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Review

Scots pine use in forestry reclamation of Kuzbass mining enterprises in Kemerovo Oblast

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Abstract. This article presents a review of scientific research on Scots pine use in reclamation of industrially disturbed lands. It is found that in mining areas, including Kemerovo oblast, predominantly Scots pine-based reclamation is most widespread. The review suggests optimal parameters for planting material, planting patterns, cultivation methods and maintenance systems for pine stands on different-type rock dumps. A large body of investigations are devoted to studying the biological characteristics of Scots pine and other tree species in sites of forest restoration and natural regeneration.

Keywords: monitoring, technogenic landscape, rock dump, woody species, sustainability, soil formation, reforestation

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Научный обзор

Сосна обыкновенная в лесохозяйственной рекультивации горнодобывающих предприятий Кемеровской области – Кузбасса

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Аннотация. Статья представляет собой обзор научных работ, посвященных исследованию сосны обыкновенной на рекультивированных участках техногенно нарушенных земель. Установлено, что в районах деятельности горных предприятий (в том числе на территории Кемеровской области) наибольшее распространение получила лесохозяйственная рекультивация с преимущественным использованием сосны обыкновенной. Проведенный анализ литературы показал, что учеными установлены оптимальные параметры посадочного материала, схемы посадки, приемы выращивания и система ухода за лесонасаждениями сосны на отвалах разного типа. Большой блок научных исследований посвящен изучению биологических особенностей сосны обыкновенной и других древесных культур на участках лесной рекультивации и естественного лесовозобновления.

Ключевые слова: мониторинг, техногенный ландшафт, отвал, древесные породы, устойчивость, почвообразование, лесовосстановление

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Introduction

The impact of mining on the environment and natural resources is multifaceted, long-term and complex. Major factors include the construction of quarries, shafts, waste piles, settling ponds, various embankments and trenches, as well as mining and other operations. These impacts transform the terrain, the hydrographic network and morphodynamic regime of rivers, channels and drains, including the composition and properties of atmospheric air causing mechanical damage and destruction of soil and vegetation.

In response to soil and vegetation disturbance, natural landscapes are replaced by technogenic sites with a very slow natural restoration, which become wastelands for a long time and remain unsuitable for active soil formation. The latter process occurs worldwide at a rate of 0.5–2.0 cm per 100 years; it takes 1500–7000 years to create the 18 cm soil layer. However, it can be accelerated through reclamation.

GOST R 59070-2020[1] defines land reclamation as a set of measures on restoration of the lost quality of lands to a level sufficient for their intended and permitted use.

The reclamation process consists of two (technical and biological) stages. The technical stage includes planning; slope formation; removal, transportation and application of soil to reclaimed lands. The biological stage involves a set of agrotechnical and phytomeliorative works aimed at restoring the ecological functions of soil, biological productivity, and species diversity of ecosystems.

According to the Russian Government Resolution No. 781 of May 29, 2025 "On Approval of the Rules for Conducting Land Reclamation and Conservation," a reclamation technology is determined based on the impact of industrial facilities and resulting disturbances to natural landscapes. Currently, the following reclamation areas do exist: agricultural, forestry, water management, recreational, construction, environmental protection, and sanitary-hygienic ones. When selecting a biological reclamation method, the climate zone, zonal biodiversity, economic feasibility, intended purpose and permitted use are considered. In accordance with GOST R 57446-2017[2], reclamation technologies must combine the criteria on the achievement of objectives of environmental protection with economic feasibility, subject to available technical capabilities for their implementation. For instance, in regions with a mainly woody vegetation, forestry reclamation is most common because of sharp reduction occurring in forested areas. Reclamation works are conducted largely on coal waste dumps formed by coal mining and less often on rock dumps of iron ore, non-ferrous metal ores, and rock products.

At the same time, in the regions with harsher natural conditions and poor soil fertility, other types of reclamation are preferred. For example, spontaneous regeneration dominates on the disturbed lands in the North due to the presence of much more resilient plant communities than artificially created ones (Kapelkina, 2021). Reclamation of disturbed lands in arid regions also requires the formation of a relief providing a rainwater collection and a selection of moisture-tolerant, primarily herbaceous, plants (Lavrinenko et al., 2017).

In contrast to agricultural crops, forest plants are believed to be more unpretentious in terms of agrochemical characteristics of regenerated soils. Less stringent requirements to the surface relief and feasible application of a thinner layer of fertile soil, or in some cases, its absence make this approach not only more effective but also a cheaper form of biological reclamation. Noteworthy is a key role of forests in the balance between ecosystems and climate processes.

In light of the utility of natural forest ecosystems restoration[3] on rock dumps, the biological stage of forest reclamation primarily promotes natural reforestation and formation of forest ecosystems with its inherent components, in addition to planted trees. Forest reclamation sites can include not only the areas with artificial afforestation of disturbed lands, but also tree stands naturally formed on lands after mining operations if their characteristics correspond to parameters of natural reforestation.

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[1] GOST R 59070-2020. Environmental protection. Reclamation of disturbed and oil-contaminated lands. Terms and definitions

[2] GOST R 57446-2017. Best available technologies. Reclamation of disturbed lands and land plots. Biodiversity restoration

[3] GOST R 72033-2025. Environmental protection. biodiversity. Restoration of forest vegetation on rock dumps. Basic provisions.

The review aim is to analyze the published literary sources on studying Scots pine in forestry reclamation of industrially disturbed lands (by the example of coal waste dumps in Kemerovo oblast).

Objectives of this study include:

1) an analysis of major research areas in the field of forest reclamation of technogenic lands (by the example of coal waste dumps in Kemerovo oblast);

2) a review of methods for optimizing the practical use of pine in reclamation;

3) an analysis of current monitoring studies of Scots pine in technogenic lands.

Materials and methods

The authors have analyzed 63 sources, including monographs and scientific articles, 12 of which belong to foreign researchers. References to current regulatory documents and legal acts are also provided.

Analysis of major research areas in the field of forest reclamation of technogenic lands (by the example of coal waste dumps in Kemerovo oblast)

Forest reclamation research cover a full set of issues dealing with the formation, dynamics and optimization of man-made landscapes. This includes assessing a forest suitability of soils in rock dumps, selecting the appropriate range of tree and shrub species based on rock classification, shape and height of coal waste dumps, steepness and aspect of slopes, hydrogeological conditions, and other factors[4].

Works on selecting tree and shrub species, most resistant to various environmental conditions, were implemented both in Russia and abroad (Breemen and Buurman, 2002; Candill, 1970; Cornwell and Kiff, 1973; Gladkova, 1972, 1973; Hellerick, 1970; Hill, 1972; Nicholson and Westmacott, 1971; Sopper and Kardes, 1972; Thirgood and Matthews, 1970; Voronina, 2006).

Based on the long-term research by L.P. Barannik et al (Barannik, 1970; Barannik and Shmonov, 1988, 2005; Barannik et al., 2005) on reclamation of lands disturbed by coal mining, 10 tree and 16 shrub species were proposed. The authors considered the assessment of forest suitability of reclaimed areas, survival and growth rates, as well as agricultural practices for creating forest plantations on reclaimed lands as key criteria for selecting species in certain territories (Barannik et al., 2008). Such indicators as the degree of shoot maturation, winter hardiness, habitus preservation, shoot formation, regularity of shoot growth, the ability to generative development and methods of propagation in rock dump conditions were studied (Kozhevnikov and Zaushintsena, 2017)). In the Kemerovo Region, Scots pine, sea buckthorn and silver birch demonstrated the best results thereby making them most suitable for growing on waste heaps. Promising woody species, i.e. Siberian larch, Siberian pine, Siberian rowan, Caragana arborescens, Tatarian honeysuckle, balsam and laurel poplars were also identified. Consistently positive results were demonstrated by growing on waste heaps Ginnala maple, English oak, small-leaved linden, Virginia lilac, and Pennsylvania ash (Klimova, 2012).

In Kuzbass, Scots pine is currently the most common species for reclamation. In 2017, Scots pine plantations on heaps of coal mining enterprises occupied approximately 11 000 ha out of more than 15 000 ha of the total forest reclamation area. Only sea buckthorn stands reached approximately 3 000 ha, silver birch stands about 0.5 and other tree crops (Siberian larch, Siberian pine, Siberian spruce) less than 0.45 thousand hectares (Ufimtsev et al., 2017). The area of pine stands in the region makes up 142.8 (or 3%) out of 5 070.7 thousand hectares with main forest-forming species[5].

The choice of pine for reclamation is largely determined by soils of coal waste dumps. In natural habitats, pine is rarely encountered on clay soils, preferring looser rocks (crystalline rocks, sandstones, limestones, and siltstones) (Ufimtsev and Manakov, 2011). Scots pine is undemanding in terms of

[4] GOST R 59057–2020. Environmental protection. Lands. General requirements for reclamation of disturbed lands

[5] Forest Plan of the Kemerovo Region for 2019–2028. Web page. URL: https://kemles.ru/dokumenty/dokumenty-lesnogo-planirovaniya/lesnoy-plan.php (accessed: 03.09.2025).

phosphorus and potassium, requiring approximately half the amount compared to other coniferous species and three to four times less than deciduous trees. Pine compensates for nitrogen deficiency through mycorrhiza, which develops rapidly in conditions of high porosity and light mechanical composition (Ermakova, 2022; Ufimtsev, 2013). Being a good self-seeder, Scots pine most quickly (unlike other conifers) reaches the height typical for this species in nature (Manakov et al., 2009). Moreover, Scots pine is one of the economically valuable coniferous tree species due to its easily available seed and planting material. Other disturbed areas, such as sand and clay quarries (Ivanova, 2020; Tolbina et al., 2019), ash and iron ore dumps (Terin, 2014; Treshchevskaya et al., 2014), quarries of construction materials (Likhanova and Zheleznova, 2012), etc. demonstrate positive results.

Nevertheless, in practice, Scots pine stands are often distinguished by low resilience. Dense plantings within stands provoke needle shedding that in conditions of insufficient soil moisture causes ground fires resulting in complete trees destruction (Knyazev and Isaeva, 2011). This situation is exacerbated by mixed plantings of Scots pine and sea buckthorn forming vast areas of dead wood owing to their fragility. In addition, Scots pine in coal waste dumps is susceptible to root rot that negatively affects the species stability (Emmrich, 2005; Heydeck, 2005). Some studies also report about a slow rate of soil cover formation due to aggressiveness of humic acids (formed under coniferous trees) towards secondary minerals (Baturina, 2009).

Studies of planting techniques providing higher survival rates at optimal planting densities, as well as monitoring of reclaimed areas to identify adaptation mechanisms are expected to facilitate the development of resilient tree stands in lands disturbed by coal-mining.

The conducted research revealed optimal parameters for planting material, planting patterns, cultivation methods, and forest care systems on different-type coal waste dumps (Barannik and Nikolaichenko, 2006; Ufimtsev et al., 2017; Zaytsev et al., 1977).

Initially, pine seedlings were planted with bare roots at a planting rate of 4 000 specimens per hectare (Barannik, 1989). However, a large number of seedlings formed dense and monostructural stands with a poor natural regeneration and extremely low species diversity (as compared to natural forest ecosystems) that was recorded during further observations of reclaimed areas. This also led to a decline in tree viability after crown closure (Ufimtsev, 2017). Besides, planting of bare root seedlings may cause injury and bending of roots followed by the underdevelopment of tree root systems.

The most advanced method for planting Scots pine is the use of one-year-old seedlings with closed root systems providing high survival rates and plant survival. Monitoring of forest plantations on reclamation sites of disturbed lands of Kuzbass coal mining enterprises indicates that 4- to 6-year-old seedlings cultivated in nurseries on fertile soils have low survival rates, are extremely vulnerable to moisture deficiency and suffer from a prolonged disease until they adapt to new environmental conditions when transplanted to low-fertility substrates of rock dumps. Such plantings may completely disappear in 10–20 years because of their low adaptive capacity. Interestingly, 4- to 6-year-old seedlings (unlike 1- to 3-year olds) are more resistant to suppressive effects of herbaceous vegetation. Therefore, they are recommended for planting on 5-year old mining reclamation sites. At the same time, planting of 2- to 3-year-old seedlings yields the best results within 2–3 years after a dump filling and grading while it is sparsely populated by herbaceous species and the surface has not become turfed yet (Tarakanov et al., 2014; Ufimtsev, 2017).

A review of methods for optimizing the practical use of pine in reclamation

Various methods for optimizing forest growth conditions are used to improve crop establishment and their adaptation on coal waste dumps and other disturbed areas. For choosing and implementation of the most effective methods, such sites should be regularly surveyed.

The most common technique for improving environmental conditions in technogenic landscapes is the combined planting of woody and herbaceous species (Nazarenko and Gamsakhurdia, 2013; Ufimtsev, 2020; Ufimtsev et al., 2017). The creation of multi-species self-sustaining forest ecosystems with developed stands, regeneration, and a continuous grass cover is achieved through applying this method that reduces the time required for restoration succession stages of vegetation, increases the bioecological value of restored areas and forms the areas with higher absorption capacity. By the age of 20, such stands represent forest-meadow communities with a crown density of 25–35% and a developed ground cover. Fruit-bearing trees (vitality category I) prevail in these stands.

For a quick restoration of forest clearings and spacious burnt areas deprived of natural seed sources, a method of planting and sowing pine crops with the increased generative potential has been developed. This involves planting of 6–7-year-old seedlings with a root ball, allowing them to thrive in sites covered by grass. This approach ensures the uniform regeneration of the reclaimed area and the formation of dense Scots pine stands (Tarakanov et al., 2014).

It is established that a type of planting material and a planting pattern influence not only the survival rate of seedlings, but also the subsequent health of forest communities in reclaimed areas (Barannik et al., 2005; Ufimtsev, 2013). A plantation density determines the biometric parameters of a crown and needles of Scots pine and, consequently, the growth and development patterns of artificially created pine stands in sites disturbed by sand extraction. Thus, with growing planting density, pine height increases as well (Ivanova, 2020). Branching characteristics, structure and relative crown length (the ratio of crown length/entire trunk length) serve as important additional indicators of vitality and may characterize the development of the assimilation apparatus of woody plants.

Current monitoring studies of Scots pine in technogenic lands

The degree of resilience of tree stands growing on reclaimed sites depends on the altering complex of morphological, anatomical, physiological and biochemical parameters at various organizational levels (Neverova and Bykov, 2015; Neverova and Zokirov, 2014). An analysis of anatomical and morphological parameters of woody plants from the anthropogenically disturbed lands makes it possible to assess resilience of both individual trees and a stand as a whole.

A study of Scots pine needles on rock dumps revealed some adaptive changes (Neverova, 2015; Tsandekova, 2013). In particular, an increase in needles tissue in the first, second and third years during the growing season and their thickening due to the mesophyll development were observed on coal waste dumps of the Kumertau brown coal mine (Egorova and Kulagin, 2006).

Biological characteristics of tree crops of all age groups in sites of forest reclamation and natural reforestation at all coal enterprises in Kemerovo oblast were thoroughly studied (Ufimtsev, 2017). The content of carotenoids and chlorophylls (Grebennikova and Silantyeva, 2015; Kolmogorova and Tsandekova, 2013; Kupriyanov, 2017), ascorbic acid (Kolmogorova and Tsandekova, 2020) and phenolic compounds (Neverova, 2015; Neverova et al., 2014) in sites of reclaimed heaps, including photosynthetic capacity (Kolmogorova, 2011), water regime characteristics (Kolmogorova, 2015) and soil-ecological state of reclamation areas (Semina et al., 2025) were studied.

Forest stands with Scots pine on rock dumps of lignite open-pit mines (Kulagin et al., 2024) and talc-magnesite deposit dumps (Chukina et al., 2025) were examined. The distribution of heavy metals in soil and various parts of a pine tree (Radosteva and Kulagin, 2011), as well as characteristics of mycorrhiza formation in Scots pine (Faizova and Zaitsev, 2012) were investigated.

Since the stage of biological reclamation involves applying a fertile soil layer to a rock dump surface, some studies of its impact on tree stands were conducted. It is shown that this procedure has a minor effect on either growth (Nicholson and Westmacott, 1971; Sopper and Kardes, 1972; Thirgood and Matthews, 1970) or a number of physiological parameters of Scots pine. For instance, the tannin content in pine trees growing on the leveled rock dumps without a fertile layer application is, on average, 26% lower during the growing season compared to that in plants from coal waste dumps containing a fertile layer (Kolmogorova, 2012).

Conclusion

Diversity of methods for restoring lands disturbed by coal mining allows to implement the biological reclamation stage most effectively with account for regional, environmental and economic conditions.

Modern concepts on restoration of technogenic landscapes envisage returning the territories, landscapes and ecosystems to conditions close to their original state, ensuring the restoration and preservation of biological diversity. Such results can be achieved through the integrated application of the traditional reclamation techniques for restoration of a fertile soil layer and the most advanced methods utilizing the best available technologies.

Reforestation of disturbed lands is a complicated task that cannot be solved without a sound scientific basis. The literature review suggests that plant selection and improvement of environmental conditions for forest-forming species are major research areas in the field of forest reclamation. Numerous studies propose not only the most resilient woody species, but also optimal parameters for planting material, planting patterns, cultivation methods and forest care systems on different-type rock dumps.

As a plant community ages, a steady increase in phytodiversity characterized by a more complex structure of phytocenosis and an increased number of tree and shrub species is noted. Since a species change during succession is associated with a gradual improvement of the technogenic environment, long-term research on plant health in reclaimed areas are needed, including biomonitoring for better understanding the adaptation mechanisms to be used in the development of highly effective reclamation methods.

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