DOI: 10.5586/aa.1762

Publication history
Received: 2018-11-20
Accepted: 2019-02-18
Published: 2019-04-09

Handling editor
Piotr Sugier, Faculty of Biology and Biotechnology, Maria Curie-Skłodowska University in Lublin, Poland

Authors' contributions
RH, AKB: idea of the study, collecting floristic data and analyzing the data, writing the manuscript

Funding
This research was financially supported by the Department of Botany and Nature Protection, Faculty of Biology and Environmental Protection, University of Silesia in Katowice, Poland.

Competing interests
No competing interests have been declared.

Citation
Hanczaruk R, Kompała-Bąba A. Changes in the vascular flora of a postflotation zinc–lead ore spoil heap of the "Orzeł Biały" mining and smelting works in Bytom (Silesian Upland) after 15 years. Acta Agrobot. 2019;72(1):1762. https://doi.org/10.5586/aa.1762

ORIGINAL RESEARCH PAPER

Changes in the vascular flora of a postflotation zinc–lead ore spoil heap of the "Orzeł Biały" mining and smelting works in Bytom (Silesian Upland) after 15 years

Robert Hanczaruk*, Agnieszka Kompała-Bąba

Department of Botany and Nature Protection, Faculty of Biology and Environmental Protection, University of Silesia in Katowice, Jagiellońska 28, 40-032 Katowice, Poland

* Corresponding author. Email: roberthanczaruk@gmail.com

Abstract

A study on vascular flora of a Zn–Pb ore spoil heap of the "Orzeł Biały" mining and smelting works in Bytom, Poland, was carried out in the 2017–2018 growing seasons. The aim of this study was to: (***i***) present the characteristics of current vascular flora that colonizes the Zn–Pb heap, (***ii***) describe its dynamic tendencies and directions of changes after 15 years, and (***iii***) identify species that can be useful for planting as a part of biological reclamation. Ninety-two mostly native species of vascular plants, belonging to 36 families and 77 genera, were found on the examined heap. In the spectrum of life forms, hemicryptophytes prevailed over therophytes and geophytes. The most numerous ecological groups were ruderal and meadow species. As regards life strategies, highly competitive species and taxa with mixed CSR strategies dominated. The basic mode of seed dispersal was anemochory. In terms of habitat preferences, species associated with moderately light, warm, fresh, neutral, and medium fertility soil dominated in the species composition of the studied flora. In 2017–2018 compared to the 2002 growing season, statistically significant differences were found in the origin, life forms, ecological groups, life strategies, mode of seed dispersal of species and their habitat preferences relative to light, temperature, pH, and productivity. Frequently recorded pseudometallophytes (*Agrostis capillaris*, *Cardaminopsis arenosa*, *Daucus carota*, *Deschampsia caespitosa*, *Leontodon hispidus*, *Plantago lanceolata*, *Silene vulgaris*, *Rumex acetosa*) can be used for planting as part of biological reclamation of the area.

Keywords

heavy metals; life history traits; postflotation wastes; pseudometallophytes; spontaneous flora; temporal changes

Introduction

The history of extraction of ore-bearing dolomite deposits in the region of Bytom–Tarnowskie Góry dates back to the beginning of the twelfth century [1]. Because the deposits of galena (Pb–Ag ores) were shallow and easy-to-extract, they were depleted in the twentieth century. The increasing knowledge in the field of exploration of ores and the further development of mining technologies (including shafts and drainage systems) in the mid-fifteenth century meant that even deeper deposits of galena began to be extracted [2]. The exploitation of ore-bearing dolomites also increased because of the significant demand from metallurgy in the twentieth century, which meant that ores that were rich in Zn and Pb were quickly depleted and deposits that were poorer in Zn and Pb had to be enriched using a flotation process [3–5]. It is estimated that 36 mln Mg of postflotation wastes that contained 2.9% Zn and 0.6% Pb were stored on postflotation Zn–Pb spoil heaps situated in the Bytom region [6,7].

The most frequent methods for managing these areas include sodding and afforestation. A higher content of heavy metals in wastes, the fine grain size of the substrate, which is easily carried by wind and water, nutrient deficiency, unfavorable air and water conditions, higher pH, and frequently salinity and insolation meant that these spoil heaps were slowly colonized primarily by herbaceous plants [8,9].

The process of spontaneous succession appeared to be the most successful. Studies that have been conducted on postindustrial sites have revealed that species that occur in the surrounding area, which constitute the local species pool, frequently play an important role in the initial stages of the formation of spontaneous vegetation cover [10]. The developing plant communities are poorer in species, and are frequently dominated by expansive or alien species. They are usually composed of common native taxa that are associated with meadow habitats, such as *Achillea millefolium*, *Daucus carota*, *Deschampsia caespitosa*, *Festuca arundinacea*, *Leontodon hispidus*, *Lotus corniculatus*, *Plantago lanceolata*, *Poa pratensis*, *Ranunculus acris*, *Rumex acetosa*, and ruderal habitats, such as *Calamagrostis epigejos*, *Melilotus alba*, *M. officinalis*, *Picris hieracioides*, *Reseda lutea*, and *Silene vulgaris* [7,9,11–13]. Plants that grow in metalliferous areas have developed different strategies that enable them to grow in hostile habitats in which there is high concentration of heavy metals in the soil substrate [14]. Most species (so-called excluders) bind toxic metal ions in the roots, thereby preventing them from being translocated into their aboveground parts. Other species, which are called accumulators, can accumulate a significant amount of metals in their aboveground parts [15].

Knowledge about the formation of plant cover on postflotation tailings has a practical aspect. The use of spontaneous succession in the reclamation of areas that have been degraded by Zn–Pb ore mining and processing permits sustainable and stable ecosystems to be created and the costs of reclamation to be reduced [10,16]. The aims of this research were to (***i***) present the current state of the vascular flora of the "Orzeł Biały" mining and smelting works dumping ground in Bytom, (***ii***) describe its directions of changes after 15 years, and (***iii***) identify the species that could be planted as a part of biological reclamation.

Material and methods

Study area

The lead and zinc spoil heap is located on the Bytom-Katowice Plateau in the Silesian Upland, Poland (N 50°20′20″, E 18°56′35″) (Fig. 1). The climate of the mesoregion is characterized by a predominance of oceanic influences over continental ones as well as the sporadic interaction of tropical air masses from the southwest via the Moravian Gate. In the coldest part of the year, arctic cold air from the north also reaches the area. The relative air humidity ranges from 68% to 84%, the mean annual temperature is +8.12°C (January −3°C, July +16.8°C), and the annual precipitation is around 723 mm, with the most precipitation being recorded in July and the least precipitation in February [17]. The spoil heap lies beside the Lubliniec–Katowice railway route and national roads (No. 79 and 94). From the east, it abuts the "Żabie Doły" nature landscape complex, the main components of which are the water reservoirs that have been created in the subsidence basins because the areas above the sites where coal, lead, and zinc ores were extracted have collapsed [5,18] (Fig. 1). The mosaic vegetation of this area is composed of rushes, some wet and fresh meadows, and agricultural crops [19].

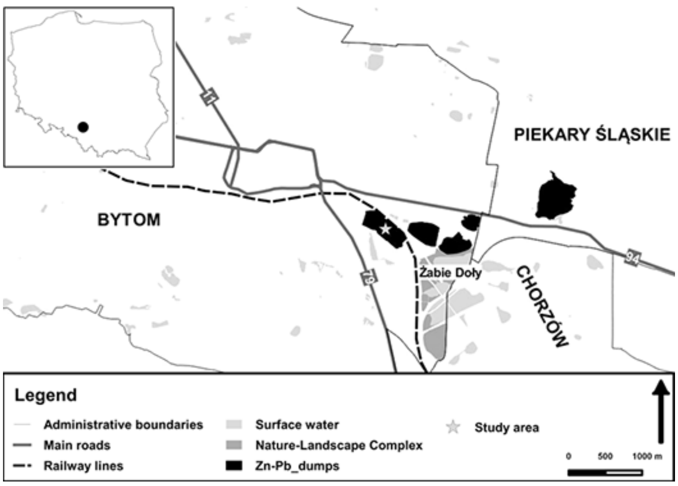

Fig. 1 Map of the study area ("Żabie Doły", Katowice Upland, Southern Poland).

The byproducts from the processing of lead and zinc ores by the "Orzeł Biały" mining and smelting works, which include 1.95 million tons of postflotation wastes containing 2.9% Zn and 1.1% Pb, were deposited on a truncated cone heap that covers 16.95 ha in the years 1926–1989. [7]. After the exploitation ceased, the heap was reclaimed three times: in the years 1971–1975, in 1987, and during the 1990s. The aim of the technical reclamation was to improve the habitat conditions of the heaps by correctly forming the top and slopes, covering them with a coarse substrate in order to improve the water conditions. Moreover, lime and fertilizers were used to improve the physicochemical parameters of the substrate [20].

During the biological reclamation, a mixture of species, including grasses (*Agrostis capillaris*, *Calamagrostis epigejos*, *Dactylis glomerata*, *Deschampsia caespitosa*, *Festuca ovina*, *F. rubra*, *F. tenuifolia*, *Lolium perenne*) and legumes (*Melilotus alba*, *M. officinalis*, *Trifolium repens*), were sown. Some trees (*Betula pendula*, *Pinus sylvestris*, *Populus tremula*, *Quercus rubra*, *Robinia pseudacacia*) and shrubs (*Cornus alba*, *Elaeagnus angustifolia*, *Hippophaë rhamnoides*, *Rhus typhina*) were also planted. However, most of them were not able to withstand the harsh conditions [7,9,12]. The vegetation cover of the spoil heaps was primarily created by perennial ruderal communities from the *Artemisietea vulgaris* class and grassland communities from the *Molinio-Arrhenatheretea*, *Festuco-Brometea*, or *Calluno-Ulicetea* classes. These communities often have an impoverished floristic composition or are dominated by one species (*Festuca ovina*, *Agrostis capillaris*, *Festuca arundinacea*, *Solidago gigantea*).

Data sampling and analysis

Field studies were carried out on the postflotation zinc–lead spoil heap of the "Orzeł Biały" mining and smelting works in the 2017–2018 growing seasons. We made 53 phytosociological relevés (5 × 5 m) in the field, primarily on the sites where relevés were made in 2002 [7]. However, since some parts of the spoil heap that were covered by vegetation were destroyed by humans (e.g., by riding quads and secondary exploitation of the flotation tanks) or due to water and wind erosion, it was often not possible to do phytosociological research on the same sites. The nomenclature of the taxa follows Mirek et al. [21]. The vascular flora of the investigated spoil heap was analyzed in terms of the share of the species that belong to botanical families [21], the frequency of the occurrence of a species, the tolerance of the taxa to an increased Zn and Pb content in the soil [22–24], the shares of the geographical-historical groups [21,25–27], life forms [22,25,26], ecological groups [25,26,28,29], life strategies [28,30,31], and the mode of seed dispersal [28]. The habitat preferences of the species were assessed based on the Ellenberg's indicator values (EIVs) for light (L), temperature (T), moisture (F), soil reaction (R), and productivity (N) [32,33]. We calculated average EIV for each phytosociological relevé as well as mean numbers of species with a given value of the indicator that occur in a given relevé.

In order to demonstrate any temporal changes in the species composition and diversity of the vascular flora of this metalliferous site after almost 15 years from the previous studies, the data that were presented in the work by Kompała et al. [7] and some unpublished data were also used for further analyses. In order to examine the significance of the differences in the species composition of the analyzed site between the 2002 and 2018 growing seasons, the nonparametric Mann–Whitney *U* test was used. All analyses were calculated in the STATISTICA 13.1 software [34].

Results

On the postflotation zinc–lead ore spoil heap of the "Orzeł Biały" mining and smelting works, there were 92 vascular plants species that belonged to 36 botanical families and 77 genera. For comparison, in the 2002 growing season, the examined flora was represented by 61 taxa that belonged to 21 families and 49 genera. The most numerous families were Asteraceae (22.8%), Poaceae (10.9%), Rosaceae (7.6%), Caryophyllaceae (5.4%), Apiaceae (4.3%), Fabaceae (4.3%), Scrophulariaceae (4.3%), and Polygonaceae (3.3%).

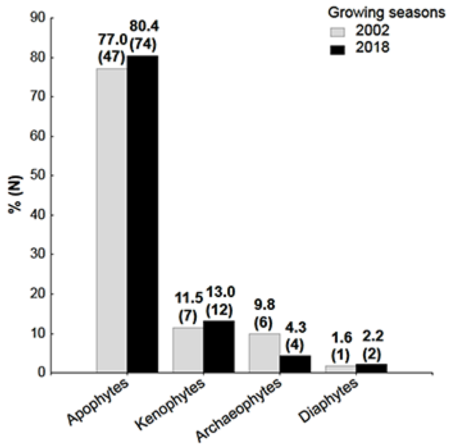

Fig. 2 Spectrum of the geographical-historical groups in the vascular flora of the post-flotation heaps. The results are given as percentage (%) and total (N) values.

It is worth emphasizing that there was an increase in the share of apophytes (from 77.0% to 80.4%). Kenophytes dominated among anthropophytes (13.0%). They were primarily represented by invasive species that are recorded quite often (frequency class III) such as *Robinia pseudacacia* and *Solidago gigantea*. The share of archaeophytes decreased (from 9.8% to 4.3%) (Fig. 2).

There was a decrease in hemicryptophytes (from 62.3% to 46.7%) and therophytes (from 19.7% to 10.9%) in the spectrum of life forms. In contrast, the participation of geophytes (from 6.6% to 16.3%) and phanerophytes, including trees (from 6.6% to 13.0%) and shrubs (from 4.9% to 10.9%), increased considerably (Fig. 3).

In the ecological spectrum, there was a decrease in the share of meadow species (from 39.3% to 23.9%) and an increase in the share of ruderal (from 24.6% to 31.5%) and forest species (from 6.6% to 14.1%) (Fig. 4).

The share of species with a high competitive ability (C-strategists) (from 47.5% to 54.3%) as well as CS strategy (from 1.6% to 4.3%) increased. Conversely, the participation of taxa with mixed strategies such as CSR (from 26.2% to 21.7%) and SR (from 13.3% to 0%) decreased (Fig. 5).

The pattern in the mode of seed dispersal did not change drastically between 2002 and 2018. Dispersal by wind (anemochory) decreased slightly from 70.5% to 67.4% and was dominant over the zoo- (from 14.8% to 17.4%) and autochorous (from 11.5% to 10.9%) modes (Fig. 6).

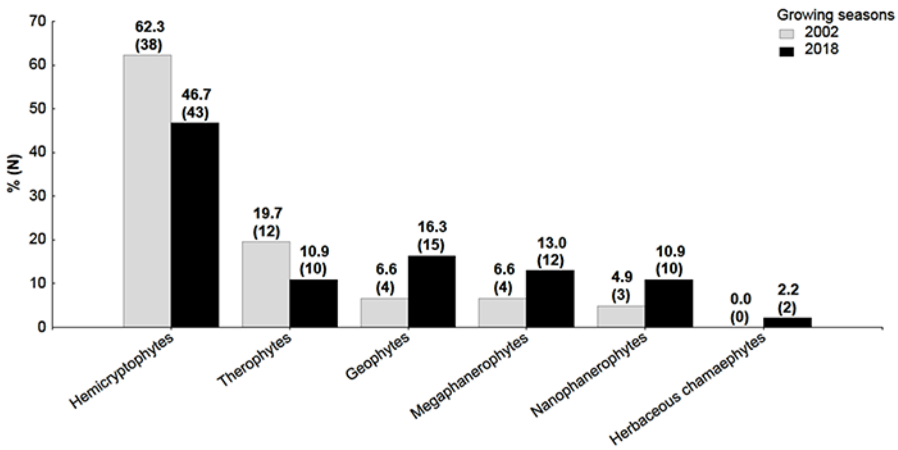

Fig. 3 Spectrum of life forms in the vascular flora of the postflotation heap. The results are given as percentage (%) and total (N) values.

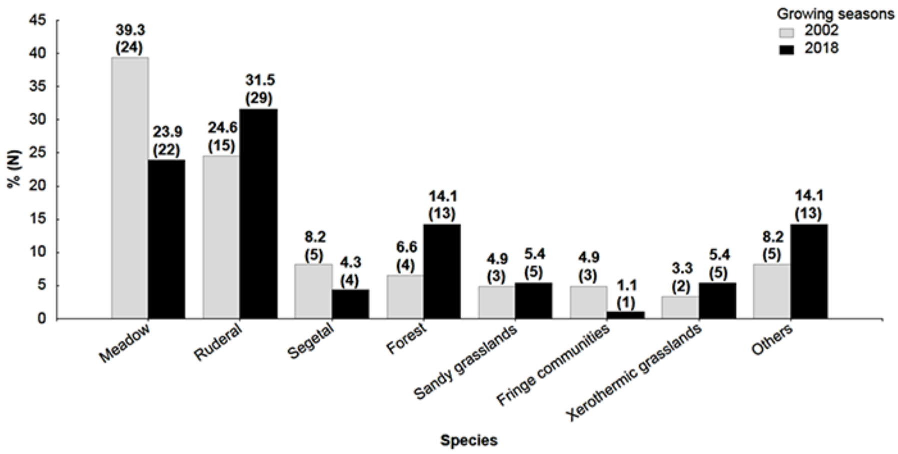

Fig. 4 Ecological spectrum of the vascular flora of the postflotation heap. The results are given as percentage (%) and total (N) values.

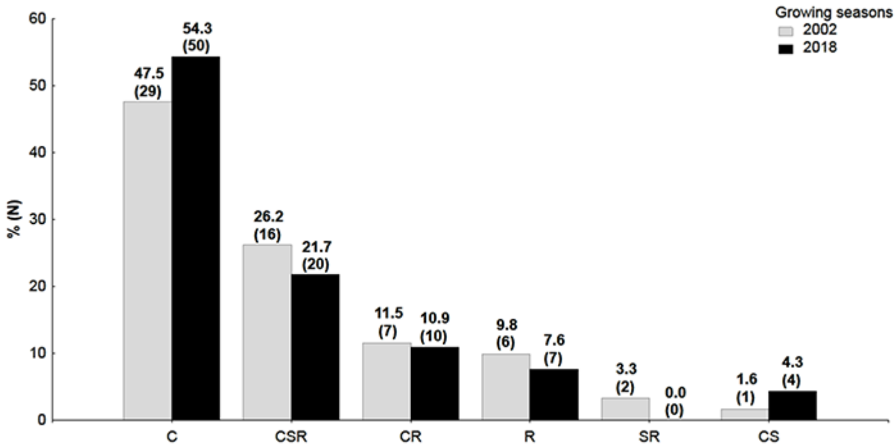

Fig. 5 Spectrum of life strategies in the vascular flora of the postflotation heap. The results are given as percentage (%) and total (N) values; C – competitors; S – stress-tolerators; R – ruderals; CSR – competitive stress-tolerant ruderals; CR – competitive ruderals; SR – stress-tolerant ruderals; CS – stress-tolerant competitors.

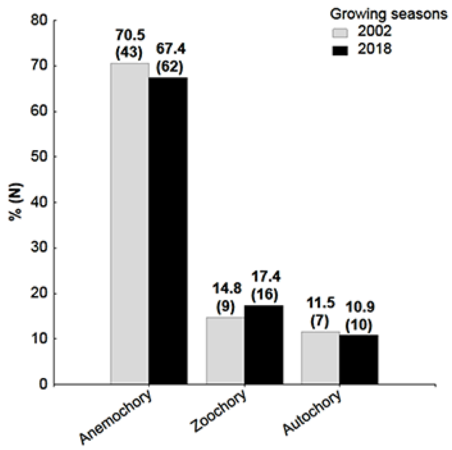

Fig. 6 Mode of seed dispersal in the vascular flora of the postflotation heap. The results are given as percentage (%) and total (N) values.

The results of the Mann–Whitney *U* test showed statistically significant differences between the 2002 and 2018 growing seasons in terms of the geographical-historical groups (origin of species), life forms, share of ecological groups, life strategies, mode of seed dispersal, comprising the vascular flora of the postflotation heap (Tab. 1).

Taking into account the number of species with a given value of the indicator, the values of almost all indices decreased between years, except for indicators of poor soils and extremely rich soils, indicators of acid to moderately acid soils, dry and moist soils (Tab. 2).

Analysis of the habitat preferences of the species calculated for relevés in terms of light, temperature, soil reaction, and nutrients showed a decrease in mean values of temperature and soil reaction, whereas the mean values of the indices for light and nutrients increased during the examined growing seasons (Tab. 3).

The pseudometallophytes that occurred most frequently were *Agrostis capillaris* (frequency class VI), *Cardaminopsis arenosa*, *Daucus carota*, *Deschampsia caespitosa*, *Leontodon hispidus*, *Plantago lanceolata*, *Silene vulgaris* (frequency class V), and *Rumex acetosa* (frequency class IV) (Tab. 4).

Discussion

The postindustrial sites that are connected with the processing of zinc and lead ores are relatively difficult to colonize by plant species. They are often a kind of environmental island in the surrounding urban landscape. The composition of the vascular flora of these areas is undoubtedly affected by many abiotic factors such as the age of the spoil heap, the physicochemical conditions of the substrate, some reclamation activities as well as biotic factors. These include species richness and species diversity as well as functional diversity. It is connected with the species traits that are associated with persistence, dispersal and regeneration after disturbances, and the composition of local flora that occurs in the vicinity of the spoil heaps. Such traits constitute the life strategies of a species and enable them to adapt to given habitat conditions, and they also related to the advancement of succession [9,12,35,36].

The current vascular flora of the postflotation zinc and lead ore spoil heap of the “Orzeł Biały” mining and smelting works comprises 92 species of vascular plants and is richer in species compared to the 2002 growing season when only 61 taxa were found. There was a decrease in common species (frequency class VI between years), whereas the number of rare species increased almost two-fold between the years examined.

Tab. 1 Changes in the origin of species, chosen plant traits, and ecological groups of the vascular flora of the postflotation heap between the 2002 and 2018 growing seasons.

Growing season	2002	2018
Origin of species		
Apophytes	16.38 [a]	11.36 [b]
Archaeophytes	1.31 [a]	0.17 [b]
Kenophytes	1.56 [a]	1.04 [b]
Diaphytes	0.06 [a]	0.08 [a]
Life forms		
Geophytes	1.19 [a]	1.19 [a]
Herbaceous chamaephytes	0.00 [a]	0.09 [b]
Hemicryptophytes	13.75 [a]	9.19 [b]
Megaphanerophytes	0.94 [a]	1.17 [a]
Nanophanerophytes	0.19 [a]	0.38 [a]
Terophytes	3.25 [a]	0.62 [b]
Ecological groups		
Meadow species	9.13 [a]	5.68 [b]
Ruderal species	5.13 [a]	3.47 [b]
Xerothermic grassland species	0.56 [a]	0.28 [b]
Forest species	0.44 [a]	1.08 [b]
Segetal species	0.63 [a]	0.09 [b]
Sandy grassland species	0.56 [a]	0.47 [a]
Life strategies		
C	8.00 [a]	5.17 [b]
CR	1.38 [a]	1.00 [b]
CS	0.31 [a]	0.17 [a]
CSR	7.13 [a]	5.70 [b]
R	1.69 [a]	0.57 [b]
SR	0.81 [a]	0.00 [b]
Mode of seed dispersal		
Anemochory	15.25 [a]	10.34 [b]
Zoochory	2.38 [a]	1.92 [b]
Autochory	1.56 [a]	0.26 [b]

Significant differences ($p < 0.05$) between years in mean number of species were marked with different letters.

We found statistically significant differences in the species composition of vascular flora between the examined periods in relation to the origin, life forms, and life strategies of the species, share of ecological groups, mode of seed dispersal as well as in the preferences of the species in terms of light, temperature, pH, and nutrients.

During the succession that occurred on the lead and zinc spoil heaps, the number of native species (apophytes) increased. Similar results have also been obtained by other scientists who studied spontaneous succession on coal mine spoil heaps [37,38], sand and gravel pits [39,40], reclaimed and spontaneously vegetated Zn–Pb mine wastes in southern Poland [41,42], or serpentinite waste dumps [43]. The composition of the vascular flora of the postmining lead and zinc spoil heaps is connected with the local species pool. In the past, the area of "Żabie Doły" was covered by rushes and wet meadows, some segetal as well as ruderal communities, in the floristic composition of which native species were primarily found. These are frequently better adapted to habitat conditions on spoil heaps than alien species [43]. Among the alien species that occurred in the vascular flora that was studied, *Solidago gigantea* was found on the top as well as at the bottom of the spoil heaps; however, it only formed rather small patches. During the reclamation works, the alien species *Robinia pseudacaccia* as well as some shrubs and trees were planted in order to improve the soil conditions of hostile habitats as well as to initiate the reclamation of the land into a forest. The black locust is a fast growing legume that has a high survival rate, a wide ecological amplitude, and its saplings are easy and inexpensive to produce in tree nurseries [44]. However, it has a negative impact on the diversity of native flora, and therefore it should not be deliberately planted. Grasses are one of the most numerous functional groups (family) in the vascular flora of a spoil heap. Plastic and fast response of grasses to many environmental stresses as well as their colonization abilities enable them to survive in environments that have been transformed by man. That is beneficial in planning reclamation works since grasses can fulfill the antierosion, soil-forming, as well as ornamental role [45]. Some of them have a well-developed root system (*Deschampsia caespitosa*, *Festuca arundinacea*) and are able to grow well in bad water and air conditions in the soil and can bind the fine material of a spoil heap, thereby protecting it from water and wind erosion. Some expansive grasses such as *Calamagrostis epigejos* can play the role of a dominant in some vegetation patches. It has the so-called internal nitrogen cycling, a wide ecological amplitude, reproduce both vegetatively and generatively, and produce a thick layer of dead organic matter [46]. Other grasses such as *Festuca ovina* or *Agrostis capillaris* are frequently found on lead and zinc spoil heaps and cover large areas [47,48]. They are tufted, often patch-forming grasses that can adjust to alkaline pH, salinity, as well as a higher content of heavy metals in the soils. The persistence and colonizing ability of *Agrostis capillaris* result from the diversity of its regenerative strategies, the mobility of seeds, and its capacity to lateral spread [49,50]. Another species that can adapt to the habitat conditions that exist on spoil heaps is *Silene vulgaris*. This species has some ecotypes that can grow in these habitats. The lack of water, a low nutrient content, and a higher content of heavy metals mean that this species has many morphological (small stature, small but thicker leaves compared to individuals from seminatural habitats), anatomical (palisade and sponge layer), and physiological adaptations (chlorophyll fluorescence) that have enabled it to survive in hostile habitats [51,52].

Tab. 2 Changes in ecological preferences of the species that constitute the vascular flora of the postflotation heap.

Growing season	2002	2018
Indicators	**Mean number of species**	
L_3	0.00 [a]	0.02 [a]
L_{4-5}	1.00 [a]	0.42 [b]
L_{6-7}	8.50 [a]	6.09 [b]
L_{8-9}	9.50 [a]	5.75 [b]
T_{4-5}	2.69 [a]	1.43 [b]
T_{6-7}	6.50 [a]	2.94 [b]
F_3	0.25 [a]	0.17 [a]
F_{4-5}	11.75 [a]	6.15 [b]
F_{6-7}	2.38 [a]	2.08 [a]
F_{8-10}	0.19 [a]	0.43 [b]
R_{2-3}	0.56 [a]	0.36 [a]
R_{4-5}	1.56 [a]	1.51 [a]
R_{6-7}	5.75 [a]	3.42 [b]
R_{8-9}	1.81 [a]	0.72 [b]
N_1	0.50 [a]	0.36 [a]
N_{2-3}	4.69 [a]	3.21 [b]
N_{4-5}	5.63 [a]	3.38 [b]
N_{6-7}	5.25 [a]	2.60 [b]
N_{8-9}	0.88 [a]	0.62 [a]

Significant differences ($p < 0.05$) between years in mean number of species are marked with different letters; L_3 – indicators of shade soils; L_{4-5} – indicators of half shade; L_{6-7} – indicators of moderately light sites; L_{8-9} – indicators of fully insolated soils; T_{4-5} – indicators of moderately warm sites; T_{6-7} – indicators of warm sites; F3 – indicators of dry soils; F_{4-5} – indicators of fresh soils; F_{6-7} – indicators of moist soils; F_{8-10} – indicators of wet site to shallow water sites; R_{2-3} – indicators of acid soils; R_{4-5} – moderately acid soils; R_{6-7} – indicators of moderately acidic and moderately alkaline soils; R_{8-9} – indicators of alkaline soils; N_1 – indicators of extremely infertile sites; N_{2-3} – indicators of poor soils; N_{4-5} – indicators of moderately rich soils; N_{6-7} – indicators of rich soils; N_{8-9} – indicators of extremely rich soils.

An increase in the fertility of the substrate made it possible for species to enter during the later stages of succession. These were mainly geophytes (e.g., *Calamagrostis epigejos*, *Calystegia sepium*, *Carex hirta*, *Convolvulus arvensis*, *Epipactis helleborine*, *Equisetum arvense*), whose share in the species composition of the examined flora increased almost threefold in the studied periods. Conversely, the share of hemicryptophytes and therophytes in the flora decreased since 2002 in favor of geophytes. Some trees (*Betula pendula*, *Populus tremula*, *Sorbus aucuparia*, *S. intermedia*) and shrubs (*Frangula alnus*, *Hippohaë rhamnoides*, *Spiraea media*) were only found in the northwest part of the heap. During succession, the participation of phanerophytes in the spectrum of life forms and the participation of forest species in the ecological spectrum of the flora increased. Most of these were introduced by humans during reclamation works [7,20]. Nevertheless, only in this part of heap was succession in the shrub-forest direction observed. This was probably due to the fact that the litter of deciduous trees and bushes is relatively easily decomposed, which enriches the soil with nutrients [10].

We expected that the number and frequency of meadow species as well as the taxa that are associated with sandy and xerothermic grasslands would increase during spontaneous succession since these species frequently overgrow these types of habitats and occur in similar natural conditions, e.g., xerothermic grasslands [10]. However, there was a decrease in the share of meadow species in favor of the ruderal taxa between 2002 and 2018. The meadow species were often dominated by common taxa, whereas rare species were dominant among the ruderal species. The decrease in the share of meadows species was probably connected with the fact that there is a lack of propagules of these species in the vicinity. Wet and fresh meadows that occurred in the vicinity of the Zn–Pb spoil heaps in 2002 have completely disappeared. The share of psammophilous and xerothermic grasslands species did not change between the years.

Anemochory appeared to be the most frequent seed dispersal mode in both the periods that were studied, followed by zoochory, which indicates the early stages of succession [37,38]. The first mode enables species to disperse for long distances as well as to get to the spoil heap from surrounding vegetation. Such a mode of dispersal is typical of some species from the Poaceae family as well as other forbs of both native and foreign origin (*Conyza canadensis*, *Erigeron annuus*, *Solidago* sp.). In turn, zoochory enables some shrubs and trees to be dispersed over a short distance [43].

As was already stated in another paper on succession at postindustrial sites, the trends can differ in respect to the life history traits [40,41]. Frequently, a transition from R-strategists to C- or S-strategists is observed in the latter stages of succession [31,53,54]. In our research, the number of C-strategists and CS-strategists increased, whereas the number of R-strategists decreased between 2002 and 2018. Řehounková and Prach [40] found that ruderals only occurred in gravel sandpits at the beginning of succession; however, they did not expand very much because of the lack of nutrients and the acid pH of the sites. On the lead and zinc spoil heaps, the number of ruderals was also lower. Some disturbances that occurred at the beginning of the succession, open or bare sites, harsh habitat conditions as well as a lack of competitors enabled them to become established.

The low level of diversity of the examined flora is probably connected with the unfavorable environmental conditions that still occur on the spoil heaps almost 50 years after the material ceased to be deposited after the period 1926–1970. The substrate of the spoil heaps still contains a higher concentration of heavy metals, mainly zinc, lead, and cadmium, which makes it difficult for vascular plant species to colonize them and grow there [7,55,56]. Long periods without precipitation and a higher average mean temperature have caused the surface and slopes of flotation tailings to undergo heavy erosion and therefore the existing plant cover has been depleted. Part of the flotation tank is currently being taken apart, which has caused further damage to the vegetation.

Tab. 3 Changes in ecological preferences of the species occurring on the Zn–Pb postflotation heap between the 2002 and 2018 growing seasons.

Growing season	2002	2018
Indicators	Mean values of indicators	
L – light	6.98 [a]	7.24 [b]
T – temperature	5.82 [a]	5.80 [b]
F – moisture	5.35 [a]	5.56 [a]
R – soil reaction	6.24 [a]	5.78 [b]
N – nutrients	4.15 [a]	4.78 [b]

The mean values of Ellenberg's indicators were calculated for each relevés in each growing season. Significant differences ($p < 0.05$) between years are marked with different letters.

Moreover, the vegetation cover of the surface of the spoil heap was devastated because local residents practised various sports on them.

About one-third species of the vascular flora of the lead and zinc spoil heap prefer an alkaline pH of the substrate. In alkaline soils, most heavy metals, even when their total content in the soil is high, occur in an insoluble form and therefore they are not available for plants. On the other hand, the pH in the root zone is usually lower than that outside of it, which can increase the availability of toxic metals for plants [35]. A high concentration of heavy metals in the soil also slows down the decomposition of organic matter and thus limits the availability of basic nutrients (nitrogen and phosphorus) for plants [36]. A sandy-clay substrate, which mainly consists of fine grains with a diameter of less than 0.5 mm, is characterized by poor water and air conditions [55,56]. Adverse graining reduces the infiltration of water during precipitation and also reduces the water uptake by soil capillaries from the deeper soil layers during drought. The consequences of this include the intensification of water erosion during precipitation and an increase of wind erosion during drought as well as large fluctuations in the temperature in the upper substrate layer [6,8]. In addition, small

Tab. 4 The list of pseudometallophytes that occurred on the postflotation heap based on [22,24].

Pseudometallophytes							
		Frequency				Frequency	
No.	Species name	2002	2018	No.	Species name	2002	2018
1	*Achillea millefolium*	III	III	35	*Lolium perenne**	I	.
2	*Agropyron repens*	.	I	36	*Lotus corniculatus*	II	.
3	*Agrostis capillaris**	VI	VI	37	*Medicago lupulina*	.	I
4	*Agrostis stolonifera*	.	I	38	*Melandrium album*[Ar]	V	II
5	*Arrhenatherum elatius*	.	I	39	*Myosotis arvensis*[Ar]	.	I
6	*Artemisia vulgaris*	II	I	40	*Oenothera biennis*	I	I
7	*Betula pendula**	.	III	41	*Padus serotina*[iKn]	.	I
8	*Calamagrostis epigejos**	IV	II	42	*Pastinaca sativa*	IV	II
9	*Cardaminopsis arenosa*	VI	V	43	*Phleum pratense*	I	.
10	*Cardaminopsis halleri*	.	I	44	*Phragmites australis*	.	II
11	*Carex hirta*	.	II	45	*Picris hieracioides*	V	II
12	*Carex spicata*	III	.	46	*Pimpinella saxifraga*	.	I
13	*Centaurium erythraea*	V	.	47	*Pinus sylvestris**	.	I
14	*Cerastium holosteoides*	.	I	48	*Plantago lanceolata*	VI	V
15	*Convolvulus arvensis*	.	I	49	*Poa compressa*	I	.
16	*Conyza canadensis*[iKn]	I	I	50	*Poa pratensis*	II	.
17	*Dactylis glomerata**	IV	II	51	*Populus tremula**	.	II
18	*Daucus carota*	VI	V	52	*Ranunculus acris*	.	I
19	*Deschampsia caespitosa**	VI	V	53	*Reseda lutea*	I	II
20	*Epipactis helleborine*	.	I	54	*Robinia pseudoacacia**[iKn]	V	III
21	*Equisetum arvense*	.	I	55	*Rumex acetosa*	VI	IV
22	*Erigeron acris*	III	II	56	*Rumex acetosella*	I	I
23	*Eupatorium cannabinum*	.	II	57	*Silene vulgaris*	VI	V
24	*Euphrasia stricta*	II	II	58	*Solidago canadensis*[iKn]	IV	II
25	*Festuca ovina**	III	III	59	*Solidago gigantea*[iKn]	II	III
26	*Festuca rubra**	I	II	60	*Sorbus aucuparia*	.	II

Tab. 4 Continued

		Pseudometallophytes					
		Frequency				Frequency	
No.	Species name	2002	2018	No.	Species name	2002	2018
27	*Frangula alnus*	.	II	61	*Taraxacum officinale*	III	III
28	*Galium mollugo*	I	.	62	*Thymus pulegioides*	.	I
29	*Hieracium pilosella*	III	III	63	*Trifolium arvense*	II	.
30	*Hieracium piloselloides*	.	I	64	*Trifolium repens**	I	.
31	*Holcus lanatus*	II	.	65	*Tussilago farfara*	.	I
32	*Hypericum perforatum*	I	I	66	*Verbascum thapsus*	.	I
33	*Leontodon autumnalis*	III	III	67	*Vicia cracca*	III	I
34	*Leontodon hispidus*	V	V	68	*Viola tricolor*	.	I

* Species planted during the reclamation. Ar – archaeophytes; iKn – invasive kenophytes. Frequency classes: I – very rare species (≤9.0% floristic lists); II – rare species (9.1–20.0%); III – quite frequent species (20.1–40.0%); IV – frequent species (40.1–60.0%); V – very frequent species (60.1–80.0%); VI – common species (80.1–100.0%).

dried grains of substrate can be blown by the wind, which exposes the roots of some plants and completely overwhelms others [9].

Some species have adapted to colonize areas with an increased concentration of heavy metals and constitute spontaneous flora. A list of 145 species of vascular flora that are confined to metalliferous areas and occur with a high frequency and abundance was prepared by Rostański et al. [24]. On the studied Zn–Pb spoil heap, they are represented by pseudometallophytes such as *Agrostis capillaris*, *Cardaminopsis arenosa*, *Daucus carota*, *Deschampsia caespitosa*, *Leontodon hispidus*, *Plantago lanceolata*, *Silene vulgaris*, and *Rumex acetosa* [22–24]. The above-mentioned taxa were also often recorded by Rostański and Kapa [57] and Skubała [12], who explored the vascular flora of other Zn–Pb spoil heaps near the study area. These species have developed a metal-exclusion strategy and can grow on soil with an increased zinc and lead content [23]. The use of pseudometallophytes in the phytostabilisation of metalliferous postflotation Zn–Pb spoil heaps not only enables the cost of reclamation works to be reduced, but also more lasting effects to be obtained than is the case with conventional methods [58]. It is also worth to notice that several frequently occurring pseudometallophytes (e.g., *Reseda lutea*, *Lotus corniculatus*, *Oenothera biennis*, *Silene vulgaris*, *Oenothera* spp.) are important sources of food for pollinators [59–61].

Although many floristic and phytosociological works have been done in the areas connected with exploitation and processing of zinc and lead ores, there is a need to conduct long-term studies on such spoil heaps that will allow to capture changes in the flora and vegetation. Results of such studies can be important in planning proper management of such sites.

References

1. Helios-Rybicka E. Impact of mining metallurgical industries on the environment in Poland. Appl Geochem. 1996;11(1–2):3–9. https://doi.org/10.1016/0883-2927(95)00083-6
2. Majorczyk R. Historia górnictwa kruszcowego w rejonie Bytomia. Piekary Śląskie: ZUP; 1985.
3. Machowski R. Przemiany geosystemów zbiorników wodnych powstałych w nieckach osiadania na Wyżynie Katowickiej. Katowice: Wydawnictwo Uniwersytetu Śląskiego; 2010.

4. Pełka-Gościniak J. Some aspects of relief transformations in area of Piekary Śląskie (Silesian Upland – southern Poland). Environmental and Socio-economic Studies. 2015;2(4):13–20. https://doi.org/10.1515/environ-2015-0045

5. Nowak J, Lutyńska S. Wpływ antropopresji na środowiska wodne obszaru Zespołu Przyrodniczo-Krajobrazowego Żabie Doły (Górny Śląsk). Archiwum Gospodarki Odpadami i Ochrony Środowiska. 2015;17(2):11–18.

6. Girczys J, Sobik-Szołtysek J. Odpady przemysłu cynkowo-ołowiowego. Częstochowa: Wydawnictwo Politechniki Częstochowskiej; 2002.

7. Kompała A, Błońska A, Woźniak G. Vegetation of the "Żabie Doły" area (Bytom) covering the wastelands of zinc-lead industry. Archives of Environmental Protection. 2004;30(3):59–76.

8. Turnau K, Gawroński S, Ryszka P, Zook D. Mycorrhizal-based phytostabilization of Zn–Pb tailings: lessons from the Trzebionka mining works (southern Poland). In: Kothe E, Varma A, editors. Bio-geo interactions in metal-contaminated soils. Berlin: Springer; 2012. p. 327–348. https://doi.org/10.1007/978-3-642-23327-2_16

9. Jędrzejczyk-Korycińska M, Rostański A. Tereny o wysokiej zawartości metali ciężkich w podłożu na Górnym Śląsku. In: Wierzbicka M, editor. Ekotoksykologia. Rośliny, gleba, metale. Warszawa: Wydawnictwa Uniwersytetu Warszawskiego; 2015. p. 171–185.

10. Szarek-Łukaszewska G, Grodzińska K. Vegetation of a post-mining open pit (Zn/Pb ores) three-year study of colonization. Pol J Ecol. 2007;55(2):261–282.

11. Jędrzejczyk-Korycińska M. Obszary dawnej eksploatacji złóż cynkowo-ołowiowych – ich bogactwo florystyczne a możliwości ochrony. Problemy Ekologii Krajobrazu. 2009;24:71–80.

12. Skubała K. 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. Archives of Environmental Protection. 2011;37(1):57–74.

13. Wójcik M, Dresler S, Sugier P, Stanisławski G, Hanaka A, Krupa Z, et al. Roślinność spontanicznie zasiedlająca składowiska odpadów cynkowo-ołowiowych – różnorodność gatunkowa oraz mechanizmy adaptacji. In: Bajguz A, Ciereszko I, editors. Różnorodność biologiczna – od komórki do ekosystemu. Funkcjonowanie roślin i grzybów. Środowisko – eksperyment – edukacja. Białystok: Polskie Towarzystwo Botaniczne; 2015. p. 51–62.

14. Siwek M. Rośliny w skażonym metalami ciężkimi środowiska poprzemysłowym. Część II. Mechanizmy detoksyfikacji i strategie przystosowania roślin do wysokich stężeń metali ciężkich. Wiadomości Botaniczne. 2008;52(3–4):7–23.

15. Baker AJM. Accumulators and excluders – strategies in the response of plants to heavy metals. J Plant Nutr. 1981;3(1–4):643–654. https://doi.org/10.1080/01904168109362867

16. Wierzbicka M, Rostański A. Microevolutionary changes in ecotypes of calamine waste heap vegetation near Olkusz, Poland: a review. Acta Biol Crac Ser Bot. 2002;44(7):7–19.

17. Portal Przyrodniczy Województwa Śląskiego, Klimat [Internet]. 2016 [cited 2018 Nov 20]. Available from: http://przyroda.katowice.pl/pl/przyroda-nieozywiona/klimat/127-klimat

18. Rozporządzenie Nr 23/97 Wojewody Katowickiego z dnia 6 lutego 1997 w sprawie wprowadzenia ochrony indywidualnej w drodze uznania za zespół przyrodniczo-krajobrazowy nieużytków, stawów oraz gruntów rolnych w gminie Bytom i Chorzów. Dziennik Urzędowy Województwa Katowickiego, 1997 Feb 10, Item 26.

19. Piontek D. "Żabie Doły" w Bytomiu. Przyroda Górnego Śląska. 2001;24:16.

20. Ledwoń K, Imielski M, Koj R. Prace rekultywacyjne prowadzone na terenie Żabich Dołów (2). Aura. 1999;4:19–20.

21. Mirek Z, Piękoś-Mirkowa H, Zając A, Zając M, editors. Flowering plants and pteridophytes of Poland – a checklist. Cracow: W. Szafer Institute of Botany, Polish Academy of Sciences; 2002. (Biodiversity of Poland; vol 1).

22. Zarzycki K, Trzcińska-Tacik H, Różański W, Szeląg Z, Wołek J, Korzeniak U. Ecological indicator values of vascular plants of Poland. Cracow: W. Szafer Institute of Botany, Polish Academy of Sciences; 2002. (Biodiversity of Poland; vol 2).

23. Wójcik M, Sugier P, Siebielec G. Metal accumulation strategies in plants spontaneously inhabiting Zn–Pb waste deposits. Sci Total Environ. 2014;487:313–322. https://doi.org/10.1016/j.scitotenv.2014.04.024

24. Rostański A, Nowak T, Jędrzejczyk-Korycińska M. Metalolubne gatunki roślin naczyniowych we florze Polski. In: Wierzbicka M, editor. Ekotoksykologia. Rośliny,

gleba, metale. Warszawa: Wydawnictwa Uniwersytetu Warszawskiego; 2015. p. 299–322.

25. Czarna A. Rośliny naczyniowe środkowej Wielkopolski. Poznań: Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu; 2009.
26. Celka Z. Relics of cultivation in the vascular flora of medieval West Slavic settlements and castles. Biodivers Res Conserv. 2011;22(1):1–110. https://doi.org/10.2478/v10119-011-0011-0
27. Tokarska-Guzik B, Dajdok Z, Zając M, Zając A, Urbisz A, Danielewicz W, et al. Rośliny obcego pochodzenia w Polsce ze szczególnym uwzględnieniem gatunków inwazyjnych. Warszawa: Generalna Dyrekcja Ochrony Środowiska; 2012.
28. Klotz S, Kühn I, Durka W. BIOLFLOR – Eine Datenbank zu biologisch-ökologischen Merkmalen der Gefäßpflanzen in Deutschland. Schriftenreihe für Vegetationskunde. Bonn: Bundesamt für Naturschutz; 2002.
29. Matuszkiewicz W. Przewodnik do oznaczanie zbiorowisk roślinnych Polski. Warszawa: Wydawnictwo Naukowe PWN; 2008. (Vademecum Geobotanicum; vol 3).
30. Grime JP. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. Am Nat. 1977;111(982):1169–1194. https://doi.org/10.1086/283244
31. Grime JP. Plant strategies, vegetation processes, and ecosystem properties. Chichester: Wiley; 2001.
32. Ellenberg H, Weber HE, Düll R, Wirth V, Werner W, Paulissen D. Zeigerwerte von Pflanzen in Mitteleuropa. 2nd ed. Göttingen: Goltze; 1992. (Scripta Geobotanica; vol 18).
33. Roo-Zielińska E. Wskaźniki ekologiczne zespołów roślinnych Polski. Warszawa: Wydawnictwo Akademickie Sedno; 2014.
34. StatSoft Polska. STATISTICA. Version 13.1 [Software]. 2016 [cited 2019 Feb 6]. Available from: https://www.statsoft.pl/statistica_13/
35. Szarek-Łukaszewska G. Vegetation of reclaimed and spontaneously vegetated Zn–Pb mine wastes in southern Poland. Pol J Environ Stud. 2009;18(4):717–733.
36. Szarek-Łukaszewska G, Grodzińska K. Naturalna roślinność w rejonach starych zwałowisk po górnictwie Zn–Pb w okolicy Bolesławia i Bukowna (region śląsko-krakowski; południowa Polska). Przegląd Geologiczny. 2008;56(7):1–4.
37. Rostański A. Spontaniczne kształtowanie się pokrywy roślinnej na zwałowiskach po górnictwie węgla kamiennego na Górnym Śląsku. Katowice: Wydawnictwo Uniwersytetu Śląskiego; 2006.
38. Woźniak G. Zróżnicowanie roślinności za zwałowisk pogórniczych Górnego Śląska. Kraków: Instytut Botaniki im. W. Szafera, Polska Akademia Nauk; 2010.
39. Kompała-Bąba A, Bąba W. The spontaneous succession in a sand-pit – the role of life history traits and species habitat preferences. Pol J Ecol. 2013;61(1):13–22.
40. Řehounková K, Prach K. Life history traits and habitat preferences of colonizing plant species in long-term spontaneous succession in abandoned gravel-sand pits. Basic Appl Ecol. 2010;11(1):45–53. https://doi.org/10.1016/j.baae.2009.06.007
41. Szarek-Łukaszewska G, Grodzińska K. Grasslands of a Zn–Pb post-mining area (Olkusz Ore-bearing region, S Poland). Pol Bot J. 2011;56(2):245–260.
42. Mańczyk A, Rostański A. Flora naczyniowa wybranych zwałów pocynkowych miasta Ruda Śląska (Górny Śląsk). Archiwum Ochrony Środowiska. 2003;29(2):31–48.
43. Kasowska D, Koszelnik-Leszek A. Ecological features of spontaneous vascular flora of serpentine post-mining sites in Lower Silesia. Archives of Environmental Protection. 2014;40(2):33–52. https://doi.org/10.2478/aep-2014-0014
44. Enescu CM, Dănescu A. Black locust (*Robinia pseudoacacia* L.) – an invasive neophyte in the conventional land reclamation flora in Romania. Bulletin of the Transilvania University of Braşov Series II. 2013;6(55):23–30.
45. Frey L. Trawy niezwyciężone (wybrane zagadnienia z historii, taksonomii i biologii Poaceae). Łąkarstwo w Polsce. 2000;3:9–20.
46. Rebele F, Lehmann C. Biological flora of Central Europe: *Calamagrostis epigejos* (L.) Roth. Flora. 2001;196(5):325–344. https://doi.org/10.1016/S0367-2530(17)30069-5
47. Kompała-Bąba A, Błońska A, Bąba W, Czyba M. Grasses in the plant communities which develop on the waste sites of zinc–lead industry (Upper Silesia, S Poland). In: Frey L, editor. Biology of grasses. Cracow: W. Szafer Institute of Botany, Polish Academy of Sciences; 2005. p. 267–282.

48. Ryś K, Radecka K, Kompała-Bąba A. Zbiorowiska z dominującym udziałem traw występujące na nieużytkach powstałych w wyniku przerobu rud cynkowo-ołowiowych. Łąkarstwo w Polsce. 2016;19:229–244
49. Bradshaw AD. Population differentiation in *Agrostis tenuis*. III. Population in varied environments. New Phytol. 1960;59(1):92–103. https://doi.org/10.1111/j.1469-8137.1960.tb06206.x
50. Grime JP, Hodgson JG, Hunt R. Comparative plant ecology. A functional approach to common British species. London: Unwin Hyman; 1988.
51. Nadgórska-Socha A, Ciepał R. Phytoextraction of zinc, lead and cadmium with *Silene vulgaris* Moench (Garcke) in the post-industrial area. Ecological Chemistry and Engineering. 2009;16(7):831–837.
52. Wierzbicka M. Przystosowania roślin do wzrostu na hałdach cynkowo-ołowiowych okolic Olkusza. Kosmos. 2000;51(2):139–150.
53. Osbornová J, Kovářová M, Lepš J, Prach K. Succession in abandoned fields: studies in Central Bohemia, Czechoslovakia. Bonn: Kluwer Publishers; 1990.
54. Prach K, Řehounková K, Lencová K, Jírová A, Konvalinková P, Mudrák O, et al. Vegetation succession in restoration of disturbed sites in Central Europe: the direction of succession and species richness across 19 seres. Appl Veg Sci. 2014;17(2):193–200. https://doi.org/10.1111/avsc.12064
55. Fajfer J, Krieger W, Rolka M, Antolak O. Opracowanie metodyki wykonania spisu zamkniętych obiektów unieszkodliwiania odpadów wydobywczych oraz opuszczonych obiektów unieszkodliwiania odpadów wydobywczych, które wywierają negatywny wpływ na środowisko. Warszawa: Państwowy Instytut Geologiczny; 2010.
56. Cieślińska K, Skalska A, Ciszek D, Krzyżak J, Pogrzeba M. Mikoryza arbuskularna wybranych gatunków roślin energetycznych uprawianych na terenie zanieczyszczonym metalami ciężkimi. In: Kutyłowska M, Trusz-Zdybek A, Wiśniewski J, editors. Interdyscyplinarne zagadnienia w inżynierii i ochronie środowiska 7. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej; 2016. p. 13–28.
57. Rostański A, Kapa D. Flora naczyniowa terenów silnie skażonych cynkiem i ołowiem na przykładzie zwałowisk poprzemysłowych ZGH "Orzeł Biały" S.A. w Bytomiu. Natura Silesiae Superioris Suppl. 2001:33–43.
58. Siwek M. Biologiczne sposoby oczyszczania środowiska – fitoremediacja. Wiadomości Botaniczne. 2008;52(1–2):23–28.
59. Denisow B, Wrzesień M. The anthropogenic refuge areas for bee flora in agricultural landscape. Acta Agrobot. 2007;60(1):147–157. https://doi.org/10.5586/aa.2007.018
60. Wrzesień M, Denisow B. The phytocoenoses of anthropogenically transformed areas with a great importance for Apoidea. Acta Agrobot, 2007;60(2):117–126. https://doi.org/10.5586/aa.2007.039
61. Antoń S, Denisow B. Floral phenology and pollen production in the five nocturnal *Oenothera* species (Onagraceae). Acta Agrobot. 2018;71(2):1738. https://doi.org/10.5586/aa.1738

Zmiany we florze naczyniowej zwałowiska odpadów cynkowo-ołowiowych ZGH „Orzeł Biały" w Bytomiu (Wyżyna Śląska) po 15 latach

Streszczenie

Badania nad florą zwałowiska odpadów Zn–Pb „Orzeł Biały" w Bytomiu przeprowadzono w sezonach wegetacyjnych 2017–2018. Celem badań było przedstawienie: (***i***) charakterystyki aktualnej flory naczyniowej zwałowiska, (***ii***) jej tendencji dynamicznych i kierunków zmian po 15 latach oraz (***iii***) wskazanie gatunków, które mogą być wykorzystane w zabiegach rekultywacji. Flora zwałowiska była reprezentowana przez 92 gatunki roślin naczyniowych, należące do 36 rodzin botanicznych i 77 rodzajów. Dominowały gatunki rodzime (apofity).
W spektrum form życiowych hemikryptofity przeważały nad terofitami i geofitami. Najliczniej reprezentowane grupy ekologiczne stanowiły gatunki ruderalne i łąkowe.
W odniesieniu do strategii życiowych dominowały gatunki o silnych zdolnościach konkurencyjnych i strategii pośredniej typu CSR. Podstawowym sposobem dyspersji nasion była anemochoria. Pod względem preferencji siedliskowych w składzie gatunkowym flory zwałowiska dominowały taksony przywiązane do podłoży umiarkowanie nasłonecznionych, ciepłych, świeżych, o obojętnym odczynie i umiarkowanie zasobnych. W porównaniu do sezonu wegetacyjnego 2002 wykazano istotne statystycznie różnice we florze pod względem pochodzenia, form życiowych, grup

ekologicznych, strategii życiowych i sposobów dyspersji nasion oraz preferencji siedliskowych gatunków względem światła, temperatury, odczynu i żyzności podłoża. Często odnotowywane pseudometalofity (*Agrostis capillaris*, *Cardaminopsis arenosa*, *Daucus carota*, *Deschampsia caespitosa*, *Leontodon hispidus*, *Plantago lanceolata*, *Silene vulgaris*, *Rumex acetosa*) zaleca się do nasadzeń w ramach rekultywacji biologicznej zwałowiska.