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Cover Photograph: Vegetation of the ash and slag dump No3 of Burshtyn Thermal Power Plant in the Ivano-Frankivsk region, Ukraine. Photograph © Uliana Semak.

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Vegetation Description and Functional Traits of Technogenic Ecotopes at a Thermal Power Plant in Western Ukraine

Uliana Semak [1,2*], Myroslava Mylen’ka[1], and Leonie K. Fischer[2]

Abstract - In thermal energy generation, the accumulation and storage of solid waste from coal combustion, such as ash and slag, are concerning issues for environmental protection. In order to develop measures to restore the ecological balance of such sites, it is essential to understand their ecological characteristics, including ongoing processes of vegetation succession, phytodiversity and plant functional traits. Therefore, the main objective of this study was the assessment of ash and slag dump vegetation using the example of a thermal power plant in Western Ukraine as a case study. The phytodiversity (e.g., species richness, floristic status, and degree of naturalization), morphological characteristics, reproductive strategy, pollination, dispersal features of plants, and Grime’s CSR strategy types of the vegetation were assessed and analyzed. Results indicate that 131 plant species were present at the study site, 80 of which were native, and mainly belonged to the three families *Asteraceae*, *Fabaceae*, and *Poaceae*. Pluriannual plants, mainly herbs, dominated the study site. Reproduction by seed and spore were the main reproductive strategies of the documented vegetation species set. Concerning dispersal, insect pollen vectors and zoochory were the most relevant strategies in the species set. The results therefore suggest that amongst various factors, ash and slag dumps sites are potential habitat for plant communities with diverse native species that include many competitive and ruderal plants. Hereby, plant-insect interactions may be key for the ecological restoration of these technogenic ecotopes. Our insights may support the development of restoration measures that help improve the ecological situation of ash and slag dumps.

Introduction

Thermal power plant (TPP) facilities exist in most regions of the world (Jones et al. 2016, Statista 2022) and severely impact the environment due to their emission of atmospheric pollutants and particulate matter, pollution of surrounding waters and soil, and occupation of large land areas for waste storage. Environmental problems of TPP facilities and their large-scale open ash and slag dumps have been demonstrated in numerous international studies (e.g., Cipranic et al. 2019 for Montenegro, Guttikunda and Jawahar 2014 for India, Mikic et al. 2014 for Serbia, Popescu et al. 2013 for Romania, Skoko et al. 2017 for Croatia, Strezov and Cho 2020 for Australia), for example, regarding the transformation or destruction of previous local ecosystems (Jones et al. 2016, Mylen′ka 2009) and their biodiversity (Nesplyak 2011, Pandey et al. 2014, Gajic et al. 2018). One way to decrease the environmental burdens of these dumps is the re-vegetation of the sites to reduce the development of dust and the subsequent dispersal of particulate matter by wind (Pandey et al. 2014, Gajic et al. 2018) through ecological restoration (Kollmann et al. 2016, Society for Ecological Restoration [SER] 2022). At a global scale, and for diverse ecosystems, ecological restoration is increasingly promoted by the current UN Decade on Ecosystem Restoration (United Nations [UN] 2022). Hereby, insight into less studied ecosystems and geographic regions is important to fill the toolbox for sustainable planning and practice in relation to nature conservation and wildlife management.

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[1]Department of Biology and Ecology, Vasyl Stefanyk Precarpathian National University, Halytska street 201, Ivano-Frankivsk 76008, Ukraine. Institute of Landscape planning and Ecology, Stuttgart University, Keplerstraße 11, 70174 Stuttgart, Germany. [*]Corresponding author: ulianasemak@gmail.com.

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Based on the key role of plants in ecosystems, ecological restoration often focuses on the reestablishment of vegetation. The starting point is typically an analysis of plant communities on the disturbed area (Alday et al. 2011, Holl 2002, Kirmer et al. 2008, Lei et al. 2016). The formation of vegetation on technogenic sites is often a result of spontaneous colonization by successive establishment of local species whose ecological requirements fit the local site conditions, and that may contribute to ecosystem restoration (Kirmer et al. 2008, Żołnierz et al. 2016). Insight about the characteristics of plant communities on disturbed land helps improve restoration measures in similar contexts regardless of geographic area, and support the development of specific methods for restoration of ecosystem stability (Gajic et al. 2018, Pandey et al. 2014).

Previous studies used categories of plant functional traits like morphological status, dispersal strategy, pollination features, and Grime’s strategies, to describe plant reproduction, survival, and competition strategies (Burda and Koniakin 2019, Di Musciano et al. 2018, Prévosto et al. 2011, Ramirez 2006). By using functional trait data of the specific vegetation on a disturbed site, information about the current structure and dynamics of the vegetation and its successional change can be provided (Tischew and Lorenz 2005). Analyzing functional trait data is important for the development of restoration measures, because functionally similar species share a higher probability of co-occurrence in plant communities (Zobel et al. 1998). In parallel, information about species richness and composition helps to understand future vegetation dynamics and succession (Prévosto et al. 2011). Insights on floristic status of plant communities are also useful, as they often link to changes in regional biodiversity or ecosystem functions (Burda and Koniakin 2019, Holl 2002, Paclibar and Tadiosa 2019).

Technogenic ecotopes like ash and slag dumps have been identified as suitable habitats for non-native species (Chu 2008). In this sense, introducing fast-growing non-native plants may help to rapidly re-establish vegetation (Holl 2002, Rai and Singh 2020) that can stabilize ash and slag dumps in instances where native species cannot cope with the environmental conditions (Ewel and Putz 2004, Kühn and Klotz 2006). However, due to some negative aspects of non-native species, including unregulated expansion or out-competition of native species, their development should be monitored to avoid homogenization of biota (Ren et al. 2008, Żołnierz et al. 2016). Other important features that facilitate the understanding of plant community condition on disturbed territories include morphological traits like lifespan and life forms. Herben et al. (2016), for example, observed highly significant associations between lifespan and disturbance level. Many previous studies have also found a large variety of life forms on technogenic sites (Alday et al. 2011, Gajic et al. 2018, Lei et al. 2016, Pandey et al. 2014, Tyler et al. 2021) that support a range of benefits for recultivation processes (Alday et al. 2014, Prévosto et al. 2011). For example, shrubs have been found to influence microclimatic conditions and assist in vegetation establishment as shading species (Alday et al. 2014). In addition to these traits, the reproductive strategy of species is a key aspect in plant selection for restoration measures, as anthropogenic disturbances often influence plant reproduction (Barret 2011). Pollination via insects, birds, or other animals is one such reproductive strategy. Plants have different levels of pollinator demand (Forup at al. 2008, Ceccon and Varassin 2014, Di Musciano et al. 2018, Kaiser-Bunbury et al. 2017), which is reflected in the degree of dependence on pollinating animals. This ranges from complete independence from pollinators to exclusive reliance on animal pollination (Clough et al. 2014, Tyler et al. 2021). Pollinators are particularly sensitive to anthropogenic disturbance (Bennett et al. 2020, Clough et al. 2014, Kaiser-Bunbury et al. 2017). Thus, they may be a limiting factor for vegetation establishment during colonization processes on large sites (Barret 2011), especially since their diversity is highly dependent on landscape context and conditions (Clough et al. 2014, Zou et. al 2017). Furthermore, dispersal traits could be an indicator of vegetation changes during succession (Latzel et al. 2011, Tischew and Lorenz 2005). Dispersal properties of plants like long-distance dispersal mechanisms (e.g., anemochorous and zoochorous species) are often associated with successful colonizers, whereas species with limited dispersal abilities are not as appropriate for the colonization of disturbed sites (Alday et al. 2011). Other studies on restoration have also included Grime’s strategies of plant species (Grime 1974) to determine stress and disturbance levels of a site (Prévosto et al. 2011, Żołnierz et al. 2016). Grime’s strategies reflect how species cope with competition, stress, and disturbance of a site and thus help identify which (successional) species can cope well with the conditions of a disturbed site during the process of vegetation establishment.

Although there is some insight into the revegetation of other highly disturbed, technogenic ecosystems, our knowledge about vegetation composition and plant functional traits of specifically ash and slag dump ecotopes is incomplete. It is necessary to address this knowledge gap to support the development of ecological restoration approaches for such sites. Therefore, this article presents the results of vegetation studies on ash and slag dumps at a power plant facility site in Western Ukraine. Because TPP have a leading role in energy production (ca. 30% of state energy before the war) and are distributed across 21 sites in Ukraine (Statista 2022, Government portal of Ukraine 2021, Flanders Investment & Trade [FIT] 2018), the environmental impact of thermal energy is highly relevant for these local landscapes. In addition to significant effects on the environment, TPP negatively impact human health in Ukraine, and are associated with an increased prevalence of respiratory and cardiovascular diseases and corresponding higher mortality rates (Myllyvirta and Gierens 2021). Our study took place on a dump site that is still used but will soon be filled completely. Our goal was to develop ecological restoration measures based on the site-specific vegetation characteristics before the imminent closure of the dump.

To describe the phytodiversity and vegetation characteristics of the studied ash and slag dump site, we address the following research questions:

1) What is the species richness and proportion of non-native species on the ash and slag dump?
2) What are the specific plant functional traits of the ash and slag dump, and how do they reflect species succession and disturbances of the site?
3) How do these vegetation features contribute to the restoration of the site?

Materials and Methods

Burshtyn Thermal Power Plant, the largest TPP in Western Ukraine with a capacity of 2400 MW (Mylen′ka 2009; Kovaliv 2013), serves as the case study site. Burshtyn TPP is located in the Halytskyi district of the Ivano-Frankivsk region, Ukraine (Figure 1a). It was built in the 1960s near Burshtyn city and became part of the city agglomeration. The city of Burshtyn, located in the immediate vicinity from the TPP (Figure 1b), is experiencing ecological changes: different land-use areas of the city are characterized by different levels of technogenic influence, with moderate pollution levels detected in residential and agricultural zones and high levels of ecosystem transformation at the industrial sites of Burshtyn TPP itself (Mylen’ka 2009).

Annually, Burshtyn TPP produces approximately 83,7265 tons of ash and 21,854 tons of slag (Center for Ecology and Development of New Technologies 2019). Burshytn TPP uses more than 200 ha of land for ash and slag dumps to store more than 28 million tons of waste. The ash and slag dumps of Burshtyn TPP are hydraulic engineering structures designed for the storage of solid waste from coal combustion. Their construction consists of a deep pit that is surrounded by enclosing dams. Trees were planted around the perimeter of the dump, and in all other areas the primary stages of natural succession have begun. Combustion products of TPPs often affect flora and fauna of the site and its surroundings, resulting in ecological imbalance (Mylen′ka 2009, Nesplyak 2011, Jones et al. 2016).

In this research, the study area is the 91 ha ash and slag dump site №3, which is used actively and located 5 km from Burshtyn TPP, covering a total of 91 ha (Figure 1c). The total storage capacity of ash and slag dump site №3 is 24,674 million m^3, and is currently filled

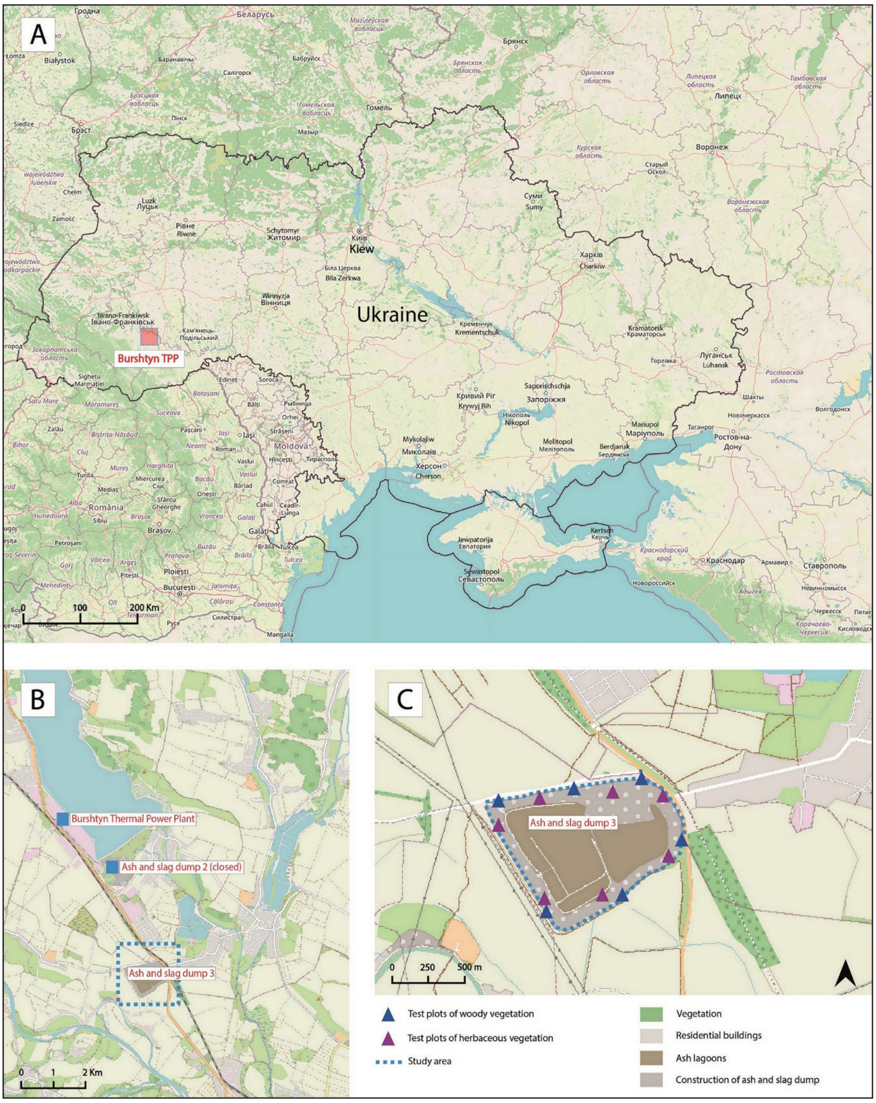

Figure 1. Location of (a) the Burshtyn Thermal Power Plant (TPP) in the Ivano-Frankivsk region, Ukraine, (b) the study area, the ash and slag dump №3 of Burshtyn Thermal Power Plant, and (c) the test plots. All maps were prepared with QGIS version 3.22.5, using OpenStreetMap data.

to 98.5 % of its capacity (Center for Ecology and Development of New Technologies 2019). The nearest residential building to the study site is in the village Slobidka Bolshivtsivska, approximately 140 m East of ash and slag dump №3.

Data collection

The vegetation of the study area was sampled from 2018–2020 during the vegetative period (i.e. May-October). All trial plots were investigated each year and species richness averaged across the years. In the study site, two different types of plant communities were assessed, that is (i) areas with predominantly herbaceous vegetation with scattered shrubs that grow in the inner part of the ash and slag dump, and (ii) areas that are dominated by trees that grow on the periphery of the ash and slag dump (Figure 2, top photo). For both areas, vegetation was sampled in strata: seven test plots with an area of 10×10 m² (herbaceous areas) and six plots of 20×20 m² (tree areas) were mapped (Yakubenko et al. 2019), resulting in a total of 13 trial plots. Since the vegetation cover in the experimental area was heterogeneous (Figure 2, bottom photo), the experimental plots were selected in representative places for the successional phases of herbaceous plant development. That is, plots were located in areas with more continuous, well-developed vegetation that captured the later stages of succession. As the aim of research was to describe plant composition in general, one overall vegetation list was compiled without any division according to plots. Coverage and abundance of species were not estimated.

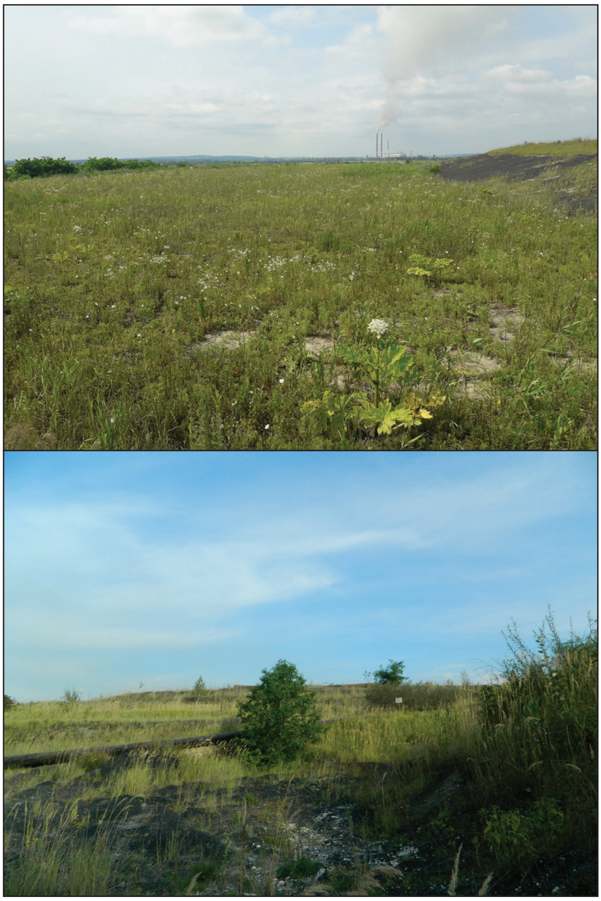

Figure 2. Vegetation of the ash and slag dump №3 of Burshtyn Thermal Power Plant in the Ivano-Frankivsk region, Ukraine. The top photo shows herbaceous plant communities on the surface of the closed part of the dump, the bottom photo shows the meager vegetation cover of herbs and grasses, interspersed with shrubs on the slope of the dump. Photo credits: Uliana Semak.

Data preparation and database

Floristic analysis was carried out based on the compiled vegetation list. Plants were identified in the field and with the help of collected herbarium material according to the current local field guide of the flora of Ukraine “The determinant of higher plants of Ukraine” (Dobrochaeva et al. 1999). To establish the corresponding trait database, species-specific information was collected from the “Datenbank biologisch-ökologischer Merkmale der Flora von Deutschland” (Biolflor) (Klotz et al. 2002), The LEDA Traitbase (Kleyer et al. 2008), World flora online (World Flora Online [WFO] 2022), and from two literary sources, namely “Ecoflora of Ukraine” (2010) and “Synanthropic flora of Ukraine and ways of its development” (Protopopova 1991). To address our research questions, we collected data on the main plant traits represented in the databases: floristic status and degree of species naturalization, life span and life form, life forms by Raunkiaer, reproduction type, pollen vector, dispersal types, and Grime’s CSR strategies (see Appendix for further details). For supporting information with the full vegetation list, see Supplemental File 1 (available online at https://eaglehill.us/URNAonline2/suppl-files/urna-217-semak-s1.pdf).

Results

Species richness and floristic status

A total of 131 floral species in 35 families and 110 genera were identified and catalogued at the study site (Table 1). The most common plant families were *Asteraceae* (30 species, 22.90 %), *Poaceae* (17 species, 12.98 %), and *Fabaceae* (10 species, 7.64 %). There were also many (8 species, 6.10 %) species belonging to *Brassicaceae*, and seven species (5.34%) to *Rosaceae*.

The species set of the study site included 80 native species (61.1 %), 37 archaeophytes (non-native species introduced before 1500 A.D.), and four neophytes (non-native species

Table 1. Systematic structure of the mapped vegetation. Other plant families included *Adoxaceae, Amaranthaceae, Betulaceae, Campanulaceae, Cornaceae, Elaeagnaceae, Equisetaceae, Geraniaceae, Juglandaceae, Lamiaceae, Malvaceae, Oxalidaceae, Papaveraceae, Pinaceae, Primulaceae, Ranunculaceae, Resedaceae, Rubiaceae, Sapindaceae, Scrophulariaceae, Urticaceae, Verbenaceae,* and *Violaceae.*

Plant family	Number of species	Number of genera
Asteraceae	30 (22.9 %)	26
Poaceae	17 (12.98 %)	14
Fabaceae	10 (7.64 %)	6
Brassicaceae	8 (6.10 %)	8
Rosaceae	7 (5.34 %)	6
Salicaceae	5 (3.82 %)	2
Caryophyllaceae	5 (3.82 %)	4
Plantaginaceae	4 (3.05 %)	3
Apiaceae	3 (2.29 %)	3
Boraginaceae	3 (2.29 %)	3
Onagraceae	3 (2.29 %)	2
Polygonaceae	3 (2.29 %)	3
Others	33 (22.31 %)	30
TOTAL	131	110

introduced after 1500 A.D.; Table 2). Within the set of non-native species, agriophytes (i.e., naturalized species that occur in natural or near-natural vegetation without further human intervention) dominated with 54.90 %, whereas 43.14 % of the non-native species were epecophytes (i.e., naturalized species that occur only in anthropogenic vegetation) and only one species had the status of an ephemerophyte (i.e., naturalized species that appear in small quantities irregularly and randomly and disappear without constant replenishment of seeds).

Table 2. Plant functional traits and distribution of species across the different categories. See Table A1 for trait definitions.

Functional traits	Categories of the trait state	Quantity of species	Percentage, %
Floristic status	Native	80	61.10 %
	Neophyte	13	9.91 %
	Archeophyte	38	29.00 %
Degree of naturalization	Agriophyte	25	49.02 %
	Epecophyte	25	49.02 %
	Ephemerophyte	1	1.96 %
Categories of life span	Annual	30	23.00 %
	Biennial	8	6.11 %
	Pluriennial	82	62.59 %
	Annual / Biennial	8	6.11 %
	Others (Annual / Pluriennial; Biennial / Pluriennial)	3	2.29 %
Categories of life forms	Tree	13	9.92 %
	Shrub	2	1.53 %
	Subshrub	2	1.53 %
	Herb	93	70.99 %
	Graminoid	16	12.21 %
	Shrub / Tree	4	3.06 %
	Shrub / Subshrub	1	0.76 %
Raunkiaer classification of life forms	Chamaephyte	2	1.53 %
	Geophyte	5	3.82 %
	Hemicryptophyte	56	42.75 %
	Makrophanerophyte	12	9.16 %
	Nanophanerophyte	4	3.05 %
	Pseudophanerophyte	1	0.76 %
	Therophyte	26	19.85 %
	Therophyte / Hemicryptophyte	14	10.69 %
	Others (Hemicryptophyte / Geophyte: Makrophanerophyte / Nanophanerophyte: Hemicryptophyte / Chamaephyte)	11	8.39 %

Table 2. Continued.

Functional traits	Categories of the trait state	Quantity of species	Percentage, %
Categories of reproduction type	By seed/by spore	73	55.73 %
	Mostly by seed, rarely vegetatively	14	10.69 %
	By seed and vegetatively	40	30.53 %
	Mostly vegetatively, rarely by seed	4	3.05 %
	Vegetatively	0	0 %
Categories of pollen vector	Insects	37	28.46 %
	Wind	26	20.00 %
	Self-pollination	6	4.58 %
	Wind / selfing	6	4.58 %
	Selfing / insects	49	37.4 %
	Wind / insects	4	3.05 %
	Wind / insects / selfing	3	2.29 %
Categories of dispersal type	Autochory	16	12.21 %
	Anemochory	12	9.16 %
	Zoochory	45	34.35 %
	Autochory / Zoochory	19	14.50 %
	Anthropochory / Zoochory	2	1.53 %
	Autochory / Anthropochory	4	3.05 %
	Anemochory / Anthropochory	7	5.34 %
	Anemochory / Autohory	7	5.34 %
	Anemochory / Zoochory	12	9.16 %
	Hydrochory / Zoochory	4	3.05 %
	Hydrochory	1	0.76 %
	Autochory / Anemochory / Anthropochory	1	0.76 %
	Epizoochory / Hydrochory / Anthropochory	1	0.76 %
Categories of ecological strategy type	C (competitors)	50	38.18 %
	CR (competitors/ruderals)	36	27.48 %
	CS (competitors/stress-tolerators)	10	7.63 %
	CSR (competitors/stress-tolerators/ruderals)	23	17.56 %
	R (ruderals)	10	7.63 %
	S (stress-tolerators)	1	0.76 %
	Sr (stress-tolerators/ruderals)	1	0.76 %

Functional traits of the plant communities

In the set of surveyed species, herbs dominated, comprising 93 species (83.21 %) of the 131 total species; 12.21 % (16 species) were graminoids (Table 2). Thirteen were woody species, and shrub and subshrub species each accounted for two species. The mixed categories shrub-tree and shrub-subshrub species together accounted for five species.

Concerning life span, pluriannual species dominated, comprising 62.59 % (82 species) of catalogued species, whereas only 6.11 % were biennials (eight species), and 23 % were annuals (30 species). There were also intermediate categories including annual-biennial, annual-pluriannial, and biennial-pluriannial that together accounted for 11 species in total. The analysis of Raunkiaer classifications of life forms for our species set showed that hemicryptophytes dominated the floral community (42.75 %, 56 species), followed by therophytes (19.85 %, 26 species). Macrophanerophytes accounted for 9.16 % (12 species), and therophytes-hemicryptophytes made up 10.69 % of all species (14 species).

Most of the species in the study area reproduce by seed and spore (55.73 %, 73 species), followed by species that use mixed reproductive strategies – reproducing by seed and vegetatively (30.53 %, 40 species). The category “mostly vegetatively, rarely by seed” includes four species (3.05 %) in the study area. No species were detected that only reproduce vegetatively.

In regard to pollination vectors of the surveyed species, 80 species (61.07 %) are either insect-pollinated or self-pollinating, of which 37 species (28.46 %) are exclusively pollinated by insects and 26 species (20.00 %) are pollinated by wind only. Approximately 69 species (52.67 %) have one way to pollinate, whereas 62 species (47.32 %) have two or more pollen vectors. Other types of pollination are far less common in the surveyed species.

There are 74 species (56.49 %) that belong to only one category of dispersal, 55 species (41.98 %) that have two dispersal modes, and two species (1.53 %) that have more than two dispersal modes. Hereby, zoochory was detected as the most important dispersal attribute on the investigated site. There were 83 species (63.36 %) that can be dispersed by zoochory: 45 (34.35 %) that are only spread by zoochory and 38 (29 %) having multiple dispersal vectors including zoochory. In the study area, 9.16 % of the species are dispersed by anemochory, and seven additional species are in the category of anemo-anthropochory and anemo-autochory (5.34 % for both categories). Sixteen species (12.21 %) disperse by means of autochory. Only one species displayed the hydrochory dispersal type, but there were five (3.82 %) additional species that have multiple dispersal vectors including hydrochory.

Our analysis of strategy types according to Grime’s CSR classification showed that plants of the C (competitors) and CR (competitors/ruderals) categories dominated the studied ash and slag dump site, comprising 38.18 % (50 species) and 27.48 % (36 species) of species, respectively. A smaller percentage of the floral species belonged to the CS category (competitors/stress-tolerators) and the R category (ruderals). Species of the SR category (stress-tolerators/ruderals) and the S category (stress-tolerators) were rare in the ash and slag dump, with percentages in these categories lower than 1.00 %.

Discussion

In this case study, the plant community of an ash and slag dump of a TPP was analyzed with regard to species richness, floristic status, morphological and reproductive characteristics, and Grime’s strategy. A total of 131 species were detected, of which the majority were native species, pluriannual herbs, and species reproducing mainly by seed and spore with insect pollen vector and zoochory as their main dispersal mechanisms.

The species richness of the ash and slag dump was mainly represented by three large floral families (i.e., *Asteraceae*, *Fabaceae,* and *Poaceae*). This finding is supported by other studies that focused on similar vegetation types in other geographic contexts such as coal waste sites in Spain (Alday et al. 2014), ash dumps in Kosovo (Mustafa et al. 2012), fly ash deposits mine wastes in Serbia (Gajic et al. 2018), and ash deposits in India (Pandey et al. 2014). The surrounding vegetation and regional biodiversity of an area has a large influence on the developing plant diversity of disturbed sites (Kirmer et al. 2008, Żołnierz et al. 2016). However, even if a large species pool exists in the closely surrounding area, species that colonize disturbed areas need to be adapted to the specific habitat conditions of the disturbed site (Zobel et al. 1998). Hereby, so-called "environmental filters" that consist of a hierarchical series of environmental factors, restrict species richness to those capable of passing the filters, meaning they fit the requirements of the site (Aronson et al. 2016). In ash and slag dumps, environmental filters can include the extreme abiotic conditions and species competition (Alday et al. 2011, Hobbs 2008, Żołnierz et al. 2016). In this regard, it is of note that our results included many plants in the family *Fabaceae*, as species within this family often perform bacteria-mediated nitrogen fixation, thereby supporting the establishment of other species via the increased amount of available nitrogen (Gajic et al. 2018, Lei et al. 2016). Thus, species of the *Fabaceae* family are highly promising for revegetation in accordance with their abilities of improving the nutritional properties of soils.

Our analysis of the floristic status highlighted the dominance of native species on the studied site. This clear predominance of native species was a surprising result, as previous studies (e.g., Hobbs 2008, Holl 2002, Paclibar and Tadiosa 2019) have found non-native plants typically dominate highly disturbed ecosystems. However, because species coverage was not examined in the research at hand, it is possible that very few dominant species may have covered a large proportion of the study site. At mine waste sites, however, common native species were shown to increase over time (Alday et al. 2011), and established native species communities on disturbed sites due to natural vegetation regeneration and the influence of surrounding ecosystems on vegetation development (Gajic et al. 2018, Kirmer et al. 2008). Therefore, we recommend that developing phytoremediation measures should include native flora and take into account the abundance of already existing native species. Additionally, their potential coverage during later successional phases should also be considered.

Regarding life span and life forms (including Raunkiaer life forms classification), we determined that pluriennial herbs and hemicryptophytes dominated the disturbed ecosystem. The variety of plants that belong to different life forms on ash and slag dumps and mining sites has been recognized in previous studies in other contexts (Alday et al. 2011, Gajic et al. 2018, Lei et al. 2016, Żołnierz et al. 2016). In our study area, pluriennial herbs dominated, but a considerable amount of the vegetation were woody species, suggesting that most of the investigated vegetation is no longer in an early pioneering stage. This connects to the general setting within the study area, where the inner part of the ash and slag dump is dominated by herbaceous vegetation and the outer part by woody vegetation. How these successional phases intersect in relation to the time of vegetation establishment and its development phases would be of interest for future research.

Reproductive pathways by seed and spore were the most common for the vegetation in our study site and are typical for early successional stages (Ramirez 2006), whereas the role of vegetative reproduction on the investigated sites was minor. In contrast, plant-insect interactions played a key role for pollination and dispersion at our study site. These results are in line with restoration studies conducted in other biomes like Mediterranean high mountain sites (Di Musciano et al. 2018) and the tropical evergreen forests of the

Mahé island (Kaiser-Bunbury et al. 2017). Our results suggest that plant composition also depends on insects as pollinators, and that wind and self-pollination (or wind and self-pollination in combination with other pollen vectors) are also common reproductive mechanisms for numerous plants. Usually, in more complex plant communities, there are less favorable conditions for wind pollination because of the tree canopy in forests, for example (Prévosto et al. 2011). However, self-pollination is typical for extreme and isolated environments, often being the only possibility for propagation (Barret 2011, Di Musciano et al. 2018). As succession progresses, the tendencies for wind and self-pollination likely decrease (Di Musciano et al. 2018, Prévosto et al. 2011). As zoochory is the most common type of dispersal for this site, plant communities were likely supported by animals, which are frequent and efficient vectors of dispersal in disturbed or restored sites (Kirmer et al. 2008, Tischew and Lorenz 2005, Vitozz and Engler 2007). There is evidence that zoochory is a typical strategy for the dispersal of diaspores in disturbed habitats such as ash and slag dumps (Willson and Whelan 1990), but effectiveness of zoochory largely depends on the disperser's behavior (Vitozz and Engler 2007) and may play a minor role in the dispersal of seeds on disturbed sites (Di Musciano et al. 2018). Surprisingly, although this site is the result of human activity, anthropochory played very little role in the observed community. This may be due to the large size of the area itself, where current human influence might only play a role at the border areas near other land uses, and the low number of people that may enter the site at all.

The Grime's CSR analysis suggests that the ecosystem already has resilient features with only low levels of stress and disturbance. This is evidenced by the predominance of competitor strategy types (C and CR). This indicates that the conditions are currently characterized by low and possibly decreasing level of stress and disturbance (Grime 1974). A predominance of C-strategists on post-mining sites was also shown by Zołnierz et al. (2016), and observed after land abandonment by Prévosto and colleagues (2011).

Ash and slag dumps seem favorable for the settlement of both common species and some species from the native species pool that are of interest for the restoration of such sites; in all, a formation of novel plant communities can be assumed. The plant functional traits of the species set thereby suggest that the vegetation of the study site is not at a pioneering stage, but rather has more complex features of a mature plant community. Thus, the development of plant communities with a high level of species diversity might benefit from new approaches to restore ecosystem balance at local and regional levels, and over longer periods to counteract the environmental challenges of TPP. The results of this study provide valuable insight for the development of practical recommendations for the restoration of plant cover on TPP ash and slag dumps.

Conclusion

Based on the analysis of the site's vegetation, an important feature of the current floral community was the dominance of native species, which reflects the prospect of their further use for restoration and may ultimately help avoid the use of non-native species. Such approaches will lead to developing plant communities closer to a near-natural, local vegetation composition. In this regard, the results of the morphological analysis suggest that both pluriennial species and woody plants may be used, depending on the specific goals, to restore the vegetation cover in the study area. Additionally, the dependence on zoochory and plant-insect interactions is highly relevant for connecting such restoration sites with their greater surroundings, and in turn supports faunal diversity in the restoration area and its neighboring landscapes.

In sum, in line with the international endeavor to restore ecosystems and thereby also including highly anthropogenic sites (UN 2022), the results of the study will directly help develop ecological restoration approaches for the specific areas of ash and slag dumps that are of environmental concern globally. The resultant knowledge on the site’s vegetation composition and traits can already serve as a unique basis to the further development of restoration measures that help improve the ecological situation on this type of disturbed land.

Author Contributions

Uliana Semak designed the methodology, Uliana Semak and Leonie Fischer explored the data, Uliana Semak led the writing of the manuscript, Myroslava Mylen’ka and Leonie Fischer revised the manuscript.

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Appendix 1. Plant functional traits considered in the study, along with references of sources and the trait states.

Functional Traits	Trait States	Definition of trait states	Information sources
Floristic status	Native	Native taxon.	BiolFlor (Klotz et al. 2002); Synanthropic flora of Ukraine and ways of its development (Protopopova, 1991)
	Archeophyte	Non-native taxon to a geographical region, immigrated before 1500 BC.	
	Neophyte	non-native taxon to a geographical region, immigrated after 1500 BC.	
Degree of species naturalization	Agriophyte	Naturalized species that have invaded natural or near-natural vegetation and can survive there without human intervention.	BiolFlor (Klotz et al. 2002); Synanthropic flora of Ukraine and ways of its development (Protopopova, 1991)
	Epecophyte	Naturalized species occuring only in anthropogenic vegetation	
	Ephemerophyte	Naturalized species that appear in small quantities irregularly and randomly and disappear without constant replenishment of seeds	
Life spans	Annual	The individual cycle lasts for a maximum of one year.	BiolFlor (Klotz et al. 2002); Synanthropic flora of Ukraine and ways of its development (Protopopova, 1991); Ecoflora of Ukraine (2010)
	Biannual	The plant grows for approx. one year vegetatively before reaching the generative phase after which it completes its life cycle.	
	Pluriannual	The plant grows longer than one year.	
Life forms	Herb	Herbaceous plant without a woody stem in which all aerial parts (i.e. above ground) die back to the ground at the end of each growing season.	BiolFlor (Klotz et al. 2002); Ecoflora of Ukraine (2010); Synanthropic flora of Ukraine and ways of its development (Protopopova, 1991)
	Shrub	Deciduous or evergreen small-to-medium-sized perennial woody plant.	
	Tree	Perennial plant with an elongated stem, or trunk, usually supporting branches and leaves.	

Appendix 1. Continued

Functional Traits	Trait States	Definition of trait states	Information sources
Life forms by Raunkiaer (1934, 1937)	Chamaephyte	Resting buds are situated on herbaceous or only slightly lignified shoots some centimeters above the soil surface protected by parts of the plant itself and/or by a snow cover.	BiolFlor (Klotz et al. 2002); Ecoflora of Ukraine (2010)
	Geophyte	Resting buds are subterranean, often on storing organs protected within the soil.	
	Hemicryptophyte	Resting buds are situated on herbaceous shoots close to the soil surface, protected by foliage or dead leaves.	
	Makrophanerophyte	Resting buds are situated on woody shoots. The medial and apical ramifications of a woody trunk form a crown.	
	Nanophanerophyte	Resting buds are situated on woody shoots, which form a stemless shoot system with strong basal ramification.	
	Pseudophanerophyte	Resting buds are on this year’s shoots forming an aboveground, stemless, strongly ramified but only slightly lignified shoot system.	
	Therophyte	Summer annuals, which can only reproduce by means of generative diaspores.	
Reproduction type	By seed/by spore	Reproduction by seed/by spore.	BiolFlor (Klotz et al. 2002); Ecoflora of Ukraine (2010)
	By seed and vegetatively	Reproduction by seed and vegetatively.	
	Mostly by seed, rarely vegetatively	Reproduction mostly by seed, rarely vegetatively.	
	Mostly vegetatively, rarely by seed	Reproduction mostly vegetatively, rarely by seed.	
	Vegetatively	Vegetative way of reproduction.	

Appendix 1. Continued

Functional Traits	Trait States	Definition of trait states	Information sources
Pollen vector	Insects	Pollination by insects.	BiolFlor (Klotz et al. 2002); Ecoflora of Ukraine (2010)
	Selfing	Spontaneous pollination within a flower. In category “selfing” there are such pollination types: pk (pseudocleistogamy) – selfing in unopened flower; kl (cleistogamy) – selfing in unopened, rudimentary flower; ge (geitonogamy) – selfing by a neighbouring flower.	
	Wind	Pollination by wind.	