ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol., Formatio Circumiectus 11 (4) 2012, 91–101

PLANT SPECIES DIVERSITY IN THE POSTINDUSTRIAL SITES – SODA WASTE DUMPS CASE STUDY

RÓŻNORODNOŚĆ GATUNKOWA ROŚLINNOŚCI NA OBSZARACH POPRZEMYSŁOWYCH – PRZYKŁAD SKŁADOWISKA ODPADÓW POSODOWYCH

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Abstract. The main aim of the study was to evaluate the diversity of herbaceous plants cover developing in the soda waste dumps in Krakow and to discuss importance of post-industrial sites for maintaining the biotic diversity. The soda waste dumps were reclaimed by covering with a topsoil, sowed with grass mixture and left without further treatment. In the investigated area 132 plots were laid out on which 133 species of herbaceous plants were identified. Species diversity on individual plots (alpha diversity) was relatively low (average Shannon-Wiener index 1.79), but the plots (beta diversity) differed considerably in species composition (the van der Maarel's coefficient in 87% cases was less than 0.4). The species occurring on the dumps were typical for many different plant communities, but meadow species and ruderal species predominated. The analysis of Ellenberg indicator values showed the highest variation for the fertility index N. Species dominating the soda waste dumps are those usually found in moderately dry and dry habitats and with neutral soil pH. The reclamation method in which a topsoil layer of low thickness was used prevented succession towards forest communities on the soda waste dumps. Because of this, non-forest communities, that are generally richer in species, can develop. The main threat to species diversity is the development of expansive species, especially the wood small-reed.

Streszczenie. Głównym celem pracy było określenie różnorodności roślinności zielnej, która wykształciła się na osadnikach posodowych w Krakowie, oraz dyskusja nad znaczeniem obszarów poprzemysłowych w utrzymaniu bioróżnorodności. Osadniki zrekultywowano poprzez pokrycie warstwą gleby, obsiew mieszanką traw i pozostawiono bez dalszych zabiegów. Na badanym terenie wyznaczono 132 powierzchnie, na których stwierdzono występowanie 133 gatunków roślin zielnych. Zróżnicowanie gatunkowe

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w obrębie poszczególnych poletek (różnorodność alfa) było raczej niewielkie (średnia wartość wskaźnika Shannona-Wienera 1,79), ale poletka (różnorodność beta) różniły się składem gatunkowym pomiędzy sobą (współczynnik van der Maarela w 87% przypadków był niższy od 0,4). Gatunki występujące na osadnikach są typowe dla różnych zbiorowisk roślinnych, lecz dominowały gatunki łąkowe i ruderalne. Analiza liczb wskaźnikowych Ellenberga wykazała największe zróżnicowanie wskaźnika żyzności. Większość to gatunki występujące na obszarach umiarkowanie suchych i suchych oraz przy obojętnym pH gleby. Metoda rekultywacji polegająca na pokryciu osadników warstwą gleby o niewielkiej miąższości zatrzymała sukcesję w kierunku zbiorowisk leśnych na osadnikach posodowych. Dlatego też mogły tu wykształcić się nieleśne zbiorowiska, generalnie bogatsze gatunkowo. Podstawowym zagrożeniem dla różnorodności gatunkowej jest rozwój gatunków inwazyjnych, zwłaszcza trzcinnika piaskowego.

Key words: species diversity, ecological restoration, soda waste dumps, Ellenberg indicator values

Słowa kluczowe: różnorodność gatunkowa, rekultywacja ekologiczna, składowisko odpadów posodowych, liczby wskaźnikowe Ellenberga

INTRODUCTION

The development of industry and urbanization generates a large number of derelict sites, which are often different types of waste heaps and waste dumps. The normal procedure for such sites is to apply technical and biological reclamation, which usually involves sowing grass and legume mixtures or planting trees and shrubs. An alternative method proposed by many authors [Bradshaw 2000, Prach and Pyšek 2001] is to use spontaneous succession, primary or secondary, in order to create a new ecosystem. The basic principles of modern ecological restoration are the same as the principles of primary or secondary succession, and the results of many studies on vegetation dynamics can be used in the reclamation [Palmer *et al*. 1997, Walker *et al.* 2009]. Knowledge of these processes allows right decisions to be made concerning the achievement of the desired reclamation results and possible technical and biological procedures [Prach and Hobbs 2008]. Many studies have shown that naturally valuable ecosystems are formed where rough spoils, usually with extreme habitat conditions, are left under primary succession [Bradshaw 2000, Bornkamm 2007]. In many cases, however, such sites cannot be left unprotected [Bradshaw 2000, Prach and Hobbs 2008]. They have to be safeguarded against the adverse impact on neighbouring areas and integrated into the landscape. This can be done using, for example, a topsoil cover. The material used is often characterized by poor quality [Bradshow 1989], usually comes from deep excavations but also from the surface layer, and may contain many components of anthropogenic origin (rubbish, debris, stones). In this case, the development of vegetation varies widely according to the material used and its thickness. The succession that takes place on areas, with degraded "soil" containing plant propagules, has the characteristics of both primary and secondary succession [Rebele 1992, Martinez-Ruiz and Fernández-Santos 2005]. Identification of the habitat conditions and the plant species will help to determine the appropriate procedures aimed at increasing the species diversity of postindustrial land. This study investigated a soda waste dumps that were reclaimed by covering with a topsoil of different origin which, as a result, had different physicochemical parameters.

The aim of the study was to evaluate the diversity of herbaceous plants cover as well as the habitat differences on the reclaimed soda waste dumps and to discuss importance of derelict sites for increasing the biotic diversity of industrial areas.

MATERIALS AND METHODS

The Krakow Soda Works "Solvay" was in operation during 1901–1994. Wastes from the production processes were deposited into sedimentation lagoons which finally covered the total area of about 85 ha (N 50°00′30″, E 19°56′26″). The waste consisted mainly of calcium carbonate in the form of fine-crystalline suspension in calcium chloride and water solution [Pałka and Sanecki 1992]. The soda waste was characterized by strongly alcaline reaction and high salinity [Boroń *et al.* 2000]. In 1995 a mineral soil cover was brought and grass and legume mixtures were sown. No detail information about applied fertilization and seed mixtures is available. From that time onwards, no management practices were carried out.

The study was carried out within the soda waste dumps complex, which had an area of 17.43 ha. In total 132 plots with a 5 × 5 m area were laid out at the nodes of a grid spaced 30 m apart. The depth of topsoil was measured and soil samples (mixed from three subsamples) were collected from each plot to determine physical and chemical parameters. Detailed results of the analysis of soil cover properties were published in another paper [Zając 2009]. On each plot, vegetation was described using the Braun-Blanquet scale. The plant cover was estimated and height of the plants was measured to calculate mean value. Species diversity was presented as the number of species on the plot and as the Shannon-Wiener diversity index [Magurran 1988], which accounted for the proportion of each species in the sample. Differences in species composition between the plots were illustrated using the van der Maarel's similarity coefficient [Wildi and Orloci 1996] and constancy, which measures the frequency of occurrence of each species. The requirements of the plants as indicators of habitat conditions were determined based on their phytosociological affiliation [Matuszkiewicz 2005] and Ellenberg indicator values [Ellenberg *et al*. 1992] for soil moisture (F), soil reaction (R) and abundance of nitrogen (N).

RESULTS

On the all plots 133 species of vascular plants were identified. Species diversity on individual plots was relatively low. There were from 2 to 33 species per plot (20.3 on average) and plots with species number between 15 and 25 were the most common (Fig. 1). Shannon-Wiener diversity index ranged from 0.26 to 2.39 (1.79 on average) and plots with the index value between 1.5 and 2.0 accounted for 31% (41 plots) (Fig. 2).

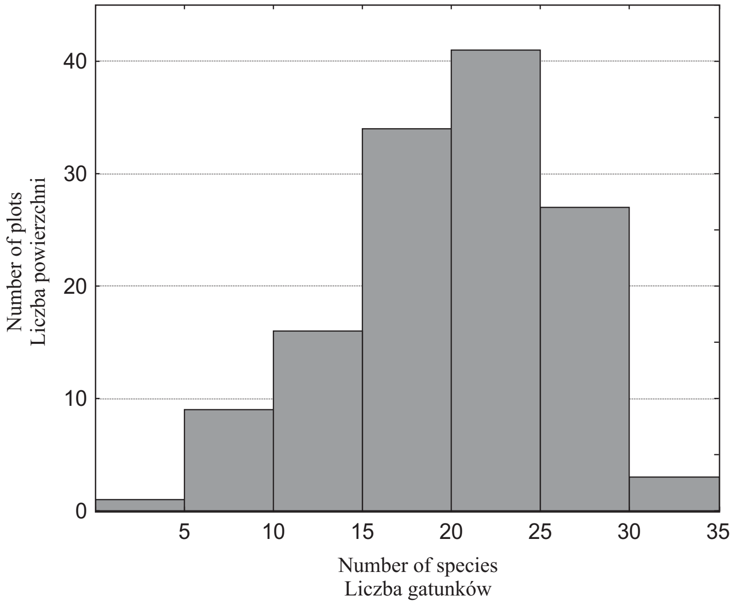

Fig. 1. Histogram of the number of species per plot (25 m^2)
Rys. 1. Histogram liczby gatunków na powierzchnię (25 m^2)

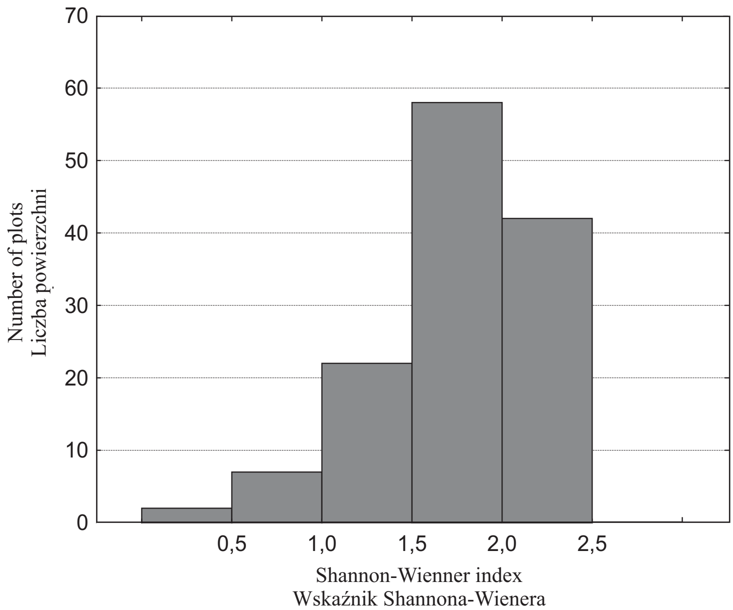

Fig 2. Histogram of the Shannon-Wiener diversity index
Rys. 2. Histogram współczynnika różnorodności Shannona-Wienera

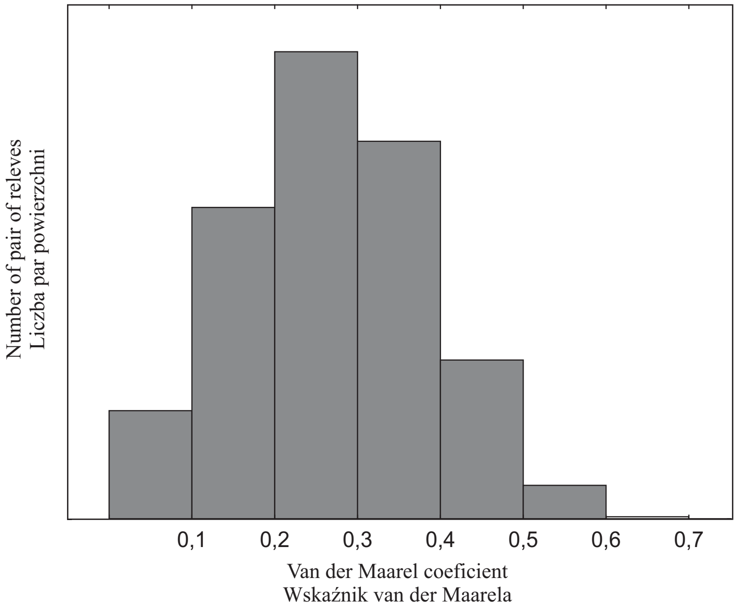

Fig. 3. Histogram of the van der Maarel similarity index between plots
Rys. 3. Histogram współczynnika van der Maarela podobieństwa pomiędzy powierzchniami

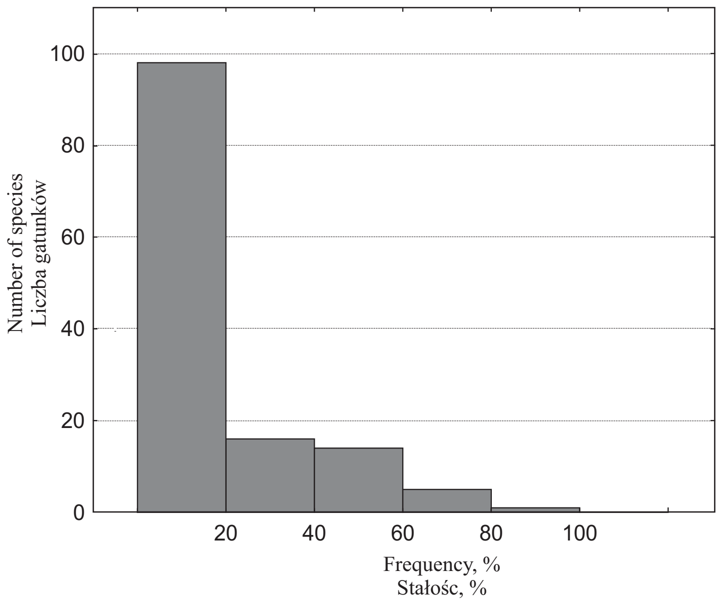

Fig. 4. Histogram of the frequency of occurrence of species
Rys. 4. Histogram częstotliwości występowania gatunków

The plots differed considerably in species composition. The van der Maarel's coefficient, which measures the similarity of species composition between each two plots, reached a maximum of 0.7, but in 7400 (87%) of the cases it was less than 0.4 (Fig. 3).

The number of species common for different plots was low. As much as 97 (what makes 73%) of the recorded plant species appeared on less than 20% of the plots (Fig. 4).

The species occurring on the soda waste dumps were typical for many different plant communities. Meadow species (class *Molinio-Arrhenatheretea*) and ruderal species (class *Agropyretea intermedio-repentis, Artemisietea vulgaris* and *Stellarietea mediae*) predominated at 35% and 28% of all species, respectively. Fringe species (*Trifolio-Geranietea*) formed a much lower proportion at 5% of all species. The species characteristics for other classes were scarce (Tab. 1) except the wood-small reed (*Calamagrostis epigejos*), which dominated on some plots.

Table 1. General characteristic of the vegetation on the settling tank
Tabela 1. Ogólna charakterystyka roślinności na osadniku

Phytosociological affiliation Przynależność fitosocjologiczna	Number of species Liczba gatunków	Number of species Liczba gatunków %	Mean plant cover Przeciętne pokrycie powierzchni %
Agropyretea intermedio-repentis	5	3.76	6.6
Artemisietea vulgaris	26	19.5	22.3
Stellarietea mediae	7	5.26	1.4
Molinio-Arrhenatherethea	47	35.3	36.7
Epilobietea angustifolii	2	1.5	14.5
Festuco-Brometea	2	1.5	0.1
Trifolio-Geranietea	7	5.26	13.2
Nardo-Callunetea	2	1.5	0.0
Phragmitetea	2	1.5	0.0
Others – Inne	33	24.8	5.3

The plants found in the investigated dumps vary considerably in their habitat requirements, expressed by Ellenberg indicator values. In terms of moisture indicator values (*F*), most species were typical of intermediate moisture and slightly dry habitats (*F* from 3 to 6), although there were some species typical for very dry and water-logged habitats (Fig. 5). The lowest variation was found in terms of reaction value (*R*). Species that require neutral and slightly alkaline habitats (*R* from 6 to 8) were dominant. Species of acidic soils occurred sporadically (Fig. 6). The most uniform distribution was found for the abundance of nitrogen (*N*), with similar proportions of the species typical of poor, intermediately fertile and very fertile habitats (Fig. 7).

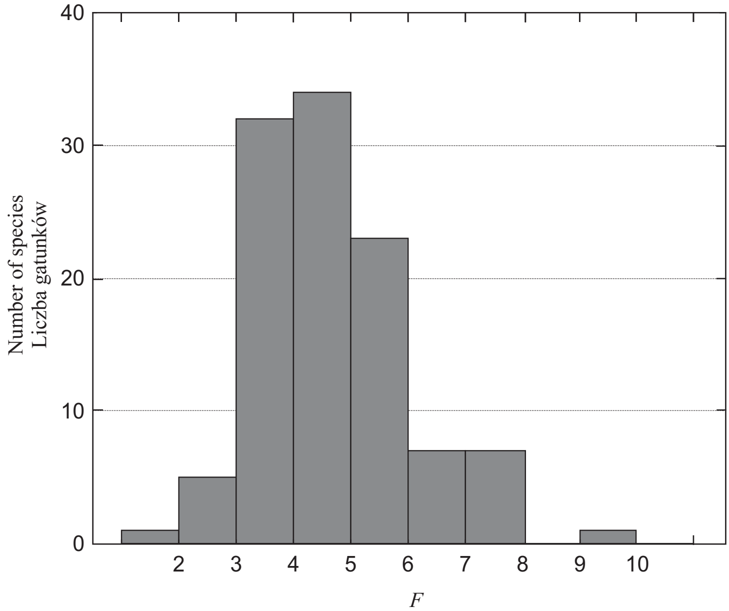

Fig. 5. Number of species with different moisture [*F*] indicator value
Rys. 5. Liczba gatunków o różnych wartościach wskaźnika wilgotności [*F*]

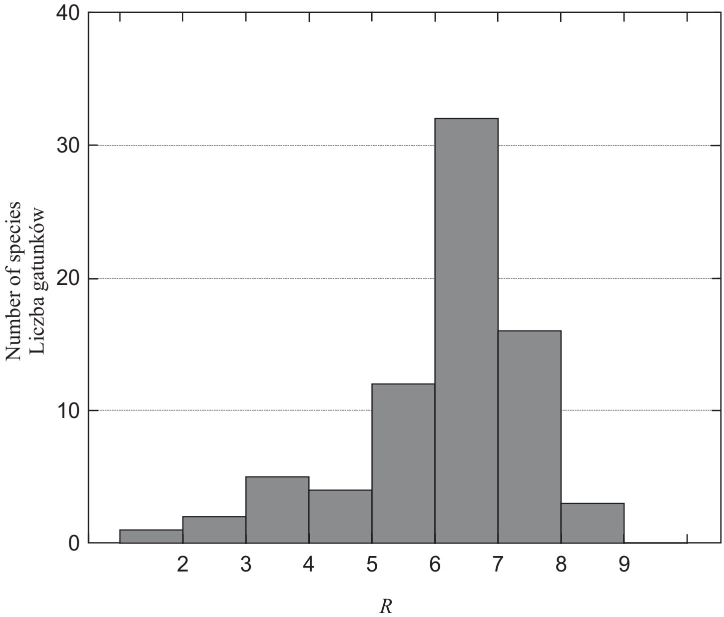

Fig. 6. Number of species with different reaction [*R*] indicator value
Rys. 6. Liczba gatunków o różnych wartościach wskaźnika odczynu [*R*]

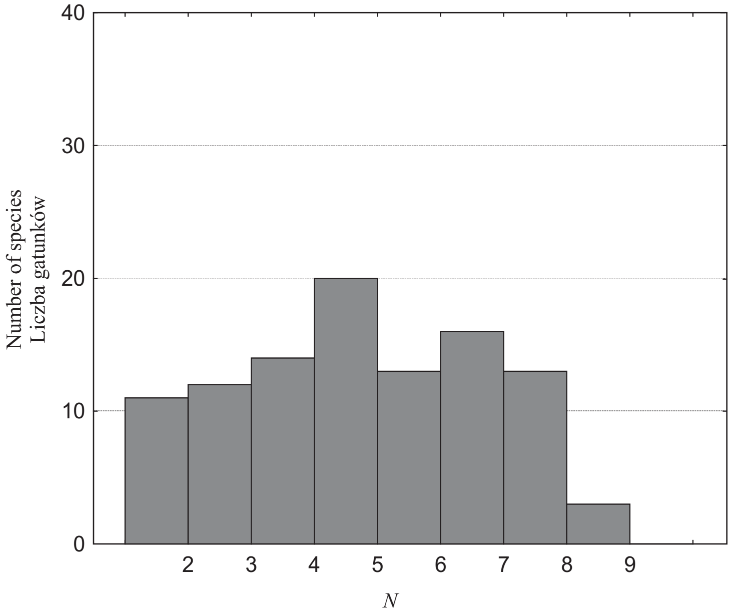

Fig. 7. Number of species with different nitrogen [*N*] indicator value
Rys. 7. Liczba gatunków o różnych wartościach wskaźnika zasobności w azot [*N*]

DISCUSSION

The spatial aspects of diversity can be describe by alpha and beta diversity [Lepš 2005]. Alpha diversity can be measured as the number of species (or another diversity index) within a particular plot (within-habitat diversity). Beta diversity shows differences between species composition of particular plots (between-habitat diversity) [Lepš 2005]. The analysis of vegetation diversity in the investigated soda waste dumps shows high beta and low alpha diversity.

The number of species per 25 m^2 area was low and in some plots very low, but fell within the range typical of many natural and anthropogenic ecosystems. The number of species found on West European grasslands ranged from 4 to 60 per 100 m^2 [Janssens *et al.* 1998]. In European meadows, the highest number of species per m^2 (79) was found in Estonia [Sammul *et al*. 2003], although high-mountain swards are also characterized by high diversity of up to 84 per 25 m^2 [Maurer *et al*. 2006]. Natural ecosystems are often characterized by a smaller number of species. In a study by Haärdtle *et al*. [2003], the maximum number of forest cover species was 65 per 100 m^2 in floodplain forests and only 37 in acid coniferous forests. A particularly wide range of species number is found in urbanized areas. In some cases, dominance of species such as *Calamagrostis epigejos* [Kirmer and Mahn 2001, Prach and Pysek 2001] and *Solidago* sp. [Bornkamm 2007] is observed. Some urban areas have a relatively large number of species [McKinney 2006].

The Shannon-Wiener index followed a similar pattern as the number of species. Several plots were characterized by very low values of this index because of the patchy distribution of some species (e.g. *Calamagrostis epigejos*, *Helianhus tuberosus*), which is typical of the early stages of succession, e.g. of post-agricultural old-field [Meiners *et al*. 2001] The rapid development of *Calamagrostis epigejos*, which limits the number of other species, is observed in many natural and anthropogenic ecosystems [Rebele and Lehmann 2001, Sodomi *et al*. 2008]. The highest values were calculated for the plots dominated by meadow species of the class *Molinio-Arrhenatheretea*. They were close to the values reported for typical grassland communities [Kryszak 2001].

The importance of soda waste dumps as a site enriching species diversity is determined by beta diversity. A considerable number of species (133) were found in a relatively small area (17.4 ha). The individual plots show little similarity to one another in terms of species composition. The distribution of similarity values between all the pairs is a good indicator of beta diversity [Magurran 1988]. In the case of the dumps, this indicator shows that over 80% of the samples have a similarity below 0.4, which is evidence that these plots share almost no species [Wildi and Orloci 1996]. Similar conclusions can be drawn based on the analysis of species constancy. As many as 85 species occur in less than 10% of all plots. High diversity of species composition between the plots may result from the short duration of community formation, but above all from the large variation of habitat conditions. Plant species on the dumps do not form typical communities which correspond to natural or semi-natural communities. Numerous factors, mainly soil factors interact to create many microhabitats. Investigated area of the dumps was covered with a topsoil of average depth 0.25 m. It was composed predominantly of the clay fraction. The topsoil showed a low phosphorus content, but the content of potassium and magnesium was very high, which may be associated with the dominant soil type and the fertilization carried out as part of the reclamation operations. Also, a very high total calcium content was stated, what probably resulted from some components from the soda waste getting to the soil cover. This probably influences the pH, which is close to alkaline [Zając 2009]. However, no increase of salinity level in the topsoil was observed. A change in the gradient of individual parameters causes some species to replace others, but this does not always translate into a change in the number of species.

Habitat variation on the soda waste dumps can be measured by the incidence of species having different requirements. The analysis of Ellenberg indicator values showed the highest variation for the fertility index *N*. The species varies from typical of very poor habitats (e.g. *Hieracium pilosella*, $N = 2$) to eutrophic (e.g. *Lamium album*, $N = 9$). The proportion of species in particular ranges of the index values was uniform. As far as soil reaction is concerned species of neutral pH requirements dominated. Species typical of alkaline soils (e.g. *Coronilla varia*, $R = 9$) had a much higher proportion than under natural conditions. This may be due to the impact of an alkaline waste relocated to the topsoil often as a result of soil animals activity [Pośpiech and Skalski 2006]. Species dominating the dumps were usually those found in moderately dry and dry habitats (e.g. *Poa compressa*, $F = 3$; *Filipendula vulgaris*, $F = 3$). The water balance, which relies on precipitation and retention, coupled with the low topsoil depth cause the root layer to dry up in the dry season. However, also species of wet habitats (e.g. *Lysimachia vulgaris,* $F = 8$) or even water-logged habitats (*Phragmites australis,* $F = 10$) appeared locally. Their occurrence was associated with local stagnation of water.

CONCLUSIONS

1. Low thickness of topsoil makes possible development of multispecies herbaceous vegetation.
2. Heterogeneous material used as topsoil hindered development of typical plant species communities but created many microhabitats suitable for numerous plant species of different ecological requirements.
3. Man made sites left for spontaneous succession can significantly increased biological diversity of urban and industrial landscape and serve as a source of seed dispersal for adjacent areas.
4. To prevent development of expansive species, which could competitively exclude other species, some management practices e.g. mowing may be necessary.

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Zaakceptowano do druku – Accepted for print: 12.12.2012