*Spergularia rubra* (L.) J.Presl & C. Presl	Ap	H, T	*Koel-Coryn*	+							z	
97	*Tanacetum vulgare* L.	Ap	H	*Artemi*	+	+		+				a	
98	*Taraxacum officinale* F. H. Wigg	Ap	H	*Mol-Arr*			+				+	a(z)	

Table 1. List of vascular flora species of the study sites with their ecological characteristics – cont.

Ghg – historical-geographical status: Ap – apophyte, Ar – archeophyte, Kn – kenophyte; Rlf – Raunkiaer's life form: C – chamaephyte, G – geophyte, H – hemicryptophyte, M – Megaphanerophyte, N – nanophanerophyte, li – liana, T – therophyte; Cl – phytosociological class; a – anemochory, z – zoochory, an – anthropochory, au – autochory, hy – hydrochory; M – value of resistance to heavy metal content in the soil: 1 – species tolerating an increased content; (Zarzycki et al. 2002)

No.	Species	Ghg	Rlf	Cl	Nasławice quarry [1]	Nasławice dumps [2]	Wiry dumps [3]	Szklary dumps [4]	Szklary quarry [5]	Grochowa dumps [6]	Sobótka dump [7]	Disperrsal type	M
99	*Thlaspi arvense* L.	Ar	T, H	*Stel med*	+	+						a(an)	
100	*Thymus pulegioides* L.	Ap	C	*Fest-Brom*	+	+		+	+	+	+	a(z)	
101	*Trifolium arvense* L.	Ap	T	*Koel-Coryn*	+	+	+		+		+	a	
102	*Trifolium campestre* Schreb.	Ap	T	*Koel-Coryn*			+		+			a	
103	*Trifolium dubium* Sibth.	Ap	T	*Mol-Arr*						+		a(z)	
104	*Trifolium pratense* L.	Ap	H	*Mol-Arr*			+				+	a(z)	
105	*Verbascum thapsus* L.	Ap	H	*Artemi*	+	+		+				a	
106	*Veronica chamaedrys* L.	Ap	C	*Mol-Arr*							+	a	
107	*Vicia angustifolia* L.	Ap	T	*Stel med*	+							au	
108	*Vicia cracca* L.	Ap	H	*Mol-Arr*	+							au(z)	
109	*Vicia hirsuta* (L.) S.F.Gray	Ar	T	*Stel med*	+							au(z)	
110	*Vicia sativa* L.	Ar	T	*Stel med*	+	+						au	
111	*Vicia tetrasperma* (L.) Schreb.	Ar	T	*Stel med*	+	+						au	
112	*Viola arvensis* Murray	Ar	T	*Stel med*	+				+			z	
113	*Viscaria vulgaris* Röhl.	Ap	C, H	*Fest–Brom*	+	+			+		+	a	

was also formed by meadow plants from the *Molinio-Arrhenatheretea* class (21%). There was a smaller share of segetal species from the *Stellarietea mediae* class (approximately 17%) and ruderal species from the *Artemisietea* class (about 14%). The share of xeric sand grassland taxa from the *Koelerio-Corynephoretea* class ranged 11%. Among the representatives of the *Festuco-Brometea* class there were present species rarely occurring in Lower Silesia, namely: *Avenula pratensis*, *Salvia pratensis*, *Festuca valesiaca*.

Species of native origin – apophytes – clearly dominated the composition of the analyzed flora, representing about 85% of all the species (Fig. 2). The second most numerous group involved archeophytes, whose share ranged nearly 11% of the total flora. Kenophytes occurred scarcely (about 4%) and they were found only on the waste dumps in Wiry and Sobótka.

Among life forms, according to the Raunkiaer's classification, the prevailing species were hemicryptophytes, constituting 58% of the flora composition (Fig. 3). The second largest group was formed by therophytes (24%). The species representing the remaining life forms proved to occur in small numbers.

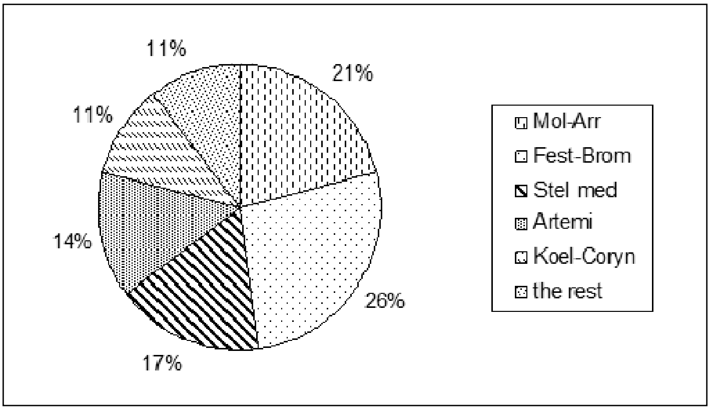

Fig. 2. Participation [%] of phytosociological classes in the flora of the study sites

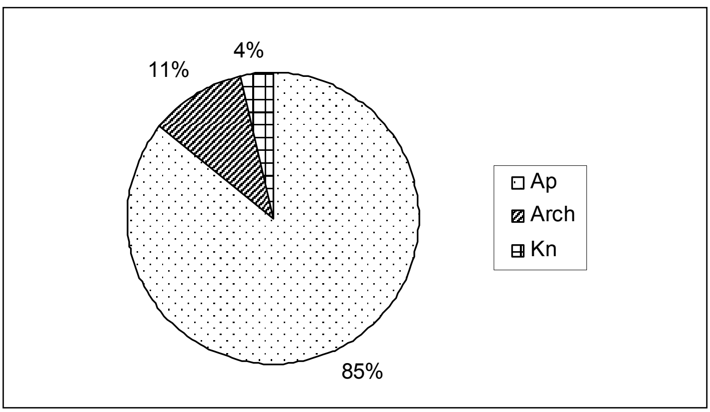

Fig. 3. Participation [%] of historical-geographical groups in the flora of the study sites. Ap – apophytes, Ar – archeophytes, Kn – kenophytes

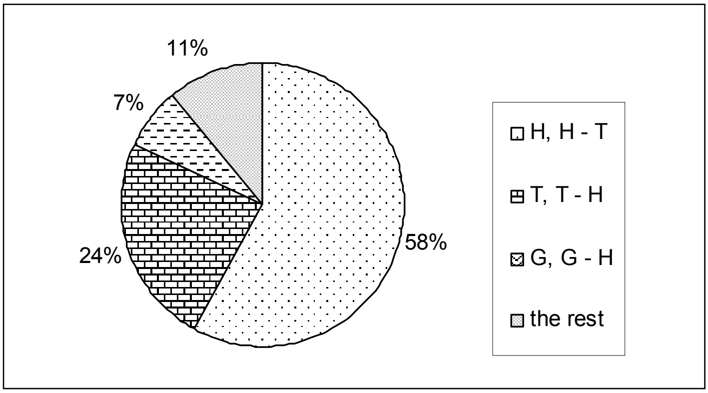

Fig. 4. Percentage of Raunkiaer's life forms in the flora of the study sites.
H – hemicryptophytes, T – therophytes, G – geophytes

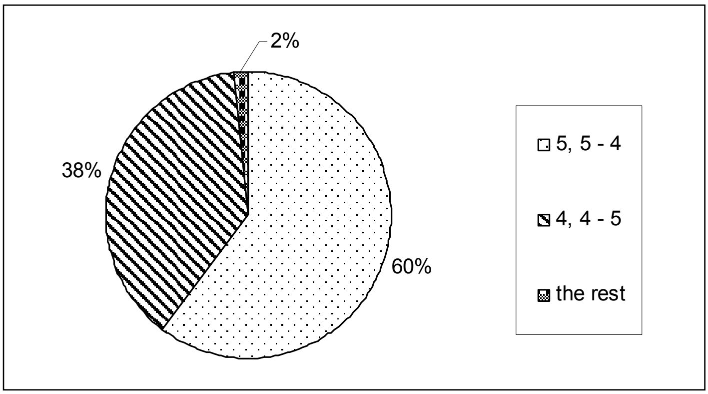

Fig. 5. Participation [%] of species representing a particular value of the light indicator (L), values after Zarzycki et al. (2002)

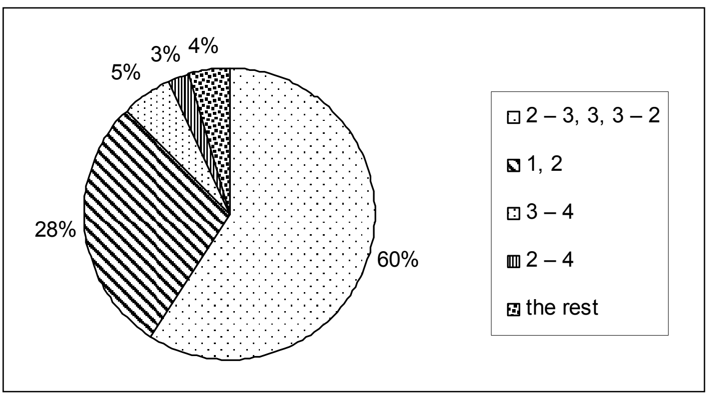

Fig. 6. Participation [%] of species representing a particular value of the soil moisture indicator (W), values after Zarzycki et al. (2002)

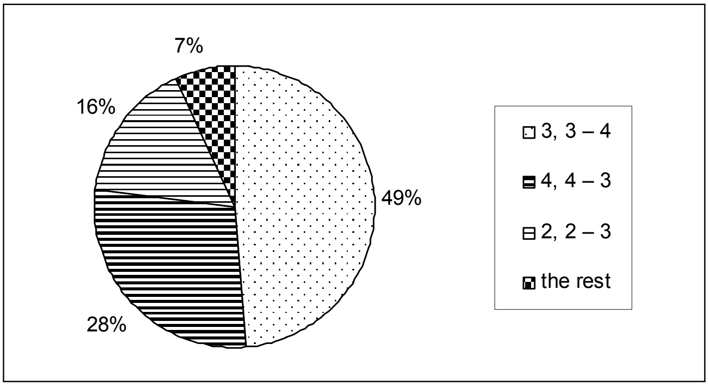

Fig. 7. Participation [%] of species representing a particular value of the trophy indicator (Tr), values after Zarzycki et al. (2002)

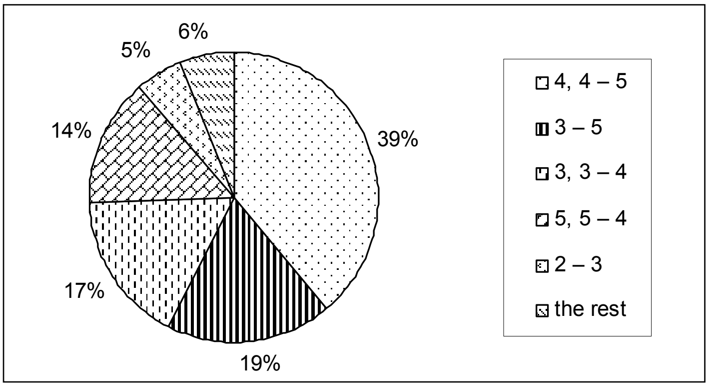

Fig. 8. Participation [%] of species representing a particular value of the soil acidity (pH) indicator (R), values after Zarzycki et al. (2002)

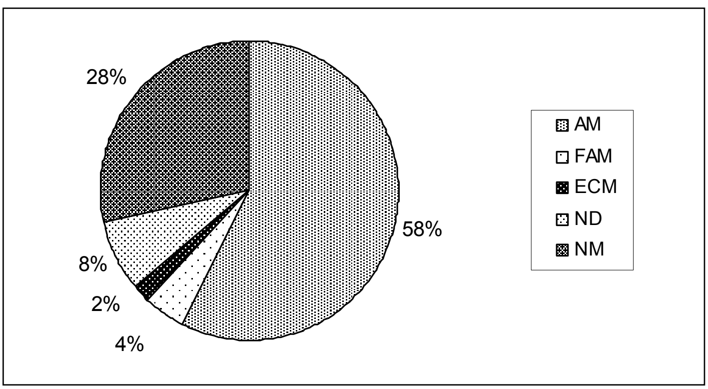

Fig. 9. Participation [%] of mycorrhizal and nonmycorrhizal plant species in the flora of the study sites based on authors' and literature data. AM – arbuscular mycorrhiza, FAM – facultative arbuscular mycorrhiza, ECM – ectomycorrhiza; ND – not data available, NM – nonmycorrhizal species

An analysis of the habitat requirements showed that nearly all of the species colonizing the study sites are either the ones requiring moderate or full light (heliophilous) (Fig. 4). In terms of soil moisture requirements the dominant were species that prefer mesic habitats (60%) and the second most numerous group was formed by xerophilous plants (28%) (Fig. 5). The most common (49% of the flora composition) were species of soils moderately poor in nutrients (mesotrophic) (Fig. 6). A considerably large group (28%) consisted of species preferring eutrophic soils, while relatively numerous taxa were the once adapted to oligothrophic habitats (approximately 16%). Regarding the soil acidity requirements (Fig. 7) the largest group (39 %) was made up of species inhabiting neutral soils. The share of species growing on moderately acidic and alkaline soils amounted 17% and 14% respectively. Many taxa featured a wide range of soil pH tolerance (19%).

Species that tolerate an increased content of heavy metals in the soil constituted approximately 12% of the total flora colonizing the study sites (Table 1). However, the dumps at Wiry and Grochowa were distinguished by a higher share of these species, ranging about 30%.

Taking into account the modes of seed dispersal, the flora of the study sites showed definite dominance of allochoric species, about 90% (Table 1). Within this group anemochoric plants were the most predominant and the share of exclusively anemochoric taxa amounted over 40%. Species spreading both in anemochoric and zoochoric way constituted nearly 24% of the flora composition. The least numerous were taxa which use only animals in order to transport their seeds (about 12%).

Investigation of the mycorrhizal status of the flora of serpentine post-mining sites showed the dominance of mycorrhizal species (64%) (Fig. 8). The most numerous group were the species with an arbuscular type of mycorrhiza (62%), including 5 species belonging mainly to the Poaceae family which were facultatively mycorrhizal. Ectomycorrhizal species constituted only about 2% of the flora. A large share of the analyzed flora consisted of nonmycorrhizal species (28%). Included in this group were mostly representatives of Caryophyllaceae, Brassicaceae and Polygonaceae families.

DISCUSSION

Vegetation of serpentine mining waste dumps and quarries developed in a course of spontaneous succession on a bare substrate without soil and plant cover and which had been made as a result of human activities. In such conditions the process of inhabiting and colonization generally proceeds slowly. This definitely affected the quantity of plant species recorded in the study, since on all of the sites the species created communities of the early stages of ecological succession. Additionally, aspects of the serpentine complex, the most significant of which were considered to be excessive values of magnesium and nickel content in the substrate, had a reducing impact on the species richness in the developing plant communities [59]. As a consequence, the flora of serpentine post-mining sites proved to be relatively poor (113 species) in comparison to the vegetation of other post- industrial sites [34, 35, 38, 41]. According to Rostański [34] on heaps located in Upper Silesia, the number of colonizing taxa depended mainly on the source of diaspores and the substrate properties as well as the age of the site, i.e. the stage of succession. In research done by Stojanowska [41], conducted on the area of different quarries of Lower Silesia, it was reported that the number of species was dependent on the size of the site, and the higher number of taxa was found in the bigger quarries.

Flora of the serpentine post-mining sites was characterized by a high degree of diversity, which was reflected in a low rate of incidence of the majority of species at particular sites. This phenomenon could result from the variability of the properties of serpentine rocks and soils and the spatial isolation of most of the sites. The most often recorded and at the same time the most numerously represented in the flora were species of dry grasslands communities from the *Festuco-Brometea* class, while definitely minor role was played by segetal or ruderal species. This structure of the examined communities indicates their floristic similarity to the semi-natural grasslands which develop on serpentines [59] and at the same time distinguishes them from the phytocenoses of other post–industrial sites connected with, for example, coal mining which are most often dominated by ruderal species [30, 35, 37, 38].

Flora of the study sites contained many valuable species including first of all taxa occuring on the red list of vascular plants of Lower Silesia [17, 18, 47]. The group of endangered or vulnerable species included: *Avenula pratensis*, *Camelina microcarpa*, *Salvia pratensis* and *Festuca valesiaca*. The last taxon should be treated as the most unique floristic specimen, whose occurrence was confirmed in Lower Silesia only in the region of Kamienny Grzbiet Ridge [46, 47]. The source of diaspores of species of dry grasslands for the study sites could be neighboring, sometimes even small patches of semi-natural communities developed on the serpentines which had not been disturbed by the raw material mining.

A predominance of apophytes is often confirmed in research conducted on man-transformed sites [15, 30, 34, 35, 43]. The phenomenon of the apophytization of the flora as a particular manifestation of synanthropization has already been noted by Faliński [6]. The dominance of native species on typically the synanthropic areas probably results from their better adaptation to the local habitat conditions in relation to species of foreign origin. Among the life forms of plants, hemikryptophytes are the most often found component of the flora of various post-industrial sites [15, 35, 36, 38]. The significant presence of terophytes in the composition of the studied communities indicates the low stability of the habitats and is characteristic for the early stages of succession. The occurrence of a bare substrate without vegetation on the area of the study sites could have favored the settlement of short-term colonizers coming from the agricultural landscape surrounding the serpentine outcrops.

Flora developed in a course of spontaneous succession on the serpentine waste dumps and quarries was well adapted to the properties of the serpentine habitat and consisted mostly of heliophilous species, preferring mesic or dry and moderately poor in nutrients habitats of neutral or alkaline reaction. The presence of species tolerating an increased content of heavy metals in the soil, particularly noted in the sites in Wiry and Grochowa, could result from the properties of serpentine rock, which is rich in metals [21, 22]. Research done by Żołnierz [59], carried out in semi-natural dry grasslands showed that the soils from Szklary and the Grochowa Massif featured the highest nickel content of all the serpentine habitats.

The type of seed dispersal plays an important role in the rate and intensity of the colonization of new areas by particular species [4]. The composition of the flora studied was dominated by anemochoric species, which are able to cover even considerable distances, what favoured migration and colonization of the new areas [4, 38]. The presence of zoochoric species indicates the effective seed dispersal by animals from shorter distances.

The arbuscular type of mycorrhiza commonly occurs in herbaceous plants and can be beneficial, especially in habitats poor in nutrients, by enhancing plant development [39]. The presence of arbuscular mycorrhiza has been recorded for different habitats rich in heavy metals [11, 31, 48] including serpentine substrates and other ultramafic soils [2, 13, 32, 49]. In metal-contaminated soils, benefits derived from mycorrhizal symbiosis range from increased nutrient uptake to improved resistance to heavy metal stress [25]. Noteworthy is the relatively high proportion of nonmycorrhizal species and facultative formation of mycorrhiza by some other species in the flora of the serpentine post-mining sites. These phenomena occur in the early stages of succession, especially in severely disturbed ecosystems devoid of the soil profile and vegetation as well as associated mycorrhizae and are regulated by environmental conditions, i.e. the type of disturbance, nutrient availability and moisture (xerism) of the habitat [1, 16, 37].

The serpentine mining waste dumps and quarries are interesting artificial biotopes that play a considerable role as secondary habitats for species migrating from dry grasslands developed on serpentine rocks. Scarce natural occurrence of the dry grassland communities has become increasingly endangered not only by the mining of raw rock materials but also by the development of tourism, which is particularly true in the Ślęża Massif. After the cessation of mining operation it is necessary to skillfully introduce a sensitive restoration of the serpentine waste dumps and quarries using the process of spontaneous succession.

CONCLUSIONS

1. The spontaneous flora of the serpentine post-mining sites was relatively poor and numbered in total 113 species of vascular plants. The unfavorable characteristics of serpentine substrate could have the reducing effect on the species richness.
2. The flora of the particular sites was highly diverse, since only 13% of the species were found on at least five of the study sites.
3. The most frequently noted and the most numerously represented were species of dry grassland communities from the *Festuco-Brometea* class. This indicates a floristic similarity of the examined communities to the phytocenoses of the semi-natural swards which develop on serpentines. At the same time the floristic composition distinguishes them from the communities of other post-industrial sites that are most often dominated by ruderal species from the *Artemisietea* class.
4. The flora of the serpentine post-mining sites contained rare and endangered species of Lower Silesia, such as *Avenula pratensis*, *Camelina microcarpa*, *Salvia pratensis* and *Festuca valesiaca*.
5. Native species, and in terms of life forms – hemicryptophytes, dominated the flora of the study sites, which is a phenomenon most often noted for spontaneously developing floras on man-transformed habitats.
6. The flora of the serpentine post-mining sites was well adapted to the characteristics of the serpentine habitat and consisted mostly of habitat-specialized taxa, such as heliophilous species which prefer mesic or dry soils, poor in nutrients and with neutral

reaction. The species which tolerate an increased content of heavy metals in the soil were more numerously found at the sites with soils particularly rich in metals.

7. The composition of the studied flora was dominated by anemochoric species, although some taxa were those that are spread only by animals.
8. The species with the arbuscular type of mycorrhiza were predominant in the studied flora. However, the share of nonmycorrhizal species was relatively significant and could be a result of both the early stages of succession and the unfavorable characteristics of the serpentine habitats.
9. The serpentine mining waste dumps and quarries are interesting artificial biotopes which play a significant role as secondary habitats for species migrating from semi--natural dry grasslands developed on serpentines. After the end of mineral extraction it should be necessary to skillfully introduce a sensitive restoration of these sites with using the process of spontaneous succession.

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CHARAKTERYSTYKA EKOLOGICZNA SPONTANICZNEJ FLORY NACZYNIOWEJ OBIEKTÓW POPRZEMYSŁOWYCH ZWIĄZANYCH Z WYDOBYCIEM SERPENTYNITU NA DOLNYM ŚLĄSKU

Celem badań było dokonanie charakterystyki ekolologicznej roślin naczyniowych zasiedlających siedem obiektów, takich jak: zwały odpadów i wyrobiska kamieniołomów związanych z wydobyciem serpentynitu na Dolnym Śląsku. Florę przeanalizowano pod kątem przynależności do grup geograficzno-historycznych. Dla każdego gatunku przyporządkowano formę życiową wg klasyfikacji Raunkiaera oraz wartości wskaźników: świetlnego, wilgotności, trofizmu, kwasowości gleby i odporności na metale ciężkie. Określono sposób dyspersji nasion oraz status mikoryzowy analizowanych gatunków. Na terenie wszystkich obiektów stwierdzono obecność 113 gatunków roślin naczyniowych, należących do 28 rodzin, z których najliczniej reprezentowane były: Asteraceae, Poaceae, Fabaceae i Caryophyllaceae. W składzie flory najczęściej notowane były rośliny muraw kserotermicznych z klasy *Festuco-Brometea*, wśród których obecne były gatunki zagrożone w skali Dolnego Śląska: *Avenula pratensis*, *Salvia pratensis* i *Festuca valesiaca*. Dominującą grupą gatunków były apofity. Wśród form życiowych najliczniej reprezentowane były hemikryptofity ale udział terofitów był także wysoki. Pod względem wymagań siedliskowych, analizowana flora składała się w większości z gatunków światłolubnych, preferujących siedliska świeże lub suche oraz umiarkowanie ubogie w składniki pokarmowe, o odczynie obojętnym. W dwóch miejscach badań gatunki tolerujące zwiększoną zawartość metali ciężkich w glebie stanowiły około 30% składu flory. Ze względu na sposób rozprzestrzeniania diaspor, najliczniej reprezentowane były anemochory. Gatunki z arbuskularnym typem mikoryzy zdecydowanie dominowaly w analizowanej florze, niemniej jednak udział gatunków niemikoryzowych był stosunkowo wysoki. Zasugerowano, iż zespół niekorzystnych cech podłoża serpentynitowego oraz roślinność terenów przyległych miały główny wpływ na skład florystyczny badanych zbiorowisk.