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VEGETATION SUCCESSION AND SOIL DEVELOPMENT IN AN AREA TRANSFORMED BY HUMAN IMPACT – RECLAIMED ASH LANDFILLS

Oimahmad Rahmonov[1], Tomasz Parusel[2]

[1,2]*University of Silesia, Faculty of Earth Sciences, Department of Physical Geography, 60 Będzińska Street, 41-200 Sosnowiec, Poland. E-mails: [1]oimahmad.rahmonov@us.edu.pl; [2]tp_oficjal@interia.pl*

Abstract. Areas affected by intensive human activity are often characterized by a great degree of natural-environment degradation. Every component of the environment undergoes remodeling. The complete destruction of primary vegetation and soil cover as a result of human activity leading to disturbances in the functioning a whole ecosystem is to be seen in southern Poland. Geobotanical- and ecological investigations pertinent to ecological restoration were undertaken. The results show the diversity of vegetation to be linked directly to a mosaic of habitats and micro-habitats and reveal the wide ecological requirement of species in an extreme environment. Geobotanical analysis documents species belonging to taxons in different syntaxonomical groups. The soil has an anthropogenic genesis and the parent rock consists of power-plant ash. The variety of successions reflects relief and the granulometric composition of the parent medium. The rate of vegetation development was conditioned by the properties of the soil.

Keywords: anthropogenic soil, ash landfills, human impact, vegetation succession, vegetation-soil relationships.

1. Introduction

Processes of ecosystem development in anthropogenically transformed areas not only reflect the human contribution but also the spontaneous vegetation succession. In the first case, all activities are legally normalized, controlled and financed by legislation (Act on the Protection of Agricultural and Forested Grounds *Ustawa o ochronie gruntów rolnych i leśnych*; Act – Geological and Mining Law *Ustawa – Prawo geologiczne i górnicze*). As they have been by-passed by land-reclamation activities, the degraded terrains are not very attractive objects for scientific research.

Thus, relatively little attention was has been paid to ecological successions in areas of ash landfills (Drużkowski *et al.* 1977; Oleś and Rahmonov 2002; Oleś *et al.* 2004; Rahmonov *et al.* 2010b).

The majority of scientific studies have focused on degraded areas resulting from mining activity and the disposal of mine wastes (Rostański 2006; Woźniak 2001; Woźniak 2006). Such areas are also characterized by the transformation of water relationships (Absalon 1998; Absalon and Jankowski 1998).

An area comprising a complex of landfills composed of power-plant ash is the geographic focus of this paper. The phytocenose character and species diversity of the vegetation is determined, as is the relationship between vegetation and soil forming processes.

2. Study area

The complex of landfills is located in the southern part of the Silesian Upland (Southern Poland). Its coordinates are: 19°12'2" E, 50°11'16" N (Fig 1). The area involved amounts to about 2.1 km^2. Upper Carboniferous deposits covered by Pleistocene fluvioglacial sands and gravels, and Holocene fluvial deposits in the Przemsza River valley, constitute the geological substrate.

The climate, typical of the entire Silesian Upland, is characterized by an average annual temperature is 7-8°C, a vegetation period lasting 210-220 days, annual precipitation of 700-800 mm and 80 days of snow cover on average. The area investigated adjoins Jaworzno III Power Station which is the source of the ash deposited in the landfill at present and in the past. The ash is delivered and deposited as an ash-water emulgate distributed through a system of pipelines (Łączny and Adamski 2002).

3. Material and methods

Material was collected in the area of the ash landfill. The ash had been deposited in settling ponds built in a former sandpit. The present topography of the ash deposit is distinctly different from that of the enclosing embankments**.** The bottom of landfill comprises the ash layer which, during later land reclamation, was covered with the thick layer of mine wastes (mainly coal shales).

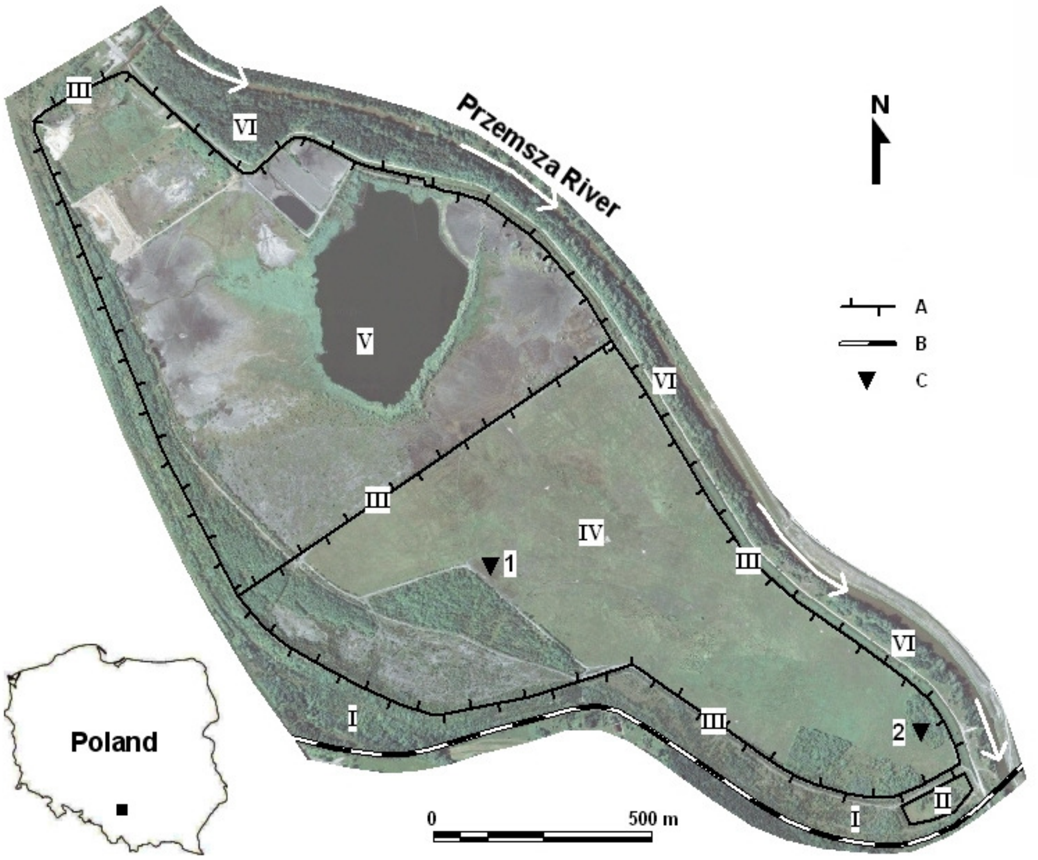

Fig 1. Ash landfill near Jaworzno III Power Station. (A – marginal embankments of landfill. B – railway line. C – soil profiles with number. Zones of landfill: I – zone railway line-marginal embankment; II – small concrete settlement tank; III – embankment of main landfill; IV – reclaimed part of main landfill; V – active part of main landfill; VI – plantings on the embankment zone of the Przemsza River. Figure based on satellite photographs from Google Maps)

A following stage of reclamation included fertilization of a layer of soil material rich in organic matter (humus). This soil provided a substrate for natural biological reclamation and the processes of natural ecological succession.

Ecological and geobotanic investigations were carried out in both that area of the landfill already abandonned and reclaimed, and in the part still in use. In the landfill, research transects were established where habitats were separated on the basis of differences in anthropogenic relief and in type of vegetation. Six zones were distinguished as shown on Figure 1 and outlined on Table 1.

In every zone, lists of plants and habitat details were recorded. On the basis of ecological indices (Zarzycki *et al.* 2002), species diversity was evaluated in terms of ecological- and geobotanic parameters. The syntaxonomic affiliation of species was determined on the basis of Matuszkiewicz (2008). Morphological analyses of soils on surfaces with advanced degrees of vegetation development were made for comparison with other parts of the landfill area.

4. Results

Within the ash landfill of Jaworzno III Power Station 6 morphologically distinct zones simultaneously hosting different plant communities can be distinguished (Table 1 and Fig 1). Individual zones do not differ essentially from one other, apart from the area of the landfill currently in use.

The processes of ecological succession in the landfill area are typically initiated by *Calamagrostis epigejos*. This high grass possesses a very wide ecological spectrum. Its strongly-developed near-surface root system facilitates the uptake of nutrients not only from the substratum, but also from atmospheric precipitation and from stagnant surface water. Rapid terrain colonization by individuals of this species leads to sodding of the upper soil horizon which, in turn, acts to inhibit the development of other plant species. *C. epigejos* is also characterized by a vegetative- and competitive-growth strategy.

Table 1. Vascular plants in the Jaworzno III Power Station landfill

Species	Ecological indicator values			Zones of landfill					
	D	H	M	I	II	III	IV	V	VI
Achillea millefolium L.	4	1-2	•	+	-	-	-	-	-
Agrostis canina L.	4	3	•	-	-	+	-	-	-
Alnus glutinosa (L.) Gaertn.	5	3	•	+	-	-	-	-	+
Arctium lappa L.	4	2	•	+	-	-	-	-	-
Arctium tomentosum Mill.	4	2	•	-	-	-	+	-	-
Arrhenatherum elatius (L.) P.Beauv. ex J.Presl & C.Presl	4	2	1	-	-	+	-	-	-
Artemisia absinthium L.	3	2	•	+	-	-	-	-	-
Artemisia vulgaris L.	4	2	•	+	-	-	-	-	-
Athyrium filix-femina (L.) Roth	4	2	•	-	-	-	-	-	+
Berteroa incana (L.) DC.	3	1	•	-	-	+	-	-	-
Betula pendula Roth	3-4	1-2	•	+	+	-	+	-	+
Calamagrostis epigejos (L.) Roth	3	1	1	+	+	-	+	+	-
Caragana arborescens Lam.	AS			-	-	-	-	-	+
Cardamine pratensis L.	4-5	2	•	-	-	+	-	-	-
Carduus crispus L.	4-5	2	•	-	-	-	+	-	-
Carex hirta L.	3-4	2	1	-	-	+	-	-	-
Cerastium semidecandrum L.	3	2	1	-	-	-	-	+	-
Chamomilla recurita (L.) Rauschert	AS			-	-	-	-	+	-
Chelidonium majus L.	2-5	2-3	•	-	-	-	-	-	+
Cornus alba L.	AS			-	-	-	+	-	-
Corylus avellana L.	4	2	•	+	-	-	-	-	-
Corynephorus canescens (L.) P.Beauv.	3	1	•	-	-	-	+	+	-
Crataegus laevigata (Poir.) DC.	4-5	2-3	•	+	-	-	-	-	-
Crataegus monogyna Jacq.	4-5	2-3	•	+	-	-	-	-	-
Dactylis glomerata L.	4	2	•	-	-	+	-	-	-
Daucus carota L.	4	2	•	+	-	+	-	-	-
Deschampsia caespitosa (L.) P.Beauv.	4	2-3	•	-	-	+	-	-	-
Deschampsia flexuosa (L.) Trin.	3-4	1-2	•	-	-	+	-	-	-
Dianthus carthusianorum L.	1-4	2	•	-	-	+	-	-	-
Dryopteris filix-mas (L.) Schott	4	2	•	-	-	-	-	-	+
Echinops ritro L.	AS			-	-	-	+	-	-
Epilobium angustifolium L.	3-5	2	•	-	-	-	-	+	-
Epipactis helleborine (L.) Crantz	4	2	•	-	-	-	-	-	+
Erigeron acris L.	2-5	2	1	+	-	-	-	-	-
Erigeron annuus (L.) Pers.	2-4	2	•	+	-	-	-	-	-
Erigeron canadensis L.	3-4	2	•	+	-	-	-	-	-
Euonymus verrucosus Scop.	1-4	2	•	+	-	-	-	-	+
Euphrasia rostkoviana Hayne	4	2	•	-	-	+	-	-	-
Galium verum L.	4-3	2	•	-	-	+	-	-	-
Hieracium pilosella L.	2-4	2	•	-	-	+	-	-	-
Hippophaë rhamnoides L.	3-5	1	•	+	-	-	-	-	-
Holcus mollis L.	3-4	2	•	+	-	-	-	-	-
Humulus lupulus L.	4	2-3	•	+	-	-	-	-	-
Hypericum perforatum L.	4	2	•	-	-	-	+	-	-
Juncus articulatus L.	4-5	3	•	+	-	-	-	-	-
Juncus conglomerates L.	4-5	3	•	+	-	-	-	-	-
Leontodon autumnalis L.	4	2	2	-	-	+	-	-	-
Medicago falcata L.	2-5	2	•	-	-	+	-	-	-
Medicago lupulina L.	2-4	1-2	•	-	-	+	-	-	-
Medicago sativa L.	2-4	2	•	-	-	+	-	-	-
Melilotus alba Medik.	2-4	1-2	•	-	-	+	-	-	-
Molinia caerulea (L.) Moench	3-5	2-3	•	+	-	-	-	-	-
Oenothera biennis L.	2-3	2	•	-	-	+	-	+	-
Padus avium Mill.	4-5	2	•	-	-	-	-	-	+
Padus serotina (Ehrh.) Borkh.	3-4	2	•	-	-	+	+	-	+
Phalaris arundinacea L.	3-5	2	•	-	-	-	+	-	-
Phragmites australis (Cav.) Trin. ex Steud.	3-5	2-3	•	-	-	+	+	+	-
Pinus sylvestris L.	3-4	1-3	•	+	-	+	-	+	+
Plantago lanceolata L.	4	3	•	+	-	-	-	-	-
Plantago major L.	3-5	2-3	•	-	-	-	-	+	-

Poa pratensis L.	4	2	•	+	-	-	-	-	-
Poa trivialis L.	4-5	2	•	+	-	-	-	-	-
Polygonum aviculare L.	2-5	1-2	•	-	-	-	-	+	-
Populus tremula L.	4-3	2	•	-	+	-	-	-	-
Potentilla tabernaemontani Aschers.	1-4	2	•	-	-	+	-	-	-
Prunus spinosa L.	4	2	•	+	-	-	-	-	-
Quercus robur L.	4	2	•	-	-	+	-	-	+
Quercus rubra L.	3-4	2	•	+	-	+	-	-	+
Robinia pseudacacia L.	2-4	2	•	+	-	-	+	-	+
Rosa canina L.	4	2-3	•	+	-	-	-	-	-
Rubus caesius L.	3-4	2	1	+	-	+	-	-	-
Rubus idaeus L.	3-4	2	1	+	-	+	-	-	-
Rumex acetosa L.	4	2	•	-	-	+	-	-	-
Rumex acetosella L.	2-4	1-2	•	-	-	+	+	-	-
Salix caprea L.	3-4	2	•	+	-	-	-	+	-
Salix cinerea L.	3-5	3	•	+	-	-	-	-	-
Salix pentandra L.	4	3	•	-	-	-	-	+	-
Salix purpurea L.	2-4	1	•	-	-	+	-	+	+
Salix rosmarinifolia L.	4	3	•	+	-	-	-	+	-
Salix triandra L.	2-4	2	•	-	-	-	-	+	-
Sambucus nigra L.	3-4	2	•	-	-	-	-	-	+
Saponaria officinalis L.	2-4	1-2	•	+	-	-	-	-	-
Scabiosa ochroleuca L.	3-4	2	1	-	-	+	-	-	-
Senecio viscosus L.	3	•	•	-	-	-	-	+	-
Solidago canadensis L.	2-4	2	•	+	-	+	-	-	-
Solidago virgaurea L.	4-3	2	•	-	-	+	+	-	-
Spergula morisonii Boreau	3	2	•	-	-	-	-	+	-
Tanacetum vulgare L.	4-2	2	•	+	-	-	+	-	-
Thymus pulegioides L.	4	2	•	-	-	+	-	-	-
Trifolium arvense L.	3-1	2	•	+	-	-	-	-	-
Trifolium pratense L.	4	2	•	+	-	-	-	-	-
Trifolium repens L.	4	2	•	+	-	-	-	-	-
Typha angustifolia L.	4-3	1-2	•	-	-	+	-	-	-
Urtica dioica L.	3-4	2	•	-	-	-	-	-	+
Verbascum nigrum L.	2	2	•	+	-	-	+	-	-
Vicia cracca L.	4	2	•	-	-	+	-	-	-

Ecological indicators: D – soil granulometric value (1 – rocks and rock crevices, 2 – rock debris, scree, gravel, 3 – sand, 4 – argillaceous clay and dusty deposits, 5 – heavy clay and loam); H – organic matter content value (1 – soil poor in humus, 2 – mineral-humic soil, 3 –soil rich in organic matter, • – indefinite); M – resistance to increased heavy metals soil contents value (1 – species tolerating increased heavy-metal contents, 2 – species requiring increased heavy metal contents, • – indefinite); AS – alien species. Zones are as shown on Figure 1.

5. Vegetation

Investigations on the vascular-plant flora in the Jaworzno landfill revealed the occurrence of 96 species (Table 1). The largest number of taxa belongs to the *Asteraceae*, *Poaceae*, *Fabaceae* and *Caryophyllaceae* families. The biological spectrum of the flora is composed of hemicryptophytes (Fig 2).

In term of light- and thermal requirements, the plant species (Figs 3 and 4) are not significantly diverse. The ecological requirements of the species with regard to granulometric composition (D), humus (H) and resistance to heavy metals in the substratum (M) are presented in Table 1. The table also details the occurrence of individual species identified in each vegetation zone.

With respect to the mosaic character of habitats in the area of the landfill, the occurrence of species characterizing many syntaxonomic units is observed on the level of classes, orders and associations. Within classes, species belonging to *Quercetea robori-petraea*, *Vaccinio-Piceetea, Rhamno-Prunetea, Phragmitetea, Molinio-Arrhenatheretea* and *Festuco-Brometea* occur. The flora is also represented by a number of orders (*Arrhenatheretalia*, *Molinietalia caerlueae*, *Epilobietalia angustifolii*, *Plantaginetalia majoris, Polygonion avicularis*) and associations (*Alno-Ulmion*, *Dicrano-Pinion*, *Pino-Quercion*).

In addition, many species are characteristic of numerous plant associations, e.g., *Spergulo-Corynephoretum* (*Corynephorus canescens*, *Spergula morisonii*), *Diantho-Armerietum* (*Dianthus carthusianorum*), *Leucobryo-Pinetum* (*Deschampsia flexuosa*) and *Arctio-Artemisietum* (*Artemisia vulgaris*, *Arctium lappa*).

The occurrence of the association *Calamagrostietum epigeji*, a one-species aggregation over a large area in the landfill, is worthy of special note. Thanks to its ecological plasticity, this grass develops very successfully in such an extreme environment. Within this association, other species of vascular plants rarely occur (Fig 8).

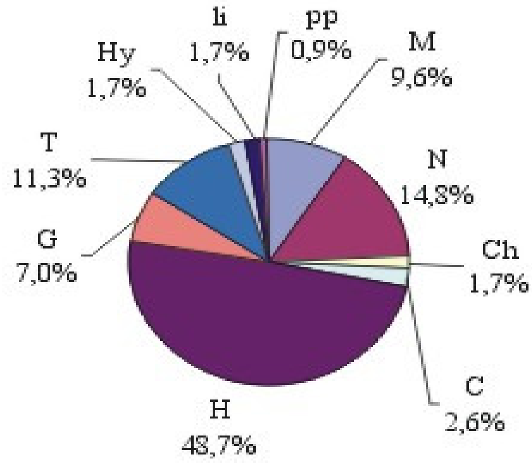

Fig 2. Plant life forms in the landfills (M – megaphanerophytes, N – nanophanerophytes, Ch – woody chamaephytes, C – herbaceous chamaephytes, H – hemicryptophytes, G – geophytes, T– therophytes, Hy – hydrophytes, li – lianas, pp – semiparasites)

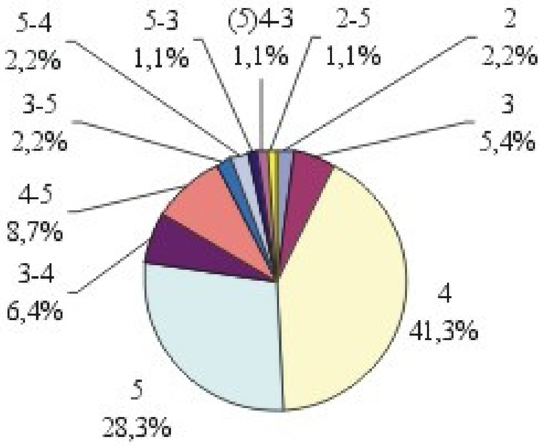

Fig 3. Plant requirement in respect of light values (2-moderate shade, 3-half-shade, 4-moderate light, 5-full light)

Plantings in the zone between the eastern embankment of the main settlement tank and the Przemsza River channel (Table 1) constitute an autonomous zone within the landfill. The tree stand here mainly involves *Pinus sylvestris*, *Quercus rubra*, *Q. robur*, *Caragana arborescens*, *Betula pendula*, *Robinia pseudacacia*, *Alnus glutinosa* accompanied by *Euonymus verrucosus*, *Padus serotina*, *P. avium*, *Sambucus nigra* and *Salix purpurea*. These artificial plantings are very poor in terms of flora. *Athyrium filix-femina*, *Dryopteris filix-mas*, *Chelidonium majus*, *Urtica dioica* occur here.

The discovery of some individuals of the protected species of the orchid *Epipactis helleborine* is very significant. In the Silesian voivodship, this species belongs to hazard category R (Parusel *et al.* 1996). The soil in which these plantings grow is covered with a significant thickness of organic matter – mainly oak-pine plant litter.

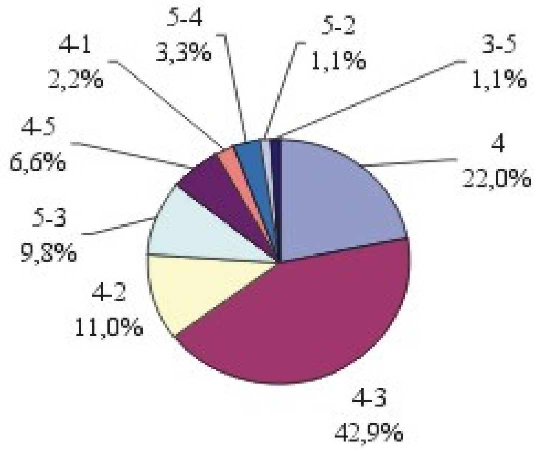

Fig 4. Plant requirement with respect to temperature (1-coldest climatic conditions, 2-moderately cold areas, 3-moderately cool climatic conditions, 4-moderately warm climatic conditions, 5-warmest regions and microhabitats)

6. Soil properties

The anthropogenic parent material is a mixture of power station ash and mine waste. The granulometric- and chemical composition (Fig 5 and Table 2) of these materials do not constitute a friendly habitat for the majority of living organisms.

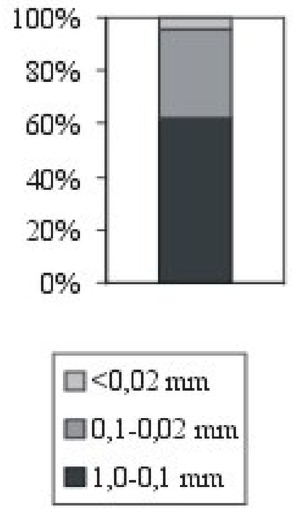

Fig 5. Granulometric composition of ash from Jaworzno Power Station III (after Maciak 1983)

A significant part of the landfill area is devoid of soil cover, especially within the part still in use. In the remainder, the soil cover has a mosaic character. Organic humus horizons display diversity in thickness and degree of organic matter decomposition, especially under artificial plantings of *Robinia pseudacacia* and *Padus serotina*. The morphological characteristics of the soil are outlined in Table 3.

Table 2. Physical and chemical properties of ash from Jaworzno III Power Station (after Maciak 1983)

Selected properties		
pH	in H_2O	9.4
	in KCl	8.8
loss ignition	% of dry matter	4.2
raw ash		95.8
clear ash		13.65
SiO_2		82.15
Nt		0.03
K_2O		0.09
Na_2O		0,08
CaO		4.93
MgO		1.41
Fe_2O_3		3.15
Al_2O_3		17.37
P_2O_5		0.02
S		0.4
heavy metals		
Cu	ppm	50
Mn		413
Zn		231
Pb		24
Cr		116
Ni		74
others		
B	ppm	21,5

Table 3. Morphological characteristics of soil in the investigated area

Profile No.	Layers depth [cm]	Profile description	Notes
1	0-15	Loose material with humus admixted (allochtonus material – anthropogenic layer for reclamation). Roots lacking.	Fig 6
	<15	Material of different sizes including black coal fragments and weathered pieces of slate. Compacted structure. Roots in fine fraction. Red to brown colouration.	
2	0-15	Consolidated material with a high proportion of humus – like müll humus. Within this layer, divided patches of initial organic horizon (Ol) ca 2 cm thick with obvious presence of fine roots .	Fig 7
	<15	Compacted layer of mine waste	

At the present stage of its formation, the anthropogenic soil cover has not developed organic horizons (O; Figs 6 and 7). In the morphological description (Table 3), the term *layer* was used because of a lack of similarity to typical genetic horizons in natural soils. The soils investigated may be classified as *Urban soils*, *Mine soils* and/or *Technogenic Superficial Formations* (*World reference base for soil resources* 2006).

Fig 6. Soil profile No. 1 (photo by O. Rahmonov)

Fig 7. Soil profile No. 2 (photo by T. Parusel)

7. Discussion

The processes of ecological succession and soil development in anthropogenically degraded areas are conditioned by substratum character and nature of disturbance. As noted above, the succession process within the settlement ponds near Jaworzno III Power Station was initiated and conditioned by *Calamagrostis epigejos* (Fig 8).

The encroachment of other plant species follows exclusively in niches free from competition and in waterlogged areas where *C. epigejos* does not occur. Embankments surrounding the landfill are covered with tree and shrub species and by herbaceous vegetation. Here the contribution of *Calamagrostis epigejos* is insignificant and it does not occur in a form of turf clumps. Arising from this fact, the species diversity is significantly greater in this area compared to the other zones of the landfill (Table 1). Similar results were obtained by Woźniak (2001, 2006).

Fig 8. Association *Calamagrostietum epigeji* in autumn (photo by O. Rahmonov)

In the landfill, particular zones are, in terms of their flora, distinctive and differ from remaining zones to a greater or lesser degree. In the railway line-embankment (zone I), a dense community is created by species from *Rubo fruticosi-Prunetum spinosae* associated with almost the complete species composition. It is a dry and sun-filled area. In this zone, clumps of arborescent vegetation occur and open surfaces are settled by meadow-brushwood ecosystems. This part of Zone 1 is characterized by the occurrence of numerous micro-depressions and micro-basins, the presence of which influences the species composition and the type of plant communities (Table 1).

Black locust (*Robinia pseudoacacia*), covering the landfill area, creates biogroups composed of tree trunks 10 m high. The biogroup has a two-layer vertical structure: top and undergrowth. In the former, mostly *R. pseudoacacia* occurs and, in the latter, *Padus serotina*. The oldest individuals of *R. pseudoacacia* are accompanied by a young generation of this species. The oldest specimen is about 15 years old. Small individuals of *Betula pendula, Caragana arborescens* and *Crataegus monogyna* are encountered within the clump, but they are not of significant biocenotic importance at this stage. In the shadow of the canopy of *R. pseudacacia*, seedlings and mature individuals of *P. serotina* are abundant whereas, under the canopy, the succeeding generations of this species are seen to develop both vegetatively and generatively.

On the open surfaces within the main part of the landfill, vascular vegetation essentially does not develop; only sporiferous vegetation tolerates the habitat conditions. Turfs form with *Polytrichum juniperinum*, *P. pileferum* and lichens from the order *Cladonia sp.* In addition, a distinct algal coating develops which, in summer, creates a dense, compact crust (Rahmonov 2010). Among vascular plants, nothing is evident except second-generation seedlings of *Corynephorus canescens* and *Rumex acetosella*. Despite snowfall and persistent freezing air temperatures over the winter, these surfaces remain partly free of snow cover due, most probably, to the combustion of coal in the mining waste that was used in the reclamation of the landfill.

In the active part of the landfill, it is species such as *Salix purpurea*, *Salix rosmarinifolia*, *Pinus sylvestris* and *Corynephorus canescens* characterised by anemochorical seed dispersal that mostly develop. In the landfill, dust pollution significantly inhibits plant development through the clogging of stoma and the covering up the whole assimilation apparatus. Even in summer, small local dust storms are of common occurrence. In such places, the association *Corynephoretum canescentis* with almost complete species composition evolves (Rahmonov and Oleś 2010).

The association *Phragmitetum australis* occurs in the immediate surroundings of the active settlement pond in the northern part of the landfill (Fig 1). The maximum height of individual *Phragmites australis* plants reaches 3 m. The fact that the water in the reservoir is prone to significant changes in level also influences the organisation of biocenoses (Rahmonov and Wach 2002).

The soils have an anthropogenic character and their morphological and chemical diversity is also conditioned by human activity. In the landfill, localized warming of the mining waste and, thus, the lack of a cover of winter snow was an unquestionable influence on the formation of the soils and their organic components (Rahmonov *et al.* 2010a). The distinct predominance of algae, fungi, lichens and *Bryophyta* over the vascular plant species reflects their potential for adaptation to extreme habitats (Rahmonov 2007).

As for the pedogenesis, the rapid formation of humus and organic horizons (O) divided into subhorizons (Ol-Of-Oh), creates raw humus (above-ground litter) under the canopy of black locust. This litter is the only source of nutrients for communities forming in poor loose sands. The basic biogens, released during the mineralization of the litter, are taken by plants and, in this way, the biological cycle continues (Rahmonov 2009).

8. Conclusion

1. Clear relationships exist between terrain forms (anthropogenics) and the types of plant communities characterizing discrete zones in the Jaworzno III Power Station ash landfill.
2. In the ash and mine waste of the landfill, the processes of vegetation succession are initiated by *Calamagrostis epigejos*, tall grass with grows in wide variety of habitat which also fulfills the role of edificator in anthropogenic landscapes.
3. The differentiation of flora in the initial stage of the succession is conditioned, in such extreme habitats, by the occurrence of free ecological niches and the lack of interspecies competition.
4. Most of the successional species are pioneers having a wide ecological spectrum in term of habitats. The determination of succession direction for the formation of any mature plant community is impossible at this initial stage.

5. Having an anthropogenic character, the soil at its present stage of development has had little influence on the development of the plant community in the landfill.
6. Post-industrial waste management is still a real problem, especially in highly industrialized areas. The results show various forms of ecological succession conditioned by markedly anthropogenic habitats. Such studies on ecological systems are important in areas subject to human impact.

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