Problems and prospects for forest restoration, conservation and protection by reclamation during mineral development in the far eastern federal district

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Abstract. The article presents the results of the research of increasing the forestry measures efficiency by reclamation and phytomelioration of land sites under negative technogenic impact within the influence of mining enterprises in the Far Eastern Federal District of Russia. The land sites withdrawn from the forest land fund in the process of mineral development are intensively polluted by toxic tailing dumps. In this regard, the aim of the study was to assess the impact of tailing dumps on the current state of forest vegetation, and to identify the prospects for restoring the productivity of technogenically polluted lands and forest protection by reclamation and phytomelioration to ensure environmental safety of mineral processing waste. It was found, that strengthening of the technogenic environmental impact, including the forest communities, caused tense ecological situation in the adjacent territories. The regularities of forest ecosystems technogenic pollution, as well as the problems and prospects for their restoration, conservation and protection were revealed. Proposals to enhance the efficiency of forestry measures using reclamation and phytomelioration of technogenic polluted forest areas have been developed, its novelty has been confirmed by the Patents of the Russian Federation.

1. Introduction

The Far Eastern Federal District (FEFD) of Russia is rich in natural resources, including mineral resources. Thus, according to the National Program for the Socio-Economic Development of the Far East until 2024 [1], it has the largest reserves (%): diamonds (81), timber (51), gold (44), gas (27), oil (17), etc. The forest reserves of Russia's Far Eastern Federal District cover 500 million hectares (45% of Russia's forests). Of these, 275 million hectares are covered by forests (2/3 of the area is dominated by conifers). During the last 10 years, the area of the most valuable coniferous forests has decreased by 328.7 thousand ha.

According to the Forest Code (2007) there are 16 kinds of forest use permitted in the Russian Federation, including geological surveys and mineral development. State or municipally owned forest areas are leased for these operations. This type of forest areas use is the most destructive to both forest
ecosystems and soil cover. It is known that large areas of productive land, including forest land, are being withdrawn for the development of mineral resources in Russia and the Far Eastern Federal District (FEFD). Their withdrawal and the intensive technogenic pollution by compounds of toxic heavy metals (HM) and arsenic of the entire ecosphere have been facilitated by the natural-resource orientation of the Russian economy without taking into account the principles of rational nature management. All of the above caused the necessity of restoration of disturbed lands productivity and the assessment of the efficiency of various methods of forest vegetation restoration on technogenic formations. This is evidenced by the analysis of existing domestic and foreign experience. Thus, the National Standard: Best Available Techniques. Reclamation of Disturbed Land and Land Sites. Restoration of Biodiversity. (as revised) (GOST R 57446-2017) [2] was developed in the Russian Federation. In the monograph by B V Boravsky et al. [3] it is recommended to assess the regional prospects for diffusion of the best available technologies, taking into account the list of priority sectors and enterprises, to prepare and start promotion of several training programs addressed to different groups of trainees. The collection of papers edited by S A Sheinfeld and Y A Manakov [4] provides practical, innovative solutions for biodiversity conservation at all stages of a coal mining company's life cycle. The review of existing international and Russian legislation, branch and corporate standards, and environmental practices in the coal-mining sector was carried out. The article by I K Yazhlev et al. [5] considers the problems of regulatory and legal support of the introduction of resource and energy-saving technologies, the development of environmental and sector-specific legislation due to the transition to new principles of regulation of relationship in rational nature management, reducing the negative environmental impact.

International experience reflects a variety of successful approaches to conservation and compensation for biodiversity loss during mineral development. In the work by A P Pinto et al. [6] it is shown that pollution of soils and water with toxic heavy metals compounds (HM) has become one of the most important environmental problems around the world, posing a threat to ecosystems and human health. The authors proposed biological remediation according to which plants and microorganisms are used to remove toxic pollutants. In their opinion, it is the most effective method, environment friendly, inexpensive and widespread. The authors believe that bioremediation is one of the green approaches to cleaning up the planet. It is prospective, efficient, ecological and economical. Masarovičová Elena et al. [7] draw attention to the enormous role of woody plants, including the phytoremediation potential of fast-growing trees such as: poplar or willow. The researchers believe that because these trees have extensive and massive root systems that penetrate deep into the soil, they can provide effective absorption of water-containing pollutants from the substrate. According to them, a new biotechnological approach has shown that woody species have important application in many phytoremediation technologies (especially phytoextraction, phytostabilization and rhizodegradation) for cleaning contaminated soil, water as well as air. The studies by H C Cortez et al [8] indicate that mining of Ag, Pb and Zn from sulphide ores in the south-east of Spain led to accumulation of large amounts of sulphide waste from their processing and intensive technogenic land pollution, for the treatment of which bioaugmentation has been proposed. A M Shackira et al [9] outlines the results of the study of heavy metal compounds phytostabilization. The researchers concluded that although the phytostabilization method is currently widespread, however, further research is needed to test and select resistant plant species for this process.

The work of Niazi, Nabeel Khan, et al. [10], devoted to the problem of phytoremediation of soil contaminated with arsenic compounds in the process of mineral development using arsenic hyperaccumulating ferns is of great research interest. The authors proved that unlike traditional (physical and chemical) methods of remediation, phytoremediation of soils contaminated with As compounds using As-hyperaccumulating fern species has become an environment friendly, cost-effective and efficient technology. Scientists believe that future research should focus on molecular genetic technologies and possibly transgenic plants with increased tolerance and absorption of As compounds from soil.
Analysis of existing domestic and foreign experience shows that there are practically no publications on forest reclamation, which would analyze long-term changes (long-term observations) in the composition of the artificial vegetation community on dumps containing toxic HM compounds. Innovative technological solutions are needed here to develop methods and ways to restore the productivity of these lands using, for example, the potential of biological systems (bioremediation). In mining enterprises of the FEFD, this problem has not been practically studied, there is very little experience that requires generalization and identification of factors affecting the condition of emerging forest phytocenoses and soils at the reclaimed areas. In this connection, the aim of the study was to assess the impact of tailing dumps on the current state of forest vegetation, and to identify the prospects for restoring the productivity of technogenically contaminated land and protecting forests through reclamation and phytomelioration to ensure the environmental safety of mineral processing waste.

Proceeding from the aim, the following tasks have been defined: 1. To analyze the existing domestic and foreign experience for restoration, protection and conservation of forests using reclamation and phytomelioration of technogenically polluted forest areas during mineral development; 2. To assess tailings dumps as a source of environmental technogenic pollution and the state of forest vegetation on technogenic formations with toxic solid wastes from mineral processing in the study area; 3. To identify the prospects and develop the proposals for improving the efficiency of forest management by reclamation and phytomelioration of technogenically contaminated areas.

2. Methods and Materials

2.1. Study area and methods of research

The research was carried out during 2011-2020 within the impact area of closed mining enterprises of the Russian Far Eastern Federal District. For mineral development, the lands of the forest fund of the Far Eastern taiga and Primorsky-Priamursky coniferous-broad-leaved forest areas were withdrawn in the past. Standard methodological approaches were used: silvicultural, forest taxation, geoeconomic, statistical. Theoretical analysis of domestic and foreign literature; scientific forecasting as well as empirical, structural, functional and system analysis were used as the methods for the Program implementation. Information legal and literary sources were used in the work. Scientific, statistical, reporting and other sectoral materials containing relevant information on the characteristics, condition and dynamics of forest land in the forest areas under study, forest management, data on forest conservation, protection and reproduction were used to carry out the research. The study is based on the Forest Plans of the entities of the Far Eastern Federal District of the Russian Federation, materials of the State Forest Register (SFR), specific regulations on forest use, reproduction, conservation and protection. Modern generally accepted physico-chemical, chemical and biological methods have been also used.

3. Results and Discussion

According to our research, about 1 million hectares of land in the southern part of the FEFD only are currently disturbed by mineral resource development. Large areas of valley forests, the "golden fund" of Russia and the Far East, have been destroyed. Even closed mining enterprises, which could not cope with the difficulties of the transition period and were bankrupt, pose a particular danger. Their tailing dumps, which contain huge amounts of highly sulphidized waste, have been left uncontrolled, with no reclamation or conservation carried out, contrary to the Russian Legislation. They are not included in the register of dangerous wastes and have resulted in intensive geochemical technogenic pollution of not only forest ecosystems, but of the entire ecosphere as whole hundreds and thousands of kilometers away from the source, far beyond the boundaries of the land allotment (borders of leased lands). This is evidenced by the results of our multi-year research of toxic waste. Within the borders of negative intensive impact of such
large closed mining enterprises as: Karamkensky GOK in the Magadan region, Solnechny GOK as well as Okhotskaya, Sever, Kherpuchinskaya, Kerbinsky gold-mining cooperatives in the Khabarovsk Krai, Khingansky GOK in the Jewish Autonomous Region are located at the territory of the Far Eastern taiga forest area. In addition, two closed mining enterprises: Khrustalnensky GOK and the Dalnevostochnaya mine in Primorsky Krai are within the impact boundaries of the Priamursko-Primorsky coniferous-broad-leaved forest area.

Researchers have shown that the past activities of mining enterprises and the lack of subsequent reclamation and drainage of tailings dumps containing toxic heavy metal compounds have caused large-scale technogenic pollution, including dusting, of adjacent forest areas and settlements [11]. The wastes from the investigated tailing dumps belong to the second hazard class (highly hazardous). In the mineral composition of the mineral processing waste of the Komsomolsky and Kavalerovsky ore districts, the main ore mineral is cassiterite, which belongs to the minerals more resistant during oxidation, so sulphides are determinative in the formation of the hypergenesis zone. In addition to the above mineral, pyrite, arsenopyrite, chalcopyrite, pyrrhotite, sphalerite and galena are also present, containing large quantities of toxic heavy metal compounds. The waste is represented by finely dispersed mass of grey, sometimes brown iron hydroxides of various shades. They are formed by sulphides oxidation and consist of the above minerals. Hypergenic processes are intensified in the waste rock strata due to the increased contact surface of the finely crushed sulphides with the weathering agents.

The size of the tailing dump areas and waste amounts, for example, in the Komsomolsky tin mining district (closed Solnechny GOK) is actually larger than in the Kavalerovsky tin mining district (closed Khrustalnensky GOK) with total area of 90 ha. 41 million tons of waste are placed in it. Correspondingly, the Kavalerovskoye area is 15 hectares and the volume of tailings is 35 million tons. Compounds of toxic heavy metals (As, Pb, Cu, Ni, Mn, Zn, Co, Cd) contained in wastes migrate through the chain: waste → snow cover → soil → surface water → bottom sediments → vegetation → human, accumulating in large quantities in environmental objects. Intensive atmospheric air pollution has been revealed, especially in the vicinity of the tailings dump. For example, from its surface area of 90 hectares, such as the closed Solnechny GOK, a gust of wind blows about 6000 m³ of sand saturated with ore elements, containing toxic heavy metals (HM) and arsenic compounds. Concentration of HM compounds for zinc in soils near the tailing dump at a distance of 0.3-3.5 km exceeds the regional background indexes 10 times, for lead – 30-46 times, for cadmium –30 times, for copper – 6-51 times. It has been established that high soil acidity (pH 4-5) determines high mobility of HM compounds and high level of their accumulation by plants. With distance from the source of pollution, for example, at a distance of 10-12 km, the content of HM compounds both in soils and in plants decreases. Obviously, tailing dumps are particularly dangerous sources of pollution. The studies carried out lead to the conclusion that their substrate (processing waste) is not suitable for plant growth. The lack of self-overgrowth is associated with the high toxicity of the tailings dump surface material. Self-overgrowing of disturbed areas is practically impossible here due to unfavourable agrophysical and chemical properties of the tailing dump surface material in relation to plants, absence of organic matter. Here, in the process of reclamation, it is necessary to create a model of the soil profile that meets the bioclimatic conditions of the region. It has been established that under effect of tailing dumps pollutants, the species composition of the vegetation cover is subject to degradation or almost complete destruction over a large area (figure 1). A survey of forest vegetation in adjacent areas revealed its unsatisfactory state. Red spots were found on the leaves of the poplar (Populus suaveolens Fisch). At one of the sites located 300 m from the tailings dump, the poplar trees accounted for 95% of all suppressed trees. It was found that the average height of trees in the surveyed sites is significantly lower than in the background area. A particularly large difference was found in Fabrichny settlement (near the tailings dump of the closed mining enterprise Khrustalnensky GOK). The coefficient of biological accumulation shows that the content of heavy metal compounds in plants depends on the presence of
mobile forms in the soil solution. For example, for Pb compounds – 6-9 mg/kg, for Zn – 5-7, Cu varies within 4-6 mg/kg. The results of space imagery analysis show that during 30 years of existence of the natural-mining technogenic system, formed, for example, in the Komsomolsky tin ore district (within the impact of the now closed mining enterprise Solnechny GOK) there is a significant landscape degradation on the territory of more than 650 km². Here the areas of technogenically contaminated areas of damaged (suppressed) forest from toxic tailing wastes increase from 4 to 19 times and more. The total area of technogenic pollution in the forest area of the Kavalerovsky tin ore district (within the impact of the closed mining enterprise Khrustalnensky GOK) is more than 450 km². Due to technogenic pollution from wastes the loss of the following most important functions of plant communities has been revealed: habitat-forming, water-protective, anti-erosion, biostation. It is known that balanced development of an area is impossible without ecological functions of vegetation. The problem of the depletion of forest resources within the boundaries of the impact of the FEFD tailing dumps is the most important problem (and not only ecological, but also economic and social). Important "forest" environmental problems include the following: 1) rapid destruction of native taiga massifs, which are the last areas where natural taiga biological diversity and many other elements of natural taiga landscapes are preserved; 2) poor efficiency of reforestation measures; 3) high number of forest fires; 4) bogging-up; 5) development of erosion processes on river valley slopes, pollution of water washed off dumps, change of rivers and lakes water regime; 6) violation of natural migration ways of animals; 7) pollution of territories by toxic heavy metal compounds from mining wastes especially stored in tailing dumps.

Figure 1. Degradation of vegetation within the influence of the tailing dump.

The rate of forest land reduction, for example, is higher in the Priamursko-Primorsky coniferous-broadleaved forest region than in the Far Eastern taiga region. Over the last century of forest exploitation in Russia, including the Far Eastern Federal District, there has been a steady decline in the biosphere properties of forests due to the gradual replacement of undisturbed forests by secondary, i.e. disturbed forests. Thus, the study of the above named problem shows that the highest content of pollutants is found in the air basin, soils, vegetation and other objects located near the tailing dumps. The environmental
situation in the study area has been assessed as critical at the distance of up to 10-12 km, unsatisfactory – up to 13-15 km, and partially satisfactory – over 20-22 km.

Thus, our research has shown that within the boundaries of closed mining enterprises in the Far Eastern Federal District of Russia there is a threat of biodiversity loss and increase in the proportion of forest areas that are not only technogenically polluted, but also covered with low-value deciduous hardwood. It is known that the effective use of forest lands negatively affected by mining industry is impossible without special rehabilitation measures. The technologies used in various regions, including the Far Eastern Federal District of Russia, to reproduce the productivity of technogenically polluted lands, previously withdrawn from the forest fund, cannot effectively contribute to the restoration of disturbed areas. The possibilities of accelerated creation of effectively functioning soil horizons as the most important structural unit of biogeocenoses to be restored on wasteful or technogenically polluted areas, have not been studied here. Therefore, there is a necessity of forests rational use and reproduction of productivity, development of measures and conditions for their successful natural and artificial restoration with biodiversity preservation. It is important to choose the method of forest reproduction not only after logging or forest fires, but also after technogenically contaminated forest areas, which should ensure the restoration of both the plantation itself and its inherent flora and fauna, and the restoration of soil functions. In most cases, the pace of reclamation operations at the mining enterprises of the FEFD is extremely low and significantly lags behind the land disturbance volume, and the reclamation technologies used have a low level of scientific intensity and ecological efficiency, which do not allow to reduce significantly the negative impact of disturbed lands on the adjacent forest areas. The impact of technogenic pollution on forest ecosystems of adjacent territories is not taken into account. At best, industrial waste is partially removed and the disturbed area is coarsely leveled, which does not meet environmental requirements. The mineral development leads to a complete loss of soil, a radical change of the habitat ecotope and a change in the direction, pace and productivity of the forest-forming process. According to the Fundamentals of National Policy for Ecological Development of the Russian Federation for the period until 2030, approved by the President of the Russian Federation on April 30, 2012, one of the central objectives of state policy is the restoration of disturbed natural ecological systems. The restoration of the original, historically established type of vegetation in the process of mineral development is only possible by land reclamation and phytomelioration as land improvement by planting woody or herbaceous vegetation. The restoration of a forest cover is also possible using intensive artificial reforestation methods, the application of bioremediation. To reduce the negative impact of deforested areas resulting from the development of mineral resources, it is necessary to carry out reclamation (technical and biological stages) by technologies using the biological systems potential (bioremediation), the novelty of which is confirmed by the Patents of the Russian Federation [12, 13]. Considering the extreme fire danger and combustibility of forest plantations in the Far Eastern Federal District, it is advisable to introduce fire-proof protective belts of poplar or larch as the main direction of phytoreclamation and firefighting arrangement in the region. Reclamation of lands disturbed by mining operations (technical and biological stages) and phytomelioration in the Far Eastern taiga and Primorsky-Primorsky coniferous-broadleaved forest areas will increase the area of forested land, which will contribute to increase in carbon storage. Artificial reforestation should ensure the use of integrated reforestation as the most effective and preserving the productivity and biodiversity of the Far Eastern phytocenoses. In addition, the restoration of forests to replace those deforested during mineral development will make it possible to compensate for the loss of carbon stocks in forests phytomass, as well as to eliminate the reduction in forest cover due to the loss of forest areas.
4. Conclusion
In the course of the research, the impact of tailing dumps on the current state of forest vegetation has been assessed. Problems and prospects of restoration of technogenic polluted lands productivity and protection of forests by means of reclamation and phytomelioration for ecological safety of mineral processing waste products have been revealed. It was established that intensification of technogenic impact on the environment, including forest communities, caused tense ecological situation in the adjacent territories. The necessity of productivity restoration of technogenic polluted forest sites within the impact area of closed mining enterprises was substantiated. The regularities of forest ecosystems technogenic pollution were studied. The proposals to enhance the efficiency of forestry measures through reclamation and phytomelioration of technogenically polluted forest areas were elaborated and their novelty was confirmed by the Patents of the Russian Federation.

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Reference
[1] The National Program for the Socio-Economic Development of the Far East until 2024 and for the term until 2035 [Natsional'naya Programma sotsial'no-ekonomicheskogo razvitiya Dal'nego Vostoka na period do 2024 goda i na perspektivu do 2035 goda – in Russian] 24.09.2020, order No 2464-r, p 128
[2] GOST R57446-2017 2019 Best available technologies. Reclamation of disturbed land and areas. Restoration of biological diversity (with amendment) [Nailuchshie dostupnye tekhnologii. Rekul'tivatsiya narushennykh zemel' i zemel'nykh uchastkov. Vosstanovlenie biologicheskogo raznoobraziya (s Popravkoi) – in Russian] Standartinform p 23
[3] Boravsky B V and Skobeklev D O 2013 Best available technologies. Aspects of practical use. (Moscow: KTS) p 128
[4] Sheinfeld S A, Litvin O I, and Manakov Yu A 2017 Collected innovation solutions for biodiversity in coal-mining sector (Novokuznetsk: InEcA) p 256
[5] Yazhlev I K, Popkov A G and Belogurova O A 2020 Problems of regulatory support for introduction of resource - energy-saving technologies in urban development [Problemy normativno-pravovogo obespecheniya vnedeniya resurso-, energosberegayushchikh tekhnologii v gradostroitel'noi deyatelnosti– in Russian] Journal of Economy and Entrepreneurship, 3 (116) pp 1000-02
[6] Pinto A P, de Varennes A, Lopes M E and Teixeira D M 2016 Biological approaches for remediation of metal-contaminated sites Phyto Remediation, pp 65-112
[7] Masarovičová Elena and Katarína Kráľová 2018 Woody species in phytoremediation applications for contaminated soils Phyto Remediation. Springer, Cham, pp 319-373
[8] Cortez H, Ballester A, González F, Blázquez L and Muñoz J A 2017 Bioremediation of sulfide mine tailings: response of different soil fractions. In Enhancing Cleanup of Environmental Pollutants, pp 169-186
[9] Shackira A M and Jos T 2019 Puthur. Phytostabilization of heavy metals: Understanding of principles and practices Plant-metal interactions. Springer, Cham, pp 263-282
[10] Niazi and Nabeel Khan 2016 Phyto remediation of arsenic-contaminated soils using arsenic hyperaccumulating ferns Phyto Remediation, Springer, Cham, pp 521-545
[11] Krupskaya L T, Orlov A M, Golubev D A, Kolobanov K A and Filatova M Yu 2020 Assessment of environmental hazard of accumulated mineral processing waste of closed mining enterprises in…
the Amur River region and Primorye [Otsenka ekologicheskoi opasnosti nakoplenykh otkhodov pererabotki mineral'nogo syr'ya zakrytykh gornykh predpriiatii v Priamur'e i Primor'e – in Russian] Mining Sciences and Technology (Russia), vol 5 3 pp 208-223

[12] The patent No RU 2569582 C1 2015 Krupskaya L T, Kirienko O A, Maiorova L P, Golubev D A, Onishchenko M S A method for recultivating the surface of a tailing dump containing toxic waste using phototrophic bacteria [Sposob rekultivatsii poverkhnosti khvostokhranilishcha, soderzhashchego toksichnye otkhody, s ispol'zovaniem fototrofnih bakterii – in Russian]

[13] The patent No RU 2707030 C1 2019 Krupskaya L T, Ishchenko E A, Golubev D A, Kolobanov K F, Rastanina N K Composition for reducing the dust load on the ecosphere and recultivating the surface of the tailings storage facility [Sostav dlya snizheniya pylevoi nagruzki na ekosferu i rekultivatsii poverkhnosti khvostokhranilishcha – in Russian]