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Transformational processes in post-technogenic ecosystems of Kolomyia lignite and Yaziv sulfur deposits in Western Ukraine

Yaroslav Henyk[1], Vasyl Popovych[2,*], Vasyl Zayachuk[3], Oleksandra Dyda[4], Nataliya Gociy[2], Pavlo Bosak[2]

[1]Department of Landscape Architecture, Landscape Gardening and Urban Ecology, Ukrainian National Forestry University, General Chuprynky str., 103, Lviv, 79057, Ukraine
[2]Institute of Civil Protection, Lviv State University of Life Safety, Kleparivska Str. 35, Lviv, 79007, Ukraine
[3]Department of Botany, Wood Science and Non Wood Forest Products, Ukrainian National Forestry University, General Chuprynky str., 103, Lviv, 79057, Ukraine
[4]Department Architectural Design, Lviv Polytechnic National University, Stepana Bandery str., 12, Lviv, 79013, Ukraine
*corresponding author: popovich2007@ukr.net

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Abstract. Restoration of post-tech ecosystems of the Western region of Ukraine takes place both through natural self-overgrowth with vegetation and through the implementation of phytomeliorative measures - artificial afforestation of disturbed areas. These processes have been studied on post-technogenic territories of Kolomyia lignite and Yaziv sulfur deposits.
Transformational processes in the study area are caused mainly by three factors: natural succession of vegetation (from the emergence of mosses and pioneering species of grasses and trees to the formation of stable plant communities); human economic activity (phytomeliorative measures for sowing grasses and creating forest crops) and cattle grazing (appearance of fruit tree species in phytocenoses). Transformational processes in edaphotopes are primarily determined by two factors - the natural succession of vegetation and erosion processes. Due to the long process of restoration of disturbed ecosystems in post-man-made areas, relatively complex and rich in species composition stable plant communities are gradually formed, which contribute to the formation of embriozems, identification of soil genetic horizons, increasing the thickness of the soil profile and approximating the physical and mechanical properties of the upper layers of the soil to the properties of natural zonal soils. The species composition and structure of vegetation in the post-technogenic territories of Kolomyia lignite and Yaziv sulfur deposits of the Western region of Ukraine have been determined. The study showed that the dendroflora of post-technological areas is represented by 59 species of tree plants.
Changes in the components of phytocenoses and edaphotopes are presented and the factors of transformation processes in disturbed ecosystems are analyzed. Stages of natural succession of vegetation in post-technogenic territories of lignite and sulfur deposits have been established. Physico-chemical properties of the formed embriozems were analyzed and their comparative analysis with zonal soils was carried out. It is established that the processes of vegetation restoration and soil formation in post-technogenic territories cause the gradual formation of complex plant groups and relatively stable and stable natural ecosystems.

Key words: ecosystem restoration, mine dumps, sulfur quarry and dump, technogenic soils, phytomelioration, vegetation, dendroflora, species diversity, succession.

1. Introduction

Mineral deposits development causes technogenic disturbance of natural ecosystems, vegetation and soil degradation, reduction of species biodiversity, and environmental pollution.

Ensuring sustainable development of territories, restoration of natural landscapes, and creation of a favourable living environment requires the implementation of reasonable measures for the revitalisation of post-technological ecosystems, which should be based on investigations of transformation processes in phytocoenoses and edaphotopes and vegetation succession in anthropogenically disturbed areas.

The research objectives are determination of the species composition and systematic structure of dendroflora in the post-technogenic territories of the Kolomyia lignite and Yaziv sulfur deposits (Western Ukraine); identification of transformations in phytocoenoses and edaphotopes of disturbed areas affected by natural and anthropogenic factors; determination of the stages of vegetation succession in post-technogenic ecosystems.

The growing needs of mankind in natural resources and the development of the mining industry have led to significant disturbances of natural ecosystems and the formation of post-man-made areas. Underground and opencast mining in the Kolomyia lignite (Ivano-Frankivsk region, Ukraine) and Yaziv sulfur (Lviv region, Ukraine) deposits has led to the formation of accumulative and denudation forms of man-made relief. The negative impact of technogenic disturbances on the natural environment (degradation and destruction of vegetation and soil cover, biota pollution, spontaneous combustion of waste) is manifested not only in places of mineral deposits, but also covers large areas (Sykorova et al., 2018; Malanchuk et al., 2018; Chetveryk et al., 2018; Filonenko, 2018). Development of measures for restoration of the disturbed lands productivity should be based on various scientific reseach on natural restoration processes and anthropogenic formation of vegetation and soil cover in post-technogenic areas (Koščova et al., 2018; Popovych et al., 2019a; Henyk, 2016; Petlovanyi & Medianyk, 2018; Petlovanyi et al., 2019; Abramowicz et al., 2021). Issues of transformation processes in post-technogenic ecosystems of Ukraine and the restoration of productivity of disturbed areas are covered in numerous scientific works. Despite of the importance of existing research, aspects of transformation processes and natural restoration of biogeocenoses in post-technogenic areas continue to be relevant, which requires new scientific research (Anfal, 2017; Nadudvari et al., 2021; Abramowicz & Chybiorz, 2020).

The development of mineral deposits leads to the formation of technogenic disturbed areas, degradation and complete destruction of vegetation and soil. Various aspects of transformation processes in post-technogenic ecosystems of the Western region of Ukraine are discussed in numerous scientific publications by leading research institutes and universities of the state.

Carrying out further research to establish the species composition of phytocenoses of post-technogenic territories, investigating of the transformation processes of successions of vegetation formation on disturbed lands remain extremely relevant and require further research to develop effective and rational measures for revitalization of technogenic disturbed ecosystems and restoration of soil productivity, formation of stable post-technogenic phytocenoses.

The direct goal of the research is to determine the species dendrological diversity of the post-technological territories of the Kolomyia lignite and Yaziv sulfur deposits, to analyse vegetation succession and transformations in phytocoenoses and edaphotopes of disturbed ecosystems.

2. Materials and methods

The subject of the research is the dendroflora of post-technogenic ecosystems of the Kolomyia lignite deposit (dumps of Zavodska and Kovalivska mines) and the Yaziv sulfur deposit (slopes of the Yavoriv quarry and sulfur dump No. 3) and transformation processes in phytocoenoses and edaphotopes of the disturbed areas.

The research was conducted according to proven methods, in accordance with the objectives of a systematic research of transformation processes in disturbed ecosystems and their assessment.

The description of existing tree plants was carried out by the route method and covered the entire area of post-technogenic territories.

The species composition of tree plants in the disturbed areas was determined according to the Ukrainian nomenclature. (Plants species composition in disturbed areas is determined in accordance with the domestic nomenclature (Kucheryavyi V.P. & Kucheryavyi V.S., 2019; Zayachuk, 2014).

The classification of tree plants is based on the system of A. Cronquist (1988).

The ecological structure of the dendroflora of post-technogenic territories was determined in accordance with (Soroka, 2008).

The main factors of the transformation of post-technological ecosystems' phytocoenoses and edaphotopes, as well as the stages of natural vegetation succession in the disturbed areas, were identified on the basis of more than twenty years of research and observations.

The morphological structure and soil properties of post-technological ecosystems were studied by laying monoliths in typical parcels, describing soil sections and genetic horizons, and taking samples for further physicochemical analyses.

Soil samples were taken from the top five-centimeter layer. Physico-chemical properties of the soil cover of disturbed and undisturbed areas were determined according to the methods proven in soil science (Snitinskyi & Yakobenchuk, 2006; Panas, 2005) in the laboratory of rapid soil analysis of the National Forestry University of Ukraine.

The objects of research are the post-technogenic ecosystems of the Kolomyia lignite deposit - the dumps of Zavodska and Kovalivska mines and the Yaziv sulfur deposit - the slopes of the Yavoriv quarry and sulfur dump No. 3.

The object of research – the post-technogenic territories of Kolomyia lignite and Yaziv sulfur deposits located in the Western region of Ukraine (Fig. 1).

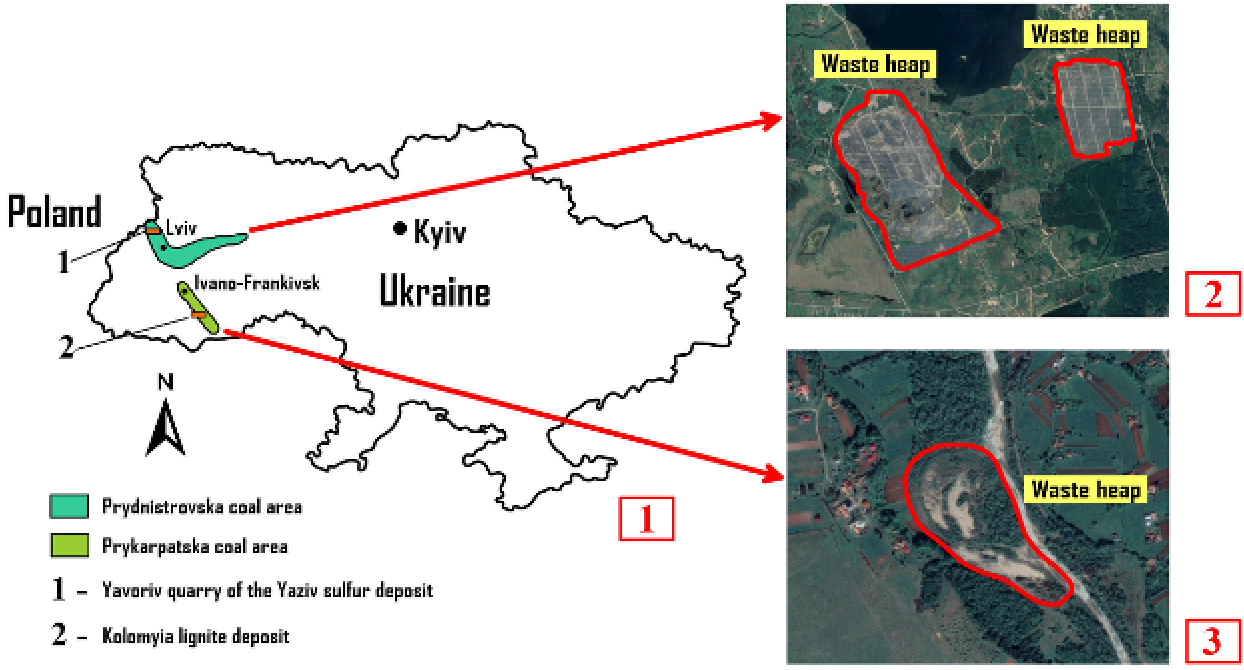


Figure 1. Location of research objects: 1 – coal areas on the map of Ukraine; 2 – dumps of Yaziv sulfur deposit; 3 – dump of Kolomyia lignite deposit.

The subject of research – transformational processes in phytocenoses and edaphotope of disturbed biogeocenoses and natural succession of vegetation in post-technogenic ecosystems.

Underground mining of lignite deposits from the upper bed in the town of Kovalivka was started by coal miner O. Shipanovskyi in the early 1890s. The average annual coal production at the four shallow (up to 25-30 m) mines was 7,000 tonnes. At the end of the 19th century, the mines were suspended due to the low thickness of the upper bed, and a new vertical shaft 75 meters deep with a more powerful lignite bed was opened instead. In the 1920s, the development of the Silesian coal deposit led to the closure of the mine, which had produced over 250,000 tonnes of coal. In 1944-46, new exploration work led to the resumption of coal production at the existing mine and the construction of three new mines, where lignite production continued until 1968. After the closure of the mines, due to the unprofitability of coal mining, a cable production facility was established on their premises. The irregularly shaped, unreclaimed dumps of Zavodska and Kovalivska mines are located within the town of Kovalivka, Kolomyia district, Ivano-Frankivsk region, 10 km from Kolomyia and 215 km from Lviv. The mine dumps are currently undergoing natural vegetation succession.

The quarrying of sulfur ore and sulfur production by Yavoriv State Mining and

Chemical Enterprise "Sirka" (capacity of 1.5 million tonnes of sulfur per year) resulted in the formation of significant technogenic areas with destroyed soil and vegetation cover in the zone of the enterprise's operations. The termination of sulfur deposits development caused by unprofitable production at the Yaziv deposit prompted the company to address the issues of phytomelioration and reclamation of disturbed lands, including the Yavoriv sulfur quarry, external overburden dumps, underground sulfur smelting fields and industrial areas. The slopes of the Yavoriv sulfur quarry and sulfur production dumps are being restored naturally and through artificial plantations. Over the past decades, annual reforestation of the affected areas has not yielded the desired results. According to the reclamation project, the disturbed lands will be used to create a recreational complex, with the centre on Yavoriv Lake, which has a water surface area of 7 square kilometres and a 12-kilometre-long coastline. The slopes of the sulfur quarry and dump are located in Yavoriv district of Lviv region, 5 km from Novoyavorivsk and 40 km from Lviv. Currently, the post-technological ecosystems of the Yaziv sulfur deposit are undergoing natural vegetation succession.

3. Results

Vegetation formation process on the dumps of Kolomyia lignite coal deposit and dumps and slopes of Yavoriv quarry of Yaziv sulfur deposit takes place depending on physicochemical properties of rock mixtures, exposure of dump slopes, microclimatic features and humidity of vegetation area.

The conducted research has shown that the dendroflora of post-technogenic territories of Kolomyia lignite and Yaziv sulfur deposits is represented by 59 species of tree plants (Table 1).

Table 1. Species composition of tree plants in mine dumps of the Kolomyia lignite deposit and slopes of the Yavoriv quarry and dumps of the Yaziv sulfur deposit

Species composition of tree plants	Mine dumps of the Kolomyia lignite deposit		Slopes of the Yavoriv quarry and dumps of the Yaziv sulfur deposit	
	Zavodska waste heap	Kovalivska waste heap	Slopes of the Yavoriv quarry	Sulfur deposit waste heap No 3
Acer campestre L.	–	+	–	–
Acer negundo L.	+	–	–	–
Acer platanoides L.	+	+	–	–
Acer pseudoplatanus L.	–	+	–	–
Alnus glutinosa Gaertn.	–	+	+	+
Alnus incana Moench	+	+	–	–
Betula pendula L.	+	+	+	+

Betula pubescens Ehrh.	–	–	+	+
Calluna vulgaris (L.) Hill	–	–	–	+
Carpinus betulus L.	+	+	–	–
Cerasus avium (L.) Moench	+	+	+	+
Cerasus vulgaris Mill.	–	+	+	–
Cornus max L.	–	–	+	–
Corylus avellana L.	+	+	+	+
Crataegus monogyna Jacq.	+	+	–	+
Euonymus europaea L.	–	+	–	–
Frangula alnus Mill.	+	+	+	+
Fraxinus excelsior L.	–	+	+	–
Fraxinus pennsylvanica Marsh.	–	–	+	–
Genista tinctoria L.	–	–	–	+
Hippophae rhamnoides L.	+	–	+	+
Juglans regia L.	+	+	–	–
Lembotropis nigrins L.	–	–	+	–
Ligustrum vulgare L.	–	–	+	–
Lonicera tatarica L.	–	–	+	–
Malus domestica Borkh.	–	–	+	–
Malus sylvestris (L.) Mill.	+	+	+	+
Padus avium Mill.	+	+	+	+
Pinus sylvestris L.	–	–	+	+
Populus alba L.	–	–	+	+
Populus nigra L.	+	+	+	+
Populus tremula L.	+	+	+	+
Prunus divaricata Ledeb.	–	–	+	+
Prunus spinosa L.	–	–	+	–
Pyrus communis L.	+	+	+	+
Quercus robur L.	+	+	+	+
Quercus rubra L.	–	–	+	–
Robinia pseudoacacia L.	+	–	+	+
Rosa canina L.	+	+	+	–
Rubus caesius L.	+	+	+	+
Rubus hirtus Waldst et Kit.	–	+	+	+
Rubus idaeus L.	–	+	–	–
Salix acutifolia Willd.	–	–	+	+
Salix alba L.	–	–	+	+
Salix aurita L.	–	–	+	+
Salix caprea L.	+	+	+	+
Salix fragilis L.	+	+	+	+
Salix purpurea L.	+	–	+	–
Salix triandra L.	+	+	+	–
Salix viminalis L.	–	–	+	+
Sambucus nigra L.	+	+	+	–
Sorbus aucuparia L.	–	+	–	–
Swida alba (L.) Opiz.	–	–	+	–
Swida sanquinea (L.) Opiz.	+	+	+	+
Tilia cordata L.	–	+	+	+

Ulmus carpinifolia Gilb.	–	–	+	–
Ulmus laevis Pall.	–	–	+	–
Vaccinium myrtillus L.	–	–	–	+
Viburnum opulus L.	+	+	+	+
Загалом – 59 видів	27	33	45	32

Investigation of the species diversity of Kolomyia lignite deposits showed that the dendroflora of post-technogenic territories (Zavodska and Kovalivska waste heaps) is represented by 37 species of 27 genera, 15 families, 14 orders and 4 subclasses (Table 2). The families of Rosaceae Juss (11 species), Salicaceae Lindl. (6 species), Betulaceae C.A. Agardh. (5 species) and Aceraceae Lindl. (4 types) are the leaders in the taxonomic composition of the dendroflora of waste heaps. The rest of the families are represented by only one species.

Table 2. Systematic composition of dendroflora of mine dumps of Kolomyia lignite deposit.

Division	Class	Quantity				
		subclass	taxon	family	genus	species
Waste heap of Zavodska mine						
Magnoliophyta	Magnoliopsida	3	11	12	22	27
Waste heap of Kovalivska mine						
Magnoliophyta	Magnoliopsida	4	12	13	25	33
Total composition of dendroflora of mine dumps of Kolomyia lignite deposit						
Magnoliophyta	Magnoliopsida	4	14	15	27	37
Total: 1	1	4	14	15	27	37

The richer species composition of the dendroflora of the Kovalivska mine waste heap is caused by the formation of more favorable soil, hydrological and microclimatic conditions for the growth of woody plants. The investigation of the species composition of woody plants by ecological structure relative to substrate trophism have shown that the most common in the dendroflora of Kolomyia coal mine dumps, as well as in the dendroflora of Mezhyrichya coal mine dumps, is a group of eutrophic woody plants, having a total of 23 species, which is 62.2% of the species diversity of the dendroflora of waste heaps. A group of megatrophic tree species is also represented on the waste heaps - 6 plants, including willow (*Salix fragilis* L.), walnut, field maple (*Acer campestre* L.), ash maple, maple (*Acer pseudoplatanus* L.) and common ash (*Fraxinus excelsior* L.), which makes up 16.2% of all woody plants in the dumps of Kovalivska and Zavodska mines. Oligotrophic species of woody plants on inactive waste heaps of mines of Kolomyia coal deposit were not detected at all (Fig. 2).

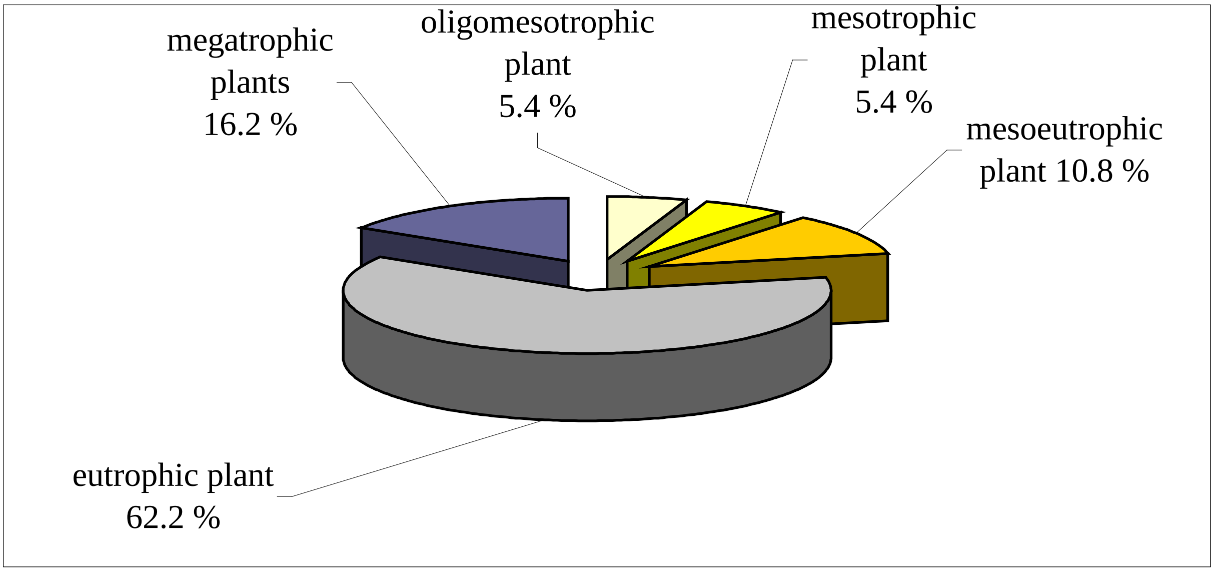


Figure 2. Ecological structure of dendroflora of mines dumps regarding the trophic nature of the substrate

Regarding the trophic nature of the substrate In terms of ecological structure in relation to substrate moisture, the group of mesophytic woody plants is the most common in the dumps of Kolomyia lignite mines, as well as in the dumps of Mezhyrichya coal deposits, which makes up 51.4% of the total species diversity of woody plants. Compared to other species, the group of mesohygrophytic woody plants – 9 species, or 24.3% of all tree species - is also significantly represented on the dumps (Fig. 3).

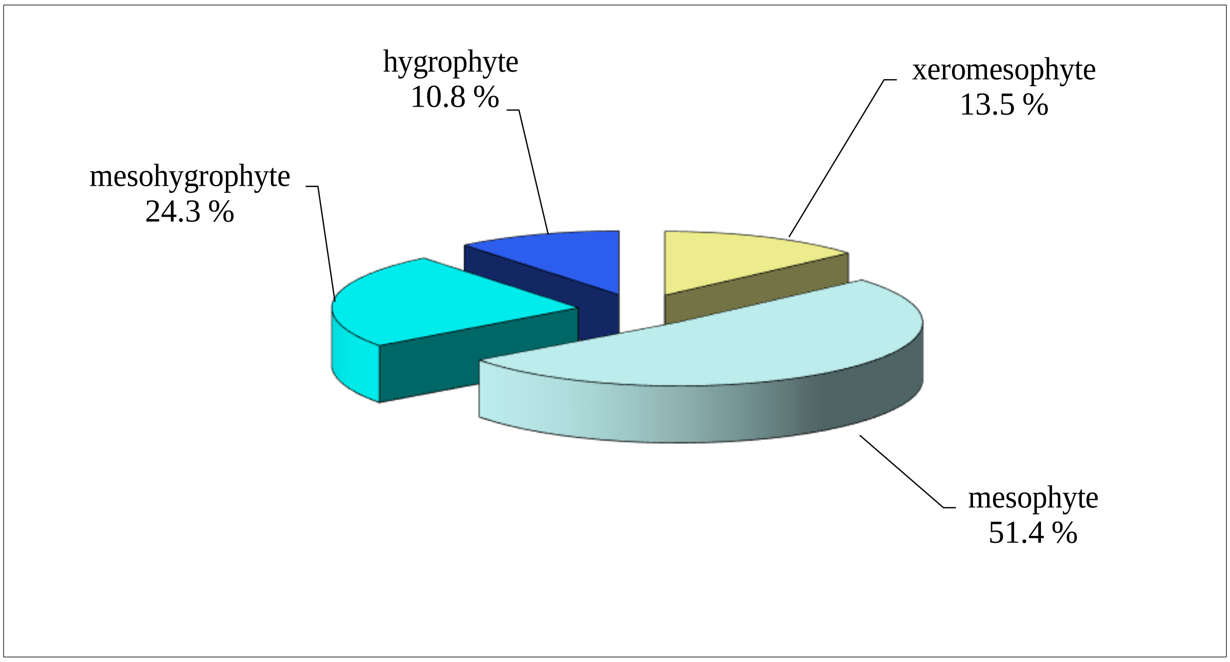


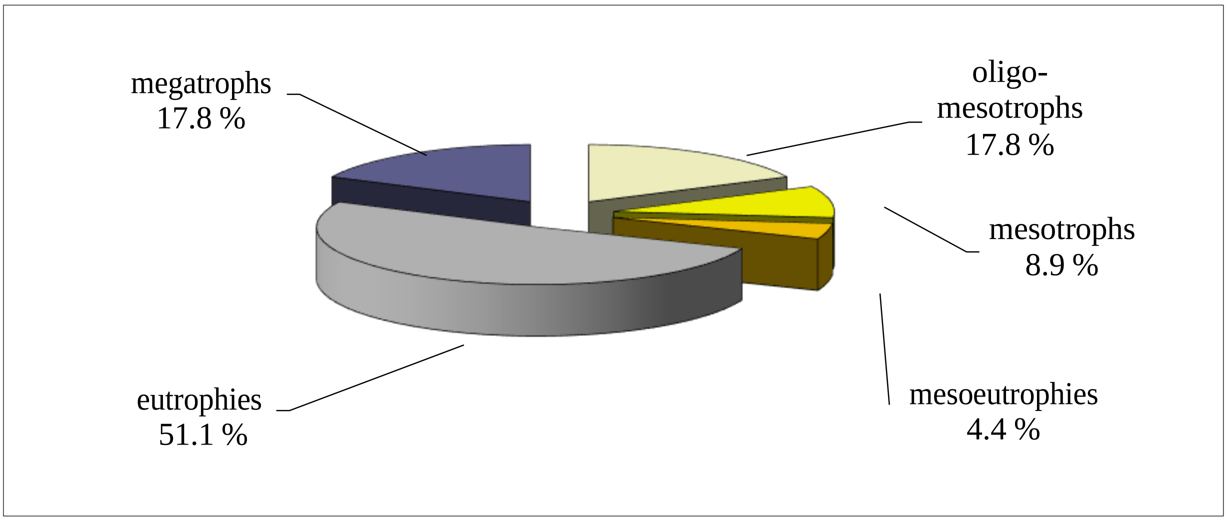
Figure 3. Ecological structure of dendroflora of mine dumps in relation to substrate moisture (author of the trophic classification Kucheryavyi & Manuilova, 2000)

At the dumps of Zavodska and Kovalivska mines of the Kolomyia coal deposit, the process of vegetation formation begins with the settlement of pioneer tree species that are less demanding of soil conditions - hanging birch, aspen and goat willow, which are characterized by the highest biometric indicators in a micro-low. The dendroflora of the post-technogenic territories of the Yaziv sulfur deposit (waste heap No.3 and the slopes of the Yavoriv sulfur deposit) is represented by 49 species belonging to 31 genera, 17 families, 14 orders and 5 subclasses (Table 3). In the taxonomic composition of the dendroflora of the dump and quarry slopes, the leading species in terms of number of species are the families Rosaceae Juss. - 12 species and Salicaceae Lindl. - 11 species, which are in total of 46.9% of species diversity. Other families are represented by 1–4 tree species.

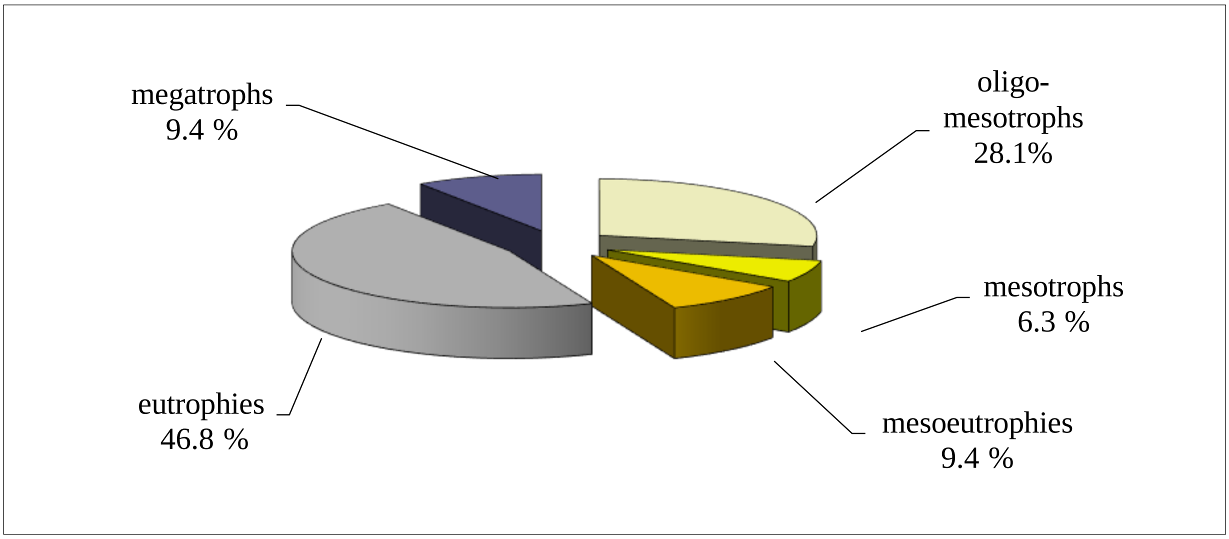
Table 3. Systematic composition of the dendroflora of the dump and slopes of the Yavoriv quarry of the Yaziv sulfur deposit.

Divasion	Class	Quantity				
		subclass	taxon	family	genus	Species
Slopes of Yavoriv sulfur deposit						
Pinophyta	Pinopsida	1	1	1	1	1
Magnoliophyta	Magnoliopsida	4	12	14	26	44
Total: 2	2	5	13	15	27	45
Waste heap #3						
Pinophyta	Pinopsida	1	1	1	1	1
Magnoliophyta	Magnoliopsida	3	11	12	22	31
Total: 2	2	4	12	13	23	32
Total in disturbed lands of sulfer production						
Pinophyta	Pinopsida	1	1	1	1	1
Magnoliophyta	Magnoliopsida	4	13	16	30	48
Total: 2	2	5	14	17	31	49

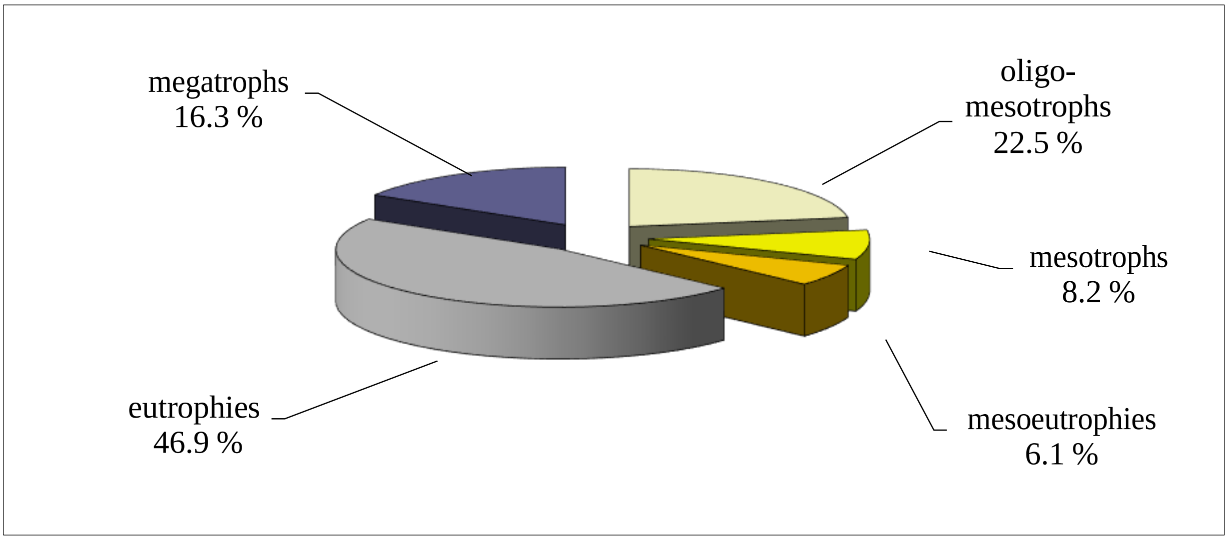
The richer species composition of the dendroflora of the sulfur quarry slopes (45 species from 27 genera and 15 families) compared to the species diversity of the heaps is caused by more favorable microclimatic conditions and better physical and mechanical properties of the soil environment. Species diversity of dendroflora formed by the natural overgrowth of disturbed lands is much richer (40 species of woody plants) compared to species diversity formed by planting forest crops (11 species of woody plants). According to the ecological structure in terms of soil substrate trophism, the most common in the dendroflora of quarry slopes and sulfur dumps, as well as of waste heaps of coal mining, is a group of eutrophic tree species, equivalent to a half of species diversity of woody plants (51.1% on quarry slopes and 46, 8% on waste heaps of sulfur production). Significant representation on disturbed lands is also characteristic of megatrophic woody plants - 8 species, or 16.3% of the total species diversity of dendroflora (Fig. 4).



a) slopes of sulfur quarry



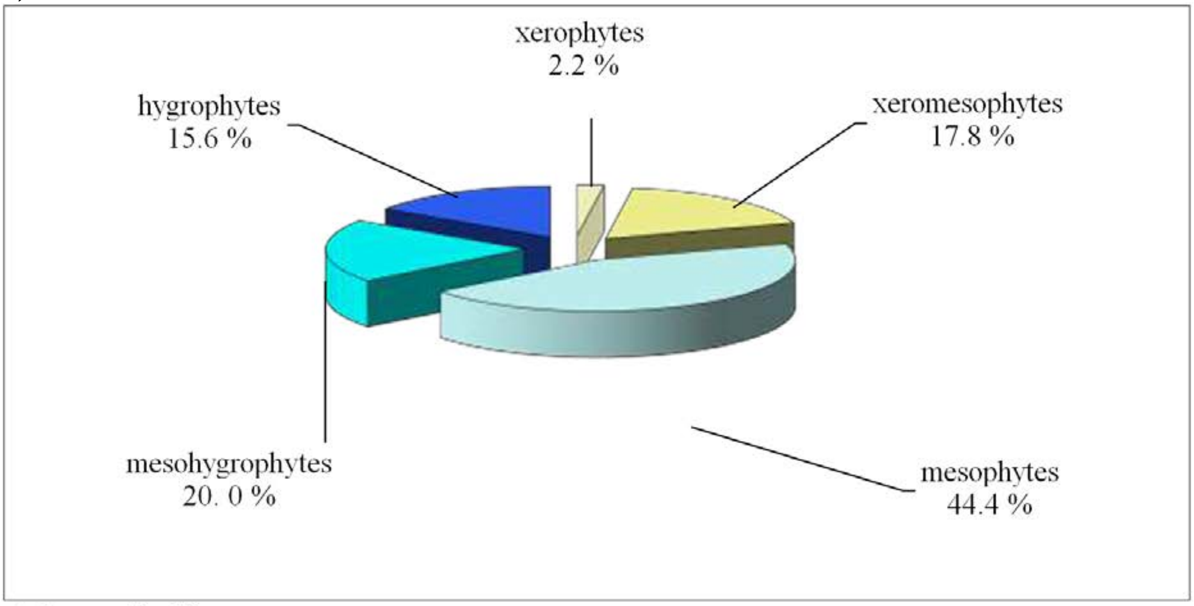
b) waste heap no. 3



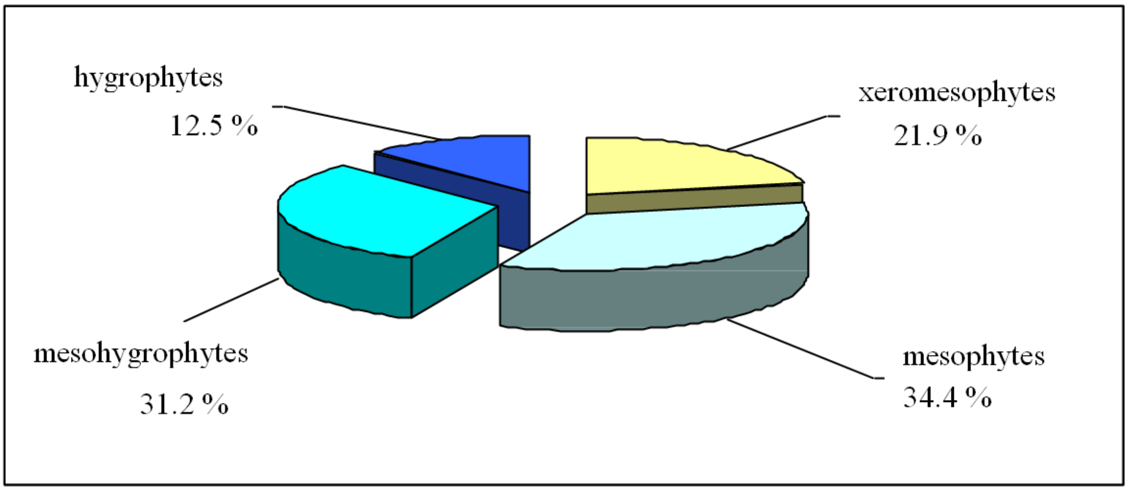
c) disturbed area of sulfur production plant

Figure 4. Ecological structure of dendroflora of disturbed lands within the area of operation of SMCE "Sirka" in relation to the trophic nature of the substrate

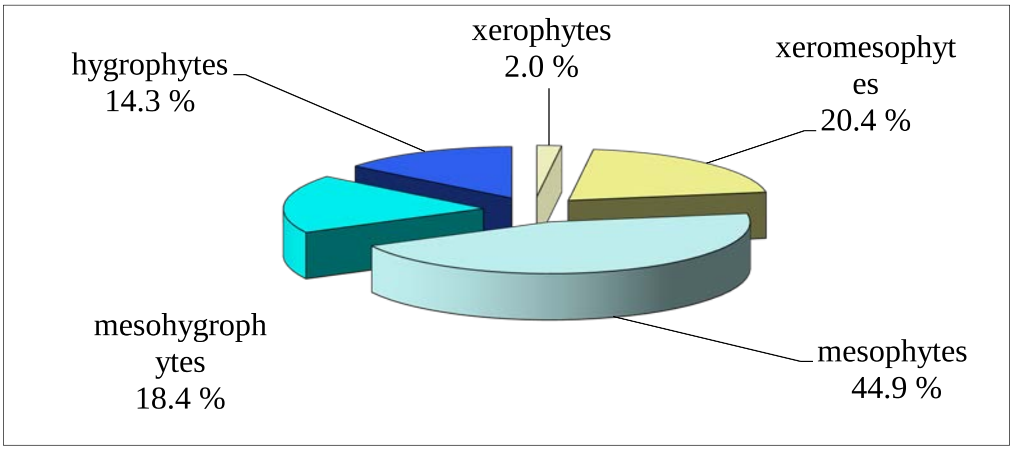
The group of mesophytic (44.9% of species diversity) woody plants is the most common in the disturbed areas of sulfur production in terms of substrate moisture. Groups of xeromesophytic and mesohygrophytic woody plants are also significantly represented - 20.4% and 18.4% of the species diversity of dendroflora of disturbed areas, respectively (Fig. 5).



a) slopes of sulfur quarry



b) waste heap no. 3



c) disturbed area of sulfur production plant

Figure 5. Ecological structure of dendroflora of disturbed lands within the area of operation of SMCE "Sirka" in relation to substrate moisture

In general, the most common in the dendroflora of post-technogenic areas in terms of substrate trophism is a group of eutrophic woody plants (dumps of Kolomyia lignite deposit - 23 species, or 62.2% of species diversity of dendroflora; dump and slopes of Yaziv sulfur deposit 46.9% of the species diversity of dendroflora), and in terms of substrate moisture - a group of mesophytic woody plants - dumps of Kolomyia lignite deposit - 19 species, or 51.4% of species diversity of dendroflora; dump and slopes of Yaziv sulfur deposit – 22 species or 44.9% of species diversity of dendroflora). Investigatio conducted in post-technogenic areas of the Western region of Ukraine have shown that transformations in phytocenoses there are mainly due to three factors: natural succession of vegetation (from pioneer tree species to continuous vegetation and stable plant communities); human economic activity (phytomeliorative measures for sowing grasses and creation of forest crops) and cattle grazing (appearance in phytocenoses of tree species *Malus sylvestris* (L.) Mill., *Malus domestica* Borkh, *Pyrus communis* L. and *Cerasus avium* (L.) Moench, which are capable to reproducing) (Table 4).

Table 4. Transformations in phytocenoses of post-technogenic territories of Western region of Ukraine

Factors of change	Changes in the components of the phytocenosis
Natural succession	increase in phytodiversity from several pioneer species of herbs and trees up to 108 species of higher vascular plants (68 species of herbaceous and 40 species of woody plants - Yaziv sulfur deposit; 33 species of woody plants - Kolomyia lignite deposit); dominance in the number of woody plants of the family *Rosaceae* Juss. and *Salicaceae* Lindl. (Kolomyia lignite deposit, 11 and 6 species respectively; Yaziv sulfur deposit, 12 and 11 species of trees grew, respectively); partaking in the plantations of introduced woody plants - *Juglans* regia L., *Robinia pseudoacacia* L. and *Acer negundo* L., which are capable to reproducing; dominance of eutrophic and mesophytic woody plants species (Kolomyia lignite deposit, 62.2 and 51.4% respectively); introduction of megatrophic woody plants - *Acer campestre* L, *A. negundo* L., *A. pseudoplatanus* L., *Juglans regia* L., *Salix fragilis* L, and *Fraxinus excelsior* L .; introduction of hygrophytic tree species - *Salix fragilis* L., *Salix purpurea* L., *Salix triandra* L. and even *Alnus glutinosa* Gaertn.; formation of sustainable renewal of woody plants under crowns of trees biogroups and in microreduction of relief; - formation of relatively stable and stable plants groups of zonal species of woody and herbaceous plants (increasing the resistance of phytocenoses to the negative effects of natural factors, in particular the daily temperature difference and wind action).
Economic activity	increasing of phytodiversity by creating forests crops (mainly from the following woody plants: *Pinus sylvestris* L., *Quercus rubra* Du Roi, *Quercus robur* L., *Betula pendula* Roth. та *Betula pubescens* Ehrh.) and sowing of grasses; partaking in the plantations of introduced woody plants - *Robinia pseudoacacia* L., *Quercus rubra* Du Roi та *Fraxinus pennsylvanica* Marsh.; - root-taking and mortality of the following breeds: *Picea abies* Karst., *Fagus sylvatica* L., *Carpinus betulus* L., *Acer platanoides* L., *Acer negundo* L. та *Juglans nigra* L. formation of relatively stable artificially created plantations from *Pinus sylvestris* L., especially on the slopes of the western and northern exposures (root-taking rate up to 78.6%).
Cattle grazing (*)	the presence in the plantations of *Malus sylvestris* (L.) Mill., *Malus domestica* Borkh, *Pyrus communis* L. та *Cerasus avium* (L.) Moench, which are capable to reproducing.

(*) domestic animals (cows, horses, goats, etc.) eat the fruits of these trees in the yards of their owners, and then leave the digested food when they graze on post-technological territories

According to investigation of the processes of phytocenoses transformation in post-technogenic areas, different in life forms, species composition and time of formation stages of natural succession of vegetation can be distinguished. They differ depending on physico-mechanical and physico-chemical properties of overburden (Table 5): - on the heaps of the mines of the Kolomyia lignite deposit: tree → tree-moss-grass → tree-grass → tree-bush-grass. - on the dumps and slopes of the Yavoriv quarry of the Yaziv sulfur deposit: grassy → mixed-grass-bush → mixed-grass-bush-tree → tree-bush-mixed grass.

Table 5. Stages of vegetation natural succession in post-technogenic territories of the Western region of Ukraine.

Stage of vegetation succession	Approximate time limits, years		Main features
	begining	end	
Mining dumps of Kolomyia lignite deposit			
I. Tree vegetation	Less than 1	5	The emergence of the first pioneering species of trees
II. Tree-moss-grass vegetation	5	10	Consolidation of pioneer trees, emergence of mosses and pioneer grass species
III. Tree-herbaceous vegetation	10	15	Formation of biogroups of trees with the presence of eutrophic species, the appearance of bushes, the formation of groups of various types of grass cover
IV. Tree-shrub-herbaceous vegetation	15	More than 25	Formation of biogroups from different by ecological structure trees and shrubs and continuous grass cover with the introduction of megatrophic cereals in the species composition
Waste heaps and slopes of Yavoriv quarry of Yaziv sulfur deposit			
I. Herbaceous vegetation	Less than 1	3	Emergence and consolidation of pioneering species of herbaceous plants
II. Herbaceous-shrub	3	10	Formation of a grass cover variety, the introduction of bushes
III. Herbaceous-shrub-tree	10	15	Formation of continuous grass cover and biogroups of woody plants with predominance in meso- and eutrophic species
IV. Tree-shrub-weed	15	More than 25	Formation of a continuous grass cover with the introduction of megatrophic cereals and biogroups that consists of different by ecological structure tree species with the presence of megatrophic

			shrubs and trees

Vegetation formation and the natural process of soil formation in post-technogenic areas for 30-50 years have contributed to the development of embryozems, in which there is a noticeable structuring of the upper layers and the definition of soil genetic horizons. Embryozems have a clear diagnosis of the humus-eluvial horizon, which is rich in roots of herbaceous and woody plants. The thickness of the soil profile of the sod embryozem on the slopes of the dumps of Kolomyia lignite deposit in the places of grass vegetation formation is up to 25 cm, and at the foot of the dumps – up to 45 cm, where the forest environment is gradually formed by different species of trees and shrubs. The formation of complex phytocenoses and the process of soil formation in post-technogenic areas lead to a gradual restoration of soil productivity - formation of organoaccumulative, sod and humus-accumulative embryozems, definition of soil genetic horizons, increase of soil profile thickness and gradual approximation of indicators of physical and mechanical properties of embryozems to similar indicators of naturally formed zonal soils. The density of the upper layer of embryozems on the dumps of Kolomyia lignite deposit in the places of grass cover formation is 1.07 $g{\cdot}cm^{-3}$, in the places of forest environment formation - 1.19 $g{\cdot}cm^{-3}$, and in the soil cover of the intact forest area – 1.27 $g{\cdot}cm^{-3}$. On the slopes of the sulfur quarry of the Yaziv sulfur deposit the density of the upper layer of embryozems formed under grass vegetation is higher (1.46 $g{\cdot}cm^{-3}$) compared to the naturally formed forest environment (1.33 $g{\cdot}cm^{-3}$) and artificially created forest crops (1.30 $g{\cdot}cm^{-3}$).

The more complex spatial structure of the vegetation of the slopes of dumps and quarries also leads to an increase in field humidity of the upper layers of the embryozem, which has a positive effect on the growth of the terrestrial part and root system of herbaceous and woody plants (Table 6).

Table 6. Physical and mechanical properties of the top layer of soil cover of post-technogenic territories of the Western region of Ukraine.

Vegetation	Physico-mechanical parameters of the upper layer of soil cover of post-technogenic territories			
	Soil dencity, d_1 g/cm^3	Density of the solid phase of the	Field humidity, W_f, %	Total porosity, V, %

		soil, d_2, g/cm^3		
Dumps of mines of the Kolomyia lignite deposit				
grass cover of the slopes of the dumps	1.07±0.02	2.37±0.03	22.25±0.34	55.04±0.82
grass and wood cover of the slopes of the dumps	1.19±0.04	2.41±0.02	24.72±0.56	50.43±1.05
grass and wood cover of the intact area	1.27±0.01	2.49±0.03	25.18±0.05	48.99±0.21
Slopes of the Yavoriv quarry of the Yaziv sulfur deposit				
grass cover of the slopes of the quarry	1.46±0.01	2.44±0.02	16.39±1.17	39.84±0.33
grass and wood cover of natural succession of quarry slopes	1.33±0.02	2.37±0.01	21.22±0.70	43.88±0.66
grass and wood cover of artificial restoration of quarry slopes	1.30±0.01	2.33±0.01	23.18±0.57	44.31±0.10

Investigation of post-technogenic areas disturbed by the development of coal and sulfur deposits have shown that transformations in the structure of soil profile, structure and mechanical composition of genetic horizons of soil cover are primarily caused by natural succession of vegetation and erosion processes (Table 6).

Table 6. Transformations in edaphotopes of post-technogenic territories of the Western region of Ukraine.

Factors of transformation	Changes in edaphotope components
Natural succession of vegetation	formation of organoaccumulative, sod and humus- accumulative embryozems; structuring of the upper layers and definition of soil genetic horizons; increase in the thickness of the soil profile - from 25 cm in turf up to 45 cm in humus-accumulative embryozems; increase in the thickness of humus-eluvial genetic horizon - from 6 cm in sod to 13 cm in humus-accumulative embryozems; approximation of indicators of physical and mechanical properties of embryozems to similar indicators of natural zonal soils (namely, density, solid body density, total porosity and aeration of the upper layers of embryozems); improving the physical and mechanical properties of embryozems under more complex phytocenoses; increase the productivity of embryozems due to formation of more complex plant structure groups.
Erosion processes	demolition of the upper layers of embryozems at the foot of the dumps; increase in the thickness of the humus-eluvial horizon in micro- depressions of the relief; increase in the productivity of soil cover in the lower parts of the slopes of dumps and quarries.

Long-term natural and artificial formation of phytocenoses complex in structure and the process of soil formation in post-tachnogenic areas cause a gradual increase in soil profile thickness, definition of soil genetic horizons, approximation of indicators of physical and mechanical properties of the upper layers of soil cover to indicators of natural zonal soils, as well as gradual restoration of disturbed areas productivity. Erosion processes lead to the demolition of the upper layers of techno-soils and embryozems from the upper slopes to the foothills and micro-lowering of the terrain, which increases the capacity of the humus-eluvial horizon and increases its productivity.

4. Discussion

Restoration of post-technogenic territories of Kolomyia lignite and Yaziv sulfur deposits (Western region of Ukraine) takes place both through natural vegetation self-overgrowth and through artificial afforestation - creation of forest crops. The dendroflora of disturbed areas is represented by 59 species of higher vascular plants and is formed depending on the physicochemical properties of embryozems and technozems, the degree of humidification of growing conditions and exposure of dumps and quarries. Dendroflora species diversity of formed due to natural overgrowth of post-technogenic areas is much richer compared to species diversity formed by creating forest crops. In the taxonomic composition of the dendroflora of post-technogenic territories, the leading species are Rosaceae Judl. and Salicaceae Lindl. According to the ecological structure, the most common in the dendroflora of post-technogenic territories in terms of substrate trophism is the group of eutrophic woody plants, and in terms of substrate moisture - the group of mesophytic woody plants. Transformations in phytocenoses and edaphotopes of post-technogenic territories are caused both by anthropogenic factors (economic activity - carrying out phytomeliorative measures and cattle grazing) and natural processes (self-overgrowth with vegetation - formation of relatively stable plant groups, which contribute to the formation of post-lithogenic soils such as embryozems). The following stages of natural succession of vegetation are distinguished in post-technogenic territories: - wood → wood-moss-grass → wood-grass → wood-bush-grass (on the dumps of mines of Kolomyia lignite deposit); - herbaceous → herbaceous-shrub → herbaceous-shrub-wood → wood-shrub-herbaceous (on the dumps and slopes of the Yavoriv quarry of the Yaziv sulfur deposit). The presence of vegetation and natural soil formation processes lead to a gradual restoration of productivity of soil cover of post-technogenic territories - formation of embryozems, definition of soil genetic horizons, increase of soil profile thickness and humus-eluvial genetic horizon, approximation of indicators of physical and mechanical properties of the upper layers of soil cover to indicators of natural zonal soils. Relatively rich species of phytodiversity, formation of stable phytocenoses of complex spatial structure, increasing soil profile thickness, definition of soil genetic horizons and approximation of properties of formed embryozems to natural zonal soils, indicate the possibility of long-term, gradual process of natural restoration of technogenically disturbed ecosystems of the Kolomyia lignite and Yaziv sulphur deposits.

Other researchers' studies of technologically disturbed ecosystems in the Western region of Ukraine have shown various aspects of vegetation succession and transformations of soil structure in post-technogenic areas.

According to the research of the National Forestry University of Ukraine conducted on the dumps of the Carpathian sulfur-bearing basin, it was shown that in artificially created plantations the highest biometric indicators (tree height, average trunk diameter and tree crown diameter) characterize woody species growing on the northern slopes. This is due to the higher moisture content of the soil cover and higher humidity in the lowest atmospheric layer (Kucheryavyi & Manuilova, 2000). The essence of changes in the phytocenotic spatial structure of vegetation cover of post-technogenic landscapes can be traced through successive rows of vegetation of disturbed areas (Meshcheryakov & Shirin, 2011; Ling Zhang et al., 2015). The following stages of succession have been identified for ecotopes of non-recultivated inactive waste heaps of mines of Chervonohrad Mining Area: wood → wood-moss → wood-weed → wood-grass → wood-bush-grass. The initial stage of self-overgrowth of non-reclaimed dumps is characterized by the settlement of pioneer tree species, mainly with the participation of common birch (*Betula pendula* Roth.) and aspen (*Populus tremula* L.), and the final stage – the emergence of eutrophic and megatrophic species in phytocenoses including black poplar (*Populus nigra* L.) and smooth elm (*Ulmus laevis* Pall.) (Bashutska, 2006; Henyk & Stasiuk, 2011). The process of vegetation formation on post-technogenic substrates of Yasenytsia sand deposit and Yavoriv sulfur deposit differs significantly from vegetation formation on coal deposit dumps and undergoes the following successive stages: stable herbaceous phytocenoses appearance of woody plants (Manuilova, 2004). The floristic composition of the groups of the coastal zone of technogenic reservoirs of Rozdilsky and Podorozhnensky sulfur deposites is quite dynamic and is constantly changing due to the emergence of new or waste of existing individual plants. The species composition of plants and their distribution depends on the properties of the soil substrate and the moisture regime. Stopping the processes of surface erosion and landslides contributes to the formation of stable vegetation with a predominance of meadow, meadow-shrub, meadow-swamp and ruderal species (Chelovechkova et al., 2018) researchers of the Institute of Carpathian Ecology of the National Academy of Sciences of Ukraine have shown that the pioneering stage of primary succession of sandy and clay areas of Yavoriv sulfur deposit, which is characterized by low density and biological productivity of vegetation, dominated by halophytic and anemochoric species. The formation of woody vegetation is characterized first by the appearance of species of the willow family (Salicaceae Lindl.), and later by species of other families (Bilonoha, 1989). In general, the formation mainly biocoenotic cover of post-technogenic areas of the sulfur deposit takes place mainly due to the species of indigenous flora and has a zonal character. During the succession, species diversity and projective cover increase, the structure of the phytocenosis becomes more complicated, and its productivity increases (Bilonoha & Malinovskyi, 2001). The formation process of productive phytocenoses in post-technogenic territories is quite long, and the species composition of plants depends on many factors. The most important of them are: the disturbance rate of growing conditions, physicochemical properties of soil-forming rocs and exposition of quarry slopes and dumps (Šebelíková et al., 2018; Henyk & Zayachuk, 2013). The research made by the Lviv National Agrarian University in the post-technogenic territories of the Carpathian sulfur basin have shown that the transformation of the soil environment is caused by mechanical, physical and chemical disturbances of soil and soil-forming rocks (Panas, 1989). The investigation of physical and chemical properties of edaphotopes of coal waste heaps within Novovolynsk mining area conducted in Lviv State University of Life Safety showed that the types of mine dumps edaphotopes are as follows - dump black rock, burnt gray rock and filled-up soil mix. Dumps edaphotopes are characterized by low humus content. High acidity of soil mixtures on reclaimed dumps inhibits the development of woody vegetation (Bosak & Popovych, 2019; Popovych & Voloshchyshyn, 2019; Popovych et al., 2019b). The investigation of the soil cover of technogenic disturbed land of Chervonohrad mining area and Prykarpattya sulfur basin conducted in the National Forestry University of Ukraine showed that agroecological features of edaphotopes at the technogenically changed areas are characterized by weak structure, low humus and plant food content. Physico-mechanical properties of soil mixtures of quarries and dumps differ but they are characterized by high porosity and field moisture, medium and highly compacted upper horizon (Henyk & Zayachuk, 2013). The investigation of technogenic landscapes of the Carpathian sulfur basin by the Institute of Carpathian Ecology of the National Academy of Sciences of Ukraine showed that the biotic activity of technogenic soils is much lower than of zonal soils. In the upper horizons of technogenic soils there is a significant excess of background sulfur content and high content of mobile sulfates. However, despite exceeding the maximum allowable concentrations of sulfur, mobile forms of manganese and copper, dumps of sulfur production in terms of physicochemical properties are potentially suitable for colonization of vascular plants (Maryskevych et al., 2008). The process of structure formation of the post-technogenic soils such as embryozems is determined by the stage of vegetation succession with the formation of the following evolutionary series: organoaccumulative embryozems turf embryozem humus-accumulative embryozem (Maryskevych & Shpakivska, 2012). Embryozems and technozems are characterized by low and medium humus content, low level of available nitrogen, alkalinity of soil solution, which generally provides potential suitability of post-technogenic soils for self-growth and formation of phytocenoses. Carrying out further research to establish the species composition of phytocenoses of post-technogenic territories, investigating of the transformation processes of successions of vegetation formation on disturbed lands remain extremely relevant and require further research to develop effective and rational measures for revitalization of technogenic disturbed ecosystems and restoration of soil productivity, formation of stable post-technogenic phytocenoses.

Conducted research on the post-technogenic territories of the Kolomyia lignite and Yazivske sulfur deposits is relevant, as it reveals transformational processes in phytocoenoses and edaphotopes and natural succession changes in vegetation in the affected areas and expands the findings of other scientists on the processes of restoration of phytocoenotic and soil cover in other post-technogenic ecosystems of western Ukraine.

Conclusions

1. The dendroflora of the post-technogenic territories of the Kolomyia lignite deposit showed that (Zavodska and Kovalivska mine dumps) is represented by 37 species belonging to 27 genera from 15 families. The leading families in terms of species diversity are *Rosaceae* Juss. with 11 species and *Salicaceae* Lindl. with 6 species, *Betulaceae* C.A. Agardh. with 5 species and *Aceraceae* Lindl. with 4 species.

2. The dendroflora of the post-technogenic areas of the Yaziv sulfur deposit (slopes of the Yavoriv sulfur quarry and waste heap No. 3) is represented by 49 species belonging to 31 genera from 17 families. The leading families in terms of species diversity are *Rosaceae* Juss. with 12 species and *Salicaceae* Lindl. with 11 species.

3. The most common group of eutrophic tree plants in the dendroflora of post-technogenic areas in terms of substrate trophicity is the group of eutrophic tree plants (dumps of the Kolomyia lignite deposit - 62.2 %; dumps and slopes of the Yaziv sulfur deposit - 46.9%), and in terms of substrate moisture - a group of mesophytic tree plants (dumps of the Kolomyia lignite deposit - 51.4%, dumps and slopes of the Yaziv sulfur deposit - 44.9%).

4. Transformation processes in phytocoenoses and edaphotopes of post-technogenic areas occur as a result of vegetation succession (natural factor), as well as phytomelioration measures and livestock grazing (anthropogenic factors).

5. The following stages of natural vegetation succession have been identified in the post-technogenic areas of the Kolomyia lignite deposit: tree → tree-moss-grass → tree-herbaceous → tree-shrub-herbaceous. The following stages of natural vegetation succession have been identified in the post-technogenic areas of the Yaziv sulfur deposit: grass → herbaceous-shrubby → herbaceous-shrubby-tree → tree-shrubby-herbaceous.

6. The formation of stable phytocoenoses and soil restoration indicate a gradual natural revitalisation of the technogenically affected ecosystems of the Kolomyia lignite and Yaziv sulfur deposits.

7. The analysis of the species composition and structure of vegetation and transformation processes in phytocenoses and edaphotopes of post-technogenic ecosystems, as well as the establishment of stages of natural succession of vegetation in disturbed areas,

will allow to carry out more effective phytomeliorative measures for formation of phytocenoses with complex structure and rich species composition for various purposes.

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