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Research Article

VEGETATION OF INDUSTRIAL WASTE LANDFILLS WITHIN THE AGGLOMERATION OF THE CAPITAL CITY OF WARSAW

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ABSTRACT
This study presents the results of examination of the vegetation on the waste landfill of ArcelorMittal-Warszawa steel mill and the furnace waste landfill of Siekierki Power Station, both sites in Warsaw. The presented analyses of the field research contain detailed floristic-phytosociological data as well as botanical and ecological evaluation of the identified plants. The vegetative structures, together with the succession trends of the vegetation cover of two examined landfills, have been shown. Ecological habitat adaptations of plants and their spatial structure have been evaluated. The inventoried flora has been subjected to taxonomic, syntaxonomic and ecological classification. 154 plant species from 48 taxones in the range of families have been identified. Families characterized by the biggest abundance of species were: Compositae, grasses and Fabaceae. More than half of the live forms indentified were hemicryptophytes. The vegetation of two landfills has been dominated by synantrophic communities (*Stellarietea mediae, Artemisietea vulgaris, Molinio-Arrhenatheretea)*, with apophytes being in the largest number. With the use of ecological indicators a broad ecological tolerance of the majority of species toward ecological factors has been observed.

Key words: industrial waste landfills, Capital City of Warsaw, vegetation cover, plant succession, ecological phytoindication.

INTRODUCTION

Warsaw city agglomeration is under the influence of a number of industrial plants. The largest impact on the city has been exerted by Warsaw Steel Mill (previously: Lucchini-Warsaw, presently: ArcelorMittal-Warsaw) and Siekierki Power Station, including their landfills of hazardous waste. Spontaneous and agro-echnical plants play important roles in the process of greening the landfills. Well developed flora reduces dust tiresomeness and landscape ugliness.

The aim of the research was to evaluate the present structure and ecological role of spontaneous plants in the phase of waste storage and rehabilitation of the examined landfills.

OBJECT OF RESEARCH

The objects of research were the landfills in ArcelorMittal Still Mill, Warsaw and Siekierki Power Plant.

ArcelorMittal Steel Mill landfill

The landfill is located in north-west part of Warsaw in Bielany county, c.a. 10 km from Warsaw down town. Its area covers c.a. 34 hectares, out of which c.a. 26 ha are in use. The terrain is virtually flat, with small hills. The landfill is partially isolated from the environment with a 30-meter shelterbelt. In the east side of the landfill, there is a commercial area and in the north-east side there is a residential area. Towards the west, North Council Cemetery is located, adjacent to Kampinoski National Park. In the north-west side there is a protected area of Młociński Forest (Figure 1).

Fig. 1. Steelworks waste landfill of ArcelorMittal steel mill in Warsaw (source: http://maps.google.pl)

The steel mill used to produce over 400 types of steel: carbonated, quality, alloys, stainless, spring and bearing steel in a form of rolled, forged and drawing products. The landfill was used to deposit industrial wastes, primarily from the Warsaw mill. It was also used as an aggregate storage area and for transition yard for the waste intended for recycling. Originally, in the site there used to be numerous technical backgrounds: industrial, office and residential buildings, roads and railroads, car parks.

The size and range of production determined the diversity of wastes: steelmaking slag, dust from exhaust gas purification, used fireproof materials, post-naturalisation residues from sewage treatment.

Since 1992 the amount of wastes decreased as slag is recycled into a construction material. Metal waste is also recycled. The main types of wastes in the landfill include: dust from exhaust gas purification, sludge from water purification, residues from sewage treatment.

The compounds that migrate to groundwater are: calcium, chrome, nickel and iron compounds. Toluene and trichloroethylene were also detected.

The landfill is c.a. 14 ha large. Since 2003 some wastes are processed into an aggregate to produce concrete. The terrain is intended for building development, yet there are still environmentally dangerous wastes. The area is partially covered with self-seeding plants.

Landfill for furnace waste from Siekierki Power Plant

The landfill is located c.a. 200 m eastwards from the power plant in Mokotów district. It lies within the city agglomeration in the vicinity of the Vistula flood bank and the Wilanówka valley. Eastwards from the landfill there is Vistula river, to the north, west and south there are rarely frequented local roads. The adjacent area is covered with low suburban building development. (Figure 2).

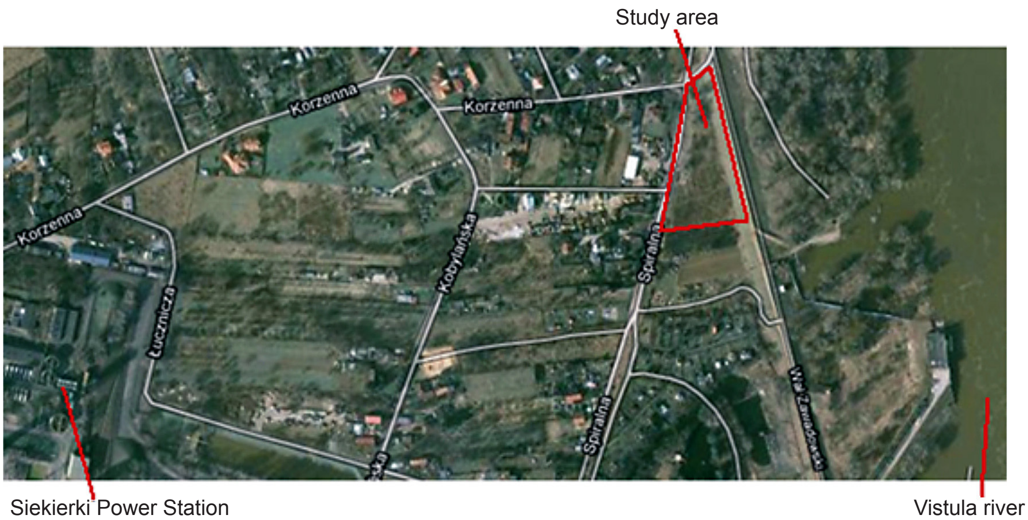

Fig. 2. Location of Siekierki Power Station and the examined furnace waste landfill (source: http://maps.google.pl)

Waste storing began in the area in 1960's. They were covered with a layer of humus and seeded with a mix of grasses and Papilionaceae. The land was partially layered with turf. Lower parts of the hills were forested Since 1994 mineral fertilization has been used (600 kg/ha, multi-ingredient fertilizers: NPK), and since 1996 the area has been sprinkled (10 mm dose of water). The vegetation was mowed twice a year. The landfill is in the final stage of rehabilitation. Spontaneous plants play an important role in the process.

RESEARCH METHOD

The methodology of research has been described in the article "The vegetaion of two council landfills in Mazowsze" [Dyguś 2013].

RESULTS OF THE RESEARCH

The vegetation analysis was conducted on the basis of the predefined qualitative and quantitative criteria of species, evident in the division into five groups: common, very frequent, frequent, rare, very rare.

Abundance and floral composition of industrial landfills' habitats

In both landfills 154 species of vascular plants were recorded, including 7 species of mosses (all of them in steel mill landfill. In the flora of ArcelorMittal Still Mill 96 species were observed, whereas in the landfill of Siekierki Power Plant, 99 species. The floral compositions of these habitats differed, as few as 26.2%, i.e. 39 species were common for both of them. Ecological analysis of the dominant flora in both sites is presented in Table 1.

Due to small areas of both sites, not many common species (i.e. 3rd degree of permanence level and the coverage of above 15%) were recorded. In steel mill landfill they included dicotyledons, typical for ruderal habitats: giant goldenrod *(Solidago gigantea),* tansy *(Tanacetum vulgare),* Coltsfoot *(Tussilago farfara),* common evening primrose *(Oenothera biennis).*Two more segetal weeds can be included in the group: Horseweed *(Conyza canadensis)* and Curly Dock *(Rumex crispus). Sheep Fescue (Festuca ovina),* a cluster grass with high potential of covering open surfaces, played an important role in capturing the landfills' habitats. Flat surfaces of the landfills were covered with trees, particularly silver birch *(Betula pendula)* and common aspen *(Populus tremula).*

In the landfill with combustion wastes from Siekierki Power Plant the group of common species included three grasses: Meadow Foxtail *(Alopecurus pratensis),* orchard grass *(Dactylis glomerata)* and couch grass *(Elymus repens).* Among the dicotyledons the dominating species included giant goldenrod *(Solidago gigantea)* and tansy *(Tanacetum vulgare).*

In the group of very frequent species (1st and 2nd degree of permanence and the coverage of 5-15%) on the surface of steel mill landfill most species included synanthropic plants, inhabiting virtually all phases of floral succession. In the initial phase of succession mosses had a significant role: *Ceratodon purpureus, Tortula muralis, Funaria hygrometrica, Bryum caespiticium*, and *Bryum argenteum*. In the initial phase of covering the landfills the species of segetal weeds there were: Field Bindweed *(Convolvulus arvensis), Cursed Thistle (Cirsium arvense)* Cleavers *(Galium aparine)* and Common Knotgrass *(Polygonum aviculare).*The floral composition of this group was supplemented by the plants of ruderal habitats such as: common wormwood *(Artemisia vulgaris),* Treacle-mustard *(Erysimum cheiranthoides),* shepherd's-purse *(Capsella bursa-pastoris),*and to smaller extent also the species of meadow flora.

In the group of very frequent plants in the landfill of Siekierki Power Plant the following grasses were observed: Arctic brome *(Bromus inermis),* Timothy-grass *(Phleum pratense),* annual meadow grass *(Poa annua),* whereas dicotyledons included: Common Knotgrass *(Polygonum aviculare),* Creeping Thistle *(Cirsium arvense)* and greater burdock *(Arctium lappa).*

The number of frequent species (the coverage of 5%) including the groups of rare and very rare species were estimated at 70% of the composition of the vegetation.

The share of taxonomic groups

The flora of habitats belonged to 48 taxones in the range of families. The most abundant number of species included the families: *Asteraceae* (complex) – 18,2% and *Poaceae* (grasses) – 14.9%. Less frequently represented were *Fabace-*

Table 1. Ecological analysis of the dominant flora of the examined industrial waste landfills

No.	Species	Fż	Ecological indicators							Gg–h	Ge	Gs	S^P	
			W	T	O	G	H	S	M				A	B
1	2	3	4							5	6	7	8	9
1	**Acer negundo**	M	3–4	3–4	3–5	3–4	1–2	–	–	Kn	Ll	*Sp*	I^{3}	II^{1}
2	*Achillea millefolium*	H	2–3	3–4	3–4	4	1–2	1	–	Ap	Ł	*M–A*	II^{+}	III^{+}
3	**Agrostis stolonifera**	H	4	3–4	3–5	2–4	1–2	1	1	Ap	R	*M–A*		II^{1}
4	*Alopecurus pratensis*	H	4	4	4	4–5	2	–	–	Ap	Ł	*M–A*		IV^{2}
5	*Anchusa officinalis*	H	3	3–4	4	3–4	2	–	–	A	R	*Av*		II^{1}
6	*Anthoxanthum odoratum*	H	3	3	3	4	2	–	–	Ap	Ł	*M–A*		II^{1}
7	*Arabidopsis thaliana*	T	2–3	2–3	3–4	2–3	2	–	–	Ap	Mp	*Sm*		II^{+}
8	**Arctium lappa**	H	3	5	4	4	2	–	–	Ap	R	*Av*		II^{1}
9	*Artemisia vulgaris*	H	3	4	4–5	4	2	–	–	Ap	R	*Av*	II^{2}	II^{+}
10	*Betula pendula*	M	3	2–3	3–4	3–4	1–2	–	–	Ap	Ll	*Q–F*	III^{1}	
11	*Bromus hordeaceus*	T	3	4	4	4	2	1	–	Ap	Ł	*M–A*	II^{1}	III^{+}
12	*Bromus inermis*	H	2–3	3	4–5	3–5	1–2	–	–	Ap	R	*F–B*		II^{1}
13	**Bryum argenteum*	–	–	–	–	–	–	–	–	–	Sg	*Sm*	II^{1}	
14	**B. caespiticium*	–	–	–	–	–	–	–	–	–	–	–	II^{2}	
15	*Calamagrostis epigejos*	G,H	3	3	3	3	1	1	1	Ap	R, O	*Ea*	II^{2}	
16	*Carex hirta*	G	2–4	2–4	3–5	3–4	2	–	1	Ap	R	*M–A*	I^{1}	III^{+}
17	**Ceratodon purpureus*	–	–	–	–	–	–	–	–	–	–	*K–C*	II^{3}	
18	*Cirsium arvense*	G	2–3	3–4	3–5	3–5	2	–	–	Ap	R	*Sm*	II^{1}	II^{1}
19	*Convolvulus arvensis*	G, H, li	2–3	3	3–5	4–5	2	–	1	Ap	R	*Sm*	II^{2}	I^{+}
20	*Conyza canadensis*	T, H	2–3	3	3–4	3–4	2	–	–	Kn	R	*Sm*	IV^{1}	II^{+}
21	*Coronilla varia*	H	2	3	4–5	2–4	2	–	–	Ap	O	*T–Gs*	II^{1}	
22	*Corynephorus canescens*	H	2	2	3–5	3	1	–	–	Ap	Mp	*K–C*	II^{1}	
23	*Dactylis glomerata*	H	3	4–5	4–5	4	2	1	–	Ap	Ł	*M–A*	I^{+}	III^{2}
24	*Elymus repens*	G	3	3–4	3–5	4	1–2	1	–	Ap	R	*Sm*		III^{1}
25	*Festuca ovina*	H	2	2	3–5	3	2	1	1	Ap	R	*K–C*	III^{1}	
26	**Funaria hygrometrica*	–	–	–	–	–	–	–	–	–	–	–	II^{1}	
27	*Galium aparine*	T, H	3–4	4–5	4	2–5	2	–	–	Ap	R	*Sm*	II^{1}	II^{+}
28	*Lepidium ruderale*	H, T	2–3	4	4	2–4	2	1	–	Ar	R	*Sm*	II^{1}	I^{+}
29	*Leucanthemum vulgare*	H	3	4	4	4	2	1	–	Ap	Ł	*M–A*		II^{1}
30	*Lolium perenne*	H	3	4	4	4	2	1	1	Ap	Ł	*M–A*		II^{1}
31	*Oenothera biennis*	H	2–3	3–4	3–4	2–3	2	–	–	Ap	R	*Av*	III^{1}	I^{+}
32	*Padus avium*	M	4	4	4–5	4–5	2	–	–	Ap	Ł	*Q–F*	II^{1}	
33	*Phleum pratense*	H	2–3	3–4	4–5	1–3	2	–	–	Ap	Ł	*M–A*		II^{1}
34	*Poa annua*	H, T	3	4	4	3–5	2	–	–	Ap	R	*Sm*		II^{1}
35	*Polygonum aviculare*	T	3	3–4	4–5	2–5	1–2	–	–	Ap	R	*Sm*	I^{2}	II^{1}
36	*Populus alba*	M	3–4	4	5	3–5	2	–	–	Ap	Li	*Sp*	II^{1}	
37	*Populus tremula*	M	3	3	3	3–4	2	–	–	Ap	Li	*Q–F*	III^{1}	
38	*Potentilla anserina*	H	3–4	3–4	4–5	4	2	1	–	Ap	R	*M–A*		II^{1}
39	*Puccinellia distans*	H	3–5	3	4–5	2–5	2	2	–	Ap	Sl	*At*	III^{+}	
40	*Robinia pseudoacacia*	M	2–3	3	3–5	2–4	2	–	–	Kn	R	*Av*	II^{1}	
41	*Rumex crispus*	H	3–4	4	4	3–4	2	1	–	Ap	R	*Sm*	III^{1}	II^{+}
42	*Solidago gigantea*	G, H	3–4	4	–	–	–	–	–	Kn	R	*Av*	III^{2}	III^{3}
43	**Syntrychia ruralis*	–	–	–	–	–	–	–	–	–	–	*K–C*	II^{1}	
44	*Tanacetum vulgare*	H	3–4	4	4	2–4	2	–	–	Ap	R	*Av*	III^{1}	III^{2}
45	**Tortula muralis*	–	–	–	–	–	–	–	–	–	–	–	II^{2}	
46	*Trifolium arvense*	T	2	1–2	3–5	1–3	2	–	–	Ap	Mp	*K–C*	II^{1}	II^{+}
47	*Tussilago farfara*	G	3–4	3–4	4	4–5	1–2	–	–	Ap	R	*Av*	III^{1}	
48	*Urtica dioica*	H	3–4	4–5	4	3–4	2	–	–	Ap	R	*Av*	II^{1}	I^{+}
49	*Vicia cracca*	H	3	4	4–5	4	2	–	–	Ap	Ł	*M–A*		II^{1}

Abbreviations to Table 1:

No. – item.

Species – Latin name of the species [Mirek et al., 2002].

FL – Raunkiær plant life-form [Ellenberg et al. 1992; Zarzycki et al. 2002]; M – megaphanerophytes (trees over 5 m high), N – nanophanerophytes (shrubs and low trees, up to 5 m high), Ch – chamephytes (trees), C – green chamephytes (Green shrubs), H – hemicryptophytes (durable perennial plants), G – geophytes (durable allium or rhizome plants), T – terophytes (annual plants wintering in a form of seeds); li – lianes (plants that require supports), pp – acultative parasites.

Ecological indicators [Zarzycki et. al. 2002]: W – soil humidity index, T – trophism index, O – resource acidity, G – soil granulometric index, H – content of organic matter, S - resistance to NaCl, M – resistance to excessive content of heavy metals, "–" – lack of data.

Gg-h – geographic and historic groups of species [Sudnik-Wójcikowska and Koźniewska 1988; Krawiecowa and Rostański 1972]: Ap – apophytes (native species), Ar – archeophytes (old incoming species), Kn – kenophyte (new incomin species, settled permanently), Ef – epherophytes (new incoming species, not settled permanently), A – presumably antropophyte, ? – uncertain group.

Ge – ecological groups of species [Ellenberg et al. 1992]: R – ruderal, Sg – segetal, Ł – grassland, Ll – broadleaed forests, B - woodlands, O – tall herb fringe communities, Mp – sandy grasslands, Mks – xerothermic grasslands, Mk – acidious grasslands, Z – bush, Ns – rockplants, Sl – halophytes, Nw – water plants; ? – uncertain group.

Gs – synthaxonomic group.

Gu – cultivated species.

Permanence level and average coverage of plants in the sites: A – slag heaps in ArcelorMittal Warsaw, B – combustion ashes from Siekierki Power Plant – Vattenfall Heat Poland S.A.

In the floral list mosses were marked with an asterisk (*).

ae (legumes), *Brassicaceae* (cross), *Rosaceae* (rose family), *Chenopodiaceae* (Goosefoot Family) and *Polygonaceae*. In the remaining 9 families the number of species was fewer than five, and most families (33) included only 1-2 species. 7 mosses from 5 families were also identified. In the habitat of the steel mill landfill they were the initial phase of the floral succession (Table 2).

Life forms of the plants (Table 1, col. 3, Table 3)

Half of the analysed flora (50.3%) in the examined industrial landfills were Hemicryptophytes, i.e. biennial or perennial plants with buds wintering on the ground, usually hidden in a rosette of leaves. The largest number of species in this form was recorded in the landfill of Siekierki power plant (57.6%) and a few percent less in steel mill landfill (47.9%). The most frequent cryptophytes in both sites were: common yarrow *(Achillea millefolium),* Meadow Foxtail *(Alopecurus pratensis),* Cock's-foot *(Dactylis glomerata)*, common wormwood *(Artemisia vulgaris),* Common evening primrose *(Oenothera biennis),* tansy *(Tanacetum wulgare)* and others.

Significant number of flora in the examined habitats (23.1%) belonged to terophytes (annual plants). The share of these plants was slightly higher in the landfill of Siekierki power plant. The highest share of terophytes included: Canadian Horseweed *(Conyza canadensis), Bromus hordeaceus,* Common Knotgrass *(Polygonum aviculare).* Significant share (11.6%) included geophytes, the plants that hide their buds in the ground. Predominant species in this group were: *Cursed Thistle (Cirsium arvense),* couch grass *(Elymus repens),* giant goldenrod *(Solidago gigantea),* Coltsfoot *(Tussilago farfara),* Wood Small-reed *(Calamagrostis epigejos),* Field Bindweed *(Convolvulus arvensis).*

Ecological indicators (Tab. 1, col. 4)

According to Ellenberg's ecological phytoindication method floral habitat conditions were evaluated. The evaluation was made on the nbasis of the following ecological resources: humidity, soil trophism, acidity, dispersion (granulometric index), content of organic matter, resistance to NaCl, resistance to excessive content of heavy metals.

Humidity (W). The habitat of the steel waste landfill was clearly of heterogenic character.

Table 2. Share of families in the flora of industrial waste landfills

Family		ArcelorMittal landfill		EC Siekierki landfill		Total flora	
		amount	%	amount	%	amount	%
Asteraceae – complex		16	16,7	22	22,2	28	18,2
Poaceae – grass		14	14,6	17	17,2	23	14,9
Fabaceae – legumes		9	9,4	10	10,1	16	10,4
Brassicaceae – cross		7	7,3	5	5,1	11	7,1
Rosaceae – rosaceae		4	4,2	4	4,0	6	3,9
Lamiaceae – lip		4	4,2	1	1,0	5	3,3
Polygonaceae – knotgrass		4	4,2	4	4,0	6	3,9
Boraginaceae – roughleaf		–	–	3	3,0	3	2,0
Cyperaceae – sedge		1	1,0	3	3,0	3	2,0
Salicaceae – willow		3	3,1	2	2,0	4	2,6
Scrophulariaceae – figwort		3	3,1	–	–	3	2,0
Rubiaceae – woodruff		2	2,1	3	3,0	3	2,0
Caryophyllaceae – the pink		2	2,1	1	1,0	3	2,0
Euphorbiaceae – euphorbia		2	2,1	2	2,0	3	2,0
Apiaceae – whorl		2	2,1	2	2,0	3	2,0
The remaining 33 families with 1–2 species	Vascular plants	16	16,7	20	20,2	27	17,5
	Mosses	7	7,3	–	–	7	4,5
Total		96	100,0	99	100,0	154	100,0

Table 3. Share of vascular plants live forms according to Raunkiaer

Vital species	ArcelorMittal landfill		EC Siekierki landfill		Total flora	
	amount	%	amount	%	amount	%
Hemicryptophytes (H)	46	47,9	57	57,6	74	50,3
Therophytes (T)	19	19,8	23	23,2	34	23,1
Geophytes (G)	13	13,5	10	10,1	17	11,6
Megaphanerophytes (M)	11	11,5	5	5,1	14	9,5
Nanophanerophytes(N)	4	4,2	2	2,0	5	3,4
Herbaceous chamaephytes (C)	2	2,1	1	1,0	2	1,4
Woody chamaephytes (Ch)	1	1,0	1	1,0	1	0,7
Total	96	100,0	99	100,0	147	100,0

Lack of competition facilitated floral settlement of initiating plants and multidirectional succession. Therefore species of dry habitats were observed (W_2), e.g. Sheep Fescue *(Festuca ovina),* Haresfoot clover *(Trifolium arvense),* mouse-ear hawkweed *(Hieracium pilosella),* Common evening primrose *(Oenothera biennis),* grey hair-grass *(Corynephorus canescens).* On the other hand, in the combustion waste landfill the species characteristic for fresh habitats were predominant (W_3): Common Bugloss *(Anchusa officinalis),* sweet vernal grass *(Anthoxanthum odoratum),* Cock's-foot *(Dactylis glomerata),* oxeye daisy *(Leucanthemum vulgare),* tufted vetch *(Vicia cracca).* Relatively numerous group of the species of wed lands (W_{4-5}) was also observed: Tufted Hair-grass *(Deschampsia caespitosa),* common comfrey *(Symphytum officinale),* Tall fescue *(Festuca arundinacea),* Cabbage thistle *(Cirsium oleraceum),* sharp dock *(Rumex conglomeratus),* common reed *(Phragmites austrialis).*This can be explained by high water contents in the combustion waste (primarily the ashes).

Habitat trophism (T). Soil fertility was reflected in the species of diversified nutritional requirements. In the habitat of steel waste landfill there were both oligotrophic species, e.g. grey hair-grass *(Corynephorus canescens),* mesotrophic (T_3), such as Coltsfoot *(Tussilago farfayra),* but also eutrophic: (T_{4-5}) Stinging nettle *(Urtica di-*

oica) and Galenia *(Galeopsis pubescens).* Similar tendency was observed in the landfill of combustion ashes.

Acidity (O). The plants in both sites were good acidity indicators (pH) of the resources: from moderately acid (pH 5-6), neutral (pH 6-7) up to alkaline (pH over 7). The species in the sites that preferred moderately acid reaction (O_3), included: Treacle-mustard *(Erysimum cheiranthoides),* sweet vernal grass *(Anthoxanthum odoratum),* Wood Small-reed *(Calamagrostis epigejos)* and others. The resources of natural and alkaline reaction were recognised with the following plants: Crown Vetch *(Coronilla varia),* Common Silverweed *(Potentilla anserina),* common wormwood *(Artemisia vulgaris),* Arctic brome *(Bromus inermis),* Cock's-foot *(Dactylis glomerata)* and Common Knotgrass *(Polygonum aviculare).* Some plants were characterised by wide range of acidity tolerance $O_{3\text{-}5}$), e.g.. creeping bentgrass *(Agrostis stolonifera),* Creeping Thistle *(Cirsium arvense),* Field Bindweed *(Convolvulus arvensis),* couch grass *(Elymus repens),* Sheep Fescue *(Festuca ovina),* hairy sedge *(Carex hirta),* grey hair-grass *(Corynephorus canescens).*

Granulometric index (dispersion) of the resource (G). In the composition of the flora there were primarily the plants that indicated sandy, clayey and dusty habitats ($G_{3\text{-}4}$), e.g.: common yarrow *(Achillea millefolium),* Common Bugloss *(Anchusa officinalis),* hairy sedge *(Carex hirta),* Canadian Horseweed *(Conyza canadensis),* Curly Dock *(Rumex crispus).* There were also species with a wide ecological amplitude that tolerate both gravel, sandy, clayey and argillaceous soils (G_2-$_5$): Weeping alkali grass *(Puccinellia distans),* Cleavers *(Galium aparine),* Common Knotgrass *(Polygonum aviculare),* tansy *(Tanacetum vulgare),* Crown Vetch *(Coronilla varia)* and others.

Content of organic matter in the resource (H). Most species in the habitats were the indicators of mineral and humus soils (H_2). The largest coverage was obtained by: Meadow Foxtail *(Alopecurus pratensis),* Canadian Horseweed *(Conyza canadensis),* Cock's-foot *(Dactylis glomerata),* tansy *(Tanacetum vulgare),* tufted vetch *(Vicia cracca).*

Index of resistance to salinity of the habitat, particularly NaCl (S). Out of 147 analysed species of vascular plants 35 (23.8%) were facultative halophytes (S_1) that tolerate increased content of NaCl, e.g. common yarrow *(Achillea millefolium),* Cock's-foot *(Dactylis glomerata),* couch grass *(Elymus repens),* Sheep Fescue *(Festuca ovina),* Curly Dock *(Rumex crispus)*. There were also 3 species that grow in the soils with increased NaCl content (obligatory halophytes – S_2): purei *(Carex distans),* Tall fescue *(Festuca arundinacea),* Weeping alkali grass *(Puccinellia distans),*

Index of resistance to excessive content of heavy metals (M). In the landfills 11 species (7.4%) tolerating increased content of heavy metals were identified (M_1). Most of them appeared the steel waste landfill: Chicory *(Cichorium intybus),* Field Bindweed *(Convolvulus arvensis),* Sheep Fescue *(Festuca owina),* Meadow fescue *(Festuca pratensis),* Bird's-foot Trefoil *(Lotus corniculatus)*. No plants tolerating increased content of heavy metals (M_2) were identified.

Historic and geographic evaluation (Table 1, col. 5, Table 4)

In the composition of the examined habitats apophytes, i.e. native plants were predominant (83.3% in the steel waste landfill and 73.7% in the combustion waste landfill). Among the foreign plants (antrophytes) kenophytes has larger share in the landfill of the steel mill, while archeophytes were more numerous in the power plant landfill. The largest coverage from the group of apophytes was obtained by: meadow foxtail (*Alopecurus*

Table 4. Geographical and historical analysis of plants

Geographical and historical groups		ArcelorMittal landfill		EC Siekierki landfill		Total flora	
		amount	%	amount	%	amount	%
Apophytes		80	83,3	73	73,7	109	74,1
Anthopophytes	Archeophytes	6	6,3	16	16,2	20	13,6
	Kenophytes	10	10,4	9	9,1	17	11,6
	Ephemerophytes	–	–	1	1,0	1	0,7
Total		96	100,0	99	100,0	147	100,0

pratensis), bindweed *(Convolvulus arvensis),* Cock's-foot *(Dactylis glomerata),* tansy *(Tanacetum vulgare).* The most expansive kenophytes included: maple ash *(Acer negundo),* giant goldenrod *(Solidago gigantea),* Canadian Horseweed *(Conyza canadensis).*Still, average coverage and levels of persistence were relatively low.

The share of ecological and syntaxonomic groups (Tab. 1, col. 6-7)

In both habitats ruderal species dominated (23%). The share of segetal species was c.a. 12%. Similar representation of meadow plants was recorded in the steel slag heaps, whereas the share in combustion waste landfill increased up to 20%. Insignificant share of plants from the group of broadleaf forests, lawns, tall herb fringe communities, sub-water and xerothermic lawns.

The flora of the examined habitats consists primarily from three syntaxonomic groups of antropogenic origin. They include: synathropic community of segetal weeds (class *Stellarietea mediae*), nitrophylic ruderal community (class *Artemisietea vulgaris*) and meadow community (class *Molinio-Arrhenatheretea*). the share of segetal and ruderal communities was estimated at c.a. 10%. Whereas the share of species from meadow communities was low in the still mill landfill (6%) and twice as high in the combustion waste landfill. The flora of the habitats was also constructed of a few other communities with smaller special diversity.

Succession trends in industrial landfills

The vegetation of industrial landfills was at different stages of development. Flat surfaces, as well as hill-side areas to smaller extent, were covered with clusters of moss and annual plants (initial succession phase), perennials (transitory phase), shrubs and trees (final succession phase). Such a mosaic of the vegetation cover was observed in steel mill landfill. In the combustion waste landfill the vegetation with the representation of transitory species was observed.

The observations and phytospciological analyses of the vegetation in the industrial landfills do not justify distinctive formations at the rank of assemblage, therefore the phytosociological diagnosis is presented at the rank of classes.

Community of *Koelerio glaucae-Corynephoretea canescentis* class. The community refers to the habitats of psammophilus grasslands. It was encountered in the plat surfaces of steel mill's slag heaps. A dominating plant in the community structure was a moss – purple horn toothed moss (*Ceratodon purpureus),* which made large clusters on small hills. The mosses were accompanied by numerous clusters of Sheep Fescue *(Festuca ovina)* and less frequently grey hair-grass *(Corynephorus canescens).* In the steel mill's slag heaps there was a typically pioneering community in its initial phase.

Community of *Stellarietea mediae* class. Flat areas and terrain depressions were covered by annual and perennial synantropic plants from *Stellarietea mediae* class. In such a broad community a few lower-class sub-communities were selected. In most cases they were annual and biennial platns from *Sisymbrietalia* and *Polygono-Chenopodietalia* classes.Annual plants made mosaic groups occupying common or neighbouring habitats, e.g. narrow-leaf pepperwort *(Lepidium ruderale),* Virginia pepperweed *(L. virginicum),* turfs of moss - *Bryum argenteum,* Canadian Horseweed *(Conyza cznadensis),* Galenia *(Galopsis pubescens),* Common Hemp-nettle *(G. tetrahit),* Guasca *(Galinsoga parviflora),* Common Knotgrass *(Polygonum aviculare)* and broadleaf plantain *(Plantago major).* At the same time a few species of perennials were observed: Coltsfoot *(Tussilago farfara),* Curly Dock *(Rumex crispus),* Tall mustard *(Sisymbrium altissimum),* Hedge mustard *(Sisymbrium officinale),* Creeping Thistle *(Cirsium arvense).*The above species were accompanied by clusters of common chickweed *(Stellaria media),* shepherd's-purse *(Capsella bursa-pastoris)* among others. The community was inhomogeneous; clusters of annual plants (terophytes) and numerous perennials were observed, what proves a transitory character of the phase.

Community of *Artemisietea vulgaris* class. The hilltops of slag heaps and their gentle slopes were covered by nitrophile perennial plants (communities of *Artemisietea vulgaris* class, *Artemisietalia vulgaris* order and lower syntaxonomic groups). The most expansive ones were: giant goldenrod (*Solidago gigantea),* tansy *(Tanacetum vulgare),* common wormwood *(Artemisia vulgaris),* Broad-leaved Dock *(Rumex obtusifolius),* greater burdock *(Arctium lappa),* Horseradish *(Armoracia rusticana),* common nettle *(Urtica dioica)* and tetterwort *(Chelidonium majus).* There were also species of stenothermic communities of high ruderal perennials that tolerate draught (*Onopordetalia acanthii* order) Common evening primrose *(Oenothera biennis),* Common Bugloss *(Anchusa officinalis)* and chicory *(Cichorium intybus)*. Numerous representation of perennials proves optimum stadium of vegetation succession in the landfills.

Community of *Molinio-Arrhenatheretea* class. Depressions and different grooves in flat terrains of the examined landfills were settled by grassland plants from *Arrhenatheretalia elatioris* order. The most broadly spread ones included: Cock's-foot *(Dactylis glomerata),* common dandelion *(Taraxacum officinale), Bromus hordeaceus*, Meadow Foxtail *(Alopecurus pratensis),* tufted vetch *(Vicia cracca),* oxeye daisy *(Leucanthemum vulgare),* sweet vernal grass *(Anthoxanthum odoratum),* Upright bedstraw *(Galium mollugo)* and common yarrow *(Achillea millefolium)*. In the ash landfill species from flood-land grasslands from the group *Agropyro-Rumicion crispi* were observed: Common Silverweed *(Potentilla anserina),* creeping bentgrass *(Agrostis stolonifera),* hairy sedge *(Carex hirta),* Tall fescue *(Festuca arundinacea),* Creeping Buttercup *(Ranunculus repens),* Curly Dock *(Rumex crispusand)* others. Significant coverage, yet by a limited number of species, of plants from *Molinietalia caeruleae* order was recorded: Meadow Foxtail *(Alopecurus pratensis),* marsh thistle *(Cirsium palustre)* and Tufted Hair-grass *(Deschampsia caespitosa)*. The community is in a typical transitory phase, however its further development is impossible to predict at this stage.

Community of shrubs of *Rhamno-Prunetea* class and trees of *Querco-Fagetea, Vaccinio-Piceetea, Salicetea purpureae* i *Alnetea glutinosae* classes. The terminal phase of succession in industrial landfills was observed thanks to the development of communities resembling forested areas (trees, shrubs, herbs). the examined areas were covered by such shrubs as: blackthorn *(Prunus spinosa)* and dog rose *(Rosa canina)*. A few species of trees entered the phase of shrubland, groove or young forest. The broadleafed species represented there included: sycamore maple *(Acer pseudoplatanus),* silver birch *(Betula pendula),* European aspen *(Populus tremula),* common ash *(Fraxinus excelsior),* wild cherry *(Cerasus avium),* Bird Cherry *(Padus avium),* Mountain-ash *(Sorbus aucuparia)* and Marsh Pine *(Padus serotina)*. Among forest species the most frequent ones was: Scots Pine *(Pinus sylvestris).*Most often the shrubs and trees grew individually, however, at slag heaps agglomeration of trees could be observed with a representation of shrubs, herbs and grass.

DISCUSSION

The presented trends of vegetation in industrial landfills in Warsaw are proved by the descriptions of similar locations in Poland and Czech [Kuczyńska et al. 1984; Cabała and Sypień 1987; Rostański 1991; Rostański 1997; Cabała and Jarząbek 1999; Woźniak, Kompała 2000; Pyšek et al. 2003; Rostański 2006].

Natural development of self-seeding plants was observed in the first year after the landfill waste was rolled. In the first phase of succession annual plants (terophytes) appeared. In the subsequent phases the share of life forms moved towards perennials (hemicriptophytes, chamephytes amd nanofanerophytes). After a few years the areas were also settled by shrubs and trees. The spatial composition included common species with broad amplitude of ecological factors. Particular role was played by monocotyledons, especially grasses, which made dense, broad turfs renewing the vegetation (biological rehabilitation).

According to geographic and historic analyses and the descriptions of Polish flora that show the synantropisation of flora in anthropogenic areas the species predominant in such places are home-grown ones (apophytes). This is also proved by the present research results. According to other researchers, the habitats under strong antropopressure are seeded primarily with foreign species (antropophytes) [Sudnik-Wójcikowska and Koźniewska 1988; Kornaś and Medwecka-Kornaś 2002].

Out of all syntaxonomic groups, ruderal *(Artemisietea vulgaris)* and segetal *(Stellarietea mediae)* species played an important role in spontaneous succession. Grassland species *(Molinio-Arrhenatheretea)* also play an important role throughout the succession. In the finals stages of spontaneous succession, depending on habitat properties, nitrophylic clusters of terophytes, perennials, shrubs *(Epilobietea angustifolii)* and sometimes also certain types of moorlands *(Nardo-Callunetea)* and sparse grasslands *(Nardo-Callunetea)*, psammophylic grasslands, broadleafed forests *(Querco–Fagetea)* and wood lands *(Vaccinio-Piceetea)* [Dyguś 1997; Rostański 2006].

In order to monitor settlement conditions in post-industrial areas a Ellenberg's method of ecological phyto-indication was used a number of times. the method is useful in evaluating settlement and ecological conditions during rehabilitation. Spontaneous seeding of vegetation may have a significant impact on phytoremediation of heavy metals, what was also proved in the present analysis.

The evaluation and speed of vegetation succession is difficult to determine in anthropogenic areas in such a short period of time (2 years). In the present analysis an attempt was made to show the changes in vegetation in industrial landfills in Warsaw.

Broader range of information (floral productivity and chemistry of both plants and resources) corresponding to the present problems is presented in a book entitled: *„Roślinność składowisk odpadów komunalnych i przemysłowych"* (Vegetation of industrial and community landfills) [Dyguś et. al. 2012].

CONCLUSIONS

In both landfills 154 species of vascular plants were recorded, including 7 species of mosses from 48 biological families. The largest share of plants were: *Asteraceae* – (18,2%), *Poaceae* (grasses) (14.9%) and *Fabaceae* (10.4%). Hemicryptophytes, i.e. biennial and perennial species (50.3%) and annual terophytes (23.1%) were predominant. The recognised composition of the flora proves initial and multidirectional succession with undeveloped floral cover of the landfills.

Synantropic*(Stellarietea mediae, Artemisietea vulgaris, Molinio-Arrhenatheretea)*,communities were dominant in the vegetation with significant representation of home-grown apophytes (74.1%). This proves exceptionally anthropogenic character of the landfills.

Ecological indexes showed heterogenic character, diversified trophy and unstable composition of the ground. Most floral species is chatrcterised by broach ecological tolerance for most factors. The plants from the group of halophytes that tolerate increased content of NaCl (23.8%) and heavy metals (7.4%) represent a significant number of species.

Spontaneous plant succession in the landfills plays a positive role, especially in the final phase of reclamation. Selecting plants for biological reclamation it is advisable to choose locally grown native species.

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