Forest restoration on the former industrial land of Sulphur quarry in the Ukrainian Roztochya

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Abstract

This paper adds to the evidence base in the discussion to what extent woodland development can be a means to restoring the land affected by mining. We investigate the formation of vegetation communities in sites on a former Sulphur quarry in the Roztochya district of the Lviv region in Ukraine to answer the research questions: How can the formation of vegetation cover affect the disturbed sites and what knowledge can be used in restoration practices elsewhere? We perform an experiment examining which types of vegetation are suitable for the restoration. We explore the influence of restored vegetation and re-emerged woodlands have on the process of soil rehabilitation and the increasing organic substance in it. We examine the impact of various combinations of vegetation on land rehabilitation. Explaining the degree of colonization of waste land by various types of vegetation helps us to reveal the trends of regenerative processes and identify the most promising for restoration tree species in affiliation with the ground vegetation. The results can assist decision-makers in choosing compatibility alliances of vegetation to sustain regeneration processes. Although this research is location specific, the knowledge developed can to a degree be applied to similar places, in the temperate zone.

Keywords

Land restoration; Afforestation; Vegetation composition; Trees communites; Species richness

Contents

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1 Introduction

The intensification of mineral extraction in the Western part of Ukraine in the early to middle half of the twentieth century and the increasing activities of mining companies more recently, have contributed to the extension of degraded land and the deterioration of the local environment. Land degradation has a wider scope than soil erosion and soil degradation. It affects the capacity of the ecosystem to provide goods and services (FAO 2018). Despite Sulphur mining practices in the district of Roztochya ended in the late 1990s, the preceding activities have had a significant impact on the land, which is currently under restoration. Land restoration is the process of ecological restoration to a natural landscape and habitat (Chabay et al. 2015), with ecological restoration assisting in the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Rehabilitation is required when the land is degraded to such an extent that it has become practically unproductive (FAO 2018).

The restoration of former mining land is important for many countries, including the USA, where afforestation, and environmental remediation of duster areas are considered crucial (Zalesny et al. 2014; Torbert et al. 1990, 2000; Casselman et al. 2007; Rodrigue et al. 2004). In the UK, Mine Site Reclamation is governed by public authorities and recovering of degraded land is an intent of environmental policy (DEFRA 2004; Cooke and Limpitlaw 2003; Sloss 2013). This also concerns the establishment of multifunctional forests on public land (Nijnik et al. 2016). In Canada, the policy framework for Mine Closure and Management of Long-Term Liabilities is jointly deliberated with aboriginal peoples on whose land the mines are partly located (Cowan et al. 2010; NRC 2011). In Germany, the practice of mine land reclamation *(i.e.* restore to productivity or use of lands that have been previously degraded by human activities or impaired by natural phenomena, OECD 2001) is under review, with the goal to better protect water catchment areas of large rivers (Elmer et al. 2013). In South Africa, the reclamation of former mining land is considered alongside the deactivation of polluted territories (Limpitlaw et al. 2005). Given that the reclamation of former mining sites is important for many countries, it is also included in the agenda of international organizations, such as the World Bank (2002).

In addition, the concept of a 'land degradation neutral world' has emerged. In 2015, world leaders adopted the 2030 United Nations Agenda for Sustainable Development (SD), which includes a set of SD goals and associated targets needed to restore a balance between humans and their environment. Goal 15, which calls to 'protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss' is particularly relevant to our research. Accepting the target of moving towards a 'land degradation-neutral world', many countries strive to achieve a balance between degradation processes and restoration activities (Montanarella 2016).

Numerous scientific publications are devoted to the assessment of land degradation. However, not enough information is fully available on the best practices for restoration, while the adoption of the SD goal, regarding land degradation neutrality, would require an in-depth analysis of such practices (Montanarella 2016). Furthermore, the best practices for land restoration (e.g. from Iceland, Czech Republic and Australia) are linked to the ecological restoration of ecosystems. Thus, they also contribute to the Aichi Target 15 of the Convention for Biological Diversity (CBD 2010), which aims to restore at least 15% of degraded ecosystems by the year of 2020.

Recent scientific papers have recorded ecological restoration experiences, including those from the mining sites in Central Europe (Prach et al. 2011). Landscape ecology studies have shown cultural landscape transformations (Palang and Fry 2003), examining the colonization of former quarries by ground vegetation (Kucheryavy et al. 2006) and analysing ecosystem regeneration processes in the Roztochya district; most notably where the enlargement of wooded cover is considered to be a decisive measure for the restoration of natural environment (Gensiruk 2002; Kopiy et al. 2006a, b).

As hydrology affects the water catchment on a much larger territory, the neutralisation of polluted localities, and sustaining the water balance and water purification on reclaimed, former industrial sites have come on the research agenda. Land reclamation and ecosystem restoration processes (Nazarovec 2013; Popa 2010; Manohina 2003) through woodland development (which are complex and almost always lengthy) are capable of delivering extensive benefits (e.g. water regulatory) while conserving and enhancing natural assets.

Expertise in restoration research, including in Ukraine has grown. However, restoration knowledge and capacity will need to develop further and be shared (e.g. between countries and research schools) if the full potential of restoration is to be achieved. Restoration knowledge concerning the most effective liaison between ground vegetation and planted, and self-seeded trees plantation also needs to be advanced. Innovative ideas and mechanisms that can facilitate and enhance restoration and are effective for both people and the environment are needed to be developed. In addition, promoting restoration’s contribution to advances in green infrastructure to a specific locality is also needed.

Therefore, in this study, we investigate the formation of different types of vegetation communities on degraded sites and their role in the restoration process of devastated lands in the Ukrainian Roztochya district. We explore the influence that restored ground vegetation and re-emerged and planted woodlands has on soil rehabilitation particularly towards the increasing organic substance in the soil. We also consider the impact from various combinations of vegetation on the process of land reclamation and investigate species compatibility. We believe that this paper adds to the existing evidence base in the discussion surrounding to what extent afforestation and/or natural regeneration can be considered as an effective means to restore land affected by mining, and what knowledge developed from the treatment of rock disposal dumps and surrounding land on this Sulphur mine in Ukraine can be used in restoration practices elsewhere.

The case study area will be introduced, consisting of 12 experimental sites. Next, we will present the methodology and discuss the characterisation of the different types of vegetation that are most productive given the natural conditions of each of the case study sites. The variety of ground vegetation associated with the types of trees, and their combination within groups will then be considered. The key results of our investigation will then be presented, reflecting on the most suitable vegetation for this specific locality and their compatibility for all key plant species. The results are important for forestry-based decisions as these can assist decision-makers with the delivery of the most effective land reclamation/restoration outcomes. Lastly, a brief discussion and concluding remarks from the investigation follow.

2 The case study area

The case study area is in the western part of Ukraine, in the Lviv administrative region ('oblast') of the Roztochya district, extending from the eastern border with Poland to the city of Lviv. The area comprises hills (stretching over 40 km), with the elevation rising between 100-120m and 400m, separating the Malopolissia lowland and the Nadsanska Valley. The district of Roztochya includes the land of Nadsanska Valley and the territory of the former Yavoriv Sulphur quarry. The system of ridges and slumps, which passes near the town of Yavoriv with lower heights, is affecting the vegetation composition, its productivity and distribution. The climate in the Roztochya district is moderately humid with features typical of a transition from the wet Atlantic type to the Continental type. Annual precipitation reaches 650-700mm and the average annual temperature is +7.4°C, with the growing season of roughly 210 days. Late spring frosts, that occur almost every year, cause a sizeable damage both to ground vegetation and forest.

The other part of the Nadsanska Valley, that was not previously under the Sulphur mine, is characterized by well-developed floodplains of rivers and passable valleys. It is much lower, compared to the Roztochya district itself, and is predominantly between elevations of 250-260m. The terrain is flat and gently rolling. The valleys of rivers are marshy. The soil is dominated by different subtypes of the soddy podzolic category. The highest points of the watershed contain light-grey and podzolized soils. In the areas of former Sulphur mining, the soil is represented by various forest-steppe types: light grey, grey and dark grey, as well as podzolized black.

In the Yavoriv quarry, Sulphur was extracted from the surface as well as the underground level, i.e. by smelting minerals with hot steam. Both practices have led to the disruption of land, deterioration of local landscapes, and spoiling of the soil and ground vegetation. The vegetation in the study area is now very sensitive to environmental conditions, the microclimate, soil texture as well as the chemical characteristics of the soil. Industrial extraction of Sulphur has now ceased, but as a result of the former mining, the area has become degraded, with rock disposal dumps and disturbed soil, the spread of erosion has shattered the land and disarrayed hydrological conditions in the area. Moreover, the environmental situation has had serious effects on agricultural production in the Roztochya district (Figure 1).

The district's intensive agriculture (the share of agricultural land comprises 57.9% of the total land) multiplied by its complex terrain and unstable soils, has contributed to the escalation of soil erosion. The share of wooded cover is barely reaching 16.8%, which is much lower than what is required for land in such an ecological condition (Gensiruk 2002). The lack of forests has resulted in a decrease of soil protection and water regulation forest functions, adversely affecting the water supply from the tributaries of Dniester and Vistula, the largest rivers of the Black Sea and the Baltic Sea watersheds.

The previous vegetation cover, before mining, can indicate direction of the succession process. Because of the quarry closure, ground vegetation has gradually re-emerged and woodland succession and small plots with planted forest, have now become visible (Figure 2). Predominant tree species in the district have been pine (*Pinus sylvestris*) (Gensiruk 2002) on sites mixed with oak (*Quercus robur*) and birch (*Betula pendula*).

Figure 1. The Nadsanska Valley with devastated, highly eroded land, and a lake on the site of the former Sulphur quarry.

Figure 2. A re-emerged woodland succession and plots of planted forest in Roztochya: mixed pine and oak (upper left), mixed pine and birch (upper right), and pine monoculture (down), growing on the formerly devastated land.

3 Methodology

To assess vegetation formation on the destructed soil and degraded land of the former industrial estate of the Yavoriv Sulphur quarry (*i.e.* rock disposal dumps and the surrounding area) we identified and laid out 12 distinctive experimental sites (PYa 1-12) (Table 1).

Table 1. Description of the 12 experimental sites under investigation PYa* 1-12.

Site	Description of experimental sites
PYa 1	Reclaimed land with a minimum amount of vegetation on the territory of the former underground mining of Sulphur No1.
PYa 2	Reclaimed land with clumps of birch (*Betula pendula*) trees on the territory of the former underground mining of Sulphur No1.
PYa 3	Birch (*Betula pendula*) - pine (*Pinus sylvestris*) clumps on the territory of the former underground mining of Sulphur No1.
PYa 4	Pine (*Pinus sylvestris*) plantation on the territory of the former underground mining of Sulphur No1.
PYa 5	A meadow on the territory of the former underground mining of Sulphur No1.
PYa 6	Non-reclaimed land on the territory of the former underground mining of Sulphur No 2.
PYa 7	A meadow on the territory of the former underground mining of Sulphur No 2.
PYa 8	Pine (*Pinus sylvestris*) plantation on the territory of the former underground mining of Sulphur No 2.
PYa 9	Birch (*Betula pendula*) clump on the dump in close vicinity to the dam.
PYa10	Pine (*Pinus sylvestris*) clump on the dump in close vicinity to the dam.
PYa11	A bed of rushes on the dump in close vicinity to the dam.
PYa12	Control site of maturing oak (*Quercus robur*) - pine (*Pinus sylvestris*) stands, in close vicinity to the former quarry.

*PYa stands for 'plot in Yavoriv' with an experimental site number that follows

The sites are spread out featuring different degrees of lightness, moisture, types of soil, ground vegetation, spread of soil erosion, and levels of degradation-rehabilitation. The distance between the sites varies. Groups of sites are located at a distance from 2.5 km to 8.5 km. Within the groups, the distance between individual sites is around 25-50 m. Such spatial distribution of the experimental sites allows us to explore various natural conditions, types of soil and the levels of soil destruction, as well as a variety of growing species and a varying intensity of vegetation (Figure 3).

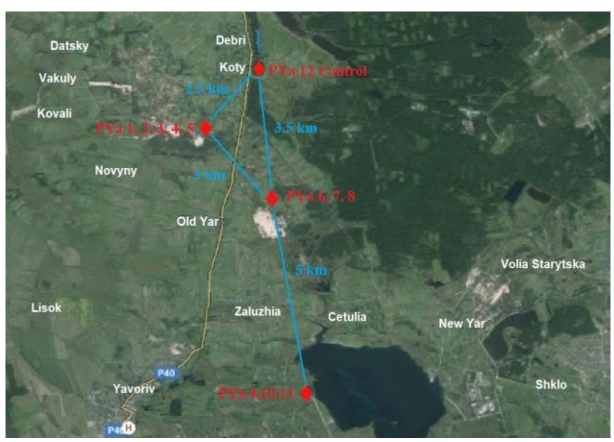

Figure 3. Spatial distribution of the experimental sites (PYa 1-12) on the land of the former Yavoriv Sulphur quarry.

First, it was important to identify taxonomic indexes of the vegetation species on the territory under investigation, and their characteristics with respect to light, moisture and soil richness. It was also important to consider which species of trees and plants are likely most suitable for planting, growing and spreading together on the same site.

The taxonomic analysis of the vegetation cover was carried out according to the Takhtajan system (Takhtajan 1980; Yakubenko and Churilov 2015). The tree species of pine (*Pinus sylvestris*), birch (*Betula pendula*), and oak (*Quercus robur*), and their varying combinations were considered. We tested theoretical assumptions through practical trials, by performing a restoration experiment on the sites with emerging and growing vegetation and examined which types of ground vegetation and tree species, according to their natural characteristics and compatibility, are most suitable in this locality for enhancing the process of land rehabilitation.

4 Results

In total, 86 vascular and non-vascular plant species of 32 families and 5 divisions of ground vegetation were identified in our experimental sites.

4.1 Ground vegetation family diversity

The most abundant families recorded were the rose family (*Rosacea*), legumes (*Fabaceae*), sunflower (*Asteraceae*), grass (*Poaceae*), rush (*Juncaceae*), and equisetaceous (*Equisetaceae*). The least common were ditrichaceous (*Ditrichacea*), club-moss (*Lycopodiaceae*), shield ferns (*Dryopteris*), pink family (*Caryophyllacea*), cabbages (*Brassicacea*), mezereon (*Thymelaceae*), honeysuckle (*Caprifoliaceae*), and marren family (*Rubiaceae*) (Table 2).

The largest number of plant families from the division of bryophytes (mosslike) (*Bryophyta*), lycopsids (*Licorpodiophyta*), articulates (*Equisetophyta*), and fernlike plants (*Polypodiophyta*) was recorded on the site of PYa 5. The largest family diversity was observed on the control site PYa 12 (18 families), with the PYa 5 meadow having 15 families; PYa 6 – a non-reclaimed area (14); PYa 3 – birch-pine clumps (12); PYa 8 – pine plantation (11), and PYa 4 – pine plantation (10 families). The smallest numbers of plant families were recorded on PYa 2 - a reclaimed area with clumps of birch trees (6 families); PYa 10 - pine clumps (6 families), and PYa 11 - bed of rushes (5 families) (Figure 4).

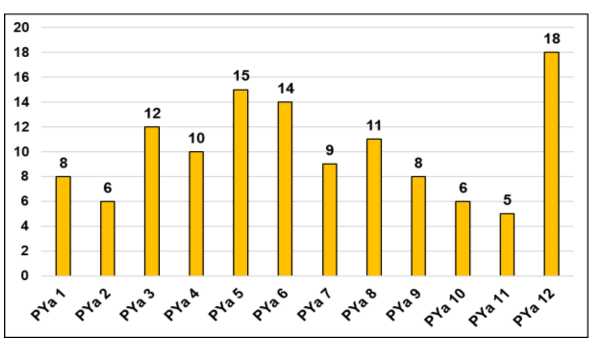

Figure 4. The distribution of ground vegetation families on the sites PYa 1-12 on the land of the former Yavoriv Sulphur quarry.

Table 2. Ground vegetation distribution throughout the experimental sites PYa 1-12.

Plant families	Experimental sites											
	PYa1	**PYa2**	**PYa3**	**PYa4**	**PYa5**	**PYa6**	**PYa7**	**PYa8**	**PYa9**	**PYa10**	**PYa11**	**PYa12**
					Bryophyta							
Aloe moss *Polytrichaceae*			+		+	+	+					
Ditrichaceae						+						
Entodontaceae			+		+			+				+
					Equisetophyta							
Club-moss *Lycopodiaceae*					+							
Horsetail *Equisetaceae*	+		+		+	+		+	+	+		
					Polypodiophyta							
Unshieldferns *Athypiaceae*					+			+				+
Shieldferns *Aspidiaceae*			+		+							
					Magnoliophyta							
Rosa *Rosaceae*	+	+	+	+	+	+	+	+	+	+	+	+
Buttercup *Ranunculaceae*				+								+
Pink *Caryophyllacea*						+						
Buckwheat *Polyconaceae*				+	+	+	+	+				
St. John-wort *Hypericaceae*		+	+		+	+						
Cabbages *Brassicaceae*				+								
Heather *Ericaceae*			+			+						
Primrose *Primulaceae*						+		+				
Mezereon *Thymelaceae*												+
Legumes *Fabaceae*	+	+	+	+		+	+	+	+	+	+	+
Evening Primrose *Onagraceae*					+					+		
Geranium Geraniaceae					+							+
Balm family *Balsaminaceae*								+				+
Umbrellas *Apiaceae*	+	+						+	+		+	+
Honeysuckle *Capricoliaceae*												+
Marren *Rubiaceae*												+
Borage *Boraginaceae*									+			
Figwort *Scrophulariaceae*				+			+					+
Plantain *Plantaginaceae*	+			+			+		+			+
Mint *Lamiaceae*								+				+
Sunflower *Asteraceae*	+	+	+	+	+	+	+	+	+	+	+	+
Convivial *Convallariaceae*												+
Rush *Juncaceae*	+		+	+	+	+	+					+
Sedges *Cyperaceae*			+		+	+						
Grass Poaceae	+	+	+	+	+	+	+		+	+	+	+
Total:	**8**	**6**	**12**	**10**	**15**	**14**	**9**	**11**	**8**	**6**	**5**	**18**

4.2 Plant species diversity

As to identified plant species, *Juncus effusus* L. (*i.e.* a forage species, mesotroph, and hygrophyte) had the highest occurrence rate (66.6%) in the study area. They are the main indicator of a soil high in moisture and can cohabit fairly on land of the planted pine. The photophilous plant species, such as *Holcus lanatus* L. - the most light-loving species of the grass family, has an occurrence rate of 66.6%, and representatives of legumes and shrubs exhibit an occurrence rate of - *Vicia cracca* L. - 58.3%, *Rubus caesius* L. - 58.3%, and *Medicago lupulina* - 50.0%, respectively (Table 3).

Table 3. The most common plant species by occurrence on the study area of the former Yavoriv Sulphur quarry.

Species	Family	Species occurrence, %	Coenomorph by Tarasov (2015)
***Phragmites communis* Trin.**	*Poaceae*	41.6	PalSilPrRu
***Medicago lupulina* L.**	*Fabaceae*	50.0	RuSilPr
***Solidago canadensis* L.**	*Asteraceae*	50.0	RuSil
***Juncus effusus* L.**	*Juncaceae*	66.6	RuPalSilPr
***Achillea millefolium* L.**	*Asteraceae*	41.6	StPr
***Phalacroloma annuum* L.**	*Asteraceae*	41.6	RuSilPr
***Solidago virgaurea* L.**	*Asteraceae*	41.6	RuSilPrPt
***Vicia cracca* L.**	*Fabaceae*	58.3	RuSilPrPal
***Equisetum arvense* L.**	*Equisetaceae*	41.6	RuSilPrPt
***Holcus lanatus* L.**	*Poaceae*	66.6	RuSilPr
***Hieracium pilosella* L.**	*Asteraceae*	50.0	RuSilPr
***Rubus caesius* L.**	*Rosaceae*	58.3	RuSilPr

Pal. – marsh plant (gelofite); **Pr.-** protractant (ray plant); **Ru.** – Ruderal (weeds); **Sil.** – Sylvante (forest plant); **St.** – steppe plant; **Pt.** - petrophil (type of rocky soils).

The ruderal, meadow, meadow-shrub, forest-meadow, meadow-swamp and meadow-steppe species appeared to be the most widespread, while the most common species were characterized by tap, rhizome, creeping rhizome, short rhizome, fibrous and caespitose root systems. These observed species of plants are capable to firmly bind to the substrate to support life processes with moisture and nutrients in the oligotrophic conditions. Along with perennials, which can form powerful root systems, herbaceous annuals and biennials were predominant. A detailed analysis of species for each of the experimental sites made it possible for us to establish the species diversity, projective coverage and ecological characteristics of plants of the prevailing phytocoenoses, *i.e*. vegetation groupings on a territory with certain mutual relations between them and the conditions inherent in their habitat (Alyokhin 1986).

Depending on the type of soil, level of its annihilation, erosion, (in)fertility, relation to the lightness of the site, moisture of the ground, compatibility with other ground vegetation and other additional factors, there emerged a different number of plant species on different sites**.** The number of plant species varied from 6 to 30 (Figure 5). The largest number of plant species was recorded on PYa 6 (a non-reclaimed area) – with 30 species; on PYa 12 (the control site) - 25 species, and on PYa 2 (reclaimed land with clumps of birch trees) - 22 species. The reason is likely in the optimal combination of species contributing to soil enrichment, the accumulation of organic substances and other favourable factors (e.g. illumination, air temperature, humidity and acidity of the soil).

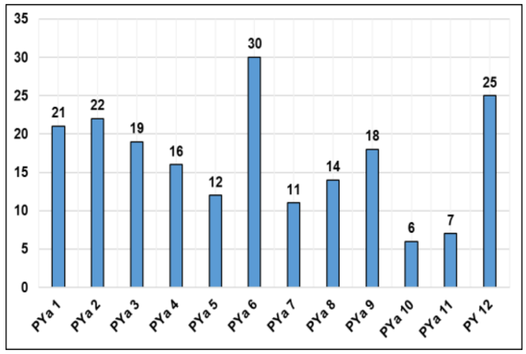

Figure 5. The number of plant species recorded in the study sites PYa 1-12 on the land of the former Yavoriv Sulphur quarry.

The lowest number of species was recorded on PYa 10 (pine clumps on the dump) - 6 species and on PYa 11 (bed of rushes of reeds) - 7 species. Apparently, this is to a large degree because pine has at some point during its growth set off a significant degree of competition. The ground vegetation has become less capable to grow in the shade, with the result of an increased acidity of the soil, as plants compete with trees for light, and for moisture and nutrients in the soil. In the conditions of PYa 11, reed was formed displacing all other species due to the powerful root system and its significant height.

Overall, the smallest number of species (up to 10 units) was recorded on 2 experimental sites, comprising 16.6% of the total area. The largest territory (50% of the total trial area) was covered with plants belonging to between 11-19 species (Table 4).

Table 4. Species saturation of the phytocoenoses on the former Yavoriv Sulphur quarry.

Characteristics	Number of species		
	up to 10	**11-19**	**>20**
Number of sites	2	6	4
Share of total trial area (%)	16.6	50.0	33.4

Ground vegetation distribution on the sites PYa 1-12 is snown in Figure 6.

4.3 Plant communities

The results indicate that ground vegetation on the analysed sites and its characteristics broad-range geographically from the Holarctic, Eurasian and European to Eurasian-North African types. We also discovered that 69.6% of the species are photophilous with respect to light; 54.5% of the species belong to mesophytes with respect to moisture, and that by the richness of soil, 38.4 % of them are mesotrophs. We also noticed that within the territory of certain experimental sites there are some significant deviations from average floristic structure indicators.

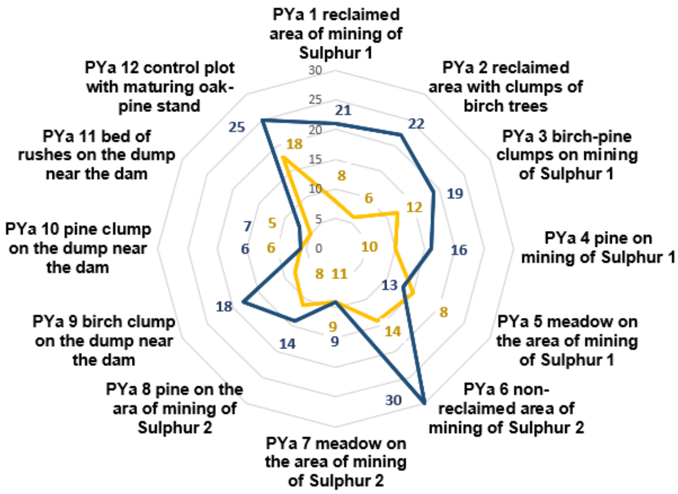

Figure 6. Ground vegetation distribution across the experimental sites PYa 1-12 on the land of Yavoriv Sulphur quarry (— number of families of ground vegetation; — number of plant species).

Under the influence of various environmental and anthropogenic factors, several plant communities were formed on both the reclaimed and non-reclaimed sites within the area of the underground mining of Sulphur No 1 specifically, where the herbaceous plants, the reed grass-annual fleabane vegetation community was formed. The re-emergence of self-seeded weeping birch (*Betula pendula*) and pine (*Pinus sylvestris*) in the reclaimed areas has contributed to a significant change in the environmental conditions of the sites and resulted in the formation of several more complex species composition of communities. The establishment of forest plantation involving pine (*Pinus sylvestris*) contributed to the formation of a pine-bentgrass-blackberry-moss community. Overall, the appearance of woody plants on reclaimed and non-reclaimed areas has added to a significant change in the energy flows and microclimate, characterized by reasonable changes in temperature, air humidity and soil moisture, as well as of the light intensity under the growing trees (Table 5).

On reclaimed areas in the underground mines, the dominant place among herbaceous plants is occupied by representatives of cereals - *Calamagrostis epigeios* (L.) Roth, *Agrostis tenius* Sibth.; sedge family- *Carex hirta* L.; sunflower family - *Phalacroloma annuum* L.; rose family - *Rubus caesius* L.; ruderal plants - *Plantago lanceolata* L.; among mosses - *Polytrichum commune* Hedw. It was also observed that the domination period of coenophobic and ruderal species is very short on such sandy soil mixtures.

On non-reclaimed sites of underground mining of Sulphur No2 we observed syngenetic successions and formed endoecogenetic successions. Among the herbaceous plants, the dominant position was occupied by *Calamagrostis epigeios* (L.) Roth., *Hieracium pilosella* L., in moist areas - *Juncus effusus* L., *Rubus caesius* L.; among mosses - *Polytrichum commune* Hedw., *Pleurozium schreberi* (Willd. Ex Brid.) Mitt.

In some localities primary syngenetic and endoecogenetic successions had a more complex vegetation structure, characterised by greater stability and productivity. The existence of such variants in succession is apparently accounted for by environmental conditions (e.g. chemical and physical properties of the soil, level of moisture content) and anthropogenic impacts (e.g. the presence or absence of reclamation).

Table 5. Plant associations of phytocoenoses on the sites of the former Yavoriv Sulphur quarry.

Experimental site	Plant communities	Floristic composition
PYa 1 - **Reclaimed land with a minimum amount of vegetation on the territory of underground mining of Sulphur No1.**	Reed grass-annual fleabane	*Calamagrostis epigeios* (L.) Roth. (C)+ *Phalacroloma annuum* L. (C_1)
PYa 2 - **Reclaimed land with clumps of birch trees on the territory of underground mining of Sulphur No1.**	Birch-reed grass-annual fleabane	*Betula pendula* Roth. (A) - *Calamagrostis epigeios* (L.) Roth. (C)+ *Phalacroloma* L. C_1)
PYa 3 **- Birch-pine clumps on the former underground mining of Sulphur No1.**	Birch-pine-sedge-moss	*Betula pendula* Roth. + *Pinus sylvestris* L.(A) - *Carex hirta* L. (C) - *Polytrichum commune* Hedw. (D)
PYa 4 **- Pine plantation on underground mining of Sulphur No1.**	Pine-bentgrass-blackberry-moss	*Pinus sylvestris* L. (A) - *Agrostis tenius* Sibth. (C) - *Rubus caesius* L. (B) - *Polytrichum commune* Hedw. (D)
PYa 5 **- Meadow on the area of underground mining of Sulphur No1.**	Plantain-mixed herbs	*Plantago lanceolata* L. (C) + Mixthoherbetum
PYa 6 **- Non-reclaimed land on the territory of underground mining of Sulphur No 2.**	Reedgrass-hawkweed-moss	*Calamagrostis epigeios* (L.) Roth. (C)+ *Hieracium pilosella* L. (C_1) - *Polytrichum commune* Hedw. (D)
PYa 7 **- Meadow on the area of underground mining of Sulphur No 2.**	Hawkweed-mixed herbs	*Hieracium pilosella* L. (C) + Mixthoherbetum
PYa 8 **- Pine plantation on underground mining of Sulphur No 2.**	Pine-blackberry -Pleurozium (moss) rush	*Pinus sylvestris* L. (A) - *Rubus caesius* L. (B) - *Pleurozium schreberi* (Willd. Ex Brid.) Mitt. (D) - *Juncus effusus* L. (C)
PYa 9 **- Birch clump on the dump near the dam.**	Field grass-hawkweed-mixed herbs	*Poa pratensis* L. (C)+*Hieracium pilosella* L.(C_1) + Mixthoherbetum
PYa 10 **- Pine clump on the dump near the dam.**	Vetch-equisetaceous-blackberry	*Vicia cracca* L.+ *Equisetum arvense* L. (C) - *Rubus caesius* L. (B)
PYa 11 **- Bed of rushes on the dump near the dam.**	Reed-vetch-blackberry	*Phragmites communis* Trin. (C)+ *Vicia cracca* L. (C_1) - *Rubus caesius* L. (B)
PYa 12 **- Control site (maturing oak-pine stand near the Sulphur open quarry).**	Pine-strawberry-blackberry-Pleurozium (moss)	*Pinus silvestris* L. (A) - *Fragaria vesca* L. (C) - *Rubus caesius* L. (B) - *Pleurozium schreberi* (Willd. Ex Brid.) Mitt. (D)

Roth, Hedw, Sibth, Mixthoherbetum, Willd. Ex Brid, Mitt., A, B, C, C_1, L are a formula for recording plant associations on the predominant Latin principle, according to Alyokhin (1986).

The processes of plant colonization on different types of soil, such as Neogene marl clay, Quaternary loam, sandy loam and sands differ across experimental sites. Ground vegetation such as *Poa pratensis* L., *Hieracium pilosella* L., *Rubus caesius* L., *Vicia cracca* L. are widespread in wet areas of dumps near the dam. In conditions of excessive periodic flooding and in the area of waterlogging, the syngenetic succession is represented by *Phragmites communis* Trin. The control site of PYa 12 is characterized by an endo-ecogenetic multi-storeyed succession with the predominance of forest species, such as oak-pine (*Quercus robur-Pinus sylvestris*) tree stands, with the prevailing pine.

5 Discussion

The restoration of degraded lands in the Ukrainian Roztochya district has focused on re-emerged ground vegetation communities and their effects on soil (Taras, 2016; Danko, 1980). It was suggested that planted tree species, such as oak (*Quercus robur* L.), northern oak (*Quercus borealis* Michx.), marple-narew (*Acer pseudoplatanus* L.), larch (*Larix decidua* L.), pine (*Pinus sylvestris*), and birch (*Betula pendula*) increase the effectiveness of land reclamation (Kucheriavy et al. 2006). Furthermore, various microorganisms capable to counter-play and neutralize Sulphur, Nitrogen, and Phosphorus were considered to play an important role in the restoration of contaminated soils (Кudysh 2009; Turnau et al. 2006).

The development of woodlands is deemed to be crucial for the region. Afforestation of former industrial, low-productive, waste, eroded, erosion-prone and reclaimed sites and/or natural regeneration of forest are considered among the most effective measures towards the recovery of devastated land. Planting of trees on hilltops, river banks, valleys and the creation of soil protection forest strips to reduce the intensity of soil erosion is also considered important.

With regards to the role of Roztochya in sustaining the environmental conditions of a considerably larger area (*i.e.* the Baltic-Black Seas region), it seems desirable to promote multifunctional land use systems and endure a relative balance between agricultural production and forestry, which are currently the main land based human activities in this region. The promotion of sustainable, multifunctional forestry (Nijnik et al. 2017) would mean the endorsement of the development of nature reserves, an increase of the recreational capabilities of the territory and an improvement in ecosystem services. There is evidence to suggest that this will provide additional benefits to local communities, while the involvement of people in the decision-making process can help in finding innovative solutions to the old dilemma of what sort of balance between economic production and nature conservation is most desirable.

Overall, on 12 experimental plots that were laid out, we identified 86 vascular and non-vascular plant species, belonging to 32 families and 5 divisions, with 83.4% of the trial area being characterized by the species diversity of 11-20 units and higher. We also discovered that the rose family (*Rosaceae*), legumes (*Fabaceae*), sunflower (*Asteraceae*), grass *(Poaceae*), rush (*Juncaceae*), and equisetaceous (*Equisetaceae*) were highly common families. Ditrichaceous plants (*Ditrichaceae*), those of the club-moss family (*Lycopodiaceae*), shieldferns (Dryopteris), pink family (*Caryophyllaceae*), cabbages (*Brassicaceae*), the mezereon family (*Thymelaceae),* honeysuckle family (*Caprifoliaceae*) and madder family (*Rubiaceae*) were the least common families of ground vegetation. These findings demonstrate species diversity and suggest towards a potential for the development of species composition of plants within the case study area.

The results from this research, carried out in both reclaimed and non-reclaimed areas, also provides evidence that several different vegetation communities were formed under the influence of ecological and anthropogenic factors, affecting both natural succession and plantations, and that these communities include reedgrass-annual fleabane, plantain-mixed herbs, reed-vetch-blackberry, birch-pine-sedge-moss, and pine-blackberry-Pleurozeum (moss)-rush.

6 Conclusions

To conclude, this research enabled us to explain the degree of colonization of waste land belonging to the former Yavoriv Sulphur mining quarry by various types of vegetation, to reveal the peculiarities of regeneration processes in the local natural environment and identify the most promising tree species in affiliation with ground plant vegetation. The results highlight the most effective liaison between ground vegetation and planted and self-seeded trees. We believe that some of these results could assist decision-makers when selecting different options, concerning compatibility alliances, and using the implied management instruments to initiate and sustain regeneration processes on devastated land. Although this research is location specific, we believe that this advanced knowledge can to a degree be applied to similar places, elsewhere, in the temperate zone.

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