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PRINCIPLES OF REVITALIZATION OF TECHNOGICALLY VIOLATED AREAS IN THE WESTERN REGION OF UKRAINE

Zasady rewitalizacji obszarów poprzemysłowych w zachodnim regionie Ukrainy

Abstract
Here are given the basic principles of revitalization of post-technogenic territories in the Western region of Ukraine. Here have been identified varieties of species in the different dumps of the mines of the Mezhyrichia coal and Kolomyia lignite mines, as well as the slopes of the Yavoriv quarry and the dumps of the Yaziv sulfur deposit. The main factors of vegetation restoration in post-technological territories highlighted the ways of choice and directions of revitalization of disturbed landscapes. Here are also revealed technological aspects of restoration of post-technological territories depending on the degree of change in the conditions of growth in places – weak, moderate-, strong-, and deeply changed. Here are established stages of natural succession of vegetation in post-technogenic territories and its characteristic features. Here are revealed the advantages and disadvantages, opportunities and threats (SWOT-analysis) of natural self-restoration of biocenoses in post-technogenic territories and territories of phytomelioration or reclamation measures. Here are outlined necessary conditions for the formation of stable plant communities in post-technogenic areas. Here are also given the basic principles of landscape formation during the planning phytomeliorative or reclamation measures.
Key words: *post-technogenic territories, natural self-restoration of vegetation, phyto-melioration, reclamation, measures for restoration of disturbed ecosystems.*

Streszczenie
W artykule podano podstawowe zasady rewitalizacji terenów poprzemysłowych w zachodnim regionie Ukrainy. Zidentyfikowano różnorodność gatunkową roślin na różnych hałdach kopalni Mieżyryczyńskiego, złożach węgla oraz hałdach kopalni Kołomyjskiego, złożach węgla brunatnego, a także na zboczach Jaworowskiego kamieniołomu siarki i hałdach Jazowskiego (złoża siarki). Zwrócono uwagę na główne czynniki odnowy roślinności na terenach poprzemysłowych oraz wybór sposobów

i kierunków rewitalizacji zaburzonych krajobrazów. Poddano analizie technologiczne aspekty rewitalizacji tych terenów w zależności od stopnia zmiany warunków miejsc wzrostu – słabo-, średnio-, silnie- i bardzo silnie zmienionych. Ustalono etapy naturalnej sukcesji roślinności na terenach poprzemysłowych i ich cechy charakterystyczne. Ujawnione zostały zalety i wady, szanse i zagrożenia (analiza SWOT) naturalnego samoodtwarzania roślinności na terenach poprzemysłowych i terenach działań fitomelioracyjnych lub rekultywacyjnych. Określono warunki niezbędne do powstania stałych i stabilnych zbiorowisk roślinnych na tych terenach. Podano podstawowe zasady kształtowania krajobrazu podczas planowania działań fitomelioracyjnych lub rekultywacyjnych.
Słowa kluczowe: *tereny poprzemysłowe, naturalna samoodnowa roślinności, fitomelioracja, rekultywacja, działania na rzecz odtwarzania zaburzonych ekosystemów.*

Introduction

Expansion of industrial and economic activities, as well as increasing human needs for natural resources, leads to changes in the formation of natural ecosystems and causes a number of negative environmental consequences – environmental pollution, soil degradation, biodiversity loss, degradation of living organisms and humans. Significant areas of natural ecosystems are directly affected by anthropogenic activities, which causes changes in the topography of the earth's surface and landscape, as well as the violation of the general ecological balance of nature [1, 2, 3, 5, 7].

The presence of significant areas of technogenic disturbed lands in Ukraine, as well as areas with degraded natural landscapes, arouse research on transformation processes in post-technogenic ecosystems and the development of new, scientifically integrated approaches to restoration of natural resources and revitalization of disturbed ecosystems.

Ensuring sustainable development of territories, restoration of anthropogenically disturbed natural landscapes and the formation of a favorable living environment, involves a number of scientifically approved measures to revitalize disturbed ecosystems and degraded areas and create instead of it a new, productive, rationally organized, aesthetic and attractive landscapes [6, 9, 10].

Studies of transformation processes in anthropogenically disturbed ecosystems of Ukraine and revitalization of post-technogenic territories are covered in numerous works of scientists from various educational and research institutions. However, despite the importance of scientific developments, aspects of natural regeneration (self-restoration) of vegetation and soil cover in post-man-made areas, phytomelioration and reclamation of disturbed lands remain relevant, which requires new research and practical developments [4, 8, 11, 14-18].

Revitalization, as a set of scientific and practical measures to restore the productivity of disturbed areas should become an integral part of the restoration and reproduction of natural resources and the creation of new aesthetically valuable and attractive landscapes [12, 13, 19, 20].

Methodological aspects of research

Revitalization processes in technogenic disturbed ecosystems have been studied in areas characterized by a significant area of accumulation and denudation forms of technological relief – Mezhyrichia coal, Kolomyia brown coal and Yaziv sulfur deposits.

The objects of research were non-recultivated and recultivated dumps of mines "Mezhyrichinska" and "Vizeyska" of Mezhyrichia coal deposit (Lviv region), non-reclaimed dumps of mines "Zavodska" and "Kovalivska" of Kolomyia coal deposit (Ivano-Frankivsk region) sulfur quarry and heap № 3 of Yaziv sulfur deposit.

The research was conducted according to approved methods, and objectives of a systematic approach to study a vegetation restoration and soil productivity in disturbed ecosystems and assessment of changes in post-technogenic ecosystems.

The study of the species composition, structure of vegetation, structure and physicochemical properties of the soil cover, as well as the study of revitalization processes in post-technogenic ecosystems of the Western region of Ukraine was conducted by field research of disturbed areas.

Establishment of stages of natural succession of vegetation, the main factors of changes in the components of the phytocenosis and edaphotope, as well as the processes of revitalization of disturbed ecosystems is carried out on the basis of research and author's conclusions.

Presenting the main material

Every year from 1.0 till 3.5 thousand hectares of productive lands are disturbed by human production and economic activities in Ukraine, most of which are agricultural lands and the country's forest fund [8]. According to the Ministry of Environmental Protection and Natural Resources of Ukraine, the area of disturbed areas in Western Ukraine is quite significant and as of 2020 is 21.4 thousand hectares. Over the last decade, the area of disturbed areas in the Western region of Ukraine has decreased by 0.6%, which is due to the processes of revitalization of disturbed ecosystems. The largest areas of violations are in Lviv and Volyn regions and count 10.7 and 5.7 thousand hectares, respectively (Table 1).

Table 1. Area of disturbed lands in the Western region of Ukraine

Administrative territories of the Western region of Ukraine	Territory of region, thousands hectares	Territory of disturbed areas by years, thousand hectares			Percentage of territory of region, %
		2010	2015	2020	
Volynska	2014,4	5,7	5,9	5,8	0,288
Transcarpathian	1275,3	0,8	0,7	0,7	0,055
Ivano-Frankivsk	1392,7	1,2	1,5	1,5	0,108
Lviv	2183,1	11,6	12,0	10,7	0,490
Rivne	2005,1	0,1	0,1	0,1	0,007
Ternopil	1382,4	2,1	2,1	2,1	0,152
Chernivtsi	809,6	0,5	0,5	0,5	0,062
Total in region	11062,6	22,0	22,8	21,4	0,193

The large area of disturbed areas in the Western region of Ukraine requires a research on vegetation and soil restoration processes and a development of new scientific approaches to revitalization of disturbed landscapes, which will help to restore the productivity of disturbed ecosystems, environmental improvement and its sustainable development.

The process of vegetation restoration on coal and sulfur heaps and sulfur quarry slopes directly depends on the degree of soil degradation, physicochemical properties of rock mixtures, exposure of slopes, microclimatic features, humidity of growing conditions and time period of plant cover formation.

Studies of the species phytodiversity of the different dumps of the "Mezhyrichinska" and "Vizeyska" mines of the Mezhyrichynsky coal deposit (reclaimed, non-recultivated, operating uncultivated) showed that its flora is represented by 41 species of higher vascular plants from 36 genera and 17 families. The phytodiversity of reclaimed dumps is much richer (41 species), compared to the phytodiversity of non-reclaimed (28 species) and existing non-recultivated dumps (9 species).

The dendroflora of the mine dumps is represented by 18 species from 16 genera and 9 families. On these territories, the most part of dendroflora is formed by species of the family *Rosaceae* Jus. – 5 species, Birch (*Betulaceae* C.A. Agardh.) – 3 species and Willow (*Salicaceae* Lindl) – 3 species. The highest density of dendroflora covers in poor soil conditions are formed by species – *Betula pendula* Roth. and *Pinus sylvestris* L.

Carrying out measures to revitalize waste heaps contributes to the formation of richer species of phytodiversity. Instead of this, the process of dumping new layers of rocks on existing heaps of coal mines prevents the formation of vegetation.

The dendroflora of the dumps of uncultivated mines "Zavodska" and "Kovalivska" of the Kolomyia brown coal deposit is much richer compared to the dumps of the mines of the Mezhyrichya coal deposit, which is primarily due to the much longer period (time) of vegetation formation on the dumps. In total, the dendroflora of the dumps is represented by 37 species from 27 genera and 15 families. In the taxonomic composition of the dendroflora leading in the number of species are the families *Rosaceae* Juss. – 11 species, *Salicaceae* Lindl. – 6 species and *Betulaceae* C.A. Agardh. – 5 species.

Woody plants cover mine dumps in fragments and biogroups and are more likely to inhabit the northern slopes, as well as areas with richer and wetter growing conditions. The greatest species diversity of woody plants is characteristic of the lower and middle parts of the slopes of the dumps of the western and northern exposures.

The dendroflora of the slopes of the Yavoriv sulfur quarry and the waste heap № 3 of the Yaziv sulfur deposit is characterized by relatively significant diversity and is represented by 49 species from 31 genera and 17 families. In the taxonomic composition of the dendroflora, the leading species are *Rosaceae* Juss. – 12 species and *Salicaceae* Lindl. – 11 species, which is almost half of the species diversity of woody plants.

Species diversity of dendroflora, formed as a result of natural regeneration (self-healing) of disturbed areas, is much richer (40 species) compared to the diversity formed by planting forest crops (11 species).

The richer species composition of the dendroflora of the slopes of the Yavoriv sulfur quarry (45 species from 27 genera and 15 families) compared to the diversity of the waste heap № 3 (32 species from 23 genera and 13 families) is due to more favorable microclimatic conditions and physicochemical properties of soil environment.

Studies in post-technologenical areas of the Western region of Ukraine have shown that revitalization processes in disturbed areas are due to two main factors: natural succession of vegetation (from the first pioneer tree species to the formation of continuous vegetation) and human economic activity – phytomeliorative crops.) or reclamation measures (creation of a suitable soil cover for vegetation growth and formation of multi-species plant groups).

In general, the process of revitalization of disturbed areas can be carried out in three ways: natural vegetation restoration (self-restoration of disturbed ecosystems), implementation of phytomeliorative or reclamation measures. The choice of ways and directions of revitalization of disturbed landscapes depends on many factors, among which the most important are:

- the degree of change in soil properties and the suitability of soil or potentially fertile species for vegetation growth;
- the degree of change in species diversity and degradation of the biocenosis;
- natural and climatic features and physical and geographical conditions of the territory of violations;
- costs of revitalization of disturbed ecosystems;
- availability of material, technical and labor resources;
- socio-economic and ecological-biological efficiency of revitalization;
- long-term plans for sustainable development of territories.

The main factor that directly affects the process of revitalization of disturbed ecosystems is the physicochemical properties of soil cover, which directly indicates the degree of change in the conditions of growth sites – slightly, moderate, strongly, and deeply changed.

Under slightly changed habitat conditions, ie in the case of a slight change in the edaphotope, the process of natural self-restoration of disturbed ecosystems is possible, or a set of environmental measures to promote the natural restoration of disturbed landscapes.

In areas with moderately changed habitat conditions, the process of long-term gradual self-restoration of soil cover and natural overgrowth of disturbed lands with vegetation is possible, as evidenced by the results of research by both foreign and domestic scientists. However, the implementation of comprehensive measures to promote natural regeneration or phyto-reclamation will significantly reduce the recovery time of post-technogenic ecosystems and prevent the negative effects of environmental disturbances.

Under strongly changed habitat conditions, depending on the degree of suitability of soils and potentially fertile species for vegetation growth, measures of either phytomeliorative or reclamation nature are possible. Instead, in the case of greatly changed habitat conditions, restoration of disturbed lands and the formation of productive phytocenoses and aesthetically attractive landscape can occur only as a result of a set of reclamation measures.

Studies and the works of other scientists suggest that with weak and sometimes even moderately altered habitat conditions, it is not rational to carry out costly phytomeliorative or reclamation measures, and the restoration of post-technogenic ecosystems can occur through natural successions of vegetation – the formation of successive stages – structure of plant communities and more stable biocenoses.

The results of scientific and practical research have identified four main stages of succession of vegetation in disturbed areas:

herbaceous → herbaceous-shrub →weed-shrub-tree → tree-shrub-weed.

The first stage takes place during the first five, sometimes more, years and is characterized by the formation of a mosaic of open plant cover, which consists of pioneer, annual and perennial undemanding to soil richness of herbaceous plants (Table 2).

Table 2. Stages of natural succession of vegetation in post-technogenic areas

Stage of succession	Approximate time limits, years		Features
	begin-ning	end	
I. Grass	from 1	5	The emergence and consolidation of pioneering, undemanding to soil conditions species of herbaceous plants
II. Herbaceous-shrub	5	10	Formation of a variety of grass cover, emergence of oligo- and mesotrophic bushes
III. Herbaceous-shrub-tree	10	15	Formation of continuous vegetation cover and biogroups of tree species (shrubs and trees) pioneer oligo- andmesotrophic species
IV. Tree-shrub-weed	15	more than 25	Formation of a continuous grass cover with the presence of megatrophs, formation of biogroups of different ecological structure of woody plants, including megatrophic shrubs and trees

The second stage is characterized by the formation of complex multi-species groups of plants with distinct zonal features. At this stage, the species composition of annual herbaceous plants decreases, the species diversity of perennial grasses increases, and appear woody plants – shrubs that are unassuming to soil conditions.

The third stage, which begins after 10 years of age, is characterized by differentiation of plant species. At this stage, a solid grass cover is formed, biogroups of woody plants are formed – oligo-, meso- and sometimes even megatrophic shrubs and trees.

At the fourth stage of the succession series, the formation of the final, close to the natural biocenosis takes place. The stage is characterized by the formation of a climax plant community, which is characterized by a complex spatial structure of the biocenosis and the presence of different life forms of grass and tree vegetation.

The main advantage of the process of natural self-restoration of disturbed areas is the formation of new, complex biocenoses without spending material, technical and labor costs (Table 3).

Table 3. Analysis of the advantages and disadvantages, opportunities and threats of natural regeneration of disturbed areas

SWOT- analysis natural regeneration of disturbed areas	Benefits	Disadvantages
	- plant recoverycover without material, technical and labor costs; - natural renewal resistant and stable plant groups; - natural renewal soil cover andformation of a powerful soil profile; - gradual natural self-restoration of productivity biogeocenosis and aesthetic attractiveness of the landscape	- a long period of formation of complex and stable biocenoses (over 25 years); - formation at the initial stage mosaic ruderal herbal cover; - formation at later stages biocenoses ofmulti-plant species with significantly different biomorphological and environmental characteristics; - non-fulfillment of the formed cenoses characteristic target economic and environmental functions; - insignificant stability of the new biocenoses to the action of adverse environmental factors
	Opportunities	Threats
	- succession development biocenoses to climax state; - formation of stable multispecies plant groups	- significant possibility of plant damage by epiphytotic of phyto diseases and entomological pests; - undesirable successional processes; - formation of wrong species composition and structure of biocenoses

However, the process of natural restoration of anthropogenically disturbed areas is characterized by a number of shortcomings, among which the main ones are: a long period of formation of stable phytocenoses; formation of biocenoses from many species with significantly different

biomorphological and ecological characteristics and low resistance of the formed biocenoses to adverse environmental factors. In addition, long-term natural self-restoration of vegetation in disturbed areas often does not lead to rapid neutralization of the negative impact and effects of anthropogenic changes on the environment.

In the case of significant changes in soil structure and physicochemical properties of edaphotope, ie under moderate, very and very strongly changed habitat conditions, a process of long-term gradual natural restoration of soil productivity and overgrowing of techgenically disturbed areas is possible, as evidenced by a number of studies conducted by both foreign and domestic scientists. However, the implementation of phytomelioration or reclamation measures will significantly reduce the time of formation of stable plant communities, restore the productivity of damaged ecosystems and prevent the negative effects of violations on the environment.

Despite the significant material and resource costs in the implementation of measures for the revitalization of post-technological areas, phytomelioration and reclamation have significant advantages over the process of gradual natural self-restoration of disturbed lands, in particular (Table 4):

- ensuring the formation of the optimal species composition of restored plant communities;
- formation of different age and complex spatial structure of biocenoses;
- prevention of undesirable successive processes of vegetation formation;
- reduction of terms of restoration of productivity of soil cover, species diversity of vegetation cover and natural landscape.

Formation of stable and sustainable plant communities in post-technogenic territories is possible only with proper financial support for phytomeliorative or reclamation measures and careful selection of plant species, which should be based on the use of local flora, ecologically adapted to geographical and climatic conditions.

While planning a set of revitalization measures to create productive biocenoses and aesthetically attractive plant communities, it is necessary to proceed from the following principles of landscape formation:

- economic feasibility of phytomeliorative or reclamation measures;
- rational organization of restored territories and landscape;
- functional feasibility of targeted use of restored lands;
- aesthetic value and attractiveness of biocenoses and restored landscape;

– compliance with sanitary and hygienic and environmental standards and requirements.

Table 4. Analysis of the advantages and disadvantages, opportunities and threats of phytomelioration and reclamation of disturbed areas

SWOT analysis of phyto-reclamation and reclamation of disturber areas	Benefits	Disadvantages
	- ensuring the formation of optimal species composition of biocenoses; - formation of different age and complex spatial structure of plant groups; - prevention of unwanted successional processes and changes of species composition and spatial structures of biocenoses; - providing the necessary plant nutrition; - reduction of recovery time of productivity of damaged territories; - formation of aesthetically attractive natural landscape	- significant material and labor costs; - involvement of significant technical and intellectual resources
	Opportunities	Threats
	- formation of different biocenoses; - formation of multispecies plant groups - formation of productive biocenoses; - formation of resistant and stable phytocenoses to influence adverse natural and anthropogenic factors external environment	- lack of funding of necessary phytomeliorative or reclamation measures; - non-compliance with technological process of phytomelioration or reclamation works; - late implementation of agronomic care and economic activities from formation of productive, resistant and stable biocenoses

Adherence to methodological approaches and technological process of revitalization measures depending on the degree of soil disturbance and changes in habitat conditions, as well as the basic principles of landscaping,

will reduce the recovery time of disturbed ecosystems and promote the formation of functional and aesthetically attractive phytocenoses.

Today in Ukraine are carried out significant complex scientific researches and practical actions on creation and formation of aesthetically attractive landscapes in the restored territories. However, the issues of soil revitalization and creation of valuable, close to natural landscapes in disturbed areas remain extremely relevant, especially in areas of intensive exploration, development of minerals in open and underground methods and activities of industrial, mining and processing companies.

The diversity of natural areas of Ukraine, physical and geographical areas, natural and climatic conditions and the nature of technological effects on natural ecosystems necessitates continuous improvement and development of new methods and ways of environmental, phytomeliorative and reclamation measures to revitalize disturbed areas. This, in turn, will not only significantly reduce the recovery time of disturbed biogeocenoses, but also create new productive plant communities and economically valuable and aesthetically attractive natural landscapes on the site of post-technological ecosystems.

Conclusion

In the context of sustainable development, measures to revitalize post-technogenic ecosystems contribute to a number of environmental, economic and social challenges, which together ensure the restoration of land resources, increase species and landscape diversity and the formation of ecological balance in the environment.

The process of revitalization of post-technogenic ecosystems depends on many factors and can take place in three ways: natural vegetation restoration (self-restoration), phytomeliorative or reclamation measures.

The relatively rich phytodiversity of species, the formation of complex and stable plant communities in the post-technogenic territories of the Western region of Ukraine indicates the possibility of a long-term, gradual process of natural self-restoration of disturbed ecosystems.

In the process of self-restoration of the biocenosis can be distinguished four main stages of vegetation succession in post-technogenic territories:

herbaceous → herbaceous-shrub → herbaceous-shrub-tree →
→ woody-shrub-herbaceous.

The advantages of the process of natural self-restoration of disturbed areas are the formation of new, complex biocenoses without material, technical and labor costs. The advantages of phytomelioration or reclamation measures are the formation of multi-species and spatially complex plant

communities and the reduction of recovery time in post-technogenic areas of productive and stable biocenoses.

The formation of resilent and stable plant communities in post-technologic areas is possible only with proper financial support for revitalization measures and careful selection of the range of species composition of plants, taking into account its bioecological characteristics.

Planning of revitalization measures for the formation of productive phytocenoses and aesthetically attractive landscapes should be carried out on the following principles: economic feasibility, rational organization, functional feasibility, aesthetic value and attractiveness and compliance with sanitary and hygienic standards and environmental conditions.

The issues of effective revitalization of ecosystems, choosing the direction of restoration of disturbed, formation of productive phytocenoses and aesthetically attractive landscapes on the sites of disturbed areas are still relevant and require further scientific and practical work, especially in post-technogenic areas.

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