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Restoration of Ground Vegetation Covers of Disturbed Areas on Brown-Coal Dumps in the South of Primorye of Russia

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ABSTRACT
The ground cover restoration of disturbed lands occurs in two ways: artificial – by remediation- and natural - by spontaneous overgrowth. The observation over these processes in dynamics allows to estimate their efficiency, the main tendencies, and influence of changing climatic conditions and to develop recommendations for optimization of these processes.
Key words: brown coal quarry, the worked-out dumps, reforestation, plant community, soil characteristics, species diversity, ground cover.

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INTRODUCTION

Every year, on a global scale, human industrial activity becomes a growing threat to the environment. In Russia, in total, more than 2 million hectares of land need to be reforested. Primorsky Krai, where an increasing number of areas are alienated for industrial facilities, landfills, quarries and ore mining dumps, is no exception. According to the Report on the environmental situation in Primorsky Krai of 2018, more than 8831,19 thous. ha of land are disturbed during the development of mineral deposits and peat, geological exploration, construction and other works (Official data 2019).

Classical reforestation is extremely expensive and labor-intensive, so alternative, less energy - and resource-intensive methods of restoring ground cover and ecosystems are needed. The situation is complicated by the fact that measures to restore soil productivity everywhere are carried out belatedly and not in full.

The purpose of the study is to study the self-restoration processes of plant community on productivity of artificial and natural overgrowth of the worked-out dumps on brown-coal quarry in long-term dynamics of the south of Primorye and to offer effective recommendations for the restoration of the ground cover of disturbed habitats.

MATERIALS AND METHODS

Observations over the floristic composition, assessment of the plant abundance on Drude's scale (Lavrenko 1964) and comparative analysis were carried out in various areas of disturbed territories on brown-coal dumps from 2004 to 2018, using Mikhailovsky district as an example, which differ in terms of growth. The analysis included a detailed geobotanical description of the vegetation. The abundance of tree and shrub cover was estimated in percentages (Vasilevich, 1969). Life forms of plants are determined according to the work of I.

G. Serebryakov (1964). The description of vegetation was conducted according to layers (Bogolyubov 1996).

Soil sampling was carried out according to the standard method (Kovrigo et al. 2000).

Studies of agrochemical soil composition were carried out in the agrochemical laboratory of FSI SCAS "Primorsky".

RESULTS

The need to monitor the productivity of natural and artificial restoration of disturbed areas and determine the duration of overgrowth on different brown coal dumps in the south of Primorye is associated with the problem of remediation of disturbed lands, and this, on the other hand, is an expensive and labour-intensive process.

As far as the main model site, the dumps of Rettikhovsky brown coal deposit, discovered in 1956, were selected for long - term observations. It entered to the development in 1961 and fully exhausted in 1991. The location of the object under study is the limits of the Blue Ridge which is the western spur of Sikhote-Alin.

According to the geological exploration two sites are allocated at the deposit: East basin and West basin, one large body of water had been formed at the bottom of every site by 2003.

In studies conducted in 2017 we found significant changes in the hydrological regime of the site; rise in the water level by several meters, as well as the unification of the Western and Eastern basins into one vast body of water during monsoon rains.

Before the beginning of the geobotanical description in 2002 and again in 2003, soil samples were taken (Table 1).

According to the results of agrochemical analysis of the studied soil samples it was determined that soils belong to the group of strong acids with high humus level, very high availability of hydrolyzable nitrogen, low content of labile phosphorus and sufficient K value. The amount of total organic matter is quite high, which is explained by the imperfection of the ignition method (Dobrovolsky 1982), because in the analysis, a significant percentage of organic matter index results from a considerable content of coal

and cinders in soil samples. Whereas, humus layer favorable for the growth of plants is absent (an exception is reclaimed areas of dumps).

According to the geobotanical data of 2003-2004, we found that 18 species of trees and shrubs and 15 species, mainly ruderal grasses, were in the processes of overgrowth.

The main tree and shrub species of plants involved in the process of overgrowth of dumps in Rettikhovsky brown coal deposits are: *Betula manshurica Gray, Salix caprea L, S. rorida Laksch., S. schwerinii E., Populous davidiana Dode, P. koreana Rehder, и Sorbaria sorbifolia (L.)* A. Br. As far as habitats, they prefer the slopes of the southern, south-western (Fig. 1), south-eastern and western exposure. All three species of willows grow on relatively leveled areas, at the base of slopes, on flat areas of dumps and on leveled areas of dump tops, and prefer sandy-clay soils, clay, with one or another content of coal particles. The processes of the flooding of the quarry led to an increase in the groundwater level and to the optimization of hydrological characteristics on the dumps. This factor, along with the decrease in salinity and acidity in the upper soil horizons under the influence of heavy rainfall, greatly contributed to intensification of restoration processes for plant growth.

At present, in the areas of overgrowth, the closed nature of the stand is noted. Its composition, as in the early observation periods, is dominated by species such as *Populus davidiana Dode*., *P. koreana Render* and *Betula mandshurica Nakia* . There was also a complete absence of *Salix caprea L., S. rorida Larsh*. in the stand composition.

The appearance of new species was noted including *Padus maackii (Rupr.) Kom*., *Alnus hirsuta Turcz*., *Ulmus laciniata (Trautv.) Mayr*, *Fraxinus mandshurica Rupr.*, *Maackia amurensis Rupr. et Maxim*., *Acer tegmentosum Maxim.*, *Kalopanax septemlobum (Thunb.) Koidz*.

The shrub layer has also been enriched with new species such as *Aser mono Maxim., A. ginnala Maxim.*, *Corylus heterophylla Fish.*, *Euonymus pauciflora Maxim*. In previous eras *Salix caprea L.*and *Sorbaria sorbifolia (L.) A. Br.* dominated in the shrub layer.

Herbaceous layer retained ruderal composition, but it became much less pronounced, sparse. Distinctive forest species such as *Ranunculus japonicus Thunb., Pyrola subaphylla Maxim.*, *Cacalia hastata L.*, *Serratula coronata L.*, *Artemisia mandshurica Kom. et Alless.),* Fragaria orientalis Losinsk*., Lathyrus komarovii Ohwi.* appeared in its composition.

In the areas exposed to reclamation effects, under the plantings of Pinus sylvestris L., the changes are also observed. Their linear size significantly increased, which is explained by the age of stand, increasing annual growth and good moisture supply.

The study area was originally located at the top of the quarry, which created xerophytic conditions, as a result, most of the trees differed in average or below average vitality. Most of all we observed 2-year– old needles, less often - 3-year-old needles, we identified significant areas of chlorosis and necrosis. Currently, the age of needles is 3-4 years, they are light green, the area of chlorosis and necrosis has significantly decreased. But along with this, there was also seed regeneration, which is not typical for the southern Primorye. This is due to the undeveloped ground cover, which usually suppresses the shoots of Scotch pine.

The active growth of *Betula mandshurica Nakia*, Populous davidiana Dode, P. koreana Rehder was noted. There is also an undergrowth of *Kalopanax septemlobum (Thunb.) Koidz*., less commonly *Aralia mandshurica Rupr. et Maxim., Abies nephrolepis Maxim*. *Sorbaria sorbifolia (L.) A. Br.* and *Rosa davurica Pall* stand out against the bushes. Small number of plant species of the ground cover is still significant, but it is already more pronounced, compared to 2003-2004.

In the lowlands the soil cover is mainly represented by ruderal species. In drier areas the species of fruticose lichens, which are typical of forest ecosystems, and other forest species as well as forest edge species were noted - *Licopodium annotinum L.*, *Dryopteris sp.*, *Carex sp.*, *Pyrola subaphylla Maxim.*, *Fragaria orientalis Losinsk.* и *Ranunculus japonicus Thunb.*

In the steppificated area overgrowth is a little different. We conducted long-term monitoring at the Novoshakhtinsky coal quarry which has begun to operate since 1963. In 1984 the questionnaire on the environmental condition was conducted among the residents of Novoshakhtinsk. The main complaints of the population were the reducing of groundwater level, the drying out of wells, the intense dust pollution. In course of time the depleted quarries were filled with water, the groundwater level rose, the ground cover was formed. In 2016 the overflow of depleted quarries took place and complaints of residents are already directed to the flooding of homes and small gardens during the monsoon rains.

Partial forest reforestation with the use of monotype plantings - *Populus davidiana Dode* и *Quercus mongolica Fisch* - was carried out on the mine dumps of Novoshakhtinsky coal quarry. In the steppificated areas where the plots were not reforested in 2003-2004, the ground cover was weakly pronounced and represented by unstable association of ruderal plants, xerophytic sagebrush-cereal association, quite large areas of relatively fresh workings were occupied by *Thymus disjunctus Klok.*

In 2017 extensive sagebrush-reedgrass association with an admixture of Leguminosae and Asteraceae was formed on the studied areas. On the lower areas closed association of *Phragmites communis Trin.* has developed. On the fertile soils Calamagrostis epigeios (L.) Roth. forms homogeneous closed association that prevents from penetration of other plant species. Under the conditions of soils on mine dumps of brown coal quarries poor in organic matter the association of *Calamagrostis epigeios (L.) Roth.* often grows with the inclusion of herbaceous plants of Leguminosae Juss family.

There is almost complete absence of herbaceous cover in monotype reclamation plantings except for the community *Eqisetum arvense L.*. and unstable association of ruderal plants. The age of plantations is about 30 years, but the introduction of other tree and shrub species is almost not

observed. Single inclusions of *Betula mandshurica (Rge.) Nakai and Salix rorida Laksch* were noted. The undergrowth is also represented by *Populous davidiana Dode* in monotype aspen forests, and by *Quercus mongolica Fisch* in oak plantations.

We also conducted episodic studies at Luzanovsky and Rakovsky coal quarries. According to the results of observations, the following representative trees and shrubs (Table 2) and herbaceous species (Table 3), overgrowth components were noted.

In the course of research we found that the territory of brown coal dumps is characterized by natural, autogenic, allogenic, regenerative, progressive, primary, secondary, anthropogenic types of successions. All species are interrelated, changing under the influence of external or internal environmental factors.

Exodynamic changes occurring under the influence of climate changes, soil conditions, topographical relief or groundwater level, as well as anthropogenic factors are observed in the research area. This includes new plant community created in the process of bioreclamation.

In the course of the research, the availability of plant community which have different degrees of durability and stability was noted.

Two main types of cenosis depending on the degree of stability were recorded on the dumps of Rettikhovsky quarry:

1) short-lived within one generation, returning to natural, for example, birch and aspen trees in the place of broad-leaved oak forests (along the dumps of the quarry) (Fig. 2);

2) long-term, for example, reforestation plantation of pine) (Fig. 3).

The dumps of Rettikhovsky brown-coal quarry are characterized by the formation of various plant communities, mainly, depending on the mesorelief.

According to the results of overgrowth process observations, case study of Rettikhovsky brown coal deposit, the following characteristics were noted:

1. Woody and grassy layers are most developed on the slopes of the southern and western exposure. On the slopes of the northern exposure it was noted only very small pockets of overgrowth in the initial degree.

2. The tree layer grows primarily on the even lands of dump or on slope microterraces of 45° and higher. The herbaceous layer is well developed on the steep slopes of 30° or at the base of the slopes of 45-60°.

3. The maximum species diversity and projective cover of the herbaceous layer were observed on structureless soils with low coal particles saturation. The tree layer is most developed on structured soils that have coal particles in their composition.

4. Both woody and herbaceous layers are characterized by high indicators of vitality, abundance and productivity on salt-washed, washing soils.

5. The greatest abundance and species diversity of the ground cover is observed in the places of the Manchurian birch growth, which indirectly indicates the intensification of the humification processes. This is due, in our opinion, to the fact that the leaf litter of this species forms light humus, alkalizes the soil and accelerates the microbiological decomposition of brown coal particles.

The pioneer stage of overgrowth should be considered the emergence of communities of ruderal grasses; and then the primary association on flat slopes or flat areas is destroyed by water erosion. Sometimes these processes are irreversible, but often, before the final stage of destruction, herbaceous plants have time to establish, and tree and shrub layers, mainly represented by various species of willow and birch Manchurian, also have time to sprout.

Further, while developing, plant roots of a tree layer fix the soil and promote decrease in erosion process and weathering, in lowlands the leaf debris gathers, thus, favorable conditions for secondary expansion of herbaceous layer are created. In the first stages, it is represented by cereals and composite plants, and then it is supplemented by Leguminosae and Rosaceae.

On steep terraced slopes, the processes of self-restoration occur more rectilinearly, initially pioneer associations of ruderal grasses are formed, then a tree layer of Manchurian birch, David's poplar and Korean poplar is formed. The final stage involves the gradual displacement of ruderal grasses by forest species.

When forming communities of ruderal grasses, the most unpretentious woody components are introduced - *Salix rorida Larsh*, *S. schwerinii E., Populous davidiana Dode, P. maximoviczii A. Henry, Betula mandshurica (Rge.) Nakai*. These plant communities are poorly resistant and do not contribute to the accumulation of soil organic matter.

In the second case, only sparse association of *salix rorida Larsh* is formed, which has a strong allelopathic effect that prevents the introduction of other tree and shrub species.

In our opinion, the weedy overgrowth of the steppificated ash-disposal area is the least promising in terms of restoring the ground cover, since a protracted period of time provides an opportunity for wind erosion. The pioneer components of weedy overgrowth are various types of wormwood which deplete the primary organic matter of the soil and inhibit the development of soil microflora.

The way out of this situation can be controlled induced introduction of disturbed habitats by diaspores of the most specific plant species for this area in combination with the microflora which is endemic for these species. For example, nodule bacteria or phosphobacteria, allowing effective assimilation of phosphorus compounds for other species, are typical for nitrogen accumulator plants.

Consolidation of diaspores on rather steep slopes – mined-out area of brown coal deposits - provides for changing their relief. For a long time it was believed that this requires a change in macro- or at least microrelief. According to our numerous observations this requires only a minor intervention in landscape reconstruction at the level of nanorelief. The most effective method for the formation of the ground cover of disturbed habitats is the contagious introduction of diaspores of consort forming species together with the associated microflora, which allows the formation of scattered spot pockets of ground vegetation that is effectively closed later.

CONCLUSION

1. Thus, we can talk about different ways of overgrowth on brown-coal dumps which include: the formation of woody small-leaved plantations or forming formations of weedy vegetation.
2. Spontaneous overgrowth does not ensure the formation of stable successions, allowing the inclusion of disturbed habitats in the natural cycle of natural plant communities.
3. The change in the hydrological regime occurring on the territory of the southern Primorye during the last 4 growing seasons can lead to radical changes in the overgrowth processes of disturbed lands.

Discussion

The longstanding history of anthropocenoses formation suggests that a person should pay attention to the trends in the formation of natural biocenoses and when violating them, follow the example of minimal intervention in their recovery.

On the basis of the conducted research, we have proposed recommendations for the reforestation of the mined-out areas for brown coal dumps in the south of Primorye.

1. Lands disturbed in the process of coal mining, within 3-5 years after workings, should be returned to land use artificially and systematically, starting from the first years of operation of the coal quarry.
2. Reconstruction works on the landscape restoration of the worked-out dumps should be carried out taking into account zonal, climatic and soil characteristics.
3. Flattening of slopes actively used for reforestation in all places of Primorye will contribute to the intensive erosion of soils, water erosion and destruction of the ground cover. Thus, on the dumps of the southern Primorye, more practical activities will be the steep slope terracing.
4. When designing reforestation, it is necessary to use native tree and shrub species resistant to the negative effects of technogenesis. As far as the basic species you can use *Pinus densiflora Sieb. et Zucc., P. pumila Rgl., Juniperussibirica Burgsd, Larix dahurica Turcz., s.l., , Betula mandshurica (Rgl.) Nakai , Populus davidiana Dode, Sorbus sabucifolia Roem..*
5. Small-leaved plantations consisting of pure species do not contribute to the soil development and the formation of ground cover. In this regard, it is recommended to plant mixed forest stands with higher stability, productivity and species diversity.
6. For reforestation activities, it is appropriate to apply the planting of oligonitrophilic poor soil-demanding species such as *Betula dahurica Pall., Quercus mongolica Fiscg., Acer komarovii Pojark..* Oligotrophy of species, their drought and salt resistance should be the main features in the selection of crops for afforestation of dumps.
7. Plants, nitrogen accumulators, should be set out with the main species, for example, you can plant the following: *Hippophae rhamnoides L., Corylus heterophylla Fisch., Alnus hirsute Turz., Caragana fructicosa (Pall.) Bess., Maackia amurensis Rupr. et Maxim.*
8. It is recommended to introduce mycorhiza of symbiotic fungi into soil neo-formation which contribute to improving the species composition of stand and, as a consequence, improving the structure of the dump.
9. To intensify the process of humus formation, highly productive microorganism strains - carbophillia, capable of processing brown coals with the formation of humic acids, should be used.

ETHICS

The authors confirm there are no ethical issues involved.

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TABLES AND FIGURES

Table 1: Analysis of agrochemical soil composition on the studied territories (slopes, pit floor)

Soil type	Humus level %	pH salt	Soil content mg/100g		
			N	P_2O_5	K_2O
soils modified by the mining industry	17,2	4,4-4,6	2,1	7,2	14,1

Table 2: The main tree and shrub species - components of overgrowth on brown coal dumps (according to 2017)

№	Family	Species
1.	Aceraceae Juss.	Acer negundo L.
2.	Betulaceae S. Gray	Betula mandshurica (Rgl.) Nakai
3.	Fabaceae Lindl. s.l.	Maackia amurensis Rupr. et Maxim.
4.	Salicaceae Mirbel	Populus davidiana Dode.
5.		P. koreana Render.
6.		P. nigra L.
7.		Salix caprea L.
8.		S. rorida Laksch.
9.		S. schwerinii E.Wolf
10.	Rosaceae Juss.	Malus baccata (Maxim.) Kom.
11.		Prunus ussuriensis Koval. et Kost.
12.		Rubus crataegifolius Bge.
13.		Sorbaria sorbifolia (L.) A. Br.
14.	Tiliaceae Juss.	Tilia amurensis Rupr.
15.	Ulmaceae Mirbel	Ulmus pumila L.

Table 3: The main types of herbaceous vegetation - components of overgrowth on brown coal dumps (according to 2017)

№	Families	Species
1.	Fabaceae Lindl.	Vicia amoena Fish
2.		V. cracca L.
3.		Trifolium pratense L.
4.		T. campestre Scheb.
5.		T. Repens L.
6.		Melilotus suaveolens Ldb.
7.		Cilycine ussuriensis Rgl. et Maack.
8.		Falcata japonica Kom.
9.	Rosaceae Juss.	Sanguisorba glandulosa Kom.
10.		Agrimonia pilosa Ldb.
11.	Asteraceae Juss.	Ambrosia artemisifolia
12.		Aster tataricus L.
13.		Cirsium setosum (Wild.) M.
14.		Erigeron canadiens L.
15.		Mulgedium sibiricum (L.) Less.
16.		Sonchus brachyotus DC.
17.		Taraxacum mongolicum Hand.-Mazz.
18.		Artemisia scoparia Wladst. et Kit
19.		A. gmelinii Web. ex Stechm.
20.		A. rubripes Nakai.
21.		Ptarmica ptarmicoides (Maxim.) Worosh.
22.		Crepis tectorum L.
23.		Achellea millifolium L.
24.		Matricaria inodora L.
25.	Onagraceae Juss.	Onagra biennis (L.), Scop.
26.	Polygonaceae Juss.	Polygonum aviculare L.
27.		Rumex crispus L.
28.	Lamiaceae Lindl.	Thymus disjunctus Klok.
29.	Poaceae Barnhart	Calamagrostis epigeios (L.) Roth
30.		C. Langsdorffii Trin.
31.		Poa pratensis L.
32.		Miscanthus sacchariflorus (Maxim.) Hack.
33.		Agropyron repens L.
34.		Phragmites communis Trin.
35.		Setaria glauca L.
36.		Critesion jubatum L.

Fig. 1. The main tree and shrub species of plants involved in the process of self-healing dumps Rettikhovsky brown coal deposit.

Fig. 2. Short-lived within one generation

Fig. 3 Long-term, for example, pine plantation recultivation