Restoration of vegetation cover in reclaimed areas with coal preparation waste in Kuzbass

Sergey Soloviev1, Irina Semina2*, Vladimir Androkhanov1,3, and Asya Shipilova2

1Institute of Soil Science and Agrochemistry of the Siberian Branch of the Russian Academy of Sciences, 630090, Ac. Lavrentieva Avenue, 8/2, Novosibirsk, Russia
2Siberian State Industrial University, 654007, Kemerovo Region, Kuzbass, Central District, Kirova str., bld. 42., Novokuznetsk, Russia
3Institute of Water and Environmental Problems of the Siberian Branch of the Russian Academy of Sciences, 656038, Molodezhnaya Street, 1, Barnaul, Russia

Abstract. The paper presents the results of research and assessment of the degree of restoration of vegetation cover in reclaimed areas with the use of coal preparation waste in Kuzbass. Reclamation of disturbed lands was carried out by backfilling the depleted pits of the former coal mine with coal preparation waste and forming a root layer on the leveled surface of the waste using materials of the fertile soil layer (FSL) and potentially fertile rocks (PFR). During the field survey of reclamation sites, it was found that when sowing perennial grasses (Bromopsis inermis, Medicago sativa, etc.) or planting trees and shrubs (Hippophae rhamnoides, Pinus sylvestris, etc.) on the root layer formed of FSL and/or PFR, favorable conditions are created in the reclaimed areas for the formation of the primary phytocenosis. Studies have also shown that in reclaimed areas where a fertile soil layer was used to form a root layer, a gradual restoration of soil properties is recorded in the surface fill layers, which in some parameters are close to natural soils common in the adjacent territories.

1 Introduction

The transition from traditional to industrial development of the economy is inextricably linked with the growth of mining and, as a result, leads to an increase in the negative load on natural landscapes and a deterioration of the general environmental situation in general.

The first attempts to neutralize the consequences of the negative impact of mining, including coal mining, on the environment by purposefully forming vegetation cover on disturbed lands began to be made in the industrially developed countries of Europe at the beginning of the 20th century [1]. On the territory of the former Soviet Union, this process began in the 50s of the XX century in the Donbass [2]. It should be noted that foreign work on the reclamation of technogenic landscapes through the formation of vegetation cover pursued agricultural and forestry goals, but at the end of the 20th century, more attention was paid to the ecological component. Among other things, in recent years, for the

* Corresponding author: semina.i@mail.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
reclamation of disturbed lands, there was a shift from a simple seeding of disturbed areas with grasses and planting of woody plants to a more meaningful and integrated approach, which consists in the development of individual reclamation projects taking into account many factors, including climate, relief, level of fertility and physical properties of rocks, etc. [2]. A huge experience has been accumulated in the restoration of soil and vegetation cover in disturbed territories in Russia and abroad [3-12]. To restore disturbed lands, various reclamation technologies are used, taking into account the specifics of local natural resources, physical and agrochemical properties of substrates, and special attention is paid to the selection of suitable plant species for the formation of vegetation cover. Still, the main condition for successful reclamation of technogenic landscapes is the creation of favorable edaphic conditions for the formation of the primary vegetation cover. A lot of works on different types of disturbed territories located in various climatic conditions are devoted to these issues [13-15]. Nevertheless, studies on the restoration of vegetation cover in reclaimed areas with coal preparation waste are relevant.

Purpose of the work: to study the processes of restoration of vegetation cover in reclaimed areas with coal preparation waste in Kuzbass and assessment of phytodiversity in areas with different root layer.

2 Materials and methods

The reclaimed sites, in administrative terms, are located on the territory of the Leninsk-Kuznetsk urban district, which is located in the western part of the Kemerovo region, in the center of the Kuznetsk depression - within the Kuzbass coal basin. In natural terms, the studied territory belongs to the Central forest-steppe region of the Kuznetsk depression, which is the most steppe part of the region. The forest-steppe nature of the landscape is more typically expressed along the periphery of the region and on the right bank of the Inya river. The area between the Inya river and Salair Ridge is now an almost pure steppe with small and extremely rarely scattered birch copses. Reclamation sites differ in age (3–9 years) and in the peculiarities of the formation of the root layer on the surface of the planned coal waste dump.

Reclamation of disturbed lands was carried out by backfilling the depleted pits of the former coal mine with coal preparation waste and forming a 20-40 cm thick root layer on the leveled surface using the materials of the fertile soil layer (FSL) and potentially fertile rocks (PFR).

In accordance with the classification of soils of technogenic landscapes, the reclaimed sites were presented: without applying FSL and PFR (site No. 1 - initial embryozem), with application of PFR (site No. 2 - lithogenic technosol), with application of FSL (site No. 3 - humus-accumulative undifferentiated technosol), with application of a mixture of FSL and PFR (site No. 4 - humus-accumulative undifferentiated technosol), and with layer-by-layer application of FSL and PFR (site No. 5 - humus-accumulative differentiated technosol). A site with natural soils - leached chernozems (site No. 6) was chosen as a control one. All selected sites are formed and characterized by a flat, undulating relief with small depressions.

To assess the degree of restoration of the vegetation cover of the reclaimed sites, a geobotanical description was carried out on five test plots with a size of 100 m², characterized by different properties of the root layer [7]. Also, in order to identify the degree of restoration of the vegetation cover of the reclaimed sites, an undisturbed phytocenosis located near the reclaimed sites was studied. Geobotanical descriptions were carried out using standard forms for their systematization and standardization of the data obtained.
3 Results and discussion

When examining the vegetation cover by the method of geobotanical descriptions (GBD) of the reclamation sites, the following features were noted.

Reclaimed site No. 2, 3 years old, with light loams and sandy loams (PFR) as a root layer, without sowing grasses (Fig. 1), is characterized by a high species diversity - 34 species (the predominant share of ruderal species is typical for the initial stages of overgrowth, GBD of site No. 2), but with a very small projective cover - no more than 15%.

![Vegetation cover on site number 2.](image)

*Artemisia absinthium* L. and *Elytrigia repens* (L.) Nevski are dominant species. The tree layer is represented by one specimen of *Ulmus pumila* L. undergrowth.

On two sites (No. 3 and 4), the biological stage of reclamation was carried out in 2013 using two methods. The first method is sowing *Bromopsis inermis* (Leyss.) Holub and *Medicago sativa* L. (GBD of site No. 4), the second — planting *Hippophae rhamnoides* L. and *Pinus sylvestris* L. (GBD of site No. 3, Fig. 2). When sowing perennial grasses, the projective cover reaches 90%, the species diversity is 16 species, dominated by *Bromopsis inermis* (Leyss.) Holub, *Elytrigia repens* (L.) Nevski, and *Poa stepposa* (Krylov) Roshev. After seven years of reclamation, *Medicago sativa* L. completely disappeared from the vegetation cover in this site. On the site with sea buckthorn and pine planting, the projective cover is 85% with a species diversity of 15 species, among which *Calamagrostis epigeios* (L.) Roth dominates in the herbaceous layer, and *Hippophae rhamnoides* L. - among the tree and shrub layer. Among the tree layer, earlier *Pinus sylvestris* L. proved to be of little use for these conditions, although it retained its presence. It should be noted that *Betula pendula* Roth, *Populus tremula* L. and *Acer negundo* L. appeared in the tree layer. Among other things, there is a ground layer in these two sites, which is represented by mosses and constituting up to 10% of the projective cover. Also, significant activity of the animal world has been established in these sites: in the first case (the predominance of the herbaceous layer), a significant number of rodent burrows are found, in the second (the predominance of the tree layer) - a large number of anthills.
In 2013, a site of mine rocks was planned (GBD of site No. 1, Fig. 3), where the biological stage of reclamation was not carried out, but only the technological stage of reclamation was carried out. At the time of the survey, a significant species diversity was recorded in this area - 20 species with a projective cover of no more than 7%. The tree and shrub layers are represented by several specimens of *Acer negundo* L., *Pinus sylvestris* L., *Populus nigra* L., and *Hippophae rhamnoides* L., and the herbaceous layer is represented by forbs of ruderal species. It is necessary to emphasize the fact that all plants represented on this site are in a depressed state, which may indicate unfavorable edaphic conditions of the root layer.

The vegetation cover at the reclamation site (HBD of site No. 5), carried out in 2011 by sowing *Bromopsis inermis* (Leyss.) Holub, is represented by 18 species of herbaceous plants with a projective cover of 80%. The dominants are *Calamagrostis epigeios* (L.) Roth, *Dactylis glomerata* L., *Poa stepposa* (Krylov) Roshev and *Bromopsis inermis*
In 2013, a site of mine rocks was planned (GB D of site No. 1, Fig. 3), where the biological stage of reclamation was not carried out, but only the technological stage of reclamation was carried out. At the time of the survey, a significant species diversity was recorded in this area - 20 species with a projective cover of no more than 7%. The tree and shrub layers are represented by several specimens of *Acer negundo* L., *Pinus sylvestris* L., *Populus nigra* L., and *Hippophae rhamnoides* L., and the herbaceous layer is represented by forbs of ruderal species. It is necessary to emphasize the fact that all plants represented on this site are in a depressed state, which may indicate unfavorable edaphic conditions of the root layer.

The vegetation cover at the reclamation site (HBD of site No. 5), carried out in 2011 by sowing *Bromopsis inermis* (Leyss.) Holub, is represented by 18 species of herbaceous plants with a projective cover of 80%. The dominants are *Calamagrostis epigeios* (L.) Roth, *Dactylis glomerata* L., *Poa stepposa* (Krylov) Roshev and *Bromopsis inermis* (Leyss.) Holub. The ground layer is also represented by mosses with a projective cover of 10%. There is a significant number of rodent burrows on the territory of the studied site.

The control site (steppe meadow) was selected a site near the study area (GBD of control site No. 6, Fig. 4), the vegetation cover of which is represented by a herbaceous layer. The projective cover is 95%, and the species diversity includes 31 species. The dominants are *Artemisia glauca* Pall. ex Willd., *Phlomoides tuberosa* (L.) Moench, *Filipendula vulgaris* Moench, and others. The activity of the animal world was also noted at the site the, in particular, there are several anthills.

Thus, a total of 76 plant species were recorded in the studied sites, a significant part of which are ruderal species.

To compare the floristic lists of the studied sites, the Jaccard similarity coefficient was used [16].

It is calculated using the following formula:

\[
K_j = \frac{c}{a + b - c},
\]

where \( c \) – the number of species common to two pairwise compared sites; \( a, b \) – number of species on sites.

Range of variation of \( K_j \) values – from 0 (lack of similarity) to 1 (equality of compared sites).

After calculating the values of the Jaccard coefficient, a symmetric matrix of similarity of sites was obtained (Table 1), which reflects the coefficients of similarity for each pair of compared sites.

Calculation of the Jaccard similarity coefficients for the species composition of the vegetation cover showed that the studied communities were divided into two main clusters (Fig. 5).

The first cluster unites a group of sites (No. 2 and No. 4), the coefficient of similarity between which is 0.31 (see Table 1). These sites are characterized by the initial stages of overgrowth with herbaceous plants. However, the biological stage of reclamation was not carried out on site No. 2, but only PFR was applied (in 2016), in contrast to site No. 4, where *Bromopsis inermis* (Leyss.) Holub and *Medicago sativa* L. were sown on the
substrate with application of a mixture of FSL and PFR in 2013. Such a significant coefficient of similarity of these sites is caused by the great diversity of species in site No. 2, not only ruderal but also native ones, the composition of which can be significantly reduced in the future, which is natural for the initial stages of succession. This process explains the high degree of similarity (0.21) of site No. 2 with the control site (No. 6).

Table 1. Values of the Jaccard similarity coefficient for the compared sites according to the species composition of the vegetation cover.

| Site No. | 1   | 2   | 3   | 4   | 5   | 6   |
|----------|-----|-----|-----|-----|-----|-----|
| 1        | 1.00| 0.16| 0.09| 0.13| 0.17| 0.18|
| 2        | 0.16| 1.00| 0.24| 0.31| 0.09| 0.21|
| 3        | 0.09| 0.24| 1.00| 0.14| 0.25| 0.15|
| 4        | 0.13| 0.31| 0.14| 1.00| 0.15| 0.23|
| 5        | 0.17| 0.09| 0.25| 0.15| 1.00| 0.06|
| 6        | 0.18| 0.21| 0.15| 0.23| 0.06| 1.00|

Fig. 5. The similarity of the studied sites in terms of the species composition of vegetation according to the calculated values of the Jaccard coefficient (from 1 to 6 - site numbers).

The second cluster is represented by sites No. 3 and No. 5, the similarity coefficient of which is 0.25. These areas are united by using FSL and PFR for dumping onto the dump surface, carrying out a biological stage of reclamation, as well as the degree of restoration of the plant community. So, at site No. 5, layer-by-layer (differentiated) dumping of FSL and PFR on the surface of the dump was carried out in 2009. After that, the sowing of *Bromopsis inermis* (Leyss.) Holub was carried out, and at site No. 3 (in 2013), a mixture of FSL and PFR was poured onto the surface of the coal preparation waste dump in an undifferentiated manner. Also, *Hippophae rhamnoides* L. and *Pinus sylvestris* L. were
planted, which, apparently, served as a positive moment for the last site, since its degree of similarity in species diversity is closest to the control (0.15).

Thus, these two clusters combine areas with active processes of vegetation cover restoration, i.e. there is a gradual increase in the share of native species in relation to ruderal species, as well as a gradual increase in species diversity. In addition, the indicators of the gradual restoration of biodiversity and plant community are the multiple traces of animals staying in these areas - the abundance of rodent burrows and the presence of anthills, which is not observed on areas that are at the initial stages of overgrowth.

It should be noted that the control site with natural vegetation and undisturbed soil cover (natural site No. 6) is biased towards these clusters (in particular, site No. 4) with the maximum similarity coefficient equal to 0.23.

The most isolated position is occupied by site No. 1 formed 4 years ago, without applying FSL and PFR to the dump surface and without carrying out the biological stage of reclamation. The isolated position of this site from the point of view of vegetation restoration can be explained by a large species diversity - 34 species and a small projective cover (15%), which indicates the initial stage of succession. A significant part of the plants on this site is in a very depressed state, which is caused by the unfavorable properties of the substrate of the root layer, consisting of carbonaceous particles and fragments of mudstones, siltstones, and sandstones.

**4 Conclusions**

1. During the field survey of reclamation sites, it was found that when sowing perennial grasses (*Bromopsis inermis*, *Medicago sativa*, etc.) or planting arboreal and shrub vegetation (*Hippophae rhamnoides*, *Pinus sylvestris*, etc.) on the dumped surface of the root layer from the PFR (potentially fertile rocks) and/or FSL (fertile soil layer), favorable conditions are created for the formation of the primary phytocenosis on the reclaimed areas. Thus, in the studied areas, which are seven years old, the projective cover is 80–90% and is close to the projective cover in undisturbed areas (95%). With an increase in the age of reclamation, an increase in species diversity is noted up to 18 species (in which a high proportion of native species is found), provided that this indicator fluctuates in different periods of time, as a result of the gradual replacement of annual plant species by perennial ruderal species and their simultaneous replacement with native species. The evidence of intensive processes of restoration of disturbed phytocenoses is the restoration of the biocenosis, the appearance of the animal population in these territories, in particular, in the studied areas aged seven years and more, a significant number of anthills and underground passages of rodents were noted.

2. On the site without FSL and PFR (No. 1), a significant species diversity was recorded - 20 species with a projective cover of no more than 7%. The tree and shrub layers are represented by several specimens of *Acer negundo*, *Pinus sylvestris*, *Populus nigra*, and *Hippophae rhamnoides*, and the herbaceous layer is represented by forbs of ruderal species that are in a depressed state.

3. The studies have shown that the best values of the soil-ecological state of the reclaimed sites were obtained in the variants with the use of a fertile soil layer for the formation of the root layer. In such areas, a stable vegetation cover is formed, and a gradual restoration of soil properties in the surface dumped layers towards natural soils common in the adjacent territories is recorded. Also, the restoration of the entire biocenosis is more active.

The research was carried out with the financial support of the Russian Foundation for Basic Research and the Kemerovo Region within the framework of the scientific project No. 20-44-42006-20.
References

1. W. Knabe, *Methode and resultat of strip-mine reclamation in Germany*, The Ohio Journal of Science 64, 2, 75–82 (1964)
2. V.A. Androkhanov, V.N. Kurachev, *Soil-ecological state of technogenic landscapes: dynamics and assessment* (Novosibirsk, 2010)
3. A.M. Shipilova, I.S. Semina, *Assessment of the soil-ecological state of the technogenic landscapes of Kuzbass, depending on the technology of reclamation of disturbed lands*, News of the Ural State Mining University 3 (47), 53–56 (2017) DOI: 10.21440/2307-2091-2017-3-53-56
4. Yu.A. Manakov, *System of protected areas of the Kemerovo region as a factor of mitigating the impact of coal mining on biodiversity*, Coal 7 (1120), 89–94 (2019)
5. T.S. Chibrik, *Some aspects of assessing the experience of biological reclamation in the coal deposits of the Urals*, News of the Orenburg State Agrarian University 5 (37), 216-218 (2012)
6. T.S. Chibrik, *Biodiversity restoration on the dumps of the Cheremshansk Nickel deposit*, Industrial botany 19, 3, 45–48 (2019)
7. M.A. Zhang, et al. *Temporal and spatial change of land use in a large-scale opencast coal mine area: A complex network approach*, Land Use Policy 86, 375–386 (2019)
8. A. Adeli et al. *Age chronosequence effects on restoration quality of reclaimed coal mine soils in Mississippi Agroecosystems*, Soil Science 178, 7, 335–343 (2013)
9. B. Bond-Lamberty, A. Thomson, *Temperature associated increases in the global soil respiration record*, Nature 464 (7288), 579–582 (2010)
10. A. Bradshaw, *Restoration of mined lands – Using natural processes*, Ecological engineering 8(4), 255–269 (1997)
11. B.R. Finkelman, *Potential health impacts of burning coal beds and waste banks*, International Journal of Coal Geology 59, 19 – 24 (2004)
12. S. Mukhopadhyay, R.E. Masto, A. Yadav, et al. *Soil quality index for evaluation of reclaimed coal mine spoil*, Science of the Total Environment 542, 540-550 (2016)
13. I.V. Zenkov, E.A. Izhmulkina, Yu.A. Maglinets, et.al. *Results of a study of the formation of an ecosystem on coal mines in the western part of the central regions of Kuzbass using ERS resources*, Ecology and Industry of Russia 22, 2, 40–45 (2018) DOI: 10.18412/1816-0395-2018-2-40-45
14. I.S. Semina, V.A. Androkhanov, E.D. Kulyapina, *Experience of using coal preparation wastes for reclamation of disturbed areas*, Mining information and analytical bulletin (scientific and technical journal) 9, 159–175 (2020) DOI: 10.25018/0236-1493-2020-9-0-159-175
15. I.S. Semina, V.A. Androkhanov, E.D. Kulyapina, *Soil-ecological state of reclaimed areas with the use of coal preparation waste*, Science-intensive technologies for the development and use of mineral resources 6, 439–444 (2020)
16. P. Jaccard, *Comparative study of floral distribution in a portion of the Alps and Jura*, Bull. Soc. Vaudoise Sci. Natur. 37, 547–579 (1901)