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EFFECTS OF POLLUTION AND CLIMATE CHANGE ON THE ECOSYSTEM COMPONENTS

Edited by
Yuriy V. Lykholat

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The book contains the study results of the environmental and soil conditions of the transformed territories, the ecological patterns of woody plants natural communities' formation as well as the features of the herbaceous communities' succession in flooded areas. The current state of forest areas is highlighted, the problems of forest management and their exploitation in Ukraine are outlined. Aspects of anthropogenic impact on natural aquatic ecosystems are shown and various biotesting methods of negative effects are characterized. The relationship between the presence of exogenous biologically active chemical compounds in the environment and damage to the endocrine system of animals has been revealed.

The scientific manuscript is intended for ecologists, specialists interested in environmental management and environmental protection. The book may be useful for graduate students and scientific researchers.

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Professor Y.V. Lykholat is the author and co-author of more than 620 scientific and methodical publictions. There are 6 monographs (one published abroad), 21 articles in Scopus and 31 in WOS, 2 textbooks, 11 educational and methodical books, 3 of which are stamped by the Ministry of Education and Science of Ukraine, 18 educational and methodological instructions, 5 guidelines for production.

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Professor Y.V. Lykholat was awarded diplomas and thanks of the Ministry of Education and Science of Ukraine, Dnipropetrovsk region, Dnipro City Council, Oles Honchar Dnipro National University, medal "For faithful service of Oles Honchar Dnipro National University " (2013), medal "25 years of the Academy of Sciences of of the Higher School of Ukraine" (2017) and the medal "For services to the city" (2019).

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INTRODUCTION

Environmental problems in Ukraine are numerous and diverse, both global ones (e.g. climate change) and inherent in individual regions. The monograph is an attempt to integrate and analyze the challenges associated with land and water resources depletion and transformation of vegetation cover.

Technogenic devastated lands in the Kryvyi Rih Mining & Metallurgical basin occupy about 29.1 thousand hectares. In thes areas soils were classified as Technosols and having unfavorable for plants properties: a small amount of macronutrients and an excess of heavy metals and very phytotoxic. The reliable relationship exists between the prevalence of woody plant species and characteristics of devastated lands. Afforestation of devastated lands will be the most effective way for protection and improvement of the human environment. The relevance of our research was due to the need to introduce innovative technologies for the reclamation of devastated lands. The objectives of our research were: (i) to reveal the origin, typology and distribution of devastated lands; (ii) to study the ecological and edaphic conditions on the territories; (iii) to identify the patterns formation for woody plant communities.

Industrial underground coal mining in the Western Donbass coal basin led to llandscapes transformation, pollution of underground and aboveground runoff waters, and violation of natural steppe herbaceous phytocenoses due to a radical change in soil nature and plant habitats in general. Our studies concern the spontaneous herbaceous vegetation in permanently flooded areas of the former pastures. We assumed that successional trajectory in the flood zone should differ from both primary successions in technogenic ecotopes and secondary successions after the disturbances. The purpose of research was to study plant species composition in the zone of permanent technogenic flooding, reveal the correlation between vegetation and habitat types having different disturbance degrees, and suggest a potential trajectory for the formation of spontaneous herbaceous vegetation over an extended period.

Forest management and exploitation in Ukraine are hampered by the fragmentation of forests between different “owners”, including State Forest Resources Agency (68.5%), Ministry of Agrarian Policy (16.7%), other ministries and agencies (1.85%).

In Sumy Region, the reduction in the area of natural reserve fund reached 17.8 % in recent years. In addition, forest ecosystems are being polluted and degraded, so forest monitoring is one of the main functional tasks of forest management.

The legal basis for forest monitoring is provided by the document "Voluntary Guidelines for National Forest Monitoring", adopted by the UN in 2017. The transition of forest management to the principles of environmentally friendly forestry provides for outright ban on the concentrated felling for primary use. This enables to preserve the biodiversity of forest ecosystems, transfer the process of reforestation into a natural pathway, and protect forests from fragmentation.

The scale of global hydrosphere pollution is so significant that processes of self-cleaning and self-healing in some parts of the world cannot neutralize the toxic effects of human economic activity. Our paper presents method of natural and drinking waters complex testing based on the methods of analytical chemistry, microbiology, radiology and biotesting, which establish the minimum risk for human health. Waters quality of centralized water supply for Kyiv (source Dnieper and Desna water in the water intakes) corresponded to the category of "safe water". Negative anthropogenic impact of megacities on the natural aquatic ecosystem was confirmed by an increase in the general toxicity index of the Dnieper waters that varied from 10 to 120 conventional units as the territory of the metropolis. Chlorination of tap water significantly increases toxicity of source water due to formation of persistent organochlorine compounds. Biotesting of artesian waters showed high quality (category "safe water") for most pumping stations located in different areas of Kyiv. Biotesting methods should be used at all stages of water quality assessment, including the final (risk characterization), in which the main criterion may be environmental and epidemiological risk assessment for public health.

The environmental and nutritional risks associated with the presence of exogenous endocrine disrupting chemical (EDCs) are closely related to their side effects on living things. Endocrine disrupting activity is inherent in many compounds, such as animal growth promoters, pesticides, antibiotics, veterinary medicines, lead and cadmium, and foods containing phytoestrogens. These agents can interfere with hormone action, and many have been shown to impact metabolic function, and increase disease risk in metabolic organs. Studies of EDCs activity should include screening of toxicants and clarification of the safe threshold for the level of EDCs in the terrestrial, aquatic and human.

CHAPTER 1

FORESTING OF TECHNOGENIC DEVASTATED LANDS AS AN EFFECTIVE FACTOR FOR ENVIRONMENTAL SAFETY AT THE MINING & METALLURGICAL DISTRICT

Vasyl M. Savosko, Yuriy V. Lykholat and Yulia V. Bielyk

As you know, environmental safety is determined by a combination of many factors at modern industrial areas, including mining & metallurgical districts. However, in most cases, the list of environmental safety factors includes: (i) "conditional planned" and impacted pollution of the environment (air, surface / groundwater, soil, etc.), (ii) the probability of accidents at industrial enterprises, (iii) efficient use of natural resources, (iv) conservation of species diversity in natural ecosystems, (v) human health, etc. However, in fact it remains the attention of researchers' current state, further development and ecological consequences for natural ecosystems and human society from separate territories, formed as a result of mining and mining & metallurgical activities.

Nowadays, such areas are called post-mining lands. Such lands are characterized by: full destruction of vegetation and soil cover, radical change of hydrological regimes as well as the formation of positive and negative forms of mesorelief. It should also be noted what impressive area of such lands (over 1.0 million hectares), their location near people's homes and their powerful negative impact on the human environment update our research (Boyce, 1975; Chajka, 2014; Denysyk et al., 2012; Kvitko & Savosko, 2018; Bielyk et al., 2019).

It is very important: (i) for these lands – clarification of origin, development of their typology and information generalization about their distribution; (ii) study of ecological and edaphic conditions on the territories of these lands; (iii) identification of ecological patterns formation for woody plant natural communities natural in their areas. Consistent consideration of these scientific problems was the purpose of our publication. The logical conclusion of our publication was a scientific substantiation of ways to use woody plant species on technogenic devastated lands for optimize of the environmental sustainability and increase environmental safety at the Kryvyi Rih mining & metallurgical district.

Technogenic devastated lands

In our opinion, it is expedient to use the term "devastated" lands " for the generalized name of territories which were formed as a result of mining and metallurgical activities at Kryvyi Rih Basin (Savosko et al., 2018b, 2019a, 2019b; Bielyk et al., 2019). By devastated lands we mean lands whose soils have partially and / or completely lost their natural potential (primarily fertility, environmental and biosphere functions) due to the influence of certain factors. Etymologically, the word "devastated" comes from the Latin word "devastatus", which means ravaged by natural and anthropic activity. That is, in our opinion, devastated lands are lands where soils are plundered in comparison with natural analogues. It should also be noted that the term "devastated lands" is not completely new to the Ukrainian scientific community. However, its use is not numerous and widespread among representatives of scientific schools of Lviv region and adjacent areas.

First of all, it should be noted that the main causes of devastated lands are the negative factor's consequences: (i) a natural origin (a natural processes results) and (ii) anthropogenic origin (a human activity's results) were the main causes of devastated lands. A combination of these factors is also possible. In this regard, natural and anthropogenic land devastation should be distinguished (Fig. 1.1). Possible cases when in soils by man u influence the natural processes change of flow direction with negative consequences.

For example, man causes natural processes an imbalance soil formation and soil erosion. Therefore, the following negative consequences are possible: acidification, alkalinization, salinization, dehumidification, loss of macronutrients and micronutrients, deflation and loss of land.

As a result, hydrogen- and aerogen-devastated lands are formed. They are a certain analogue of unproductive lands. Certain natural phenomena (volcanic eruptions, forest fires, earthquakes, tsunamis, etc.) can lead to more radical negative consequences for lands. In particular, it may be the entry of exogenous elements into the soil, changes in the hydrological regime of the soil, the destruction of vegetation and the loss of humus-containing soil layer. As a result, geogenically devastated lands were formed. They are a definite analogue for degraded lands (Fig. 1.1).

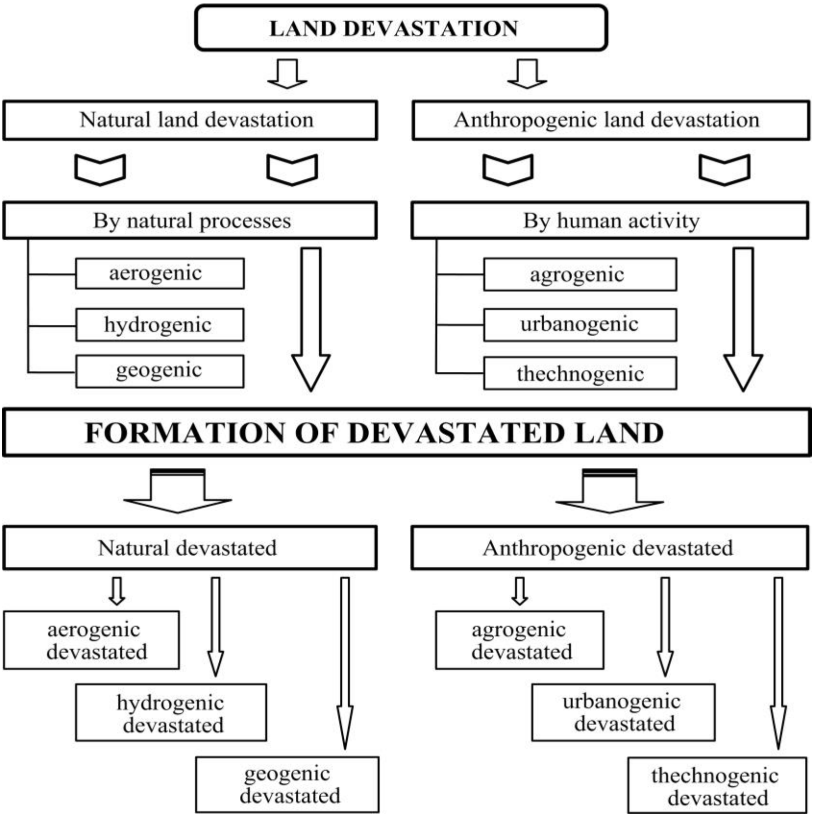

Fig. 1.1. **Conceptual pattern of devastated lands basic categories formation**

Anthropogenic impact on land resources and soil condition is primarily characterized by a significant increasefor all the previously mentioned negative consequences, inherent in natural devastation.

In addition, anthropogenic factors additionally lead to: destruction of soil cover, accumulation of human waste on the surface, extraction of rocks from the subsoil. As a result, there was the formation of an area without soil cover and the occurrence of positive / negative mesorelief's forms. As a result, agrogenic, urbangenic and thechnogenic devastated lands were formed. They are analogs of disturbed and worked lands (Fig. 1.1).

At mining and metallurgical areas, it is very important to study mainly thechnogenic devastated lands to ensure environmental safety in these districts. This term should be understood as land plots, the soils of which have completely lost their natural fertility potentials due to the impact of human industrial activities. Identification features for such lands are: complete destruction of vegetation cover and soil cover, change of soil's hydrological regime, as well as, in most cases, occurrence of the mesorelief form.

All varieties of thechnogenic devastated lands should be organized into three conditional groups, which are determined by the peculiarities of their relief (Fig. 1.2).

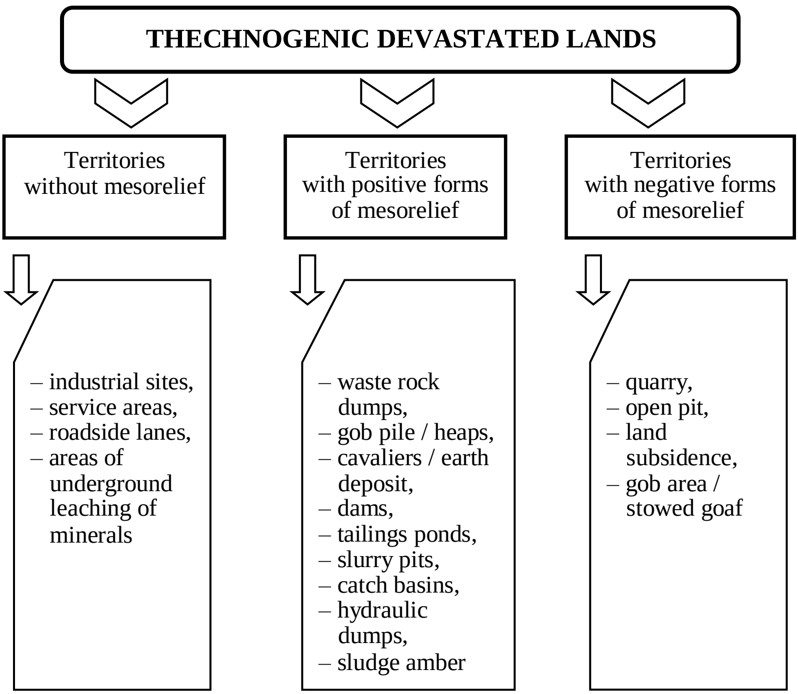

Fig. 1.2. **The main types of the thechnogenic devastated lands**

To the first group we include the same areas where the elements of the mesorelief are virtually absent. However, on such lands anthropogenic impact was manifested only in the destruction of vegetation and soil cover, as well as in changes of the hydrological regime (man-made aquifers formation). In most cases, the devastated lands that we belong to this group are represented by: industrial sites (locations of enterprises), service sites (locations of ancillary services), roadside lanes, as well as areas of underground leaching of minerals (Fig. 1.2).

Since the second half of the twentieth century features of mining and metallurgical activity was the formation of a significant amount of waste and extraction from the bowels of a large number of rocks that were irrelevant for further use. Due to this, there was an urgent need to organize technological processes and build special structures for their preservation. In these rock fill were located: overburden rocks, substandard minerals and industrial waste. Depending on the time and technology of formation, artificial embankments were named: waste rock dumps, gob pile / heaps, cavaliers / earth deposit, dams etc. (Fig. 1.2).

Modern mining and metallurgical activities annually generate a significant amount of special waste. This waste is in a liquid and / or suspended state. So for their storage the construction and operation organization of special hydraulic structures were needed. Depending on their characteristics, the name of the waste, as well as historical habits such structures were named: tailings ponds, slurry pits, catch basins, hydraulic dumps, sludge amber etc. (Fig. 1.2).

Devastated lands with a negative mesorelief mainly represented by: quarry, open pit, land subsidence, gob area /stowed goaf (Fig. 1.2). The Quarry and open pit were formed immediately in the open method of mining. While, the land subsidence and a gob area / stowed goaf were derivatives of the underground mining (extraction of irone minerals). They were formed only over time as a result of subsidence and collapse of rocks in underground voids.

The first man-made devastated lands, in our understanding, began to form in the Paleolithic era at the same time as the first mining. The oldest known was about 40 thousand years later, the Lion's Cave, Swaziland, South Africa. However, until the middle of the twentieth century, due to the limited technical capabilities of man, the area of such lands was insignificant. Only an industrial and tumultuous era since the second half of the last century caused the formation of the impressive diversity and large areas of such land.

In the Kryvyi Rih Mining & Metallurgical District the thecnogenic devastated lands began to form in 1881, simultaneously with the start of industrial iron ore mining. However, the peculiarities and intensity of this process were different and depended on the then socio-economic preconditions, as well as trends in the use of mining technologies. The main factor in the formation of such devastated lands was the ratio of underground (mine) and open (quarry) methods of ore mining.

In this area the largest size of the thechnogenic devastated lands were formed during 1955–1991. At this time in Kryvyi Rih District were built five superpowers ore mining and processing plants, modern heavy-duty production at the metallurgical plant (Pluhina et al., 1981; Tereschenko, 1992; Mazur & Smetana, 1999; Denysyk et al., 2012). At this Basin during the 70s and 80s of the 20th century the annual levels productions were: iron ore mining 150–190 million tons, production of concentrators (agglomerate, rolling stock, concentrate) 40–50 million tons, smelting of pig iron and steel 10–15 million tons (Bulava, 1990; Mazur & Smetana, 1999; Pluhina et al., 1981; Tereschenko, 1992; Malahov, 2009). Such an impressive scale of mining and metallurgical activities naturally influenced on the formation of thecnogenic devastated lands in this area.

By our generalization, in the Kryvyi Rih mining and metallurgical District the size of thecnogenic devastated lands is about 29.1 thousand hectares (Table 1.1). Quite naturally, most of these lands were formed in the period 1955–1990.

Table 1.1

Thecnogenic devastated lands in Kryvyi Rih mining and metallurgical District (after L. M. Bulava (1990), V. L. Kazakov (Kazakov, 1999), I. M. Malahov (Malahov, 2009) with additions and generalizations)

Thecnogenic devastated lands	Average		Maximal		Size	
	length, km	width, m	depth, m	height, m	thousand hectares	%
Quarry	7.5	1.2	400	–	5.20	17.87
Waste rock dumps	4.5	1.2	–	90	7.00	24.05
Tailings ponds	3.2	2.0	–	70	9.00	30.93
Land subsidence and gob area	4.3	0.5	1300	–	4.40	15.12
Industrial sites	–	–	–	–	3.50	12.03
TOTAL					29.10	100

With, the thecnogenic devastated lands that were formed in the late nineteenth century and early twentieth century, as well as in the interwar period, in most cases they were "absorbed" by the following "waves of nature transformation". Such lands remained in small quantities, and today they are historical and biological artifacts (Bulava, 1990; Kazakov, 1999; Malahov, 2009).

In general, at Kryvyi Rih mining and metallurgical District from 29.1 thousand hectares of thecnogenic devastated lands 25.6 thousand hectares (87.87% from total size) are territories where anthropogenic mesorelief was formed. Among such areas devastated lands with positive forms of mesorelief (waste rock dump and tailings ponds) are dominant (62.50% from total size).

Ecological and edaphic conditions of the thecnogenic devastated lands

In the Kryvyi Rih mining & metallurgical District reclamation works provided by the legislation were not actually conducted on thecnogenically devastated lands after the end of their use. Over time, spontaneous soil cover and vegetation are formed on their territory. These phenomena have become a testing ground for a variety of scientific studies (Dobrovol'sky et al., 1979; Dobrovol'sky, Shanda, 1982; Denysyk et al., 2012). Finding out the essence of soil and vegetation restoration is the key to development and implementation effective measures for their reclamation. The first step to learn about the ecological features of thecnogenic devastated lands is a comprehensive study of primitive (initial) soils in these areas

In the devastated lands of the Kryvyi Rih area, the initial pedogenesis was carried out on the following parent rocks:

a) iron quartzites (different geological composition and particle size),

b) shales (usually large particle size – more than 100 mm),

c) loesslike loams (non-carbonate and carbonate),

d) clays (different genesis and different particle size distribution). In general, geological rocks are a significant factor for the initial soil formation on devastated lands. At the same time, the most favorable for the formation of soils are forest-like loams, as well as clays, loams and sand loams from the sedimentary cover. The least favorable conditions for soil formation are observed in tailings ponds and slurry pits tailings and sludge storages.

According to the recommendations of the World reference base (WRB), soils on devastated lands in Kryvyi Rih area can be classified as *Technosols* (WRB, 2015). On some devastated lands the following soils were formed:

a) *Spolic Technosol* (*Ochric*) – on the waste rock dumps of old mines (historical name is "cavaliers");

b) *Spolic Technosol* (*Phytotoxic, Arenic, Aridic, Magnesic*) – on Tailing ponds facility of Underground Iron Mines;

c) *Spolic Technosol* (*Humic, Loamic, Calcaric*), *Spolic Technosol* (*Ochric*, *Loamic*) and *Spolic Technosol* (*Arenic, Aridic, Magnesic*) – on waste rock dumps of ore mining and processing plants;

d) *Spolic Technosol* (*Ochric, Loamic, Dolomitic, Calcaric*) – on Waste rock dumps of Granite Quarry Plant.

Physical and chemical characteristics of soils

The results of our research show that on the devastated lands at the Kryvyi Rih area chemical and physical properties of young soils are characterized by unfavorable indicators (Table 1.2). Thus, the organic matter content of the soi ranged from 7.93% to 22.10% (average 9.10%–12.88%).

Table 1.2

Chemical composition of the *Technosol* from devastated lands at Kryvyi Rih Mining & Metallurgical District (X ± SE)

Devastated lands	Organic matter content, %	pH		Cation-exchange capacity		
		pH_{H2O}	pH_{KCl}	Total, mMol /100 g	Ca, % from total	Mg, % from total
1	2	3	4	5	6	7
Waste rock dumps of old Iron Mines (old name “Cavaliers”)	9,97±1,05	7,58±0,01	6,74±0,02	6,62±0,26	59,67	40,33
Tailing ponds of Underground Iron Mines	–	8,81±0,02	8,10±0,01	7,80±0,35	85,88	14,12
	–	8,79±0,01	8,09±0,02	7,93±0,32	89,03	10,97
	–	8,92±0,01	7,92±0,01	8,47±0,38	88,55	11,45
	–	9,01±0,01	8,23±0,02	7,00±0,31	83,86	16,14
	–	9,14±0,02	8,23±0,01	6,34±0,21	73,66	26,34
	–	9,19±0,01	8,59±0,02	6,00±0,19	62,17	37,83
	–	8,90±0,01	8,38±0,01	6,74±0,25	60,39	39,61

(Continued Table 1.2)

1	2	3	4	5	6	7
Tailing ponds of Underground Iron Mines	–	7,72+0,01	8,06+0,02	2,60+0,13	35,77	64,23
	–	7,51±0,02	7,64±0,01	2,06±0,11	54,85	45,15
	–	8,82±0,01	8,34±0,02	4,14±0,19	45,17	54,83
Waste rock dumps of ore mining and processing plants	16,20+0,89	8,83+0,01	7,88+0,01	25,12+1,25	52,75	47,25
	11,16±0,86	8,51±0,02	7,35±0,02	6,66±0,20	68,32	31,68
	12,85±1,02	8,08±0,01	7,22±0,04	9,57±0,38	56,53	43,47
	9,53±0,78	7,66±0,02	7,49±0,01	9,14±0,39	53,06	46,94
	8,75±0,99	8,57±0,01	7,79±0,01	11,56±0,42	49,05	50,95
	7,93±1,11	8,45±0,01	7,99±0,01	7,72±0,23	43,91	56,09
Waste rock dumps of Granite Quarry Plant	11,44±1,14	8,72±0,02	7,42±0,02	7,42±0,27	73,58	26,42
	11,09±1,19	9,18±0,02	7,35±0,02	7,30±0,25	79,45	20,55

Note. $\overline{X}$ – mean, SE – standart error, «–» – organic matter is absent in the roots soil layer (0–20 cm).

These values are lower by 2.5–3.5 times than in the *Chernozems*, which are native soils of this area. It should also be noted that there was no accumulation of organic matter in the soils that were formed on nailing ponds of underground iron mines. This fact can be explained by the characteristics of the tailings as an unfavorable material for soil formation.

In the zonal soils of the Kryvyi Rih area the soil acidity is in *Chernozems ordinary* – 7.00–7.15 and in the *Chernozems southern* – 7.25–7.55 (Savosko, 2015). However, in the soils of devastated lands, these characteristics are higher. Thus, the actual acidity of soils ranges from 7.08 to 9.19 (average 8.18–8.81), the metabolic acidity of soils ranges from 7.60 to 8.06 (average 6.74–8.59). In general, soil formation on the devastated lands of this district was obtained in very alkaline conditions.

As know, cation exchange capacity (CEC) is a measure of how cations can be retained on the surfaces of soil particles. Usually, in the zonal soils of the Kryvyi Rih area CEC reaches values: in *Chernozems ordinary* 35–40 mmol / 100 g soil and in *Chernozems southern* 30–35 mmol / 100 g soil (Savosko, 2015). According to our research, in the soils of devastated lands CEC values were by 2–20 times lower (Table 1.2). CEC values ranged from 2.01 mmol / 100 g soil to 25.12 mmol / 100 g soil (average 5.62–10.18 mmol / 100 g soil). It is important to note that in the natural soils of this district ss part of CEC, 75–80% is Calcium and 15–25% is Magnesium.

While, in the soils from devastated lands as part of CEC, the percentage of Calcium ranged from 35.77% to 89.03% (average 56.16–71.81%) and the percentage off Magnesium ranged from 10.97% to 64, 23% (average 28.19–43.84). It should also be noted that in some cases in the composition of CEC the proportion of Magnesium was greater than the proportion of Calcium.

The macronutrients and heavy metals content in soils

In some model sites at devastated lands of Kryvyi Rih area (Petrovsky waste rock dumps) we investigated the content of macronutrients (Potassium, Sodium, Calcium, Magnesium, Sulfur and Phosphorus) and heavy metals (Iron, Manganese, Zinc, Lead, Copper and Cadmium) in soils. The obtained results allowed us to comprehensively assess the geochemical and biogeochemical characteristics of these soils (Bielyk, et al., 2020).

Analysis of the results showed that in soils from the devastated lands of the Petrovsky dump macronutrient content was characterized by multi-vector patterns. So, Potassium and Sodium concentrations are mostly either at the level of control values, or slightly higher (by 10–13%). As an exception only at one experimental site the amount of these macronutrients in the soil was lower than the control (7–8%).

In some experimental sites we found a serious deficiency of Calcium and Magnesium in the soil. Since the concentrations of these macronutrients were 2–5 times lower than the control values. In other research sites, we found excessive amounts of Calcium and Magnesium in the soils of these devastated lands (by 1.3–2.5 times higher than control). Increased Sulfur content (in some cases up to 4–5 times) was found in the soils of all experimental plots. This fact may have a phytotoxic effect on the plant. Phosphorus concentrations in soils were at the level of control values in only one site. While on some sites the concentrations of this element were significantly higher than the control (24–42%), and on others were below the control (1.5 times).

In the soils of the devastated lands at Petrovsky dump, we found an increased content of Iron, Manganese, Copper, Cadmium and Zinc (in part). These metal concentrations were 1.2–5.9 times higher than the control values. It should also be noted that in these soils Lead concentrations were 1.5–27 times less than the control values. In the soils of these devastated lands Zinc was characterized by multi-vector patterns of its concentration.

Thus, in some experimental sites the values of Zinc content in the soil were below control (7–14%), in other experimental areas were slightly higher than control (1.4 times). And in one site the concentrations of this metal in soils were on the same level with the control values.

Phytotoxicity of soils

As we noted earlier, among thecnogenic devastated lands the tailings ponds are the most dangerous, which greatly destabilize the state of the environment in industrial areas. In this regard their in-depth study is very important, in particular, the assessment of phytotoxicity of their soils. The method of phytotesting, as a type of biotesting, is widely used in modern environmental research. It should also be noted that lately to clarify and study the chemical regimes of soils various extractants have been proposed. These extractants mimic the action of the root system of plants. Practical approbation of such extracts allowed choosing from them the most adequate / perspective for further use in agrochemistry, soil science, geochemistry and environmental protection. That is why it is so important to conduct a study of direct phytotesting of soils from devastated lands of tailings with the use of various extracts.

In the middle of the last century at the Kryvyi Rih area a number of mine ore mining and processing factories were built, which also led to the construction of mine tailings ponds. However, in the future mine beneficiation of iron ore lost its relevance.

In most cases mine tailings ponds were also left without reclamation. Over time, in their territory spontaneous plant community and young soils were formed. In this context mine tailings ponds at Kryvyi Rih area are a unique, from a scientific point of view, "landfill" for various environmental studies (Savosko, 2011b, 2014, 2016; Savosko et al., 2020).

Analysis of the results proved that at the Kryvyi Rih area the soils of the devastated lands of mine tailings ponds are characterized by significant differences in phytotoxicity. This phenomenon is manifested in the suppression of morphometric parameters of test plants. This was proved by the following methods of phytotesting of these soils: direct phytotesting and use of several extracts (distilled water, 0.05 *N* Trilon-B, 1 *N* sodium chloride). It was also found that for future practical phytotesting of soils in virgin lands 1 N sodium chloride is the most promising reagent.

Soil scientists have proved that a single-normal solution of sodium chloride, due to active interaction with the soil absorption complex, quite informatively indicates its qualitative and quantitative characteristics. Therefore, this reagent is widely used in various chemical studies for soil samples.

The analysis of the obtained experimental data showed that there was a small statistically significant suppression of all biometric parameters of the test plant sprouts (ryegrass pasture (*Lolium perenne* L.) cultivar "Drohobych-2"). Thus, the root length of the test plants was 15–40%, and the height of the aboveground part of the test plant was 40–65% lower than the control values ($P < 0.05$). Also, it should be noted that the aerial part of the test plant was more sensitive to this environmental factor. This phenomenon was found in all variants of the experiment (Fig. 1.3).

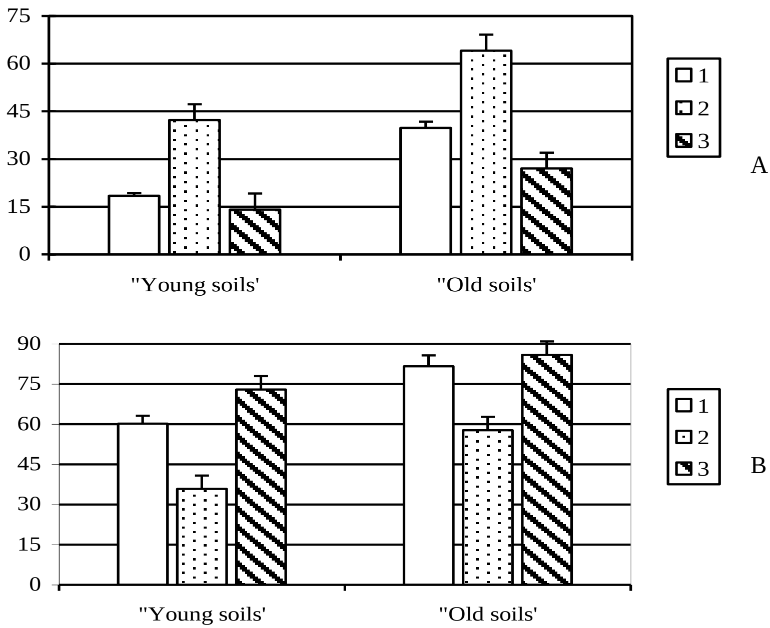

Fig. 1.3. **Phytotoxicity of soils of mine tailings ponds devastated lands at Kryvyi Rih Mining & Metallurgical District:**
A – GII (Growth Inhibition Index); B – percentage to control;
«Young soils» – from Artem mine tailings ponds,
«Old soils » – from Lenin mine tailings ponds;
1 – root length, mm; 2 – height of the aboveground part, mm; 3 – the ratio of height.

Among the studied soils were more phytotoxic samples from the tailings ponds of the Artem mine ("young soils"). This fact can be explained primarily by the age of these devastated lands and the peculiarities of the technological scheme of their formation.

In general, the ecological and edaphic conditions of thecnogenic devastated lands at the Kryvyi Rih mining and metallurgical district are characterized by:

a) fragmentary soil cover of low-power primitive soils;

b) unfavorable for plants physical and physicochemical properties;

c) in most cases, a small amount of macronutrients and an excess of heavy metals;

d) in some cases very phytotoxic properties. Therefore, it is important to analyze and identify environmental patterns of formation of natural woody plant community on the devastated lands at the Kryvyi Rih area.

Woody plant community on thecnogenic devastated lands

In our time, the formation of woody plant communities are considered to be the very most promising method for reclamation of the thecnogenic devastated lands in industrial areas. Herewith, these man-made woody plant communities must be able to realize their ecological potential as a natural forest (Bekarevich et al., 1971; Boyce, 1975; Lykholat et al., 2019; Savosko, Kvitko, 2017).

That is why, since the late 60's of the twentieth century, numerous scientific studies have been conducted regularly. The main purpose of these studies was to identify the composition and structure of spontaneous vegetation on thecnogenic devastated lands. It was believed that understanding the philosophy of these process will be the scientific basis for future technology of the restoration, optimization and reclamation such lands (Bielyk, et al., 2019; Savosko et al., 2018b, 2019b). Since the species of plants that grow naturally on these lands are the most adapted to their ecological conditions and are therefore promising for future woody plant communities.

Taxonomic composition of the woody plant communities

We summarized the results of our own research (Savosko & Alekseeva, 2007; Bielyk & Yevtushenko, 2018; Savosko et al., 2018b, 2019b; Bielyk et al., 2019, 2020) as well as data from publications other scientists (Davyidov et al., 1971; Dobrovol'sky, 1980; Pluhina, 1981; Tereschenko, 1992; Reva et al., 1993; Tarasov et al., 2003; Korshikov et al., 2008; Saphonova & Reva, 2009; Denysyk et al., 2012; Korshikov & Krasnoshtan, 2012; Korshikov et al., 2012; Lysohor et al., 2017; Pavlenko et al., 2017). As a result, we found that in the devastated lands in the Kryvyi Rih area, the taxonomic composition of woody plants includes 81 species from 46 genera and 23 families (Fig. 1.4). It should be noted that among these woody plants, 78 species (96.3% of their total number) are from Angiosperms (Magnoliophyta) and only 3 species are (3.7%) from Angiosperms (Pinophyta). However, all these plant species are found in the central and northern parts of the Kryvyi Rih area.

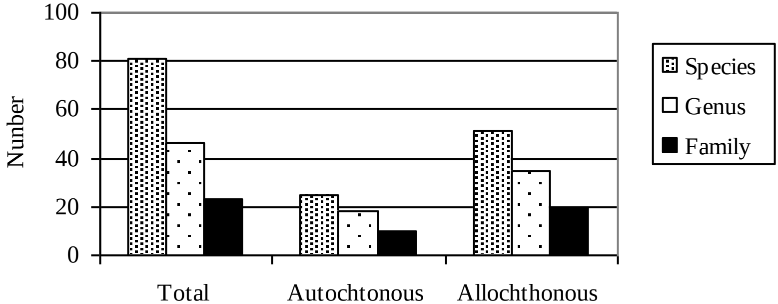

Fig. 1.4. **Taxonomic characteristics of woody plant species naturally growing on thecnogenic devastated lands at Kryvyi Rih Mining & Metallurgical District Rih**

The analysis showed that among the tree species by the number of genera and species of the leading families are: Rose (Rosaceae) – 14 genera and 22 species, Willow (Salicaceae) – 2 genera and 12 species, Maple (Aceraceae) – 1 genus and 6 species, Legume (Fabaceae) – 4 genera and 5 species, as well as Elm (Ulmaceae) – 1 genus and 4 species. Other families of woody plant were less taxonomically rich and in 39% of cases the families were mono-species. Among the genera of woody plants, the most numerous were: Poplar (*Populus*) – 10 species, Maple (*Acer*) – 6 species, as well as Elms (*Ulmus*) and Cherries (*Prunus*) 4 species each.

Biogeographical characteristics of the woody plant communities

Recently, researchers have used different terms to refer to "Native" and "Non-native" plant species in the biographical analysis of the flora. However, in our opinion, it is most appropriate to use the terms "Autochtonous" and " Allochthonous" species. The autochthonous plant species for a certain territory are species that have arisen or have lived within its boundaries since ancient times. The alachthonous species of plants for a certain area are species that are outside their natural areals.

It should be noted that there are still some methodological difficulties in determining the biogeographical status of plant species: "Autochtonous" ore "Allochthonous". Not intending to enter into this discussion, we later used the following assumption. We believe that for Kryvyi Rih area the alachthonous species of woody plants are only those species that are common in the natural flora of this area. Alachthonous species should be present in the flora of the Dnipropetrovsk region (Tarasov, 2005) and in the flora of the Right-Bank steppe Dnieper (Kucherevsky, 2004).

Analysis of the results showed that among the woody plant species that grow naturally on the devastated lands of Kryvyi Rih area, 25 species (or 30.9% of their total number) from 18 genera and 10 families are autochthonous. While the allochthonous e 51 species (69.1%) from 35 genera and 20 families (Fig. 1.4). In my opinion, this distribution of woody plant species in relation to their natural areals is somewhat paradoxical. However, this result once again emphasizes the ecological uniqueness of the devastated lands at this district.

With the help of the principles of floristic zoning of the globe A. L. Takhtadzhan (Taktadzan, 1978), we produced a biogeographic analysis of woody plant that grow naturally on devastated lands of Kryvyi Rih area. Woody plants,which were found on thecnogenic devastated lands at Kryvyi Rih area, were naturally distributed in the Boreal, Ancient Mediterranean, Madrean subkingdoms of the Holarctic kingdom (Taktadžan, 1978). The areal of 9 species (11.11% of their total number) are located within one floristic area, the areal of 22 species (27.16%) are located within two oblasts, the areal of 38 species (46.91%) are located within oblasts and the areal of 7 species (8.64%) are located within four or more oblasts. It should also be noted that the five species, as hybrids, have an uncertain origin.

It should also be noted that woody plant species are distributed over 10 geographical elements from 4 groups of areals. Due to the antiquity of the culture, we were not able to establish a natural areals for the following 3 species: Sour Cherry (*Cerasus vulgaris* Mill.), Domesticated Apple (*Malus domestica* Borkh.) and Garden Plum (*Prunus domestica* L.). Due to the hybrid origin, we did not establish a natural range for the following 2 species: Berlin Laurel Poplar (*Populus* × *berolinensis* K.Koch) and Gray Poplar (*Populus canescens* Sm.).

On the whole, the biogeographical characteristics of woody plant species, as they grow naturally on the devastated lands of Kryvyi Rih area, are very special.

Synanthropic and invasive characteristic of the woody plant communities

According to modern ideas in phytoecology (Protopopova et al., 2002, 2009; Kucherevsky, Shol, 2011), all species that grow naturally in the conogenic biotopes are synanthropic plant species. Because such plant species benefit from the effects of anthropogenic changes in the environment. Therefore, it is expedient to consistently characterize woody plant species that naturally grow on the devastated lands of Kryvyi Rih area according to synanthropic criteria – as apophytic and as anthropophytic (adventitious) fraction of synanthropic flora.

In the modern sense, apophytes are alachthonous species that have fully or partially adapted to anthropogenic habitats. According to the degree of naturalization among epiphytes (Protopopova et al., 2014; Zavialova, 2017) there are:

a) evapophytes (prefer anthropogenic biotopes),

b) hemiapophytes (common in both natural and anthropogenic biotopes),

c) eventopophytes (common mainly in natural biotopes) and only occasionally grow in anthropogenic habitats).

The analysis of the obtained results showed that in the apophytic fraction of woody plant species by the degree of adaptation to the ecological conditions of the devastated lands hemiapophytes predominate – 16 species or 64%. For such species, devastated lands of this area are not unalterable habitats.

The second position is occupied by eventoapophytes – 8 species or 32%. These species accidentally got into the same territory, as they are mainly common in natural habitats. Evepophytes are only 1 species or 4%, but they are best adapted to the difficult ecological devastated lands of Kryvyi Rih area.

Anthropophytic (adventitious) species of rolsin are characterized by three features (Protopopova et al., 2002; Kucherevsky & Shol, 2011):

a) by time of application,

b) by method of application,

c) by degree of naturalization.

At the time of introduction of woody plant species among adventitious species euneophytes predominate – 35 species or 62.50%. These species came to Ukraine in the XX century at the same time as large-scale mining of iron ore, which led to the formation of a modern anthropogenic landscape in this area. Significantly fewer of the adventitious species are neophytes (19 species or 33.93%). They came to our country in the XV–XIX centuries. Only 2 species (3.57%) are archaeophytes, ie such. They came to Ukraine before XV century.

It is established that by method of introduction among anthropophytic woody plant species ergasiophytes predominate – 48 species or 85.71%. These species were deliberately introduced into this area ("relict cultures").

Among anthropophytic woody plant species xenophytes were significantly less than only 6 species or 10.71%. The leading method of their introduction was accidental entry into new areas due to unintentional human activities. Acolyutophytes have the smallest number only 2 species or 3.57%. They got to new areas also as a result of unintentional human activity. However, the ecological conditions of devastated lands are most favorable for the growth and development of these species.

We found that ergasiophytes dominate (20 species or 35.71%) by degree of naturalization among anthropophytic woody plant species that grow naturally in the devastated lands of Kryvyi Rih area. These species have an average level of naturalization – they are wild cultivated plants. Epecophytes have much lower positions – 12 species or 21.43%. Species from this category were maximally naturalized exclusively in anthropogenic habitats. Colonophytes have a slightly smaller number (9 species or 16.07%). These species are able to form colonies or primary populations and begin to spread due to Diasporas formed in the new conditions.

Fractions of ephemerophytes and aerophytes have the smallest number of 8 and 7 species or 14.29 and 12.50%, respectively. However, the degree of their naturalization differs significantly. Thus, ephemerophytes are characterized by an inability to adapt to new areals. While, aerophytes are characterized by a complete naturalization and to natural and to anthropogenic habitats. These species are also able to compete with native species.

Recently, among anthropophytic plant species, researchers have singled out and analyzed the so-called invasive species. Since these plant species are characterized by extremely intensive methods of reproduction in the secondary area (particularly in devastated lands) and a high degree of naturalization (Protopopova et al., 2002; Shol, 2016; Zavialova, 2017). In this regard, invasive plant species deserve special attention because of their significant threat to biological diversity for the Kryvyi Rih area, as well as for Ukraine and the world. It should also be noted that such species are very dangerous for the local flora and especially for rare and relict species. In addition, uncontrolled invasion of adventitious species can interfere with natural succession processes and significantly reduce the potential for self-healing of certain areas (Protopopova et al., 2002, 2009, 2014). That is why the prevention of possible consequences of plant species invasions remains above the urgent problem of the XXI century.

The creation of lists is potentially dangerous for woody plant species is an effective way to prevent. The experience of A. V. Zavialova (Zavialova, 2017) is very successful and promising. This author proposed the identification and ordering of plant species that are dangerous to the phytodiversity of the nature reserve fund of Ukraine. In addition, this author proposed at different levels (according to the degree of threat) three lists of plant species:

a) Black List,

b) Gray List,

c) Watch List.

Black List contains the most dangerous invasive plant species. Gray List contains dangerous invasive plant species. The Watch List contains potentially dangerous species of invasive plants. Among the anthropophytic woody plant species that naturally grow on the devastated lands of the Kryvyi Rih area, 4 species are from the Black List. Such species are Desert False Indigo (*Amorpha fruticosa* L.), Northern Red Oak (*Quercus rubra* L.), Ashleaf Maple (*Acer negundo* L.), Black Locust (*Robinia pseudoacacia* L.).

The following 7 species are from the Gray List: Copal Tree (*Ailanthus altissima* (Mill.), Common Lilac (*Syringa vulgaris* L.), Chinese Elm (*Ulmus pumila* L.), Honey Locust (*Gleditsia triacanthos* L.), Thicket Shadbush (*Amelanchier spicata* (Lam.), Russian Olive (*Elaeagnus angustifolia* L.), Black Chokecherry (*Prunus serotina* Ehrh). 1 species is from the Watch List Siberian Peashrub (*Caragana arborescens* Lam.).

Recently, plant species that are characterized by the highest invasive potential have been additionally allocated to a separate group. This group is called “key-stone” (Richardson et al., 2010) or transformer species (Protopopova et al., 2009, 2014). significantly change the living conditions of natural plant populations. For example, they change the modes of lighting, humidification, composition of mineral resources and so on. Thus, they affect the natural species composition of plant communities in certain areas. Therefore, these species (key species / species-transformers) deserve special attention.

Generalized scientific publications (Protopopova et al., 2002, 2009, 2014) the following should be noted. Among the anthropophytic woody plant species that grow naturally on the devastated lands of Kryvyi Rih area, the following species are "species-transformers": Copal Tree (*Ailanthus altissima* (Mill.), Desert False Indigo (*Amorpha fruticosa* L.), Crack Willow (*Salix fragilis* L.), Ashleaf Maple (*Acer negundo* L.), Russian Olive (*Elaeagnus angustifolia* L.), Black Locust (*Robinia pseudoacacia* L.).

In our district, scientists from Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine pay special attention to the problem of plant invasions. In particular, V. V. Kucherevsky and G. N. Schol proposed (Kucherevsky & Shol, 2011) and tested (Shol, 2016) a new method for assessing the invasive threat of adventitious species. According to the method of these researchers, among anthropophytic woody plant species that grow naturally on the devastated lands of Kryvyi Rih area, some species pose a very significant invasive threat to natural flora and biodiversity. Such plant species are: Copal Tree (*Ailanthus altissima* (Mill.), Desert False Indigo (*Amorpha fruticosa* L.), Chinese Elm (*Ulmus pumila* L.), English Walnut (*Juglans regia* L.), Ashleaf Maple (*Acer negundo* L.), Sycamore Maple (*Acer pseudoplatanus* L.), Russian Olive (*Elaeagnus angustifolia* L.), Black Locust (*Robinia pseudoacacia* L.), Clammy Locust (*Robinia viscosa* Vent.), European Plum (*Prunus domestica* L.), Myrobalan Plum (*Prunus divaricata* Ledeb).

In addition, the following species pose a significant threat to the flora and biodiversity of this area: Siberian Apricot (*Armeniaca vulgaris* Lam.), Common Lilac (*Syringa vulgaris* L.), Cherry Sour (*Cerasus vulgaris* Mill.), European Smoketree (*Cotinus coggygria* Scop.), White Mulberry (*Morus alba* L.).

Environmental conditionalities of the woody plant communities' distribution

All the leading environmental factors that determine the distribution of woody plant species in the devastated lands of Kryvyi Rih area, we have organized into three conditional levels: macro-, meso-, micro-level. We assume that macro-environmental factors are formed by the global preconditions for the growth and development of tree species. The meso-level is determined by the genesis and diversity of devastated lands. The microlevel is the result of geological conditions and orographic features in individual locations (Savosko, 2011a; Savosko et al., 2018b, 2019b).

The devastated lands of Kryvyi Rih are located on large plains - more than 100 km in the meridional direction. This fact has allowed us to organize our experimental plots into separate ecological series (ecoseries) according to climatic gradients: air temperature and precipitation. Another important environmental factor at the macro level is time – the duration of the development of spontaneous vegetation on devastated lands. According to this indicator, we have formed a separate eco-series. As you know, the concept of "devastated lands" unites very diverse in origin areas. Therefore, we have arranged the devastated lands in a separate ecological series according to the indicators of diversity of ecological conditions.

Based on such assumptions, we calculated the correlation matrix, which was formed on the values of Spearman's rank correlations. To do this, we used the ordering of woody plant species in ecological series on thecnogenic devastated lands of the Kryvyi Rih Mining & Metalurgical District. In the calculations, we also used the following leading indicators of the prevalence of woody species: the number of taxa and the proportion of ecological spectra (biogeographical, biomorphic and ecomorphic). The results obtained are shown in Table 1.3.

The results of correlation calculations confirmed that a reliable relationship exists between the prevalence of woody plant species and characteristics of thecnogenically devastated lands of Kryvyi Rih area (Table 1.3). 18 correlation coefficients were statistically significant (for a possible 32). The direct relationship (r^2> 0) was present in 10 cases and the inverse correlation was observed in 8 cases (r^2 <0). In 7 cases there was a weak connection (0.3 <│r^2│ <0.5), in 6 – medium (0.5 <│r2│ <0.7), in 1 – strong (0.7 <│ r2│ <0.9) and in 4 – a very strong (│r2│ > 0.9) correlation.

Table 1.3

Correlation matrix of dependencies between indicators of woody plant species prevalence and ecological characteristics of the thecnogenic devastated lands at Kryvyi Rih Mining & Metalurgical District

Prevalence rates of woody plant species		Characteristics of thecnogenic devastated lands			
		temperature air	volume precipitation	duration of vegetation formation	diversity of environmental conditions
Number	Species	0,343*	–0,429*	0,686**	0,971***
	Genus	0,257	–0,229	0,600**	0,943***
	Families	0,286	–0,371*	0,457*	0,857***
Relative share	Autochtonous	–0,343*	0,429*	–0,686**	–0,914***
	Trees	0,286	–0,600**	–0,229	0,171
	Mesotrophs	0,514**	–0,257	0,343*	–0,229
	Xero-mesophytes	0,114	0,200	–0,400*	–0,286
	Heliophytes	–0,229	0,029	–0,629**	0,286

Note. Spearman's rank correlation coefficients are significant at the significance level: * – P < 0.05; ** – P < 0.01; *** – P < 0.001.

The duration of vegetation formation and the diversity of ecological conditions have the most significant and statistically significant effect on indicators of distribution of woody plant species on thecnogenic devastated lands of Kryvyi Rih area. For these characteristics of devastated lands, the highest number of correlation coefficients with the highest bond strength was found. The number of species and the proportion of aboriginal species were the most dependent from the characteristics of devastated lands.

As we noted earlier, the lack of continuous soil cover is a leading feature of the conogenic devastated lands of Kryvyi Rih area. Rocks (where the processes of primary soil formation take place) actually perform the functions of natural soil. However, the intensity and success of primary pedogenesis is insignificant (for natural reasons).

Therefore, primitive soils of devastated lands are characterized by unfavorable for the growth and development of woody plant species physical, chemical and physico-chemical properties (Dobrovolskiy & Shanda, 1982; Savosko, 2005, 2010; Savosko et al., 2010, 2011a; Savosko, Bulachova, 2011; Savosko & Mykhailenko, 2012; Mazur et al., 2015).

Physical, chemical and physico-chemical characteristics of the rocks from which the day surface is formed thecnogenically devastated lands Kryvyi Rih area is an important environmental factor. This factor greatly determines the growth and development of woody plant species. According to our observations, in the case of the formation of the day surface of devastated lands only from loose rocks (clay, loam, and sometimes humus-containing soil layers), the spontaneous vegetation cover was formed exclusively by herbaceous plant species. In such conditions, artificial planting of trees and shrubs was unsuccessful. In the case of the formation of the day surface of devastated lands only from crystalline rocks (quartzites, shales, etc.), the spontaneous vegetation was very, very liquefied and represented only by grassy species. However, in the case of the formation of the daily surface of devastated lands from loose and crystalline rocks, the best ecological conditions were created for the emergence and spread of woody plant species.

It is important to note that thecnogenic devastated lands of Kryvyi Rih area are characterized by very diverse forms of mesorelief. In general, the best conditions for trees and shrubs are micro-depressions, as well as the lower part of the slopes and the adjacent berm strip.

Foresting of thecnogenic devastated lands

The planting of artificial forest plantations on unproductive, degraded, as well as on disturbed and used lands is considered a promising area of afforestation. It is proved that artificial forest plantations are an effective measure for phyto-optimization of human habitat and a factor environmental safety in modern mining and metallurgical areas. Afforestation of territories is especially relevant for the regions located in the arid steppe zone, in particular for the Steppe Dnieper of Ukraine (Bekarevich et al., 1971; Zverkovsky, 1997; Brovko & Brovko, 2012; Lykholat, 2016a, 2016b; Lykholat et al., 2019; Travleyev et al., 2005).

Artificial forest plantations planted in the 50s and 80s of the XXth century throughout the Steppe zone of Ukraine became a reliable guarantee for: *a*) moisture conservation on agricultural lands, *b*) prevention of wind erosion (deflation) of soils, *c*) conservation and development of biodiversity, *d*) creation of a basis for the ecological network and *e*) creation of a basis for comfortable human existence.

Nowadays, reclamation (recultivation according to Ukrainian tradition) is the only generally recognized and "legal" technology for the restoration of devastated lands (Bekarevich et al., 1971; Travleyev et al., 2005; Savosko, 2011a; Demidov et al., 2013). According to the current regulations, modern reclamation technology provides:

a) landscaping of devastated lands (primarily – leveling the surface and sloping),

b) applying a shielding layer of loose rocks and a layer of fertile soil,

c) creation of artificial plant communities.

It should be noted that the theoretical foundations of reclamation for disturbed (devastated) lands were developed in the 60–70s of the XX century. It was an era of extensive economic and agricultural development. Therefore, the introduction of agricultural production on disturbed / devastated lands was considered the most appropriate direction of their reclamation. In some cases, the formation of continuous forest stands was recommended. As an exception, the introduction of other areas of reclamation was allowed: water management, recreational, sanitary, construction, hunting, etc.

In this regard, in most cases, no reclamation work has been carried out on such lands in the mining and metallurgical districts of Ukraine. In addition, research has shown that the created massive forest plantations on devastated lands were unstable and low-yielding. At the same time, the intensity of the initial soil formation under such plantations was much lower in comparison with the self-developing territories. That's why in our time, changing the paradigm of phyto-optimization of devastated (disturbed and used) lands in mining and metallurgical districts is very important.

Conceptual bases of afforestation

In our opinion, afforestation thecnogenic devastated lands at Kryvyi Rih Mining and Metallurgical District will be the most effective measure for optimizing the human environment and for the environmental safety of this area.

However, we need to be clearly aware of the mission, purpose and objects of this event (Fig. 1.5). In the classic version, the reclamation of disturbed lands is aimed at achieving the minimum goal and the maximum goal. The minimum goal is to stop the negative impact of these lands on the environment and the maximum goal is to return to the re-practical use of these lands.

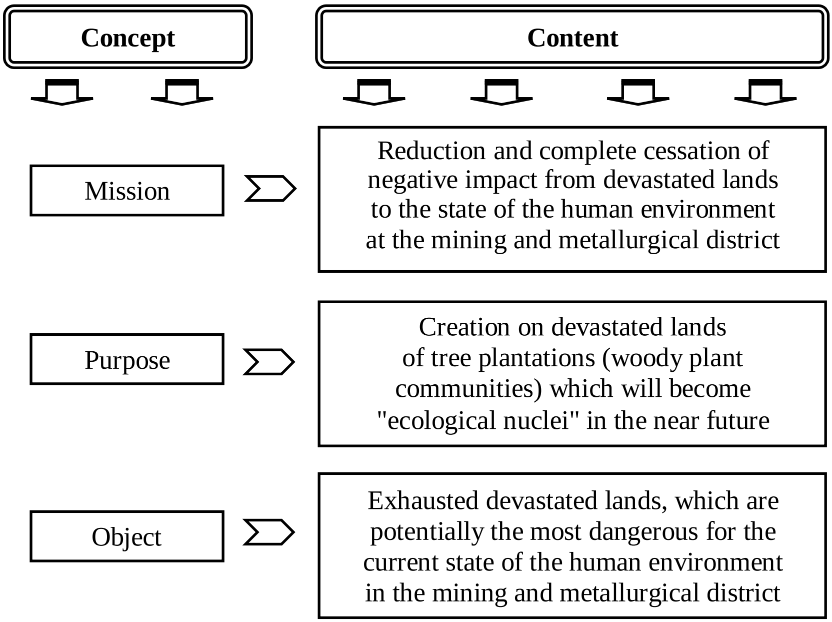

Fig. 1.5. **Conceptual pattern afforestation of technogenic devastated lands at Kryvyi Rih Mining & Metalurgical District**

In our convincing opinion, the main mission of afforestation of thecnogenically devastated lands at Kryvyi Rih Mining and Metallurgical District is to reduce, and eventually completely stop the negative impact of devastated lands on the human environment. In this case, the re-practical use of these lands is not excluded. The main purpose of afforestation of thecnogenically devastated lands at this area is to create plantations of woody plant species, which should become "ecological nuclei" in the near future.

However, such plantations should be created in areas that are most favorable for the growth and development of tree species.

The species composition of future woody plant communities should be as balanced as possible and and maximally promote the fastest formation of their phytogenic field (Savosko, 2011a, 2016; Savosko & Kvitko, 2016, 2017; Savosko et al., 2018a). In this case, new woody plants community will be:

a) ecologically resistant to the conditions of devastated lands,

b) successfully grow and develop,

c) spread their seeds in all their territories.

Exclusively such communities, we call the "ecological nuclei" of future ecosystems in thecnogenic devastated lands.

We believe that in Kryvyi Rih Mining & Metalurgical District the afforestation of quarries, tailings ponds, land subsidence and gob area and most industrial sites are not priorities in order to optimize the environment and increase environmental safety. Nowadays, most of the quarries in the region (by area) are operational. The tailings ponds are exclusively all working and are located at a considerable distance from residential areas. Industrial sites in most cases are also operational and at one time were well landscaped. In our opinion, the first afforestation should be performed on the waste rock dumps, which are located near residential areas. Only these areas of devastated lands are the most dangerous for the human environment in the Kryvyi Rih district. A detailed inventory of such areas is a matter of the near future.

Practical afforestation measures

We believe that practical measures of afforestation of thecnogenic devastated lands at Kryvyi Rih Mining and Metallurgical District involve the implementation of certain steps according to the classical scheme (Fig. 1.6).

The first step of practical measures for landscaping of devastated lands is their comprehensive ecological assessment. During this assessment, special attention is paid to the geomorphological, geochemical, biogeochemical and agrochemical characteristics of thecnogenic devastated land areas.

It should be recalled that according to our observations, in the case of the formation of the day surface of devastated lands exclusively from loose rocks, the spontaneous vegetation is formed exclusively from herbaceous plant species.

In the case of the formation of the day surface of devastated lands exclusively from crystalline rocks, the spontaneous vegetation is very, very liquefied and is represented only by grassy species.

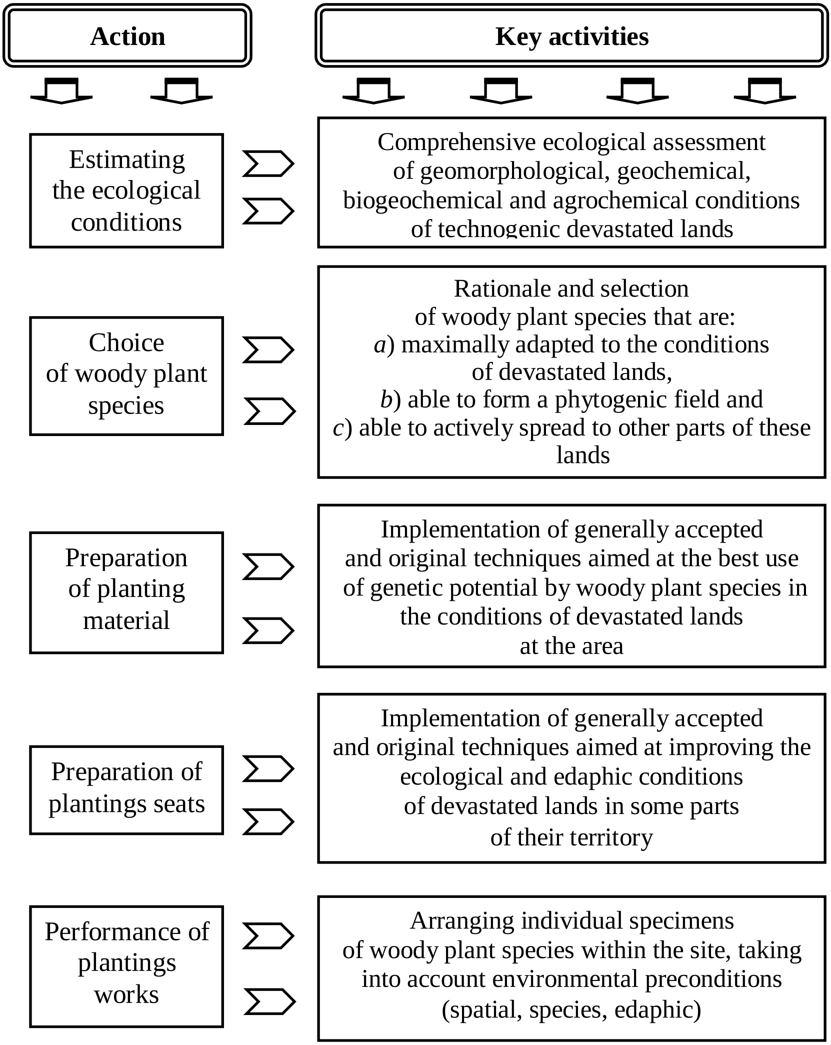

Fig. 1.6. **Practical measures for afforestation of thecnogenically devastated lands at Kryvyi Rih Mining & Metalurgical District**

However, the simultaneous presence of loose and crystalline rocks on the surface of devastated lands creates the best ecological conditions for the emergence and spread of woody plant species. Such conditions should be clarified for the localization of future "ecological nuclei".

According to our own observations, thecnogenic devastated lands of Kryvyi Rih area are characterized by very different forms of mesorelief and microrelief. These landforms determine the redistribution of precipitation. As a result, separate locations are formed, which are most favorable for the growth and development of woody plant species. In most cases, such locations are dislocated in the microdepressions, as well as in the lower slopes and adjacent berm bands.

The second step in afforestation of thecnogenic devastated lands at Kryvyi Rih area was the selection of resistant species of woody plants. We summarized the results of our own research (Savosko, Alekseeva, 2007; Savosko, 2011a; Bielyk & Yevtushenko, 2018; Savosko et al., 2018b; Bielyk et al., 2019), as well as the scientific achievements of predecessors. First of all, we analyzed the publications of teachers of Kryvyi Rih State Pedagogical University (Davyidov et al., 1971; Dobrovol'sky et al., 1979; Dobrovol'sky, 1980; Dobrovol'sky, Shanda, 1982; Reva et al., 1993, Saphonoiva & Reva, 2009; Denysyk et al., 2012) and employees of the Kryvyi Rih Botanical Garden (Pluhina et al., 1981; Tereschenko, 1992; Mazur & Smetana, 1999; Korshikov et al., 2008; Korshikov, Krasnoshtan, 2012; Korshikov et al., 2012; Mazur et al., 2015; Lysohor et al., 2017; Pavlenko et al., 2017).

In addition, we analyzed the achievements of teachers of the Oles Honchar Dnipro National University (Zverkovsky, 1997; Tarasov et al., 2003; Travleyev et al., 2005; Lykholat et al., 2019), teachers of the Dnipro State Agrarian and Economic University (Bekarevich et al., 1971; Demidov et al., 2013), employees Institute for Nature Management Problems and Ecology (Shapar et al., 2005) and lecturers at th National University of Life and Environmental Sciences of Ukraine (Brovko & Brovko, 2011, 2012), as well as global achievements (Sheoran et al., 2010; Kowalska & Sobczyk, 2012; The Forestry Reclamation Approach, 2016).

As a result, we have formed a list of woody plant species promising for afforestation of thecnogenic devastated lands at the Kryvyi Rih Mining and Metallurgical District.

In our opinion, for afforestation of thecnogenic devastated lands Kryvyi Rih Mining & Metalurgical District it is advisable to plant the following species of trees: Ashleaf Maple (*Acer negundo* L.), Black Locust (*Robinia pseudoacacia* L.), Clammy Locust (*Robinia viscosa* Vent.), Common Ash (*Fraxinus excelsior* L.), English Elm (*Ulmus minor* Mill.), English Oak (*Quercus robur* L.), English Walnut (*Juglans regia* L.), European Black Pine (*Pinus pallasiana* D.), Lombardy Poplar (*Populus italica* (Du Roi) Moench), Mahaleb Cherry (*Prunus mahaleb* L.), Northern Red Oak (*Quercus rubra* L.), Plains Cottonwood (*Populus deltoides* Marsch.), Russian Olive (*Elaeagnus angustifolia* L), Scots Pine (*Pinus sylvestris* L.), Siberian Apricot (*Armeniaca vulgaris* Lam.), Silver Birch (*Betula pendula* Roth), Staghorn Sumac (*Rhus typhina* L), White Poplar (*Populus alba* L.).

Ror afforestation of thecnogenic devastated lands Kryvyi Rih Mining & Metalurgical District it is advisable to plant the following species of shrubs: Bloodtwig Dogwood (*Swida sanguinea* L.), Common Lilac (*Syringa vulgaris* L.), Desert False Indigo (*Amorpha fruticosa* L.), Dog Rose (*Rosa canina* L.). European Black Elder (*Sambucus nigra* L.), European Privet (*Ligustrrum vulgare* L.), European Smoketree (*Cotinus coggygria* Scop.), Sea-Buckthorn (*Hippophae rhamnoides* L.), Siberian Peashrub (*Caragana arborescens* Lam.), Tatarian Honeysuck (*Lonicera tatarica* L.).

The third step of afforestation of thecnogenic devastated lands at Kryvyi Rih area is the effective implementation of generally accepted and original techniques. These techniques should be aimed at making the best use of the genetic potential of woody plant species in the difficult conditions of devastated lands.

The list of such techniques includes: pre-treatment of the plants root system by solutions that contain macro-and micronutrients, nutrients and / or phytohormones. Also promising is the preliminary immersion of the root system in a suspension solution consisting of water, clay and soil.

The fourth step of afforestation of thecnogenic devastated lands of Kryvyi Rih area is the preparation of planting sites. This measure should be aimed at improving the ecological and edaphic conditions of devastated lands within individual locations. It is advisable to carry out preliminary detoxification of soils from devastated lands. Thus, according to the results of our research, the use of optimum doses of improvers (combinations of Cretaceous-water, Cretaceous-Trilon B) cause a statistically significant decrease in the levels of phytotoxicity of soils from mine tailings at Kryvyi Rih area. To plan work on site preparation, it is advisable to create ecological models of land reclamation.

These models were proposed by teachers and staff of the former Dnipropetrovsk Agrarian University for the steppe zone of Ukraine (Bekarevich et al., 1971; Beresnevich et al., 2003). Researchers have proposed six variants of models of the structure of artificial edaphotopes within individual locations. These have appropriate names that reveal their essence: 1) basic / universal model, 2) model of increased fertility, 3) hydromeliorative model, 4) geomeliorative model, 5) local model and 6) special model.

The fifth step in afforestation of thecnogenic devastated lands of Kryvyi Rih area is the implementation of planting work. Initially, it is very important to arrange individual specimens of woody plant species within the site, taking into account environmental conditions. In our opinion, such prerequisites are:

a) compliance with the species structure of future groups,

b) rational spatial arrangement of individual specimens,

c) maximum consideration of the edaphic characteristics of each location. Planting work should be performed according to the classic recommendations in the autumn (October–November).

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