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The Role of Spontaneous Succession in Reclamation of Mining Waste Tip in Area of Ruda Śląska City

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Abstract. Coal exploitation has produced a huge amount of mining waste whose considerable part is being piled on the waste dumps. The analysis was carried out in the area of Ruda Ślaska city. The waste dumps are located within the city limits. The spontaneous processes of succession can thus help to manage such urban landscapes in compliance with the principles of sustainable development.

The majority of such territories are managed and restored. However, some areas avoid reclamation processes and instead undergo the process of spontaneous vegetation or even landscape succession. The aim of the research is first and foremost to characterize the spontaneous succession of vegetation in terms of habitat requirements to which we include light, temperature, humidity, trophic conditions, reaction (pH), granulometric composition and plant life forms. In the second place the aim was to determine the direction of the spontaneous succession of vegetation as well as to demonstrate the usefulness of such types of research while planning the reclamation of the post-mining areas that have been deformed to suit the urban landscape.

The result of the analysis showed the occurrence of 108 vascular plants in I and 60 in II waste dump. It was mostly photophilous species that prevailed on both waste dumps. They were mostly native as well as non-native species. Some species like *Calamagrosits epigejos, Robinia pseudoacacia, Betula pendula* have high biological productivity despite unfavorable conditions. The overgrown dumps shaped the image of the city landscape in a specific way. However, the investigation showed that the number of species on the waste dumps increases with time. The results of the research into the conditions that reign on the dumping grounds provide the basis for projects of reclaiming the post-mining sites, in particular the waste dumps, from raw material extraction, as well as demonstrate the usefulness of the spontaneous succession of plants.

Keywords: mining waste dump, vascular flora, plant succession, city landscape.

Conference topic: Sustainable urban development.

Introduction

Since the 18th century intense industrial activity and mining have been carried out in the region of Upper Silesia, including the area of Ruda Śląska. The industrial activities led to numerous adverse environmental changes. In the urban areas they gave rise to many territories affected by the extraction and processing of raw materials and waste management (Żmuda 1973). The coal exploitation produced a large amount of mining waste in the city. Only a small portion of it is used in various technological processes and in construction. Most of these wastes are deposited in the form of dumps. They are part of the urban landscape of Upper Silesia. In the vast majority the areas with waste dumps have been reclaimed in the effort to remedy the mining damage done to the natural environment in compliance with the Polish environmental law (Act of 9 June 2011, Geological and Mining Law). For financial reasons, in many areas, these processes have not been conducted. Such surfaces undergo a natural succession of vegetation. Succession of vegetation on post-mining areas has been examined in Poland (Rostański 2006; Olszewski 2009; Woźniak 2010; Rahmonov *et al.* 2015) as well as in other countries (Novak, Prach, 2003; Lukešová 2001). The composition and type of bedrock has a significant role in the pace of development of succession in such areas.

In the past, the majority of these areas underwent reclamation. However, the process of ecosystem regeneration on post-exploitation areas has not received sufficient attention in terms of scientific research. Materials referring to the succession at the non-reclaimed sandy parts (Czylok, Rahmonov 2004) indicate that local vegetation is of primary character whilst developing ecological systems – considering the occurrence of many rare vegetation species connected with early succession stages – have a unique character.

The aim of the study was to analyze the vascular flora on post- mining dumps with the aid of ecological indicator values to determine the direction of spontaneous succession of vegetation and to determine the suitability of this type of research when planning the rehabilitation of the deformed areas and shaping the urban landscape.

Study area

The study included two waste dumps located in the central and northern part of the city of Ruda Slaska, in southern Poland (Fig.1). They differed only in their age (referred to in the analysis as I-the older "Klara" and II-the more recent "Bielszowice"). The more recent waste dump (I) was created in the 70s of the twentieth century, while the older one (II) had already existed before World War II.

Both waste dumps are made of a similar post-mining material (mainly mudstones, claystones and carbonaceous shale). Therefore, the developmental stage in terms of overgrowth and the impact upon the city landscape is also different.

The objects are distinct from the city landscape. They are prominent due to their specific anthropogenic sculpture which clearly distinguishes them against other elements of the urban landscape. The analyzed objects were not subject to reclamation and arose as a result of spontaneous succession (not only of vegetation but also landscape).

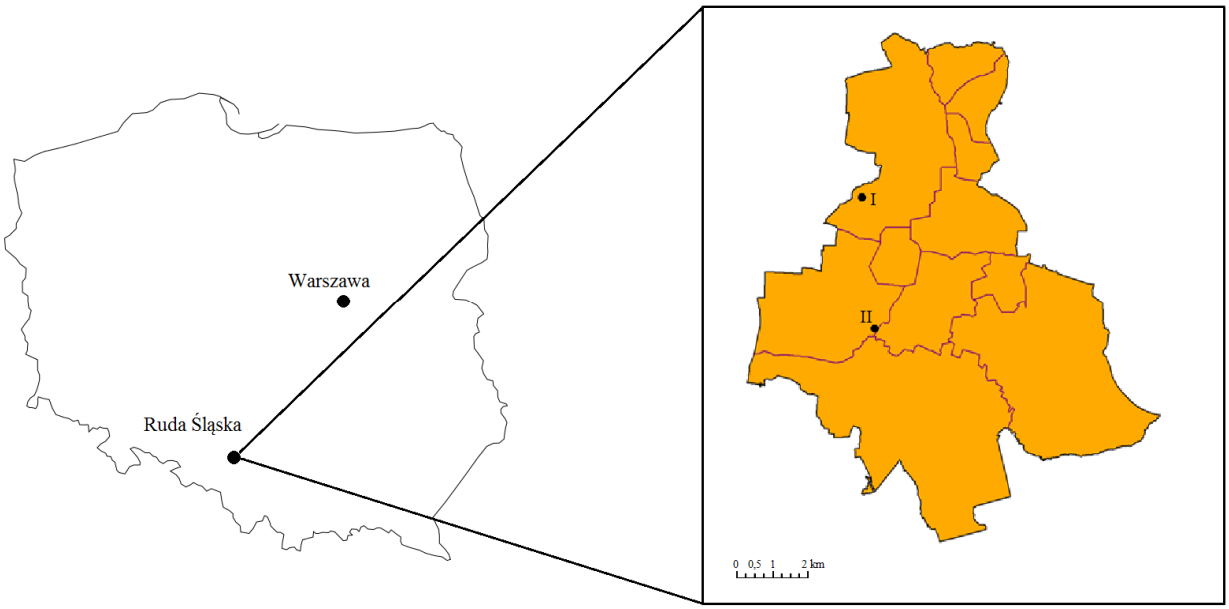

Fig. 1. Location of study area: I – the older waste dump; II more recent waste dump

Materials and methods

In line with the objectives of the present analysis floristic materials were collected at both waste dumps. They consisted in preparing an inventory on the surfaces with varying degrees of stabilization and vegetation coverage. Individual species were marked with the aid of a key for the determination of the plants growing on the Polish lowland (Rutkowski 2004).

The flora used for the research was analyzed in terms of habitat requirements. The analysis was performed using a number of ecological indicator values widely used in the studies of vegetation (Zarzycki *et al.* 2002). For this purpose, the following environmental indicators were taken into consideration: light, temperature, humidity, trophic conditions, reaction (pH) and the granulometric composition of the soil, forms of plant life forms corresponding to the survival of the species in various environments. The above factors presented in the form of numerical data reflect the functioning of the vascular plants in edaphic and climatic conditions. As such, they showed the reaction of species to habitat factors. However, they describe the conditions suitable for the species which usually grow in a given environment and do not depict their full ecological amplitude (Roo-Zielinska 2004). Most indicators are a 5-point scale and show the intensity of the phenomenon. Some of the species have a broader spectrum of tolerance, and the indicators are represented as intervals.

Results

Ecological Requirements of plants

The studies on waste dump vegetation revealed the presence of 128 species of vascular plants (108 on the older waste dump and 60 on the more recent waste dump). Most of them are either hemicryptophytes or phanerophites. In terms of lighting conditions the objects under study do not show significant variation (Fig. 2). It is mostly the

pioneering photophilous species such as *Berteroa incana, Betula pendula, Cichorium intybus, Medicago falcata, Populus tremula, Ranunculus repens, Rubus idaeus, Tussilago farfara* whose presence has been reported.

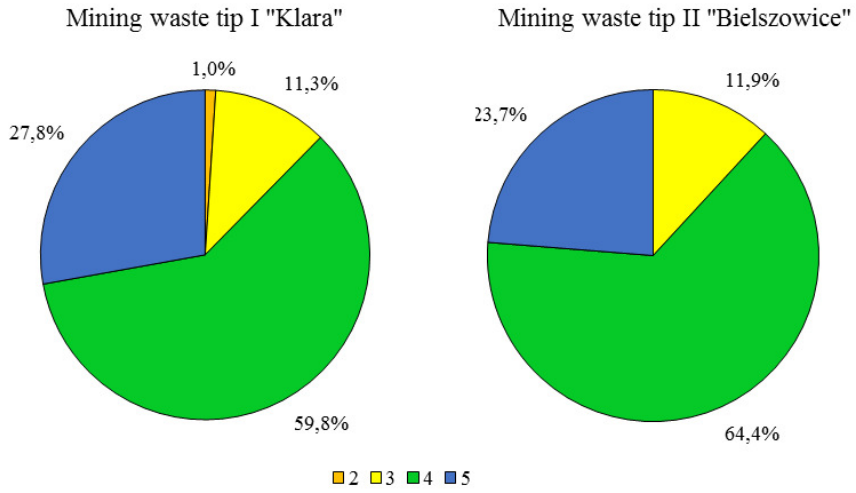

Fig. 2. The differentiation of species accordings to light requirement value: 2 – moderate shade, 3 – half-shade, 4 – moderate light, 5 – full light

The dumps under research did not differ significantly also in terms of thermal conditions. They are covered in species characteristic for the moderately warm climatic conditions (Fig. 3) such as *Acer negundo, Alnus glutinosa, Artemisia vulgaris, Dianthus deltoids, Molinia caerulea, Padus serotina, Solidago canadensi, Solidago gigantean.* On the other hand, the percentage of species growing on areas with moderately cool climatic conditions is lower. They include for instance: *Acer pseudoplatanus*, *Campanula patula, Plantago major, Ranunculus repens, Sorbus aucuparia, Trifolium pratense, Trifolium repens, Urtica dioica.* In addition, a species called *Avenula pratensis*, which grows in the warmest regions and micro-habitats, was detected on the older waste dump.

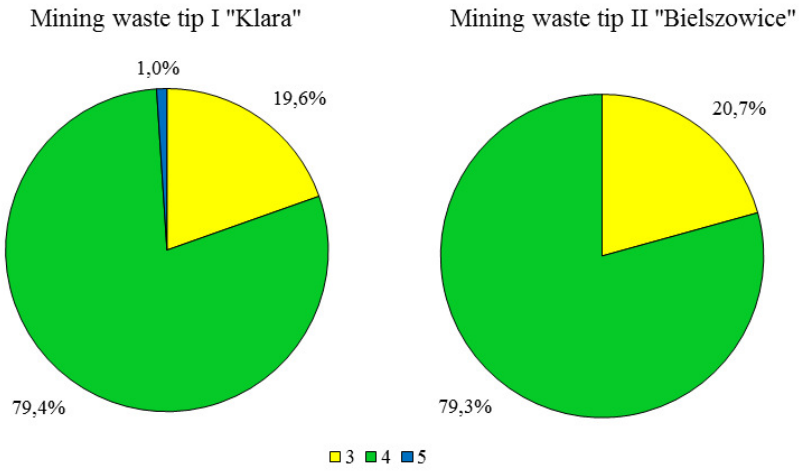

Fig. 3. The differentiation of species accordings to temperature requirement value: 3 – moderately cool climatic conditions, 4 – moderately warm climatic conditions; 5 – warmest regions and microhabitats

The moisture conditions of the waste dumps under research were optimal. The majority of plants grown on a fresh soil (Fig. 4) such as: *Calamagrostis epigejos, Centaurea jacea, Deschampsia flexuosa, Lonicera nigra, Silene vulgaris, Senecio vulgaris, Tilia cordata, Vicia cracca*. In contrast, species growing on a dry and moist soil are much less numerous. In addition, species typical for wet and aquatic habitats have been reported on both waste dumps. They include, among others: *Alnus glutinosa, Epilobium hirsutum, Lemna minor, Phragmites australis, Polygonum amphibium, Typha augustifolia, Typha latifolia.* Differentiation as to the humidity requirements is closely related to granulometric composition and to the retention capacities.

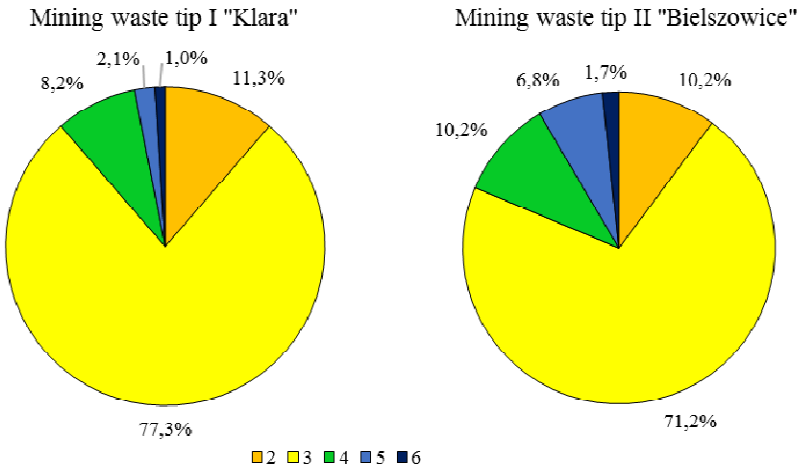

Fig. 4. The differentiation of species accordings to soil moisture requirement value:
2 – dry; 3 – fresh; 4 – moist; 5 – wet; 6 – aquatic

The analyzed waste dumps are diverse in terms of the presence of species requiring a specific amount of trophic conditions (Fig. 5). The richness of nutrients is associated with the bedrock, namely the Carboniferous rocks. The older dump can be characterized through higher amount of species typical for the rich soils. To such species we can include: *Acer pseudoplatanus, Aegopodium podagraria, Cornus sanguinea, Fraxinus excelsior, Heracleum sphondylium, Populus alba, Populus nigra, Ranunculus repens*. The percentage of species typical for moderately poor and poor soils is considerably smaller. Among them we encounter *Agrostis canina, Calamagrostis epigejos, Cichorium intybus, Conyza canadensis, Lonicera nigra, Populus tremula, Robinia pseudoacacia, Succisa pratensis.* In addition, a species typical for very rich soils has been spotted here: *Amaranthus retroflexus.*

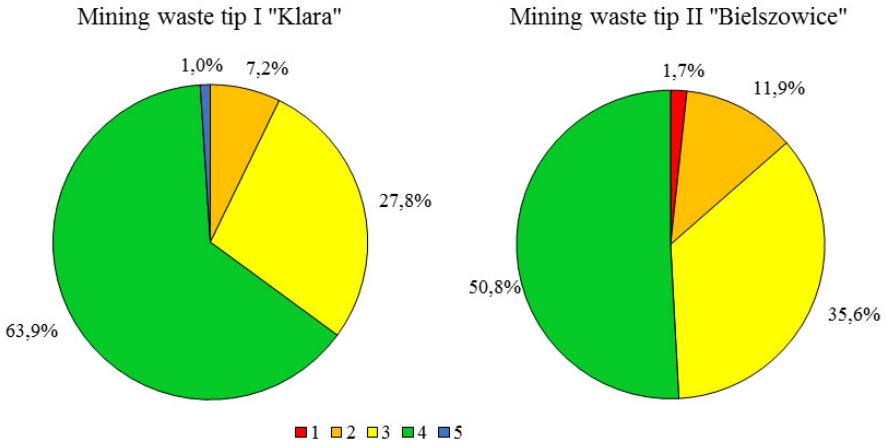

Fig. 5. The differentiation of species accordings to trophy requirement value:
1 – soil extremely poor (extremely oligotrophic); 2 – soil poor (oligotrophic); 3 – soil moderately poor (mesotrophic); 4 – soil rich (eutrophic); 5 – soil very rich (extremely fertile)

According to the data shown in the graphs (Fig. 6) the more recent dump can be characterized by a greater diversity of species in terms of their pH preferences. The percentage of species typical for the neutral pH is smaller in comparison with the older dump. On the other hand, the amount of the species characteristic for moderately acidic soils is higher. The former include for example *Aegopodium podagraria, Alnus glutinosa, Carex brizoides, Cerasus avium, Hypericum perforatum, Poa annua, Sambucus nigra, Tussilago farfara.* The latter are represented by: *Agrostis canina, Conyza canadensis, Larix decidua, Lathyrus sylvestris, Populus tremula, Sorbus aucuparia, Sarothamnus scopiarus, Viola tricolor.*

This is mainly due to the presence of the carbonates typical for gangues. Moreover, species typical for acidic and strongly acidic soils have been reported on the more recent dump: *Andromeda polifolia, Calluna vulgaris, Deschampsia flexuosa.*

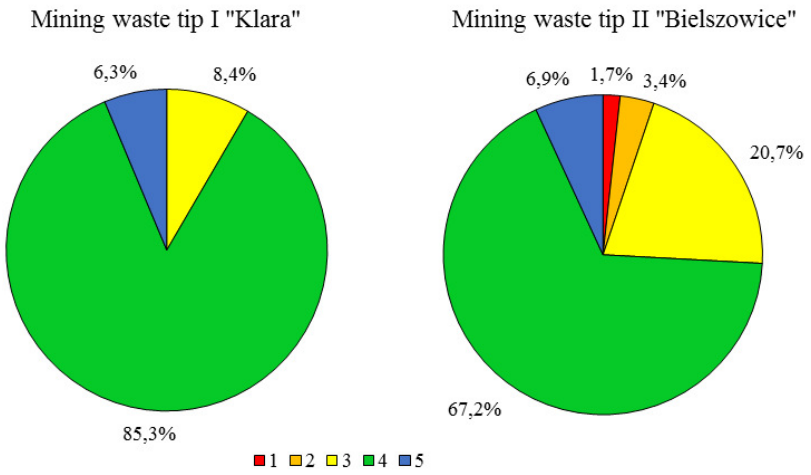

Fig. 6. The differentiation of species accordings to soil reaction requirement value:
1 – highly acidic soils, pH<4; 2 – acidic soils, 4≤pH<5; 3 – moderately acidic soils, 5≤ph<6;
4 – neutral soils, 6≤pH<7; 5 – alkaline soils pH≥7

The analyzed waste dumps can be characterized by a high percentage of species growing on argillaceous clay and dusty deposits (Fig. 7) such as *Achillea milefolium, Hypericum perforatum, Prunus spinosa, Quercus robur, Ranunculus acris, Salix alba, Siccisa pratensis, Trifolium pratense, Viccia cracca.* It should be emphasized that the deposited rock undergoes rapid physical weathering and thus the amount of silt fraction increases. It does not always favor the colonization of species. Their percentage is larger on the more recent dump. However, there is a smaller percentage of species growing on the sands.

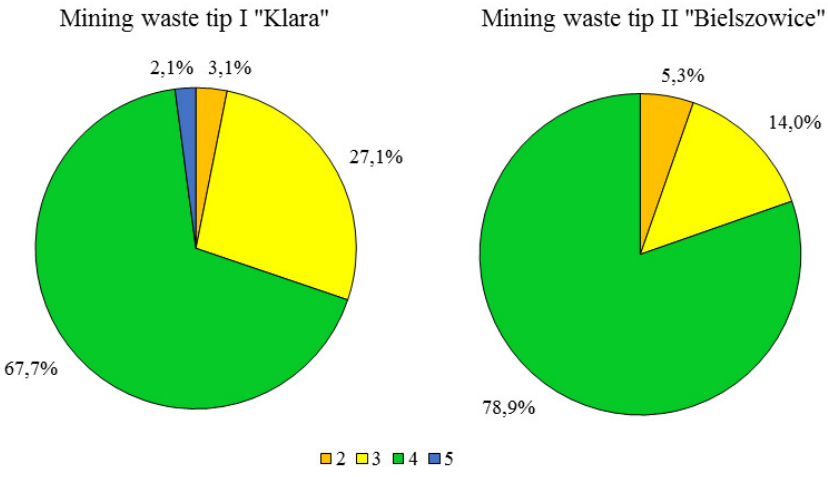

Fig. 7 The differentiation of species accordings to soil granulometric requirement value:
2 – rock debris, scree, gravel; 3 – sand; 4 – argillaceous clay and dusty deposits; 5 – heavy clay and loam

The direction of succession

Natural succession (Fig. 8) is initiated by the species with different ecological requirements. The first stage is initiated by species such as *Cardaminopsis arenosa, Conyza canadensis.* Throughout the intermediate stage it was *Calamagrostis epigejos* that dominated everywhere. Similar situations were observed by other authors (Rahmonov, Parusel 2011).

The last stadium usually amounts to mixed forests, mainly involving various species of shrubs and trees (*Betula pendula, Populus tremula*) with different ecological requirements. All of them are species associated with fresh/dry habitat and wetlands.

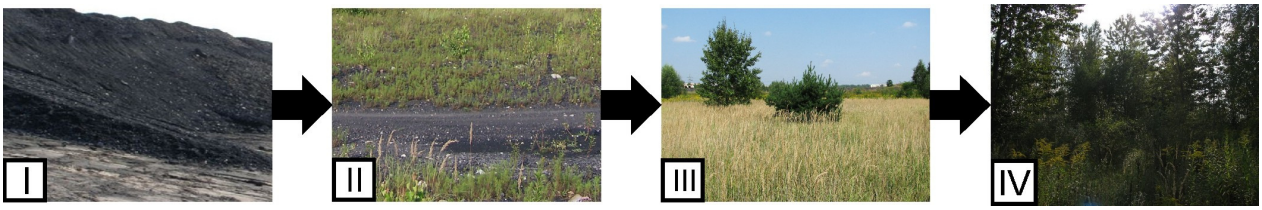

Fig. 8. Spontagneous succession on mining waste dumps: I – waste dump before spontagneous succession; II – initial stage of succession; III – intermediate stage of succession; IV – terminal stage of succession

Discussion

Post-mining waste dumps as well as other mining objects are habitats of extreme edaphic conditions due to both the composition of the bedrock as well as the content of different nutrients. It undoubtedly exerts influence upon the direction and pace of succession and the formation of initial soil (Rahmonov *et al*. 2015; Rahmonov 2016).

They affect the surrounding landscape and shape its character. The rate of encroachment of vegetation on such surfaces is dependent upon many factors, both natural and anthropogenic. In the first case the plant life history and its ecological amplitude are of utmost importance. The time that has elapsed since the processes of formation of vegetation began also plays an important role. The ecological succession taking place on the waste dumps is influenced by factors such as, among others, the granulometric structure, the chemical reaction and the salinity of the ground, water conditions as well as the thermal activity of dumps. The reclamation treatments, as well as the vegetation found in the areas surrounding the dump should be also mentioned.

The vascular plants are characterized by the inidcator ability – it has a set of diagnostic features that allow to determine the status and processes in the environment of their functioning. The flora and plant communities are highly sensitive to changes in environmental conditions. They can be characterized by a set of diagnostic features that allow to determine the status and processes in the environment of their functioning and the functioning of the entire system (Roo-Zielinska 2004). The species that occur on the waste dumps can be characterized by a wide range of tolerance towards most of the analyzed environmental indicators. The indicator values for temperature and soil moisture are similar for both waste dumps. The presence of on both dumps species typical for wet and water habitats is determined by the micro-diversity of the habitat and thus riparian alders may be formed on parts of them (Rahmonov 2014). The occurrence of two species which have a higher demand for water (*Polygonum amphibium* and *Phragmites australis*) on "Klara" is associated with the presence of the area of the former species. The ground contains an impermeable layer, therefore, there are conditions to retain the water and the wetland is formed. By contrast, the presence of such species on "Bielszowice" is related to the nearby area of water reservoir.

On the older dump there were more species that require a substrate with a neutral pH, as well as more nutrients. A higher amount of species typical for the rich soils on the older dumps can be caused by various factors, such as the presence of *Robinia pseudoacacia*. This species is capable of nitrogen assimilation. Therefore, it increases the nitrogen supply to the developing soil by anthropogenic human activities (Różkowski *et al.* 2015). The organic matter from plant remains takes longer to break down on the waste dump grounds. It is the main source of organic nitrogen compounds in the soil. In areas where biocenosis was destroyed, but the soil was preserved, the succession takes place relatively quickly. However, the areas of waste dumps can be characterized by such a strong metamorphosis (which may even amount to a complete destruction of habitat conditions) that the spontaneous formation of the vegetation cover is a succession of primary character (Rostański 2006).

Thus, the process of the overgrowth begins with a bedrock unoccupied by the plants through single plant specimens and the creation of non-forest vegetation with an ever increasing amount of trees and shrubs until forest is formed.

Succession may also occur at different rates on different parts of the waste dumps, depending on the time elapsed since the end of tipping and local habitat factors. Proper selection of species in the process of shaping the landscape is essential especially on the dumps which are unfavorable for any type of vegetation.

For this reason, it would be desirable to allow the damaged areas to regenerate by means of spontaneous succession involving proper species (Rahmonov *et al.* 2004). Piekarska-Stachowiak *et al.* (2014) propose similar approach supporting spontaneous landscape succession. The mining waste dumps in southern Poland are inseparable elements of the urban landscape. At the same time they are the source of environmental pollution through dust and the water runoff to the rivers as well as the infiltration into the ground. For this reason the management of these objects should be most urgent for the city authorities. Economic problems are often an obstacle and that is why

natural succession. can be used for this purpose. The areas directly subject to the cities can be reclaimed, and the ones further off can regenerate themselves.

In the latter case, species typical for this habitat may occur, forming respective ecological systems. Such an arrangement will be much more stable and diverse in terms of species composition and the landscape. The vegetation systems that are formed on the municipal dumps have many functions. One of them is to stabilize the dump and prevent dustiness as well as the transfer of other molecules associated with the mineral composition of the dump.

Due to the important role of the vegetation on dumps, as well as the existence of specific conditions in a given area, the process of rehabilitation should be preceded by a floristic and ecological research in order to identify the individual potential of the degraded land and the possibility of using natural processes that take place on a given area.

The study clearly shows that natural and spontaneous succession of vegetation, despite a long period, will lead to the creation of aesthetic landscape and stable ecological system despite such an extreme environment. The observation and understanding of the succession mechanisms on such surfaces with known periods of formation also facilitates the planning and development of other objects of similar origin.

Conclusions

1. The species of vascular flora found on post-mining dumps have a broad spectrum of tolerance towards the analyzed environmental indicators. On both dumps the percentage of species of a particular indicator value of light, heat and humidity of the soil is similar. The values for trophic conditions, the pH and the granulometric composition of the substrate are different.

2. The ecological succession that occurs on the waste dumps is influenced by many factors, including grain size distribution, the chemical reaction of the substrate, water conditions as well as the dump's thermal activity. Factors such as the reclamation treatments and the surroundings are equally important for the succession.

3. The system of vegetation, which forms on the waste dumps has many functions. One of them is to stabilize the ground, to prevent the dustiness and the movement of light mineral particles.

4. The areas post-mining waste dumps undergo irreversible changes in terms of all components of the environment – the terrain, the water ratio in the vicinity. The soil cover and vegetation are entirely destroyed. Such a strong destruction of the habitat conditions is a reason why the ecological succession taking place on the waste dumps is a succession of primary character.

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