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Article

Floristic composition of the vegetation of the colliery spoil heaps in Khakassia

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Abstract. Between 2020 and 2023, floristic analysis of the phytocenoses of the Izykhsky and Chernogorsky colliery spoil heaps in the semiarid conditions of Khakassia, revealed 363 species of higher vascular plants belonging to 207 genera (*Artemisia*, *Potentilla*, *Poa*, etc.) and 53 families, at various stages of vegetational succession. It was established that the vegetation developing on the territory of the colliery spoil heaps in Khakassia differs from the zonal steppe flora by the presence of a developed tree-shrub tier, primarily consisting of *Ulmus pumila*. The dominant families Asteraceae, Poaceae, Rosaceae, Brassicaceae, and Fabaceae are typical of the boreal flora of temperate latitudes. Three stages of succession are identified, the most widespread being the complex communities stage (315 species). Eurasian species predominated in the heap flora. As the succession progressed, the proportion of Holarctic and cosmopolitan species decreased, while the percentage of Siberian species increased by 2.2 times. The Khakassia spoil heap vegetation is shown to be most similar to the open-pit mine spoil heap flora in the Republic of Tyva. At the complex phytocoenosis stage, the spoil heap vegetation is represented by forest (38.1%), steppe (22.5%), and adventive (24.1%) floral assemblages. Hemicryptophytes and cryptophytes (50–60%) predominated over other biomorphs. More than a third of the species in the spoil heap area were mesophytes, with mesoxerophytes and xerophytes ranking second and third.

Keywords: biomorphological analysis, belt-zonal groups, chorological analysis, ecological groups

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Научная статья

Особенности флористического состава растительности отвалов угольных разрезов Хакасии

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Аннотация. С 2020 по 2023 гг. в результате флористического анализа в составе фитоценозов отвалов угольных разрезов «Изыхский» и «Черногорский» в субаридных условиях Хакасии на разных стадиях сукцессии было выявлено 363 вида высших сосудистых растений из 207 родов (*Artemisia*, *Potentilla*, *Poa* и др.), принадлежащих 53 семействам. Установлено, что на территории угольных отвалов в Хакасии формируется растительность, отличающаяся от зонального степного типа наличием развитого древесно-кустарникового яруса, преимущественно из *Ulmus pumila*. Ведущие семейства Asteraceae, Poaceae, Rosaceae, Brassicaceae, Fabaceae типичны для бореальной флоры умеренных широт. Выявлены три стадии сукцессии, наиболее распространена стадия сложных сообществ (315 видов). Во флоре отвалов преобладали евроазиатские виды. С ходом сукцессии доля голарктических видов и космополитов снижалась, а процент сибирских видов увеличивался в 2.2 раза. Наибольшее сходство флора отвалов Хакасии имела с отвалами разрезов в Республике Тыва. На стадии сложного фитоценоза флора отвалов угольных разрезов была представлена видами лесного (38.1%), степного (22.5%) и адвентивного (24.1%) комплексов. Гемикриптофиты и криптофиты (50–60%) преобладали над остальными биоморфами. На территории отвалов более трети видов являлись мезофитами, на втором и третьем местах располагались мезоксерофиты и ксерофиты.

Ключевые слова: биоморфологический анализ, поясно-зональные группы, хорологический анализ, экологические группы

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Introduction

Industrial activities during open-pit coal mining create large areas of spoil heaps, which provide specific landscapes and conditions. Natural vegetation is one of the most important factors influencing spoil heap floral succession (Manakov et al., 2011). The spontaneous overgrowth of colliery spoil heaps has been studied in Kuzbass (Kupriyanov et al., 2010; Manakov et al., 2011; Ufimtsev and Belanov, 2018), Tyva (Sambuu, 2014), and Khakassia (Lamanova and Safronova, 2013; Lavrinenko, 2016; Safronova et al., 2018). Due to the development of the coal mining industry in Khakassia, the study of spoil heap revegetation successions in this region becomes extremely relevant.

The purpose of this paper is to identify the features of the formation of the floristic composition of vegetation on colliery spoil heaps in the semiarid zone of Khakassia.

Material and methods

From 2020 to 2023, a detailed field survey was conducted to study the vegetation of the Izykhsky and Chernogorsky open-pit coal mine spoil heaps (the latter since 2021), reclaimed in the 2000s, as well as the spoil heap of the Izykhsky open-pit mine, where reclamation work began in the 1980s. The spoil heaps are located in a semiarid zone: the Chernogorsky open-pit mine in the drier conditions of the Uybat steppe, and the Izykhsky open-pit mine in the Koybal steppe, where conditions are moderated by the proximity of the Abakan and Yenisei rivers.

The region has a continental climate, with average annual temperatures from 1.8 to −1.0 °C. The absolute minimum temperature is recorded in January: −40.6 °C, and the absolute maximum temperature is in July: +35.6 °C. Annual precipitation ranges from 250 to 300 mm. The region's hydrographic network includes the Abakan and Yenisei rivers, as well as several lakes (Kuminova et al., 1976; Lysanova, 2000).

The spoil heaps from the 1980s to the 2000s are terraced landforms composed of sandstones, siltstones, and, rarely, carbonaceous mudstones. The heaps reach heights of up to 400 meters above sea level. Since the 2000s, the heaps have been deposited using stacking technology.

The soils of the region are common and southern chernozems. Zonal vegetation is represented by true short-grass steppes (Kuminova et al., 1976). The vegetation cover of the region has been transformed by anthropogenic factors (mining, infrastructure, and agriculture).

A total of 276 geobotanical descriptions were made using the standard methodology (Voronov, 1963). Species were identified using identification keys (Krasnoborov et al., 1979; Flora Sibiri, 1988–2003). Species names were checked using the Plantarium[1] and Plant List[2] websites. The stages of vegetation syngenesis follow Yu.A. Manakov and A.N. Kupriyanov (2009). The classification of biomorphs is given according to I.G. Serebryakov (cited from: Serebryakova et al., 2007). Ecological groups were determined according to T.K. Goryshina (1979). Biomorphs, ranges, belt-zonal groups, and ecological groups are given according to A.I. Tolmachev (1965), A.V. Kuminova et al. (1976), L.I. Malyshev (2012), L.I. Malyshev and G.A. Peshkova (1984), N.V. Stepanov (2014), E.S. Ankipovich and E.G. Lagunova (2015). The data were processed using IBIS 7.2 (Cherosov and Zverev, 2000; Zverev, 202;). Cluster analysis with STATISTICA 8.2 software using Euclidean distance was performed for flora comparison.

Results

Communities (n = 4) with a total projective cover (TPC) of 13% and seven species were identified at the pioneer group stage in the spoil heaps of the Chernogorsky open-pit coal mine; for phytocenoses at the simple phytocenosis stage (n = 33), the corresponding figures were 32% and 9 species, and for the complex community stage (n = 111), the figures were 66% and 11 species. On the spoil heaps of the Izykhsky open-pit coal mine and its old spoil heaps, simple (TPC 32–40%, 10–24 species) and complex phytocenoses (TPC 68–83%, 16–19 species) were identified.

The flora of higher vascular plants in the surveyed spoil heaps of the Chernogorsky and Izykhsky open-pit coal mines includes 363 species from 207 genera and 53 families. The spoil heap flora is dominated by the families Asteraceae, Poaceae, Rosaceae, Brassicaceae, and Fabaceae (Table 1).

The ten most represented families included 256 species, or 70.5%. A higher ranking for the family Rosaceae and a lower diversity of representatives of the family Fabaceae are also recorded, compared to the zonal flora. The families Brassicaceae, Chenopodiaceae, and Scrophulariaceae were often represented by weedy species. The high ranking of the family Salicaceae is explained by reclamation experiments and the proximity of water sources and settlements.

Table 1. Dominant families of the flora of higher vascular plants of the Khakassia spoil heaps.

Number in order of dominance	Family	Number of genera	Species	
			number	% of total
1	Asteraceae	28	64	17.6
2	Poaceae	40	55	15.2
3	Rosaceae	33	38	10.5
4	Brassicaceae	17	28	7.7
5	Fabaceae	13	25	6.9
6	Chenopodiaceae	6	14	3.9
7	Scrophulariaceae	7	10	2.8
8–9	Salicaceae	2	9	2.5
8–9	Lamiaceae	8	9	2.5
10	Polygonaceae	5	4	1.1

[1] Plantarium, 2025. Web page. URL: https://www.plantarium.ru (accessed: 10.11.2025).

[2] Plant List, 2025. Web page. URL: http://www.theplantlist.org (accessed 10.11.2025).

The flora of the spoil heaps is distinguished by the presence of species of 21 families: Equisetaceae, Hypolepidaceae, Convallariaceae, Asparagaceae, Betulaceae, Ulmaceae, Amaranthaceae, Papaveraceae, Grossulariaceae, Aceraceae, Linaceae, Nitrariaceae, Euphorbiaceae, Elaeagnaceae, Onagraceae, Cornaceae, Monotropaceae, Plumbaginaceae, Gentianaceae, Valerianaceae, and Dipsacaceae. *Ulmus pumila* L. from the family Ulmaceae is widely distributed through self-seeding.

The total composition of the flora of the Uybat steppe of the Ust-Abakan and Koybal steppes of the Altai districts of Khakassia, taking into account the latest publications (Ankipovich and Lagunova, 2015; Ebel et al., 2020; Kurbatsky, 2016; Shaulo et al., 2019, 2020) includes 377 species. According to the above-mentioned authors, the dominant families of the zonal flora are arranged in the following order: Asteraceae (15.0% of the total number of species), Fabaceae (11.9%), Poaceae (11.7%), Lamiaceae (6.6%), Brassicaceae (6.4%), Caryophyllaceae (5.6%), Rosaceae (5.0%), Boraginaceae (4.2%), Liliaceae and Scrophulariaceae (4.0% each). Species from the dominant families of the steppe flora accounted for 74.4% of the total number of species. The decline in the abundance of the family Rosaceae compared to the flora of the spoil heaps, is explained by the displacement of species of this family by weeds of the families Boraginaceae, Brassicaceae, and Scrophulariaceae. The families Fabaceae, Lamiaceae, and Liliaceae are also widely represented. In the steppes, unlike the spoil heaps, the families Chenopodiaceae, Salicaceae, and Polygonaceae are absent from the top ten.

The genera *Potentilla, Artemisia*, and *Poa* (Table 2) are dominant in the flora of the spoil heaps.

Table 2. Genus-specific structure of the flora of higher vascular plants of the spoil heaps of Khakassia.

Genus	Species	
	number	% of total
Artemisia	14	3.9
Potentilla	13	3.6
Poa	10	2.8
Leymus	6	1.7
Salix	5	1.4
Atriplex	5	1.4
Lepidium	5	1.4
Astragalus	5	1.4
Galium	5	1.4
Cirsium	5	1.4
Taraxacum	5	1.4
Populus	4	1.1
Allium	4	1.1
Rumex	4	1.1
Plantago	4	1.1
Festuca	4	1.1
Medicago	4	1.1
Chenopodium	4	1.1

Multispecies genera accounted for 29.5% of the total number of species. Representatives of the genera *Potentilla*, *Poa*, *Leymus*, *Allium*, *Galium*, *Astragalus*, and *Festuca*, found in spoil heaps, are also common in the steppes. In the steppes of Khakassia, the most species-rich genera are *Astragalus*, *Artemisia*, *Oxytropis*, and *Potentilla*. Species from the genera *Artemisia*, *Lepidium*, *Atriplex*, and *Cirsium* were primarily weedy. Species of the genera *Rumex*, *Populus*, and *Salix* were observed in areas with high humidity.

The flora of the Uybat and Koybal steppes of Khakassia, is dominated by the genera *Astragalus* (15 species), *Potentilla* (14), *Artemisia* (13), *Oxytropis* (10), *Poa, Carex* and *Leymus* (8 species each), *Stipa, Allium, Taraxacum* and *Senecio* (7 species each).

The genera *Salix*, *Atriplex*, *Lepidium*, *Galium* and *Cirsium* were found in the spoil heaps of coal mines but are absent from the lists of dominant genera of the flora of the above-mentioned steppes.

A characteristic feature of the spoil heap flora is the small number of species within families and genera. At the current stage of succession, the biodiversity of open-pit spoil heaps is ensured by new families and genera colonizing the area, rather than by increasing biodiversity within the families or genera whose representatives are already present. According to A.I. Tolmachev (1974), the predominance of species-poor and especially monotypic genera within the specific flora (for the open-pit spoil heaps of Khakassia, this is 189 genera out of 207) indicates that this flora was relatively new (compared to the local steppe flora) and was largely formed by the migration of species from adjacent territories.

A comparison was made between the floras of open-pit spoil heaps in Khakassia (based on succession stages and geographic location) and the natural steppes of the Altai and Ust-Abakan districts of Khakassia, as well as with the colliery spoil heaps in the southern steppes of Kemerovo Region (Kupriyanov et al., 2010) and Tuva (Sambuu, 2014) (Figs. 1, 2). Vegetation from similar climatic conditions in neighboring regions was brought for comparison, to identify specific features in the revegetation of the colliery spoil heaps.

It was shown that at the stage of complex phytocenosis, the flora of the studied spoil heaps differs significantly from the flora of the steppes of Khakassia and also from spoil heaps in the southern forest-steppe of the Kemerovo Region, but is similar to that of colliery spoil heaps in the steppes of the Republic of Tyva (Fig. 1).

The similarity in the species composition of pioneer assemblages and the steppes of Khakassia can be explained by steppe plant seeds having been carried by the wind from adjacent regions. Floristic compositions are similar at the assemblage and simple phytocenosis stages but differ prominently at the complex phytocenotic stage (Fig. 2**A**).

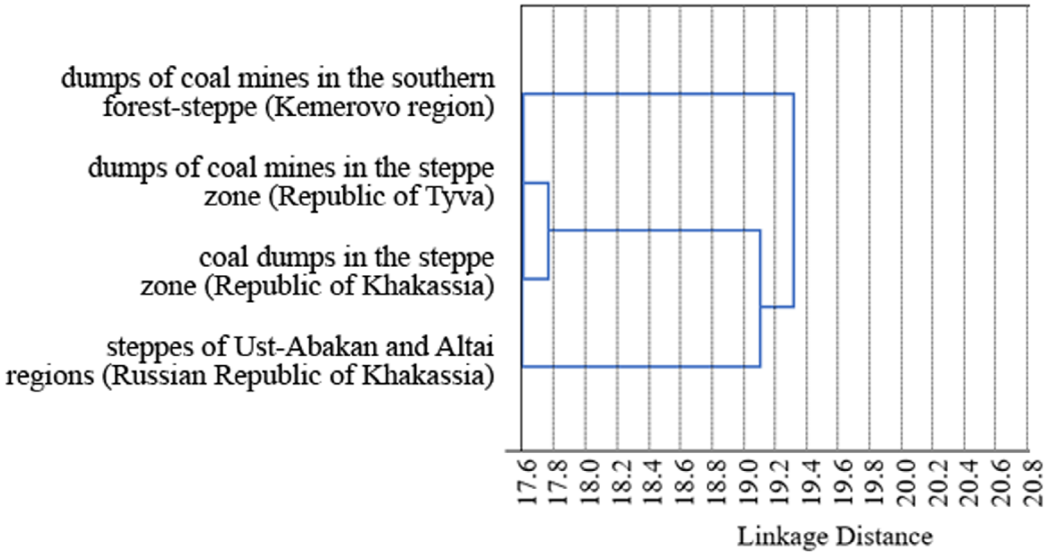

Fig. 1. Similarities between the vegetation of colliery spoil heaps, the steppes of Khakassia and spoil heaps in neighboring regions.

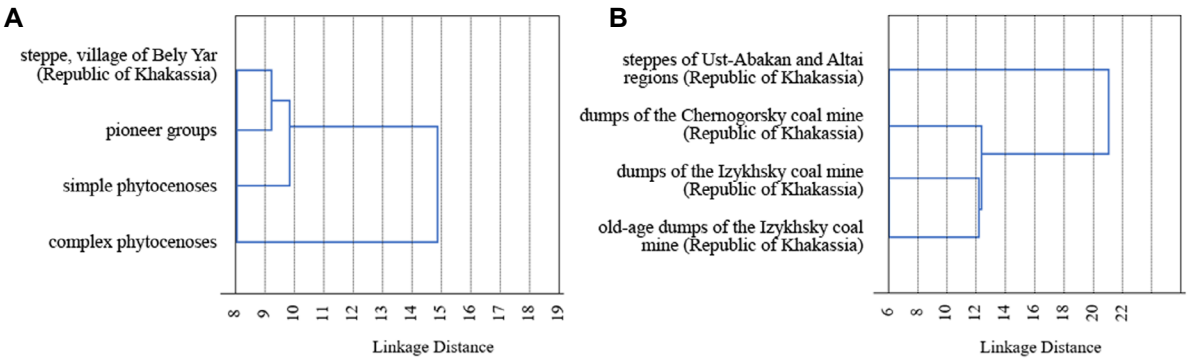

Fig. 2. Similarity of the vegetation of colliery spoil heaps in Khakassia at different stages of succession (**A**) and at different geographical locations (**B**) to the the steppe vegetation.

The floristic compositions of the Chernogorsky and Izykhsky open-pit mine spoil heaps are similar (Fig. 2**B**). A list from the Chernogorsky open-pit mine spoil heaps includes 175 plant species and reflects more arid conditions; 205 and 213 species, respectively, were found in the Izykhsky open-pit mine heaps and the old Izykhsky spoil heap.

The flora of Khakassia's open-pit colliery spoil heaps in the subarid zone and the flora of the surrounding steppes can be classified as typically boreal. The proportions of plant species ranges show the possible origin of this vegetation (Table 3).

In the early stages of succession, the flora was dominated by Asian species, mainly of Eurasian origin (*Calamagrostis epigeios* (L.) Roth, *Bromopsis inermis* (Leyss.) Holub, *Saussurea amara* (L.) DC.). As succession progressed, the proportion of Holarctic and cosmopolitan species decreased. The percentage of Siberian plant species increased significantly (by 2.2 times). Species diversity during the transition from the first to the second stage of succession increased by 203%, and from the second to the third – by 160%. The proportion of Asian species remained unchanged. At the stage of complex phytocenosis, the ratio of species on the studied spoil heaps was approximately the same: Asian species ranked first, Siberian species ranked second, and Holarctic species ranked third. Cosmopolitans ranked fourth.

A small number of species with North Asian (*Potentilla longifolia* Willd. ex Schltdl., *Glycyrrhiza uralensis* Fisch. ex DC.), Middle Asian (*Psathyrostachys juncea* (Fisch.) Nevski), Central Asian (*Heteropappus altaicus* (Willd.) Novopokr.), East Asian (*Allium anisopodium* Ledeb.), Mongolian-Daurian (*Convolvulus chinensis* Ker Gawl.) and American-Asian (*Artemisia glauca* Pall. ex Willd.) ranges were found on all the studied spoil heaps. The species *Elymus dahuricus* Turcz. ex Griseb. has a Mongolian-East Siberian origin. Common are Euro-Siberian (*Festuca valesiaca* Gaudin, *Hippophae rhamnoides* L.) and, to a lesser extent, South Siberian species (*Populus laurifolia* Ledeb., *Potentilla tanacetifolia* Willd. ex Schltdl.).

Thus, the flora of the Khakassia spoil heaps was dominated by species with wide ranges, reflecting the general floristic characteristics of the lowland areas of southern Siberia. The proportion of cosmopolitan species at the pioneer grouping stage amounted to 25% of the total number of species, indicating a significant transformation of the landscape.

In terms of zonal belts, the flora of higher vascular plants of the colliery spoil heaps of Khakassia is represented by species of forest, steppe, adventive and azonal assemblages (Table 4).

The forest group primarily includes forest-steppe vegetation: *Elytrigia repens* (L.) Nevski, *Hieracium umbellatum* L., *Medicago falcate* L., *Otites wolgensis* (Hornem.) Grossh. Forests in the semiarid climate zone of Khakassia are represented by poplar forests, small pine forests, and birch groves. Less common are the light coniferous (*Pinus sylvestris* L., *Larix sibirica* L.) and nemoral groups (*Populus laurifolia*, *Padus avium* Mill.).

The widespread distribution of steppe landscapes in the study area determined a significant percentage of steppe species: *Iris lactea* Pall., *Stipa capillata* L., including a small number of mountain-steppe (*Veronica incana* L., *Artemisia frigida* Willd.) and desert-steppe species (*Leymus racemosus* (Lam.) Tzvelev, *Leymus angustus* (Trin.) Pilg.).

The azonal component is not dominant and is found in lowlands and intermontane basins.

Table 3. Habitats of the species of the Khakassia colliery spoil heaps. Here and below, the main habitats are highlighted in bold; a dash indicates the absence of a species.

Geographical range	Succession stage					
	grouping		simple phytocenosis		complex phytocenosis	
	number of species	% of total	number of species	% of total	number of species	% of total
Cosmopolitans	**10**	**25.0**	**21**	**17.4**	**46**	**14.6**
Holarctic	**10**	**25.0**	**27**	**22.3**	**51**	**16.2**
Asian	**15**	**37.5**	**45**	**37.2**	**130**	**41.4**
American-Asian	1	2.5	1	0.8	3	1.0
Eurasian	8	20.0	24	19.8	72	22.9
Middle Asian	–	–	4	3.3	6	1.9
Central Asian	4	10.0	3	2.5	9	2.9
North Asian	1	2.5	8	6.6	29	9.2
East Asian	1	2.5	2	1.7	6	1.9
Mongolian-East Siberian	–	–	–	–	1	0.3
Mongolian-Daurian	–	–	3	2.5	4	1.3
Siberian	**5**	**12.5**	**28**	**23.1**	**88**	**27.8**
Euro-Siberian	3	7.5	18	14.9	60	19.0
South Siberian	2	5.0	9	7.4	25	7.9
Altai-West Sayan	–	–	–	–	1	0.3
Western Sayan-Baikal	–	–	1	0.8	1	0.3
East Sayan	–	–	–	–	1	0.3
Total	40	100	121	100	315	100

Table 4. Belt-zonal groups of higher vascular plants of colliery spoil heaps in Khakassia.

Belt-zonal group	grouping		Succession stage simple phytocenosis		complex phytocenosis	
	number of species	% of total	number of species	% of total	number of species	% of total
Forest	**11**	**27.5**	**31**	**25.6**	**120**	**38.1**
Dark coniferous forest	–	–	–	–	8	2.5
Light coniferous forest	4	10.0	14	11.6	48	15.2
Nemoral	1	2.5	1	0.8	13	4.1
Forest-steppe	6	15.0	16	13.2	51	16.2
Steppe	**8**	**20.0**	**32**	**26.4**	**71**	**22.5**
Steppe	8	20.0	17	14.0	39	12.4
Desert-steppe	–	–	2	1.7	1	0.3
Mountain-steppe	–	–	13	10.7	30	9.5
Hyparctomontane	–	–	–	–	1	0.3
Azonal	**4**	**10.0**	**15**	**12.4**	**48**	**15.2**
Adventive	**17**	**42.5**	**43**	**35.5**	**76**	**24.1**

Individual species (*Poa pratensis* L., *Psathyrostachys juncea*, etc.) were used in reclamation. The azonal meadow group of species (*Mulgedium sibiricum* (L.) Cass. ex Less., *Vicia cracca* L.) was predominant, but representatives of the bankside vegetation (*Cynoglossum officinale*, *Jacobaea erucifolia*) and wetland groups (*Typha latifolia*, *Poa palustris*) are also present. During the first stage of succession, species of the adventive and forest groups predominated. By the third stage, the proportions of steppe and azonal species remained virtually unchanged, the proportion of adventive species decreased to just over half (55%) of its former value, and the proportion of the forest group increased by 1.4 times.

A comparison of chorological groups with zonal-belt groups was conducted (Table 5). The zonal-belt structure is characterized by the predominance of adventive species (88 species in total), primarily cosmopolitan and Eurasian in origin. The forest group is represented primarily by light coniferous and forest-steppe groups of Euro-Siberian and Eurasian provenance.

The steppe group species are of diverse Siberian and Asian origin. The meadow groups consist primarily of Holarctic and Euro-Siberian species.

According to the classification of I.G. Serebryakov, from 50 to 56.9% of the biomorphological spectrum of the flora of the spoil heaps is occupied by herbaceous polycarpic plants (Table 6), which is typical of the temperate zone of the Northern Hemisphere (Serebryakova et al., 2007)

As succession progressed, a tendency toward an increase in the proportion of herbaceous polycarpic species was observed. A diversity of taproot polycarpic species (*Dianthus versicolor* Fisch. ex Link, *Potentilla acaulis* L.) is characteristic of steppes, steppe meadows, and forest-steppes; this group also predominated on spoil heaps.

Long-rhizome plants (*Elytrigia repens*, *Iris lactea*, *Calamagrostis epigeios*) and short-rhizome forms (*Medicago falcata*, *Geranium sibiricum* L., *Geum aleppicum* Jacq., *Achillea asiatica* Serg.) are common

Table 5. Representation of chorological groups in the belt-zonal spectrum of the flora of spoil heaps.

Belt-zonal group	**Cosmopolitans**	**Holarctic**	**Asian**								**Siberian**				
			American-Asian	Eurasian	Middle Asian	Central Asian	North Asian	East Asian	Mongolian-East Siberian	Mongolian-Daurian	Euro-Siberian	South Siberian	Altai-West Sayan	Western Sayan-Baikal	East Sayan
Forest	**4**	**14**	**1**	**38**	**1**	**1**	**18**	**3**	**1**	**2**	**39**	**8**	–	–	**1**
Dark coniferous forest	1	2	–	–	–	–	1	–	–	–	4	–	–	–	–
Light coniferous forest	2	9	–	18	–	–	6	–	–	1	13	4	–	–	–
Nemoral	–	1	–	4	–	–	2	1	–	–	3	2	–	–	–
Forest-steppe	1	2	1	16	1	1	9	2	1	1	19	2	–	–	1
Steppe	**–**	**4**	**2**	**14**	**9**	**14**	**9**	**4**	**–**	**4**	**11**	**16**	**1**	**1**	**–**
Steppe	–	2	1	7	4	9	4	2	–	–	10	7	–	1	–
Desert-steppe	–	–	–	1	2	1	–	–	–	–	–	–	1	–	–
Mountain-steppe	–	2	–	6	3	4	5	2	–	4	1	9	–	–	–
Hyparctomontane	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Azonal	**5**	**22**	**–**	**10**	**–**	**–**	**3**	**–**	**–**	**–**	**13**	**2**	**–**	**–**	**–**
Adventive	**46**	**16**	**–**	**17**	**–**	**–**	**–**	**–**	**–**	**–**	**9**	**–**	**–**	**–**	**–**
Total	55	56	3	79	10	15	30	7	1	6	72	26	1	1	1

Table 6. Biomorphological spectrum of higher vascular plants of spoil heap flora at different stages of succession.

Biomorph	Succession stage					
	grouping		simple phytocenosis		complex phytocenosis	
	number of species	% of total	number of species	% of total	number of species	% of total
I. Woody and semi-woody plants						
Trees	3	7.5	5	4.1	15	4.8
Shrubs	1	2.5	2	1.7	20	6.3
Semi-shrubs	–	–	1	0.8	2	0.6
Semi-dwarf shrubs	–	–	3	2.5	5	1.6
Dwarf shrubs	–	–	1	0.8	1	0.3
II. Herbaceous polycarpic plants						
Rhizome plants	10	25.0	27	22.3	93	29.5
Long-rizome plants	4	10.0	12	9.9	46	14.6
Short-rhizome plants	6	15.0	15	12.4	47	14.9
Taproot plants	7	17.5	21	17.4	48	15.2
Clump-forming, tussock-forming grasses	3	7.5	7	5.8	21	6.7
Hemicryptophyte rosettes	–	–	1	0.8	5	1.6
Stolon forming plants	–	–	–	–	3	1.0
Bulb plants	–	–	3	2.5	4	1.3
Vines	–	–	1	0.8	2	0.6
Parasitic plants	–	–	–	–	3	1.0
III. Herbaceous monocarpic plants						
Herbaceous annuals	8	20.0	24	19.8	42	13.3
Herbaceous biennials		20.0	25	20.7	48	15.2
IV. Floating and underwater plants						
Floating plants	–	–	–	–	3	1,0
Total	40	100	121	100	315	100

Table 7. Distribution of environmental groups in the colliery spoil heaps in Khakassia.

Ecological group	Succession stage						Key site (heap)					
	grouping		simple phytocenosis		complex phytocenosis		Chernogorsky		Izykhsky		Izykhsky (old spoil heap)	
	number of species	% of total	number of species	% of total	number of species	% of total	number of species	% of total	number of species	% of total	number of species	% of total
Xerohalophytes	1	2.5	–	–	1	0.3	1	0.6	1	0.5	1	0.5
Xerophytes	9	22.5	29	24.0	73	23.2	44	25.1	47	22.9	49	23.0
Mesoxerohalophytes	–	–	3	2.5	4	1.3	3	1.7	3	1.5	3	1.4
Mesohalophytes	–	–	2	1.7	3	1.0	1	0.6	2	1.0	2	0.9
Mesoxerophytes	14	35.0	44	36.4	92	29.2	60	34.3	57	27.8	58	27.2
Mesophytes	15	37.5	39	32.2	114	36.2	60	34.3	80	39.0	80	37.6
Mesohygrophytes	1	2.5	4	3.3	17	5.4	5	2.9	10	4.9	12	5.6
Hygrophytes	–	–	–	–	10	3.2	1	0.6	5	2.4	7	3.3
Hydrophyte	–	–	–	–	1	0.3	–	–	–	–	1	0.5
Total	**40**	**100**	**121**	**100**	**315**	**100**	**175**	**100**	**205**	**100**	**213**	**100**

in meadows and forests. In the colliery spoil heaps of Khakassia, the proportions of these forms were approximately equal.

A distinctive feature of vegetation succession on spoil heaps is the predominance of meadow communities with the spread of long-rhizome species (*Elytrigia repens*, *Vicia cracca*) at the simple, less often complex, phytocenosis stage.

At the first stage of succession, the proportion of herbaceous monocarpic plants was significant (from 24% on the old spoil heap of the Izykhsky open-pit mine to 36% on the heap of the Chernogorsky open-pit mine), with annuals (*Panicum miliaceum* L., *Androsace septentrionalis* L.) and biennials (*Chamaerhodos erecta* (L.) Bunge, *Berteroa incana* (L.) DC.) in a 1:1 ratio. Subsequently, the proportion of monocarpic plants decreased with a predominance of biennials. Among them, cosmopolitan species (*Medicago sativa* L.) and Holarctic species (*Crepis tectorum* L., *Atriplex sagittata* Borkh.) are common.

The results of the analysis of the ecological spectrum of species, closely related to the water availability of the territories, are presented in Table 7. In the spoil heaps, more than a third of the species were mesophytes, mesoxerophytes occupied second place, and the proportion of xerophytes, typical steppe inhabitants, amounted to 22.5% to 25.1%. For comparison, in the background short-grass steppes, according to T.G. Lamanova (1978), the proportion of xerophytes and mesoxerophytes accounted for up to 50%.

The proportion of plants from wet habitats (mesohygrophytes, hygrophytes, hydrophytes) did not exceed 6%. Halophytes were few in number, but some species were highly consistent: *Salsola collina* Pall., *Saussurea amara* (L.) DC., *Taraxacum bessarabicum* (Hornem.) Hand.-Mazz.

An analysis of the ecological spectrum revealed a slight discrepancy between the habitat humidity level and the semiarid region in which the Koybal and Uybat steppes of Khakassia are located. This was supported by the presence of atypical steppe-zone trees and shrubs (*Ulmus pumila*) across all the studied spoil heaps. In the humidity level, the vegetation of colliery spoil heaps of Khakassia is closer to meadow steppes. This is likely due to the presence of moisture-retaining loamy or dense substrates, uneven micro- and mesorelief, as well as condensation on rocks and the influence of the hydrographic features of the studied area.

Discussion

E.S. Ankipovich et al. (2019) presented an analysis of the flora of the Chernogorsky colliery spoil heaps. The resulting vegetation list consisted of 47 species of higher vascular plants belonging to 35 genera and 16 families. The chorological structure comprises six groups, with Holarctic and Eurasian species predominating. In our study, Asian species remain dominant. At the successional stage of the complex phytocoenosis, an abundance of mesophytes (36.2%) and herbaceous taproot and rhizome polycarpic plants, characteristic of boreal flora (44.7%), is observed, which is consistent with the study discussed (Ankipovich et al., 2019).

Several authors (Doronkin et al., 2019; Lamanova et al., 2019; Safronova et al., 2022) also studied the floristic composition of the Chernogorsky colliery spoil heaps from the 1970s to the 2000s. Specifically, the floristic list of northern-facing slopes included 40 species of higher vascular plants from 35 genera and 18 families. The most species-rich families were Asteraceae and Poaceae, indicating the steppe location of the study area. Mesoxerophytes predominated.

This study identified species listed in previous studies (Ankipovich et al., 2019; Doronkin et al., 2019; Lamanova et al., 2019; Safronova et al., 2022), but with different projective cover values. Furthermore, a detailed study of the Chernogorsky and Izykhsky spoil heaps resulted in a vegetation list of 363 species.

The family Fabaceae dominates the flora of the short-grass (Kuminova et al., 1976) and rocky (petrophytic) steppes of Khakassia (Lamanova, 1978) and has many endemic species. This is because the Minusinsk-Khakassia steppes became one of the centers of speciation of the family Fabaceae at the end of the Pliocene (Polozhiy, 1964). The genera *Astragalus*, *Oxytropis*, *Artemisia*, and *Potentilla* are multispecies genera of short-grass and petrophytic steppes. The low prevalence of the genus *Astragalus* and the absence of the genus *Oxytropis* from spoil heaps are likely due to difficulties in legume seed dispersal: the seeds are heavy, do not germinate every year, and are often damaged by seed feeders (Voronkova and Kholina, 2017).

The colonization of spoil heaps by vegetation occurred at the expense of the local flora. For example, the spoil heap of the Chernogorsky open-pit mine was dominated by forbs and grasses: *Agropyron pectinatum* (M. Bieb.) P. Beauv. and *Hordeum jubatum* L. On the plateau, *Salsola collina*, *Artemisia sieversiana* Willd., *Agropyron pectinatum*, and *Erysimum cheiranthoides* L. dominated; on the northern

slope, *Salsola collina*, *Hordeum jubatum*, and *Agropyron pectinatum*; on the eastern slope, *Artemisia tanacetifolia* L., *Salsola collina*, and *Leonurus glaucescens* Bunge dominated (Doronkin et al., 2019). Almost all of these species were also found on spoil heaps.

To compare the flora of Khakassia's open-pit spoil heaps with steppe communities, we used a modern summary of the flora of higher vascular plants for the steppes of the Ust-Abakan and Altai districts of Khakassia (Ankipovich and Lagunova, 2015), supplemented by species from the works of other authors (Ebel et al., 2020; Kurbatsky, 2016; Shaulo et al., 2019). The flora of all Khakassia grasslands, including the Uibat and Koibal steppes, comprises 530 species, or one-third of the entire flora of Khakassia. Compared with the floras of the island steppes of Altai, Transbaikalia, and Yakutia (Kuminova et al., 1976), the number of species in the flora under consideration can be considered quite high, while the general taxonomic structure of these regions, on the one hand, and the Uybat and Koybal steppes, on the other, is somewhat similar. A.V. Kuminova et al. (1976) reported that the family Fabaceae can change its position (in natural short-grass steppes, species of this family outnumber the family Rosaceae). The first two families (Asteraceae and Poaceae) are typical of the steppes of Khakassia. The remaining families may yield third place to the family Brassicaceae, and sixth place to the family Lamiaceae.

Conclusions

The restoration of the vegetation cover of the Izykhsky and Chernogorsky spoil heaps in the subarid zone of Khakassia is occurring through a series of successional changes, each characterized by increasing complexity of the species and spatial structure of communities. Three stages of succession have been identified, with complex communities being the most common. The disturbed lands of open-pit coal mines in the subarid zone of Khakassia, are overgrown by predominantly xeromesophytic herbaceous and arboreal-shrub vegetation.

The flora of higher vascular plants in the surveyed open-pit spoil heaps in the subarid zone of Khakassia differs from the flora of the Khakassia steppes and includes 363 species from 207 genera (of which *Artemisia*, *Potentilla*, and *Poa* are the most numerous) and 53 families typical of the boreal flora of temperate latitudes (Asteraceae, Poaceae, Rosaceae, Brassicaceae, and Fabaceae). Eurasian species predominated in the spoil heap vegetation. With succession, the proportion of Holarctic and cosmopolitan species decreased, while the percentage of Siberian species increased 2.2 times.

At the complex phytocenosis stage, the vegetation of colliery spoil heaps is represented by species of zonal (forest, steppe), azonal, and adventive associations. Depending on the conditions and stage of plant community succession, areas of long-grass *Stipa* dominated steppe, and short-grass steppes, meadow, meadow-steppe, and forest-steppe phytocenoses, shrub thickets, and park-forests, primarily composed of *Ulmus pumila*, have been identified on the heaps. Weed species are recorded in the floristic composition, which is more characteristic of the early and middle stages of succession and is an indicator of anthropogenic transformation of plant communities. Biomorphological analysis revealed a predominance of rhizomatous herbaceous polycarpic plants at all stages of succession and a decrease in the proportion of annuals at the complex phytocenosis stage. The predominance of herbaceous polycarpic species (50–60%) is characteristic of temperate vegetation, as these species are adapted to the harsh winter season. On the spoil heaps, more than a third of the species were mesophytes, followed by mesoxerophytes and xerophytes. The decline in the prevalence of xerophytes, coupled with an increase in mesophytes on spoil heaps located in the steppe zone, can be explained by the occupation of temporary ecological niches by weeds, and by changing conditions—the emergence of water-retaining horizons and the development of a man-made landscape with varying altitudes.

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