A zonal forest approach for restoring degraded lands in the Kostanay region

Yelena Simancuk[1*], and *Andrej* Kurrijanov[2]

[1]NLC «Akhmet Baitursynuly Kostanay Regional University», Kostanay, Kazakhstan
[2]Kuzbass botanical garden Federal Research Center of Coal and Coal Chemistry SB RAS, Kemerovo, Russia

Abstract. This article presents the findings of a comprehensive investigation into the current state of natural vegetation cover on iron ore dumpsites operated by mining enterprises within the Kostanay region of Kazakhstan. We propose a holistic approach to enhancing the sustainability of the iron ore industry through forest reclamation, utilizing zonal plant species for the revegetation of these degraded landscapes. This approach centers on the ecological reclamation of iron ore dumpsites through the strategic implementation of native, zonally adapted plant species. By meticulously selecting plant communities that flourish within the specific ecological zones of the Kostanay region, the proposed method aspires to re-establish a self-sustaining ecosystem on the degraded land. The significance of this scientific undertaking transcends the immediate benefits associated with restoring ecological equilibrium. By adopting such strategies, the iron ore industry can contribute meaningfully to environmental preservation in a multifaceted manner. Reclaimed dumpsites can evolve into natural filters, facilitating water purification and mitigating potential pollution stemming from mining activities. Additionally, the re-establishment of native vegetation fosters biodiversity, thereby providing crucial habitat for a diverse range of flora and fauna.

1 Introduction

Over the past decade, global temperatures have risen by 1°C, leading to an increase in the frequency and intensity of extreme weather events such as droughts, floods, and wildfires. These events, in turn, exacerbate land degradation, air pollution, disease spread, and threaten food security [1–3].

* Corresponding author: simyeandr.ksu@mail.ru

One of the main factors causing climate change is the anthropogenic increase in the concentration of greenhouse gases, primarily carbon dioxide, caused primarily by the expansion of mining activities [2–4].

In view of the escalating environmental degradation caused by mining activities, land reclamation has emerged as a critical issue. Forest reclamation, a promising approach that entails the creation of forests on mine waste dumps using diverse tree and shrub species, offers a viable solution for restoring these disturbed landscapes.

2 Materials and methods

Within the framework of this study, we investigated the degree of natural overgrowing of iron ore dumps of the two largest enterprises of the Kostanay region (Republic of Kazakhstan): SSGPO JSC and Kachary Ruda JSC (Figure 1), on the territory of which a large number of dumps with a total area of about 6 thousand hectares have been formed [5].

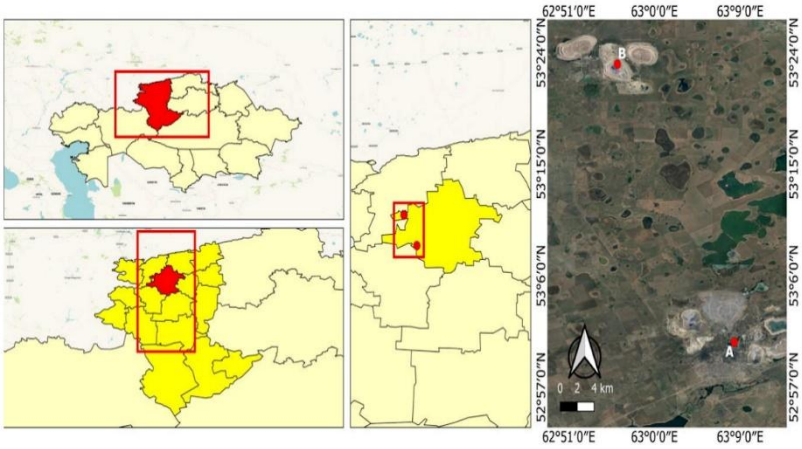

Fig. 1. Location of the studied dumps: A) JSC "SSGPO"; B) JSC "Kachary Ruda"

Five iron ore dumps were studied: the Southeastern of the Sokolovsky deposit, the Southwestern of the Sarbaisky deposit, the Southwestern of the Yuzhno-Sarbaisky section, the "Old" dump in the vicinity of the town of Rudny; and the railway dump No. 7 within the boundaries of the village of Kachar [5].

Based on the surface characteristics of the dump, two groups of technogenic eluvium can be distinguished: non-saline with a neutral reaction of the medium (loams and sandy loams of the Quaternary period, limestones, tuffs, porphyrites and other rocks) and highly saline (opokas, Chegan and lignitic clays of the Cretaceous period, some clays of the ancient weathering crust). Natural overgrowth occurs more quickly on non-saline technogenic eluvium and extremely slowly on saline ones [5–7].

The studied region is mostly dry steppe and forest-steppe, with occasional forests and meadows. The climate is continental with large temperature swings [5].

To investigate the flora of technogenic ecotopes, a route-expeditionary reconnaissance method was employed. Qualitative and quantitative assessment of plants was conducted in accordance with established general botanical methods [5].

3 Results and Discussion

Despite their prolonged existence, iron ore dumps have not developed into mature zonal or intrazonal communities. Consequently, phased forest reclamation is crucial to accelerate the restoration of plant cover, which will stabilize the dump soils, improve edaphic and microclimatic conditions, and, in the long term, mitigate greenhouse gas concentrations in the atmosphere.

Current priorities in forest restoration are focused on the establishment of sustainable, self-sustaining communities with high biodiversity. This implies that forests should align with the natural conditions and ecological characteristics of the native vegetation [5].

During the study of natural vegetation on dumps, we collected and identified 192 species. After analyzing literature sources, the list of technogenic flora of dumps was expanded to 284 species of higher plants. Among this diversity of flora, we found 107 synanthropic and 28 adventive species. Most of the species belong to meadow and steppe flora (104 species each) with 16.5% of weed species. Herbaceous (86.5%) species predominate over woody/semi-woody (13%), floating/submerged (0.5%).

The collected data was used to develop methodological recommendations for forest reclamation for mining enterprises. The guidelines provide for the organization of the entire complex of forest reclamation work, from the design stage of mining and the mining process, the dump formation to the preparation of the surface of dumps for reclamation purposes and the implementation of the biological stage.

A comprehensive analysis of factors determining soil suitability for forest reclamation was conducted during the development of the aforementioned recommendations. This analysis revealed several key findings:

1. Overburden rocks, initially classified as unsuitable, were further divided into subgroups: potentially fertile but nitrogen-deficient and low-fertility (limited suitability) [8].
2. Habitat type, determined by moisture regime: dry, fresh, moist, and wet.
3. Hardness of technogenic eluvium of overburden rocks, which affects the hydrological regime and, consequently, forest growth conditions. The optimal range for forest growth is hardness from 5 to 15 kg/cm^2 [8].
4. Exposure and slope steepness shape soil moisture regime and forest growth conditions in specific locations.

In addition, we applied a method of evaluating Forest Suitability Index based on relative indicators, which allowed us to compare different territories and identify the most promising areas for afforestation.

Effective implementation of the mining and technical stage of reclamation establishes a foundation for the biological stage and reduces overall costs. This stage involves measures to improve soil conditions, such as leveling excessively compacted overburden dumps and applying soil amendments tailored to the dump type. After mining activities, the biological reclamation stage commences, involving careful selection of suitable plant species, with resilience to environmental stressors being a key criterion, unlike in landscaping. Plants should be able to: withstand the adverse properties of technogenic eluvial rocks; form symbiotic relationships with microorganisms; and have a well-developed root system to prevent soil deflation [8].

The group of the most promising plants for forest reclamation of post-technogenic territories includes: *Pinus sylvestris* L., *Betula pendula* Roth, *Hippophaë rhamnoides* L. The following are also considered promising at the waste dumps of SSGPO JSC and Kachary Ruda JSC: *Elaeagnus angustifolia* L., *Ulmus pumila* L., *Caragana arborescens* Lam., *Lonicera tatarica* L., *Populus* × *sibirica* G. Kryl. et Grig. ex A. Skvortsov. *Tamarix ramosissima* Ledeb. is a promising species for use on saline soils.

Species that are unable to fully adapt to the harsh conditions of opencast dumps but can survive if the soil is improved are classified as conditionally suitable: *Ulmus laevis* Pall., *Ribes aureum* Pursh, *Prunus besseyi* L. H. Bailey. Several willow species (*Salix acutifolia* Willd., *Salix caprea* L, *Salix caspica* Pall.) are suitable for use in reclamation projects due to their remarkable adaptability and tolerance to harsh environmental conditions.

Recommended plant species for forest reclamation of the studied dumps are presented in Table 1.

Table 1. Assortment of plant species for reclamation of the dumps of SSGPO JSC and Kachary Ruda JSC

Species	Forest Suitability Index	Limitations
Coniferous trees		
Pinus sylvestris	I-III $_{1-3}$	Heavily salinized dense clayey soils
Deciduous trees		
Betula pendula	I-III $_{1-3}$	Heavily salinized dense clayey soils
Populus × sibirica	I-III $_{2-3}$	Heavily salinized dense clayey soils
Ulmus pumila	I-II $_{2-4}$	
Fraxinus pennsylvanica Marshall	I-II $_{2-3}$	Heavily salinized dense clayey soils
Elaeagnus angustifolia	I-II $_{2-3}$	
Shrubs		
Hippophae rhamnoides	I-III $_{1-3}$	Highly saline soils
Caragana arborescens	I-III $_{1-3}$	Heavily salinized dense clayey soils
Lonicera tatarica	I-II $_{1-3}$	Heavily salinized dense clayey soils
Ribes aureum	I-II $_{2-3}$	Low soil humidity
Cerasus besseyi	I-II $_{3-4}$	Low soil humidity
Tamarix ramosissima	I-II $_{3-4}$	Low soil humidity
Salix acutifolia, S. caprea, S. caspic	I-II $_{3-4}$	Low soil humidity

Note: The forest suitability index consists of two digits: the Roman numeral indicates the forest suitability class based on the potential soil fertility (I - high, II - medium, III - low); the Arabic numeral reflects the soil water balance regime (1 - excessive, 2 - sufficient, 3 - deficient).

To expedite land restoration on technogenic substrates and establish optimal conditions for tree growth, it is recommended to combine tree planting with the sowing of perennial grasses [8]. Under the tree canopy, where light is limited, shade-tolerant grasses such as *Poa pratensis* L. and *Agrostis gigantea* Roth. should be sown. In the inter-rows, where there is more light, leguminous grasses such as *Melilotus officinalis* (L.) Lam. and *Onobrychis arenaria* (Kit.) DC. are suitable.

This technology accelerates soil formation, prevents soil erosion, enhances soil water-physical properties, suppresses weed growth, and creates favorable conditions for the development of microflora. The co-planting of trees and grasses creates a sustainable ecosystem that ensures the long-term growth and development of forest plantations.

Our investigation of iron ore dumps revealed the presence of the aforementioned species. This fact serves as indisputable evidence of the limited suitability of these soils for the cultivation of the studied species.

Forest reclamation of disturbed lands is an intricate process that necessitates a comprehensive set of forest protection measures. These essential measures must be meticulously incorporated into the project documentation [9]. The timely and skillful implementation of forest protection measures, guided by the expertise of qualified professionals, ensures the preservation of forest plantations and young stands, enhances the

resilience of forest stands to pests and diseases, accelerates reforestation, and ultimately leads to the establishment of sustainable and productive forests.

4 Conclusion

Forest reclamation of iron ore dumps in the Kostanay region is a scientifically sound and expedient measure with a comprehensive positive effect. It will improve the environmental situation, increase the economic potential of the region, and improve the quality of life of the population.

It is important to note that forest reclamation is a long-term solution to the problem of climate change. Forest plantations will absorb carbon dioxide for many decades.

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