JEE Journal of Ecological Engineering
Volume 20, Issue 2, February 2019, pages 209–217
https://doi.org/10.12911/22998993/93870

Received: 2018.07.30
Revised: 2018.09.01
Accepted: 2018.11.10
Available online: 2018.12.10

Diversity of Vegetation Dominated by Selected Grass Species on Coal-Mine Spoil Heaps in Terms of Reclamation of Post-Industrial Areas

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ABSTRACTS

Grasses have a considerable potential for the adaptation to various, often extreme, habitat conditions. The aim of the work was to present the vegetation diversity of the coal-mine spoil heaps with the dominant share of grasses and to identify the main factors responsible for this diversity in the aspect of post-industrial land reclamation. The communities differ in reference to the species preferences to light, moisture, soil fertility and reaction, which is reflected in the wide variety of microhabitats in the area. It was shown that the increase in the abundance of certain grass species, including *Calamagrostis epigejos, Festuca rubra, Festuca arundinacea, Phragmites australis*, has a significant negative impact on the species richness, species diversity and the uniformity of distribution of species of the plant community. Preliminary analyses revealed that on post-mining waste, the biomass production of the dominant species is negatively correlated with biodiversity. The knowledge about the biology and ecology of grass species, as well as on the assembly rules may be used in the reclamation of degraded areas. Gaining the knowledge about the vegetation diversity of the coal-mine spoil heaps with the dominant share of grasses can be useful in planning the reclamation works, taking into account natural processes, which leads to the creation of a permanent vegetation cover at a given site, protecting it against water or wind erosion. In the future these areas may provide a number of important ecosystem services.

Keywords: grass species, dominants, diversity, biomass, coal-mine spoil heaps, plant community, reclamation

INTRODUCTION

Coal mine spoil heaps that were formed as a result of long lasting mining activity are an inseparable element of the Upper Silesian landscape. These sites are very specific habitats, often without soil and vegetation cover that is linked to the absence of a soil seed bank and lack or low amount of nutrients in the substratum. In addition, they can be characterized by high temperature, salinity, significant fluctuations in moisture, and thermal activity. Instability of the coarse grain substrate causes its susceptibility to the water or mass erosion [Maciak, 1999; Bradshaw, 2000; Woźniak, 2010; Chmura et al., 2011; Chmura et al., 2013; Molenda et al., 2013; Markowicz et al. 2015]. All these factors contribute to the difficulty of colonizing them both by plant and animal species. However, the results of many studies revealed [Rostański and Woźniak, 2007; Woźniak, 2010; Błońska et al., 2013; Nicia et al., 2014], that there are species which colonize this area during spontaneous succession and form plant communities and are frequently different from those recorded on other anthropogenic sites. The vegetation patches that occur on coal mine spoil heaps are frequently dominated by single species that are characterized by high frequency and abundance, giving them a specific physiognomy. The dominant species have a set of functional traits [e.g. height, high seed production, parameters of leaves, biomass, root traits] that help them successfully compete with accompanying species and reduce their abundance in patches [Frieswyk et al. 2007; Ryś et al.,2016]. Therefore, they play a crucial role in shaping both the abiotic [soil formation, nutrient and water cycling] and biotic components of plant communities [Simberloff and Von Holle, 1999]. In reference to such species, a „mass ratio hypothesis [MRH]" was formulated that explains the influence of some species on ecosystem processes or services. According to Grime [1998] the influence of dominant plants is proportional to their abundance in a given community. The MRH hypothesis was also confirmed during the experimental studies conducted by Díaz et al. [2007] or Mokany et al. [2008] who stated that the functioning of ecosystem is determined by the morphological, physiological or phonological traits of species that significantly contribute to the production of a biomass.

Grass species play an important role in colonization of such harsh areas [Kompała, Woźniak 2001; Rostański and Woźniak, 2007; Ryś et al., 2016], because they can adapt to various, often extreme, environmental conditions that occur on a post-industrial sites. They frequently possess wide ecological amplitude [Kozłowski et al. 2000]. The ability to reproduce vegetatively and to lateral spread via rhizomes as well as dispersal by wind, enables them to spread into new sites and occupy them [Frey 2000; Rostański, Woźniak, 2007]. They frequently play a pioneer role, influencing the soil formation and its physical and chemical properties. Since most of them have a well-developed root system, they also protect the soil against water and wind erosion. Therefore, they are very useful in the reclamation practice. [Frey, 2000; Woźniak, 2010]

The aim of the study is [i] to present the differentiation of spontaneous vegetation dominated by chosen grass species occurring on the coal-mine spoil heaps; [ii] to identify the main factors responsible for this diversity in the aspect of post-industrial land reclamation; [iii] to find the relations between cover of a dominants and chosen diversity indices and plant biomass.

MATERIALS AND METHODS

Site description

The study area is situated in the central part of the Silesian Upland in the mesoregion of the Katowice Upland [Kondracki, 2002]. The following coal-mine spoil heaps were selected for detailed studies (Fig. 1.) [Hałda „Sośnica", Hałda „Wesoła", Hałda «Maria», Hałda «Kostuchna»]. They were formed during 1900-1995 as a result of intensive exploitation

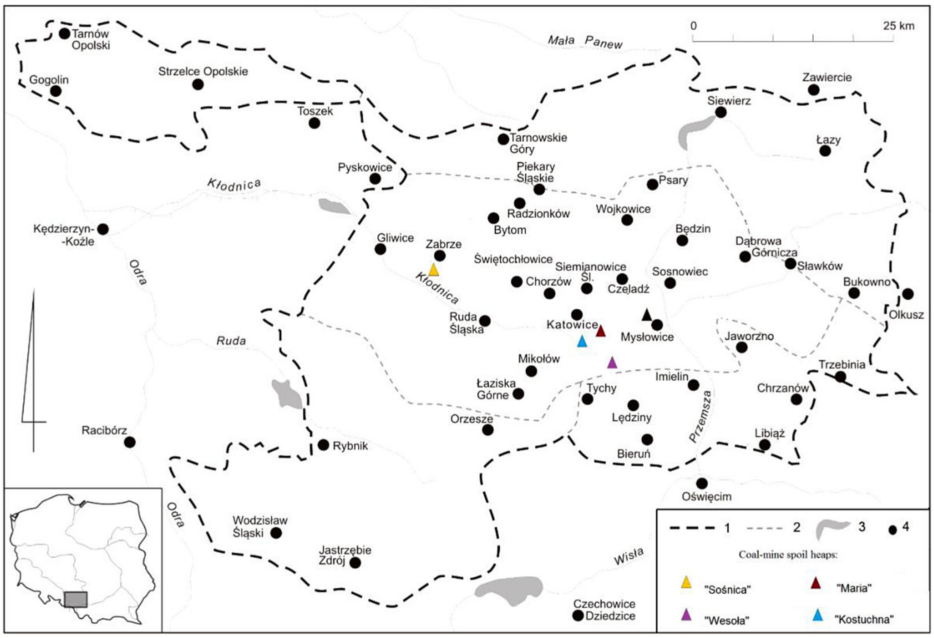

Fig. 1. Location of coal mine spoil heaps [marked in colour] in the study area [Woźniak, 2010, changed]
Explanations: 1 - Area of the Silesian Upland macroregion, 2 - Katowice Upland mesoregion, 3 - water reservoirs, 4 - cities

of hard coal by such coal mines as: KWK „Sośnica-Makoszowy", KWK „Mysłowice Wesoła", KWK „Murcki" (KWK „Murcki – Staszic" – Ruch „Boże Dary") [Mitek, 2015; Pełka-Gościniak, 2015]. The spoil material consists mainly of waste rock and other industrial wastes from mining excavations. Some reclamation works were undertaken, mainly involving afforestation [Mitek, 2015; Gajos et al, 2010; Pełka-Gościniak, 2015]. The technical reclamation work enabled to shape the slopes resulting in embankments construction of super-level and convex dome shape, often irregular slopes and a flat top, with an average height of > 30 m. Most parts of the heap are covered with non-forest vegetation. The dumping grounds are used for tourist purposes, i.e. for cycling and motor sports, as well as by hikers [Probierz et al. 2017].

METHODS

In the experiment, 70 sample plots were established in patches dominated by the chosen grass species. They have a shape of a circle with a radius of 3 m. In each sample plot, the species composition was noted together with the abundance of species evaluated on a 10-degree scale (<1%, 1-5%, 5-10%, and then every 10%). Moreover, smaller plots with a side of 0.5 m were established on 70 sample plots, from which the surface parts of plants (biomass) were collected: separately for a dominant and the rest of species (accompanying species). Shortly after collecting, the fresh mass of species was immediately weighed using a field weight. The samples were then dried at 105ºC in an incubator for 24 hours in the air and weighted again (weight of dry biomass was obtained) as a result of which the weight of dry biomass was obtained (dried at 105°C).

On the basis of the classification results, a synoptic table was prepared. The diagnostic species were determined using as a measure of fidelity phi coefficient of association. The species were classified into ecological groups on the basis of Matuszkiewicz [2001] and Oberdorfer et al. [1990]. Species richness, Shannon-Wiener diversity index (*H'*), Simpson dominance index (D), Evenness index (E) were calculated in JUICE 7. 0. 64 [Tichý, 2002] in order to show the relation between the abundance of a dominants and other characteristics of a community [Tichý, Holt, 2006]. In order to present the habitat preferences of the species that constitute the plant communities, the average Ellenberg's indicators values (L, F, R, N) were calculated for each sample plot [Ellenberg et al. 1992] in JUICE 7 0. 64 [Tichý, 2002]. The groups of communities were compared using the non-parametric Kruskal-Wallis test [StatSoft, INC. 2011]. The names of species were adopted after Mirek et al. [2002].

RESULTS

The hierarchical classification of 70 sample plots enabled us to distinguish 5 groups (clusters) of communities dominated by grasses such as wood small-reed (*Calamagrostis epigejos*); flattened meadow-grass (*Poa compressa*); red fescue (*Festuca rubra*); tall fescue (*Festuca arundinacea*) and common reed (*Phragmites australis*) (Table 1) They contain from 8 to 17 plots. The number of species recorded in individual clusters ranges from 23 to 55 species. In individual communities, from 3 to 15 diagnostic species were recorded. High fidelity (phi> 50) to the given community characterized such grass species as: *Festuca rubra, Festuca arundinacea, Poa compressa* or *Phragmites australis.*

Taxonomic diversity

The most diverse communities in reference to floristic composition were characterized by high abundance of such species as: flattened meadow grass *Poa compressa* (*H'* – 1.89), wood small reed *Calamagrostis epigejos* (*H'* – 1.42), tall fescue *Festuca arundinacea* (*H'* – 1.45), whereas the communities with dominance of common reed *Phragmites australis* (*H'* – 0.91) were less diverse. *Phragmites australis* has the highest average abundance (70%) in patches (Fig. 2a). During studies, the patches with the lower abundance of 20% were rarely recorded. In comparison with other plant communities, the recorded values of Simpson's dominance index were the highest (Fig. 2d). In the patches with such dominants as *Calamagrostis epigejos* (1), *Festuca rubra* (3), *Festuca arundinacea* (4), the mean cover of dominants plant ranges from 30 to 60%.

The values of Simpson dominance index range on average from 0.25 (*Poa compressa* com.), following 0.41 (in case of *Calamagrostis epigejos, Festuca arundinacea*), 0.53 (*Festuca rubra com.*) to 0.62 (*Phragmites australis* com.). *Poa compressa* has the average abundance in patches 30%. The maximum abundance of this species reaches 40%.

Table 1. The characteristics of plant communities occurring on coal-mine spoil heaps of the Katowice Upland

No	Diagnostic species:	Constant species:	Dominant species:	Number of grasses
Ce (17)	*Calamagrostis epigejos 44.2, Senecio viscosus 31.0*	***Calamagrostis epigejos 100,** Poa compressa 53, Solidago gigantea 53*	*Calamagrostis epigejos 88, Solidago gigantea 6*	6
Pc (17)	*Achillea millefolium 30.3, , Calamagrostis epigejos 32.4, Daucus carota 36.2, Echium vulgare 41.0, **Erigeron annuus 55.9,** Leontodon autumnalis 38.3, Lotus corniculatus 38.0, **Picris hieracioides 50.6,** Plantago lanceolata 44.4, **Poa compressa 57.8,** Rumex crispus 38.3, **Taraxacum officinale 48.7***	***Calamagrostis epigejos 88, Daucus carota 82,** Erigeron annuus 65, Hieracium piloselloides 59, Lotus corniculatus 65, Medicago lupulina 65, **Picris hieracioides 88, Poa compressa 100,** Solidago gigantea 53, Taraxacum officinale 71*	*Poa compressa 71*	10
Fr (15)	*Festuca arundinacea 30.9, **Festuca rubra 59.7,** Vicia cracca 33.1, Vicia hirsuta 33.4,*	*Festuca arundinacea 67, **Festuca rubra 100***	*Festuca arundinacea 7, Festuca rubra 87*	2
Fa (8)	*Chenopodium album 37.3, **Conyza canadensis 56.6,** Fallopia convolvulus 32.0, **Festuca arundinacea 65.4,** Festuca rubra 34.3, Filago arvensis 32.0, Medicago falcata 32.0, **Phleum pratense 45.9,** Poa pratensis 39.1, Polygonum aviculare 32.0, Sisymbrium altissimum 32.0, Sorbaria sorbifolia 32.0, Stachys palustris 32.0, **Thlaspi arvense 45.9***	*Conyza canadensis 62, Daucus carota 62, **Festuca arundinacea 100,** Festuca rubra 75*	*Festuca arundinacea 100*	6
Pha (13)	*Agrostis gigantea 35.6, Arrhenatherum elatius 35.6, Bidens frondosa 35.6, **Phragmites australis 77.5,** Poa palustris 45.0, Urtica dioica 35.6*	*Calamagrostis epigejos 54, **Phragmites australis 100,** Solidago gigantea 62*	*Phragmites australis 92*	7

Explanations: Ce – community *Calamagrostis epigejos,* Pc – community *Poa compressa*, Fr – community *Festuca rubra*, Fa –community *Festuca arundinacea*, Pha – community *Phragmites australis*

Dominant species and their impact on species richness, species diversity, evenness, biomass

No statistically significant correlation was found between the abundance of a dominant and the number of species (Table 2). The largest average number of species was recorded in the patches (Fig. 3) dominated by *Poa compressa* [average 13 species], followed by *Festuca arundinacea* (average 10 species) and *Calamagrostis epigejos* (average 10 species). In the remaining panels with the participation of both *Festuca rubra* and *Phragmites australis* as dominant species, the total number of species was slightly lower (mean of 6-8 species).

Statistically significant negative correlations were found between the cover of the majority of dominants and the values of Shannon-Wiener diversity index (H') and evenness (E). Only in the case of *Poa compressa*, there was no statistically significant correlation between the flattened meadow grass cover and the species diversity of the patches. The dominant cover, on the other hand, had a negative effect on the values of the evenness index.

Table 2. Spearman's rank correlation coefficient between cover of dominant species and selected variables (statistically significant results are highlighted in red; p<0.05)

Grass-dominated community	1	2	3	4	5
Variable:	abundance of the dominant [%]				
• No. species richness	-0.03	0.46	0.24	-0.71	-0.55
• Shannon-Wiener diversity index (H')	-0.72	0.04	-0.57	-0.91	-0.80
• Evenness index (E)	-0.89	-0.72	-0.68	-0.91	-0.80
• Simpson's dominance index (D)	0.84	0.26	0.65	0.91	0.78
Fresh biomass of a dominant (weight)	0.81	0.73	0.54	0.17	0.76
Fresh biomass of accompanying species (weight)	-0.22	0.41	-0.36	-0.04	0.24
Dry biomass of a dominant (weight)	0.86	0.50	0.07	0.43	0.58
Dry biomass of accompanying species (weight)	-0.16	0.33	-0.52	0.16	0.14

Explanations: 1 - *Calamagrostis epigejos* com., 2 – *Poa compressa* com., 3 – *Festuca rubra* com., 4 – *Festuca arundinacea* com., 5 – *Phragmites australis* com.

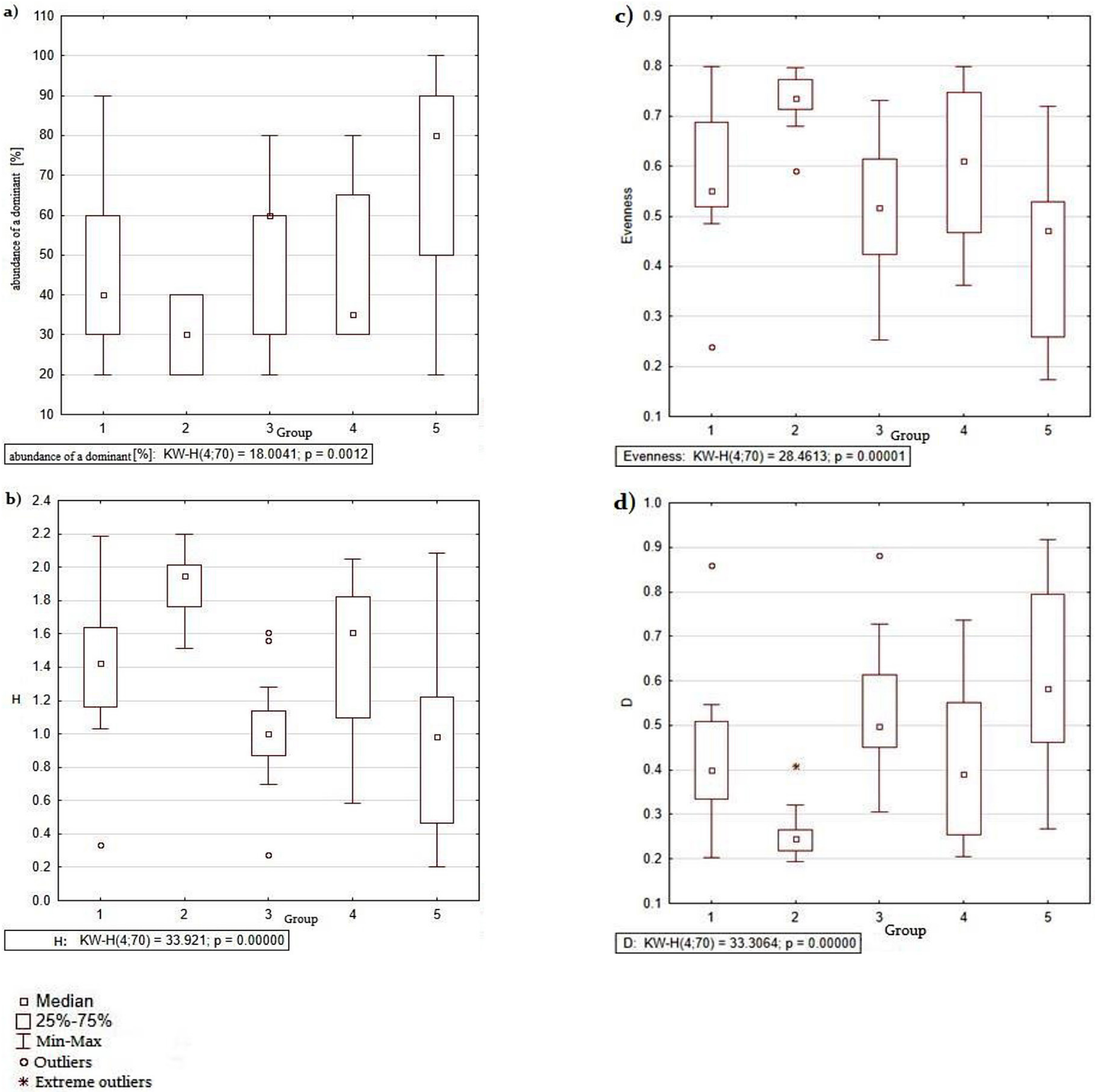

Fig. 2. The comparison of grass-dominated communities in reference to: a) abundance of a dominant; b) Shannon-Wiener diversity index (H'); c) Evenness (E); d) Simpson's dominance index (D). Abbreviations: 1 – *Calamagrostis epigejos* com., 2 – *Poa compressa* com., 3 – *Festuca rubra* com., 4 – *Festuca arundinacea* com., 5 – *Phragmites australis* com

The fresh biomass of dominant species was different in the patches of the most frequent vegetation types. The highest fresh biomass was found in the patches dominated by *Phragmites australis* and *Calamagrostis epigejos*, whereas the lowest in the patches dominated by *Poa compressa* (Fig. 4a). There were no statistically significant correlations between the fresh biomass of accompanying species and the dominant cover (Fig. 4b).

Habitat preferences of species occurring in grass-dominated communities on the coal-mine spoil heaps

While comparing the grass-dominated communities in terms of habitat preferences of species, it was shown that the communities of *Phragmites australis* are significantly different due to the habitat preferences of species in terms of humidity, higher nutrient content and attachment of species to shady places. The statistically significant differences were observed between the *Phragmites australis* community and the *Poa compressa* and *Festuca rubra* communities in relation to light (L) and moisture (F) (Fig. 5a, 5b).

The patches with *Phragmites australis* consist of the species that prefer wet soils and shady places. In contrast, in the floristic composition of patches with *Poa compressa* and *Festuca rubra*, the species that are confined to dry soils and open places were found. The statistically significant differences were found in the floristic compo-

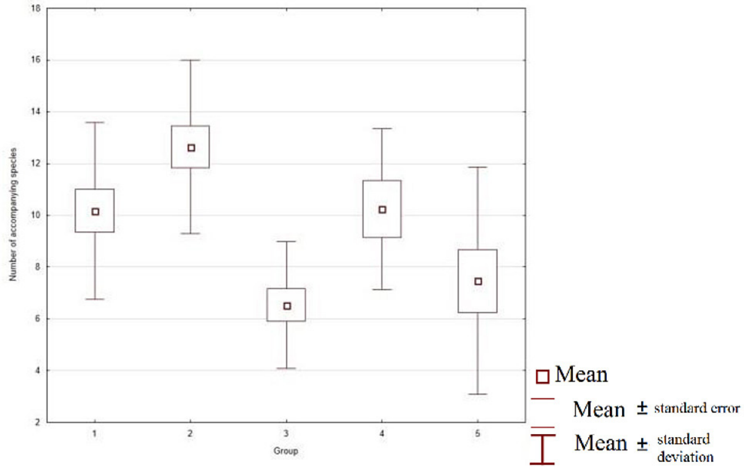

Fig. 3. The comparison of grass communities in reference to number of accompanying species
Abbreviations: 1 – *Calamagrostis epigejos* com., 2 – *Poa compressa* com., 3 – *Festuca rubra* com., 4 – *Festuca arundinacea* com., 5 – *Phragmites australis* com.

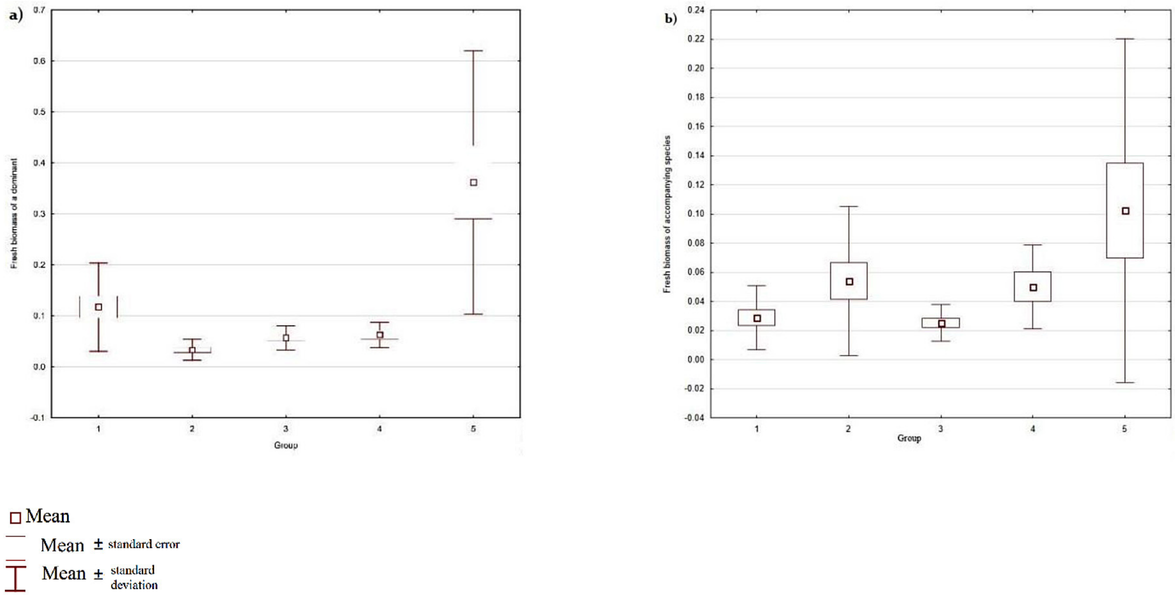

Fig. 4. The comparison of grass communities in reference to: a) fresh biomass of a dominant; b) fresh biomass of accompanying species. Abbreviations :1 – *Calamagrostis epigejos* com., 2 – *Poa compressa* com., 3 – *Festuca rubra* com., 4 – *Festuca arundinacea* com., 5 – *Phragmites australis* com.

sition of the *Phragmites australis* community, in reference to nitrogen, in comparison to other communities. In the floristic composition of the communities with high abundance of *Poa compressa, Festuca rubra* and *F. arundinacea* the species that prefer a lower nitrogen concentration in the soil, in comparison to *Phragmites australis* com., were found. In the floristic composition of the patches with *Poa compressa*, more species that prefer alkaline soils, in comparison to the phytocoenoses dominated by *Festuca rubra, Festuca arundinacea* or *Phragmites australis*, were observed.

DISCUSSION

The data on the biology and habitat preferences of species that spontaneously colonize spoil heaps and form plant communities can be used in the planning reclamation works on various post-industrial wastelands. These species are better adapted to harsh habitat conditions. The use of floristic criteria allowed to distinguish 5 plant types of communities. In the plant communities that develop in post-mining waste dumps, very often one of the most abundant species gives them specific physiognomy and has influence on the diversity of communities. In the case of our

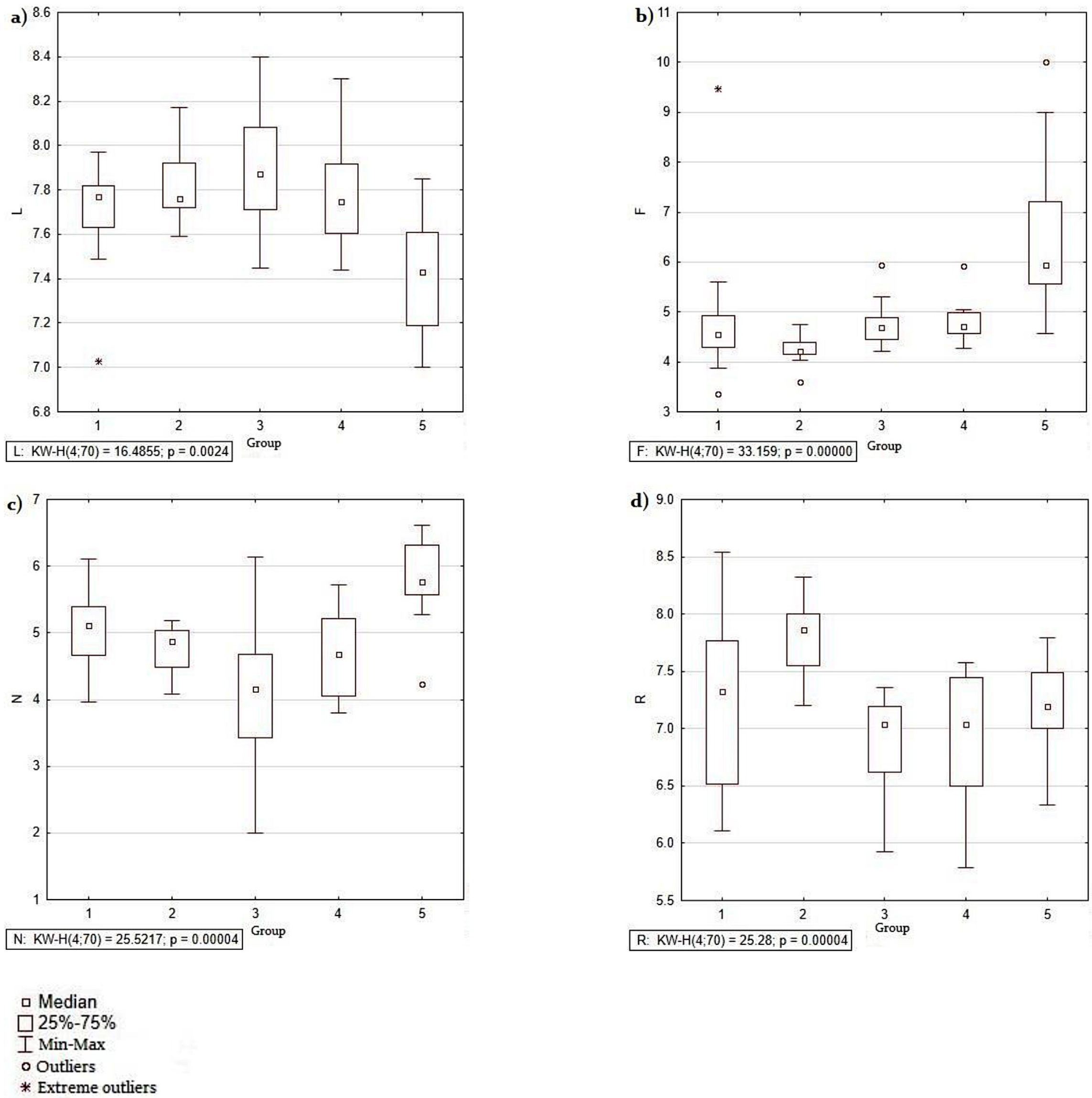

Fig. 5. Comparison of distinguished plant communities in terms of habitat preferences of their species with respect to: a) - light (L): 6 to 7 to full light (8 to 9), b) – moisture (F): fresh substrates (4-5) to wet substrates (8-9), c) - nitrogen (N) content: from poor (2-3) to the rich (6-7); d) – soil reaction (R): moderately acidic substrates (4-5) to slightly acidic and alkaline substrates (6-7);

1 - *Calamagrostis epigejos* com., 2 - *Poa compressa* com., 3 - *Festuca rubra* com., 4 - *Festuca arundinacea* com., 5 - *Phragmites australis* com.

research, such grass species as *Calamagrostis epigejos, Poa compressa, Festuca rubra, Festuca arundinacea, Phragmites australis* played the role of dominants.

The mosaic of habitats in post-industrial areas generates a different course of vegetation succession [Woźniak, 2010; Woźniak and Cohn 2007; Kompała-Bąba, 2013; Woźniak et al., 2015] and has an influence on the presence of species with different life strategies, representing different ecological groups, and having diversified habitat preferences in terms of light, moisture, nitrogen content or soil reaction. Therefore, they can use the limited resources occurring on wastes, e.g. water, nutrients, from coal dumps, in different ways and utilize a given dimension of ecological niches. The grass-dominated communities presented in this paper differ in the quantitative and qualitative share of species representing different ecological groups, e.g. meadow species predominated in the patches of the communities of *Festuca rubra* or *F. arundinacea*, grass species in the patches of *Poa compressa,* perennial ruderal species in of *Calamagrostis epigejos* patches. The species occurring in the floristic composition of the examined plant communities prefer the sites ranging from sunny (*Festuca rubra, F. arundinacea*) to shaded (*Phragmites australis*), from dry (*Poa compressa*, *Calamagrostis epigejos*) to wet (*Phragmites australis*), from nitrogen-poor (*Poa compressa, Festuca rubra, F. arundinacea*) to rich (*Phragmites australis*), from acidic to alkaline (*Poa compressa*) substrates. Our results confirmed the results obtained on similar post-industrial sites by Rostański, [2000; 2006]. Rostański [2000] studying the flora of post-industrial areas, found the considerable diversity of flora in terms of the habitat conditions [moisture and soil fertility, the reaction of the substrate], and the species recorded are often characterized by a wide range of most ecological factors. However, in the flora of post-industrial areas [hard coal mining heaps, sodium heaps], a clear share of mesophilous and moisture-demanding species [Cohn et al. 2001] and of aquatic and rush habitat species [Rostański, 2006] was often observed. According to Rostański [2006] the share of these ecological group of species can be linked to the heterogeneity of the landfilled waste, which is related to the quantity of mineral colloids in the substratum that occur on heaps.

CONCLUSIONS

1. On the basis of the floristic criterion, 5 plant communities dominated by different grass species were distinguished. One species often played a dominant role in them, and cover 20-100% of a patch.
2. The communities differ in reference to the species preferences to light, moisture, soil fertility and reaction, which is reflected in the wide variety of microhabitats in the area.
3. It was shown that the increase in the abundance of certain grass species, e.g. *Calamagrostis epigejos, Festuca rubra, Festuca arundinacea, Phragmites australis*, has a significant negative impact on the species richness, species diversity and the uniformity of distribution of species in the plant communities.
4. Preliminary analyses revealed that on post-mining waste, the biomass production of the dominant species is negatively correlated with biodiversity.
5. The knowledge about biology and ecology of grass species, as well as on the assembly rules may be used in the reclamation of degraded areas.

Acknowledgements

This study was a part of InfoRevita project TANGO ID: 268600 financed by NCN. We wanted to thank the students participating in the project InfoRevita for their excellent technical support.

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