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Meadow species in the early stages of succession on the ash settler of power plant EDF Toruń SA in Toruń, Poland

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Abstract. The paper is to present the trends of typical species of meadow habitats to colonize the frontier habitats. The area of research is the fly-ash landfills in the power plant EDF Toruń SA in Toruń. Several times, during the year mix of fly-ashes and slug, resulting from the combustion of coal, is transported by pipeline and this is mixed with water. Floristic research was conducted twice: in 2013 and 2015 year. Within an area of about 7 hectares 84 species of vascular plants (43 species in 2013 and 61 in 2015) were inventoried including 14 characteristic species of meadows. The presence of these species disturbed strong evidence of a wide ecological range and adaptations to survive adverse conditions of habitats. The results demonstrate that meadow species as *Festuca arundinacea*, *Festuca rubra*, *Lolium perenne*, *Poa annua, Rumex acetosa* and *Taraxacum officinale, Poa trivialis* and *Viccia cracca* can be helpful in restoration of fly-ash landfills.

Key words: fly-ashes, mix of ash and slug, *Molinio-Arrhenatheretea*, plant succession, pioneer plants.

1. Introduction

Meadow communities were created and maintained under constant human interaction that determines their permanence in space and time. Because of the hemicryptophyte dominance, meadow communities can be classified as stable and colonizing habitats with undisturbed ground. In habitats strongly transformed by human activity meadow species meet particularly difficult survival conditions. Continuous disturbance and the impact of heavy metals lead to development of special tolerance mechanisms by plants resulting in their slowdown in growth (Rees & Rose 2002). Developed under stress conditions communities are usually highly dependent on supplies of energy and matter from the outside. Abandonment of human activity leads to the emergence of systems with specific composition and properties not found in natural areas (Molenda 2013). Many grasses are thought as pioneer species and they are used in restoration of degraded lands (Antonkiewicz & Radkowski 2006).

The aim of the study is to present the trends of typical species of meadow habitats to colonize the pioneer habitats. Typical plants for meadow communities can be pioneer plants, because they are hardy species which are the first to colonize previously disrupted or damaged ecosystems. This first step of ecological succession ultimately leads to a more biodiverse steady-state ecosystem (Duram 2010).

2. Research area

The area of research is waste landfills in the power plant EDF Toruń SA in Toruń, Poland (Figs 1-3). The main waste generated in the EDF Toruń SA is the furnace wastes in the form of ash and slag mixture, resulting from the combustion of coal. Other waste represents a small share in the total amount of waste produced in this power plant. Waste from combustion in water boilers WP-120 in EC1 is hydraulically transported to the landfill, where floristic stud-

Figure 1. The pipeline drained a mixture of ash and slug to the landfill in EDF Toruń SA

Figure 2. The deposited wastes arising in thermal power plant EDF Toruń SA in March 2015

Figure 3. The landfill with mixture of ash and slug in EDF Toruń SA in July 2015

ies were conducted by our team. The landfill is also regularly watered to reduce dismantle fly-ashes by the wind. The investigated area reached ca. 7 ha. Characteristic of ash-slag is the presence of alternating layers of coarse and fine grain size. The thickness of these layers varies (from a few millimeters to 1 centimeter). Between them residues of completely unburned carbon can be found which have a capability to swell, which facilitates the penetration of water and air intensifying later weathering processes (Gilewska et al. 2007). The maximum water capacity of fly-ash deposits ranges from 65 to 124% by volume but only 20% of the water is available for plants. The remaining part is hygroscopic and hydration water included in the crystal lattice of minerals and chemical bonding. The pH is alkaline (about 9) which is associated with the presence of hydroxides of alkali metals (Rosik-Dulewska 2010).

3. Methods

Two intensive surveys were made in 2013 and 2015 to collect naturally growing plant species during different seasons on an area of fly-ash landfill. The presence of species was noted. Plant species were identified according to Rutkowski (2007) and named according to Flora Europaea (Tutin et al. 1964-1980). Meadow species were identified following Matuszkiewicz (2007) as typical of syntaxonomic class of *Molinio-Arrhenatheretea*. For each meadow species life-form according to Raunkiær classification was identified (Müller-Dombois & Ellenberg 1974). Moreover, Ellenberg indicator values (Ellenberg et al. 1992) of light availability, temperature, soil humidity (moisture), soil fertility and soil acidity (pH) were included to characterise habitat preferences of fly-ash landfill meadow flora. To find patterns of flora composition in both investigated growing seasons indirect ordination – Principal Components Analysis (PCA) was applied with the use of CANOCO 5.0 package (ter Braak & Šmilauer 2012).

4. Results

4.1. Floristic composition

Vegetation on the fly-ash landfill was sparse and most of the substrate surface was bare. However, in total 84 species of vascular plants (43 species in 2013 and 61 in 2015) were noted, including 14 characteristic species of meadows. Most of the species were typical of disturbed habitats. The richest groups (17 species – 21% of flora) represent species characteristic of the *Artemisietea vulgaris* and *Stellarietea mediae* class of plant associations (Fig. 4).

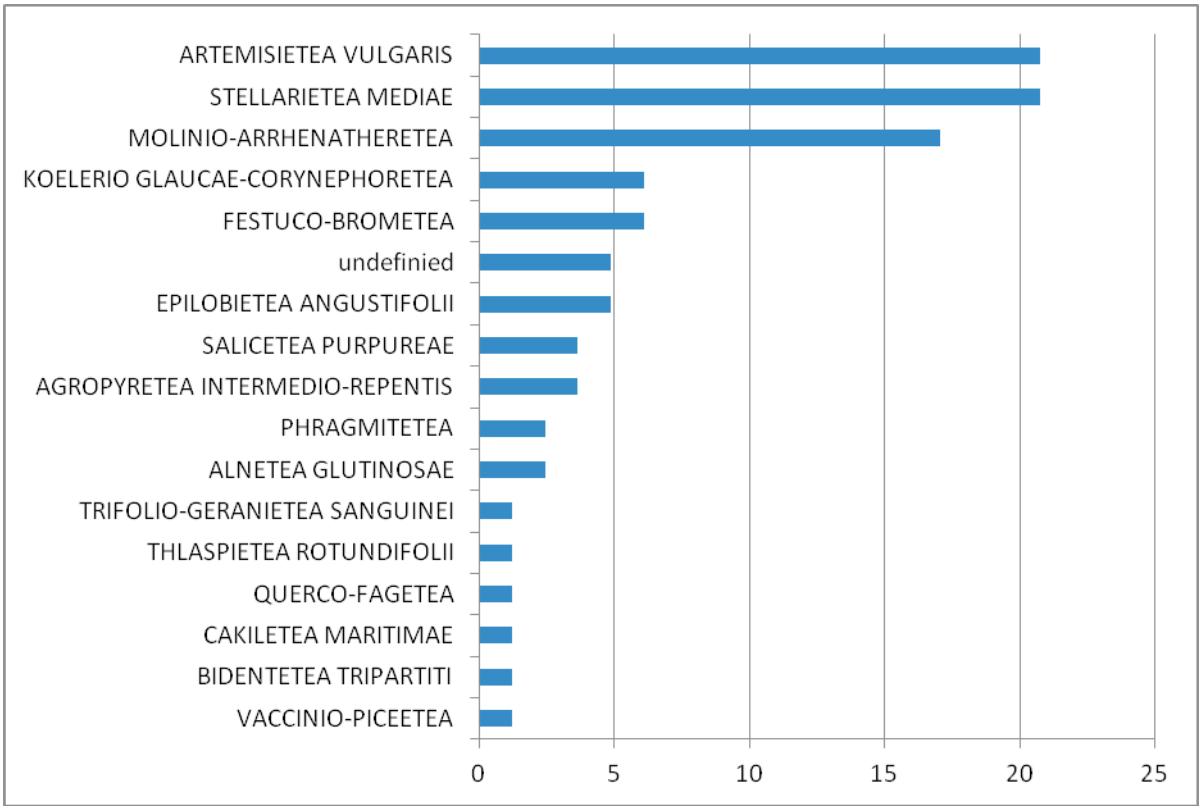

Figure 4. Percent of species representing syntaxonomical classes of plant associations (according to Matuszkiewicz 2007)

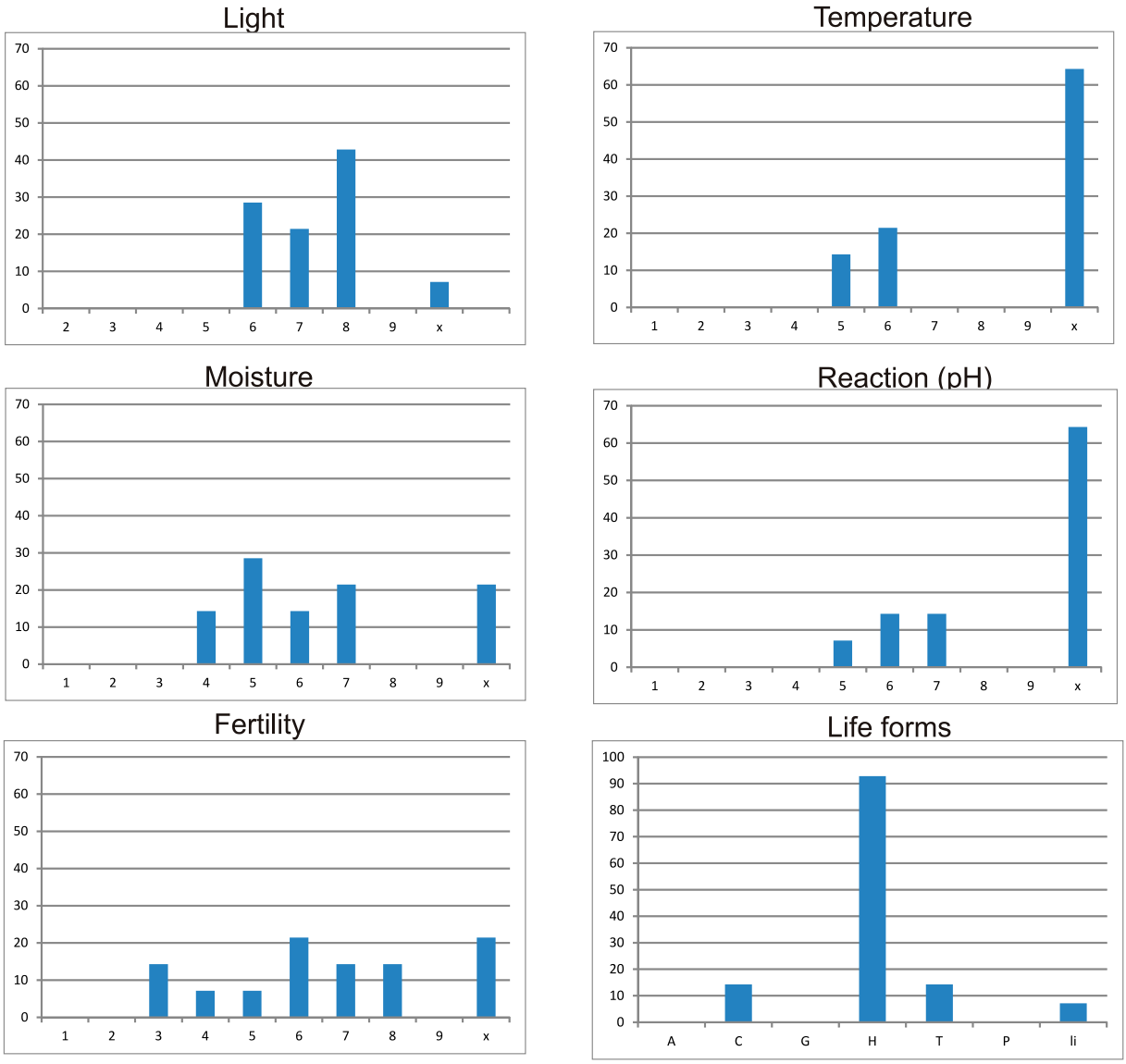

Figure 5. Environmental preferences of meadow species together with life forms - percent of species with certain Ellenberg indicator value and life-form. A - hydrophytes, C - chamaephytes, G - geophytes, H - hemicryptophytes, T - therophytes, P - phanerophytes, li - lianes

About 17% (14 species) were characteristic of meadow communities from *Molinio-Arrhenatheretea* class. Among them, species typical of fresh meadows (*Festuca rubra*, *Taraxacum officinale*, *Dactylis glomerata*, *Trifolium repens*, *Trifolium dubium*) and for so called carpet communities (*Lolium perenne*, *Lolium multiflorum*, *Poa annua*) were found. Moreover, species with relatively wide range of occurrence in meadow plant communities were noted, i.e. *Festuca arundinacea*, *Rumex acetosa*, *Vicia cracca*, *Plantago lanceolata*, *Poa trivialis*, *Avenula pubescens* and *Deschampsia caespitosa*. The relatively wide range of environmental conditions in fly-ash landfill is expressed by the presence of species typical of dry habitats (*Festuca ovina*, *Corynephorus canescens*, *Carex arenaria*, *Rumex acetosella*, *Helichrysum arenarium*) together with typical of wet ones (*Alisma plantago-aquatica*, *Phragmites australis*, *Salix cinerea*, *Lycopus europaeus*).

4.2. Ecological properties of species

Among species classified as typical of meadows, taxons with undefined preferences to temperature and soil acidity were dominating (Fig. 5), i.e. *Avenula pubescens*, *Dactylis glomerata*, *Deschampsia caespitosa*, *Plantago lanceolata*, *Poa annua*, *Poa trivialis*, *Rumex acetosa*, *Taraxacum officinale*, *Trifolium repens* (temperature) and *Vicia cracca*

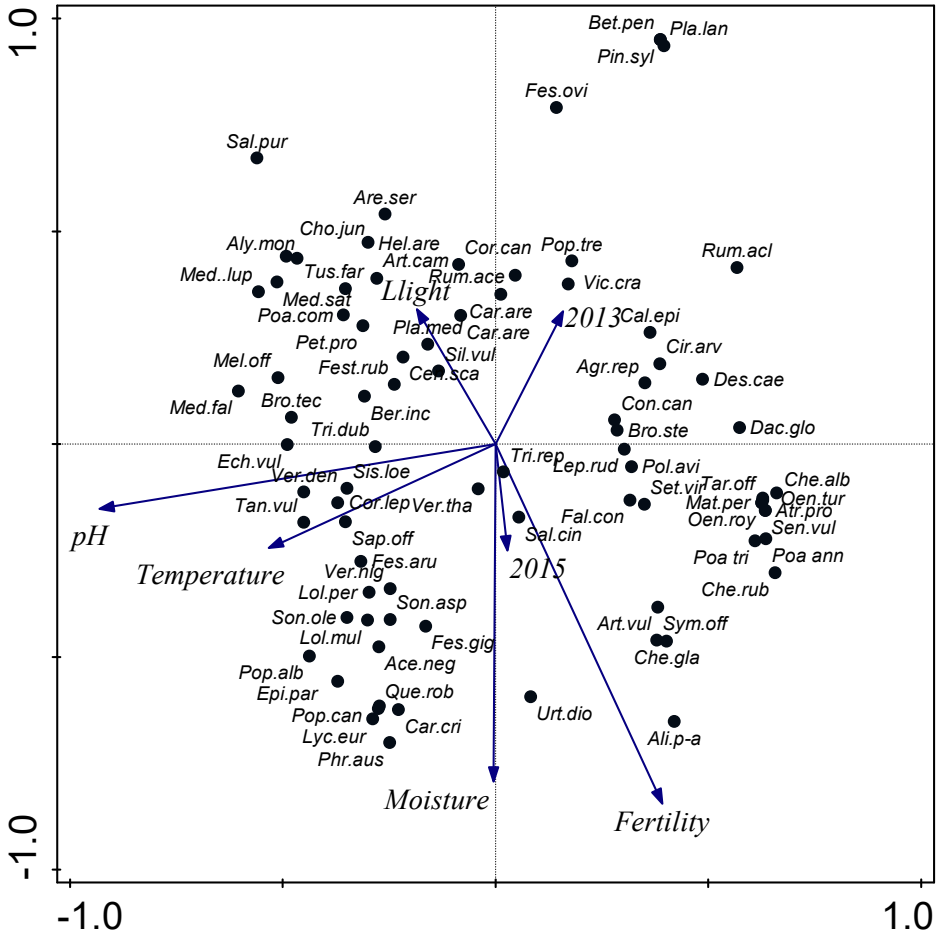

Figure 6. Results of PCA ordination of investigated flora (axes I and II). Meadow species present in both investigated periods are circled. The species name abbreviations: three letters of genus name plus three letters of species name, i.e. *Fes.aru – Festuca arundinacea*

(pH). The most diverse was the group of soil fertility indicators. There were indicators of low nitrogen content in the soil *(Deschampsia caespitosa*, *Festuca rubra*), indicators of soils moderately rich in nitrogen (*Festuca arundinacea*, *Dactylis glomerata*, *Rumex acetosa*, *Trifolium repens*) and indicators of soils rich and very rich in nitrogen (*Lolium perenne*, *Poa trivialis*, *Poa annua*, *Taraxacum officinale*). Soil humidity indicators, indicate fresh (*Festuca rubra*, *Trifolium dubium*, *Trifolium repens*, *Plantago lanceolata*, *Dactylis glomerata*, *Tatraxacum officinale*) to moist soils (*Vicia cracca*, *Poa annua*, *Poa trivialis*, *Deschampsia caespitosa*, *Festuca arundinacea*) in the investigated site. Most of the considered species prefer sites of good light conditions. The dominant life-forms were hemicryptophytes (Fig. 5). However, *Vicia cracca* is also classified as liane, *Poa trivialis* and *Trifolium repens* as cryptophytes, *Poa annua* and *Trifolium dubium* as therophytes.

4.3. The pattern of species composition

The main gradient of flora composition was determined by differences between species without preferences to pH, light and temperature conditions (right side of the PCA ordination diagram, Fig. 6) and species with defined preferences to these factors (left side, Fig. 6). However, the second gradient of flora differentiation was related to the successional stage (year of observation) and directly correlated with fertility gradient. Moreover, in the second year of observation more indicators of higher moisture were noted (Fig. 6). Among meadow species five were noted in both monitored years, i.e. *Rumex acetosa*, *Festuca rubra*, *Festuca arundinacea*, *Taraxacum officinale* and *Poa annua* (Fig. 6). In the first monitored year *Avenula pubescens*, *Dactylis glomerata*, *Deschampsia caespitosa*, *Plantago lanceolata*, *Trifolium dubium* and *Trifolium repens* were present. In the second observation these species were ab-

sent but *Lolium perenne*, *Poa trivialis* and *Vicia cracca* were observed.

5. Discussion

Reclamation and revegetation of fly-ash disposal sites is a serious world-wide problem (Haynes 2009). Fly-ash is produced in significant quantities (ca. 70-75% of coal combustion residues) as a result of combustion of coal for electric and thermal power generation (Pierzynski et al. 2004; Haynes 2009). The major coal combustion residues producing countries are USA, China, India and former Soviet Union countries (Asokan et al. 2005). In Poland ca. 90% of the energy is produced from coal (Filipiak 2013). There is estimated that ca. 400 milion tons of fly-ash is left in landfills (Szczygielski 2010). The ability of fly-ash deposits revegetation has been investigated in many countries over the world: in USA (Bilski et al. 2011), in India (Raj & Mohan 2008; Babu & Reddy 2011; Pandey et al. 2015), China (Chu 2008), Australia (Jusaitis & Pillman 1997) and Kosovo in Europe (Mustafa et al. 2012). Some of that research was focused on natural revegetation. The number of species naturally found on fly-ash landfill in our work was similar to that research i.e. 58 in India (Pandey et al. 2015), 125 in Kosovo (Mustafa et al. 2012) and 11 find in China (Chu 2008). Among them the most richest groups were characteristic for disturbed habitats and represented the *Artemisietea vulgaris* and *Stellarietea mediae* class of plant associations. The similar proportion of species representing syntaxonomical groups were noted in the experiment of flora dynamics on fly-ash substrate (Dyguś et al. 2014). However, under experimental conditions species typical of *Stellarietea mediae* class dominated (42%), followed by *Molinio-Arrhenatheretea* (21.7%) together with *Artemisietea vulgaris* (18.1%). The plant communities grouped in *Stellarietea mediae* and *Artemisietea vulgaris* class grow in extreme habitats, under heavy anthropogenic influence, especially on strong disturbed soils (Matuszkiewicz 2007). The group of species under interest, i.e. characteristic for meadow communities from *Molinio-Arrhenatheretea* class, was third in terms of abundance in the investigated area. Meadows develop in habitats under constant human pressure, which however, does not cause significant disturbance of the soil structure. The presence of meadow species in the ash landfill is related to their ability to capturing the pioneering microhabitats formed in the grasslands as result of grazing, moles *Talpa europaea* activities or damage during mowing. Most of the species in *Molinio-Arrhenatheretea* group belong to family *Poaceae*. Grasses are commonly found on industrial waste lands in Poland, in Silesia region (Rostański 2000), in Western Pomerania (Kowalski et al. 2005), in Kujawy (Piernik et al. 1996, 2015). Among grasses typical of *Molinio-Arrhenatheretea* class *Festuca arundinacea*, *Festuca rubra*, *Lolium perenne* and *Poa annua* were reported as well growing on fly-ash deposits (Kostuch & Twardy 2006; Pricop et al. 2011; Majtkowski & Majtkowska 2012; Bajor et al. 2014; Dyguś et al. 2014). These four species were noted as well in the investigated area. Most of the meadow species have undefined preferences to temperature and soil acidity, what proves their environmental plasticity. Especially plasticity to pH is interesting, because the fly-ash deposits pH is alkaline (about 9), which is related to the presence of alkali metal hydroxides (Rosik-Dulewska 2010). Soil humidity indicators indicate fresh to moist soils in the investigated site. The maximum water capacity of the fly-ash ranges from 65 to 124% but only 20% of the water is available for plants (Rosik-Dulewska 2010). The remaining part of the water is hygroscopic and hydration contained in the crystal structure and chemical bonds. However, the fly-ash landfill is regularly supported by new fly-ash and watered so water conditions for plants are not bad. The most diverse was the group of soil fertility indicators in the investigated site. There were indicators of low nitrogen content in the soil, indicators of soils moderately rich in nitrogen and indicators of soils rich and very rich in nitrogen. In general fly-ash deposits are characterised by low organic matter content and low nitrogen availability (Rosik-Dulewska 2010), but both organic carbon and nitrogen can increase during successional stages as consequence of organic matter deposition after each growing season. Following Raunkiaer, the dominant life forms among meadow species found in the fly-ash landfill included hemicryptophytes. It is the typical structure for this group. The similar structure of life forms was noted by Mustafa et al. (2012) in fly-ash deposits in Kosovo.

The observed pattern in species composition was determined by species without certain preferences to pH and temperature condition and by successional stage gradient. In the second year of observation more indicators of higher fertility and moisture were noted. Increase of fertility could be possibly due to organic matter decomposition within succession process, whereas increase in soil moisture is due to intensive watering of fly-ash landfill by power plant after 2013. In the period between 2008 and 2013 the landfill was not used and water condition for plant species could be worse. The water supply associated with hydraulic transport of ash, has large impact on the development of spontaneous vegetation in landfills **(**Kostuch & Twardy 2006). In the continuously disturbed area five meadow species were noted in both monitored years, i.e. mentioned above grasses *Festuca rubra*, *Festuca arundinacea*, *Poa annua* and *Rumex acetosa* and *Taraxacum officinale.* In the experimental study on flora dynamics on fly-ash substrate (Dyguś et al. 2014) *Poa annua*, *Rumex acetosa* and *Taraxacum officinale* were observed as self-sown species. *Festuca arundinacea* and *Festuca rubra* were cultivated

with great success (Antonkiewicz & Radkowski 2006; Bajor et al. 2014; Dyguś et al. 2014). These five species together could be also thought as successful in the natural succession on fly-ash deposits **(**Kostuch & Twardy 2006). In the later successional stage in 2015 among meadow species *Lolium perenne*, *Poa trivialis* and *Viccia cracca* were observed, as similar in the experimental study by Dyguś et al. (2014). These species could be also considered as successful in fly-ash revegetation.

Based on our results it could be concluded that meadow species as *Festuca arundinacea*, *Festuca rubra*, *Lolium perenne*, *Poa annua, Rumex acetosa* and *Taraxacum officinale, Poa trivialis* and *Viccia cracca* can be helpful in restoration of fly-ash landfills.

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