Primary succession of plants of technogenic dumps of the Kabardino-Balkarian Republic

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Abstract. The article presents data on the regularities of the flow of primary succession on the terraces of the tailing dump of the Tyrnyauz tungsten-molybdenum combined plant. In the accumulative ecotope of old-age terraces of the lower level of the dump, grass-wormwood and herb-wormwood communities dominate with a projective cover of up to 60%. In the transeluvial ecotope of middle-aged terraces, there are ruderal-natural grass-forb grass communities with a projective cover of 37%. In the eluvial ecotope of young terraces of the upper level, there are monodominant explent communities with a projective cover of 13%. Old age terraces have the greatest similarity with the zonal flora and have characteristics of relatively high species richness and saturation. With an increase of succession length, there are changes in the dominant life forms (from terophytes to hemicryptophytes), a decrease in the proportion of species with wide ranges (pluriregional, holarctic, and palaearctic), an increase in the number of stenobionts and hemistenobionts. A number of species growing in extreme conditions of ecotopes of middle and upper terraces are characterized by the absence of deviations from ecological regimes and indifference to elevated concentrations of Mo and W. High toxicity of the substrate constrains the speed of transition from initial to subsequent stages of primary succession. To restore vegetation, it is necessary to carry out both biological and technical remediation.

1. Introduction

An important factor determining the direction of succession and the duration of its individual stages is the initial state of the substrate and the ecotope as a whole. Significant heterogeneity of the surface of technogenic landscapes causes a high contrast of the modes of insolation, water and mineral nutrition, in which regeneration biogeocenoses are forced to develop [1].

Chemical pollution to a greater extent than the type of community and the group of soils affects the species saturation and the projective cover of the species. [2]. The features of the succession process on toxic substrates are the high duration of the pioneer stage of succession, the insignificant coverage of vegetation for a long time, the poverty of the floristic composition, the small number of dominant species, the simplified spatial structure, the predominance of species-asserctors [3–5]. Ecologically plastic ruderal species with wide ranges and mechanisms of protection against high concentrations of toxic elements represent plant communities of pioneer stage [6–14].

On the territory of the Kabardino-Balkarian Republic (KBR), there is JSC “Tyrnyauz tungsten-molybdenum combined plant” (TTMCP), which has referred to the tails of the concentrating plant and has accumulated over 80 million m³ of tailings of the tungsten, molybdenum and copper, bismuth concentrates with high toxicity and high solubility in groundwater. The average content of main metals...
in the surface layer of industrial waste is (g/t): W – 420, Mo – 145, Zn – 290, Cu – 69, Sr – 315, Rh – 118 [15].

Due to the relatively poor study of the characteristics of the flow of primary succession on a toxic substrate, the purpose of the study was to monitor the composition of the plant community in dumps from non-ferrous metal enrichment of № 1 TTMCP tailings.

2. Materials and methods

In the course of monitoring the vegetation cover of the tailing dumps (2016–2018), a mountain steppe at a distance of 3–4 km up the valley of the r. Baksan (ground) and ecotopes at different levels of the terraces of the western slope of the tailing dumps have become the object of the study. The climatic conditions of the tailing areas are close to arid ones with an average annual precipitation of about 350 mm. The climate adjacent to the tailing areas is temperate with an average annual precipitation of 600 mm. The soils are dark chestnut, the reaction of the upper horizons (0–40 cm) is neutral and slightly alkaline (pH = 6.9–7.5), the total nitrogen content is 0.26 %, and water-soluble salts are 0.05–0.06 %.

The alluvial landscape of early-age upper terraces (Tu) has high density of the soil, a strongly alkaline reaction of the substrate (pH = 9.3–9.5). The transit transluvial landscape of middle-aged terraces (Tm) is distinguished by a more loose and moist soil covered with a continuous thin layer of young soil up to 2 cm thick with an alkaline substrate reaction (pH = 8.3–8.7); the accumulative landscape of the lower old-age terraces (Tl) – wet soil with a primary soil layer up to 5 cm and a less alkaline reaction of the substrate (pH = 7.9–8.2).

In the course of the monitoring, there was a geobotanical survey of the terraces of the tailing and the ground site, and botanical descriptions were drawn up with an indication of the values of the projective cover of the species during the maximum development of grass stand (July–August). In total, the researchers have compiled 40 descriptions of the pioneer group flora and 8 descriptions of the background landscape. The size of accounting sites was 5 x 10 m2. The similarity of the plant communities of the terraces and the background area was estimated by the Jacquard coefficient (Kj), the degree of uniform distribution of the abundance - by the Pielou index (E), the species richness - by the Shannon – Weaver index (H). For the analysis of species diversity, curves of “dominance – diversity” were used.

Ecological assessments of species were determined by amplitude and point ecological scales. According to the values of climatic (It clim.) and soil (It soil) of tolerance indices, the researchers divided herbaceous plant species into stenobiont (SB), hemistenobiont (HSB), mesobiont (MB), hemieubriobous (HBB) and eurybiotic (EB)[16]. For the ecological-geographical analysis of vegetation, reports on the flora of the KBR were used [17]. Life forms of plants were determined by Raunkier’s classification. The content of Mo and W in the soil and plant samples was determined by the method of mass spectrometry with inductively coupled plasma. The degree of resistance of individual plant species to heavy metals was assessed by the coefficient of biological absorption (CBA) and the translocation coefficient (TC).

3. Results and discussion

In the communities of old-age terraces there are grass-paniculate-wormwood and herb-paniculate-wormwood communities dominated by Artemisia scoparia Waldst., herb-wormwood dominated by A. austriaca Jacq. and A. marschalliana Spreng. Due to the high floristic saturation, the total projective cover of herbaceous plants reaches 60 %. On the middle-aged terraces, a ruderal-natural grass and forb community there is a projective cover of 37 %. Among the cereals are most abundant Festuca valesiaca Gaudin, Elytrigia repens (L.) Nevski, Melica transsilvanica Schur, Setaria viridis (L.) P. Beauv., Achnatherum caragana (Trin.) Nevski. Herbs represented with xerophilic and ruderal species (Verbascum thapsus L., Cichorium intybus L., Achillea millefolium L., Pyrethrum partenifolium Willd., Scabiosa bipinnata K. Koch, Tussilago farfara L. and others). 13 % of monodominant communities were found on young terraces with herbaceous plants Tussilago farfara L. and Cirsium vulgare (Savi) Ten. Bushes of sea buckthorn (Hippophae rhamnoides L.), planted for the purpose of primary
reclamation, are in a depressed state and dry massively.

The floristic composition of the studied ecotopes includes 71 species of vascular plants. The plant community of old-age terraces is characterized by the most equal distribution of abundance by taxa, relatively high species richness and richness compared to middle-aged and young terraces. The total projective cover of Tl is 1.3–2.8 times higher than that of Tm and Tu (table 1).

| Terraces | Species richness, pcs. | Species saturation, pcs./m² | The total projective cover, % | E | H |
|----------|------------------------|-----------------------------|-------------------------------|---|---|
| Tu       | 19                     | 6.5±1.8                     | 39.0                          | 0.52 | 2.23 |
| Tm       | 53                     | 18.6±2.4                    | 84.1                          | 0.65 | 3.49 |
| Tl       | 62                     | 24.1±3.2                    | 108.8                         | 0.76 | 4.50 |

The shape of the “dominance – diversity” curves indicates an increase in biodiversity and an increase in the dominance of species in the successive age range due to a decrease in the stress load of ecotops. The low S-shaped curve of the “dominance – diversity” curve of Tl is close to Preston’s log-normal distribution (most species of this ecotope have an average abundance; there are few dominant and isolated species). The rank distribution of species of ecotope Tu is approaching the geometric distribution of Motomura, which is a characteristic of poor low-species communities in the early stages of succession. The rank distribution of the ecotope types Tm is characterized by a low compliance of the geometric model, approaching a lognormal one.

Chemical contamination of the substrate leads to a decrease in the coefficients of similarity between communities and an increase in taxonomic diversity by reducing the species richness of the types and families and increasing the proportion of monotypic taxa [2]. Old age terraces of TTMCP have the greatest similarity in floristic composition with middle-aged terraces (Kj,t = 0.53) and ground ecotope (Kj,g = 0.29). The smallest similarities with the background ecotope have early-age terraces (Kj,g = 0.13). Compared with the monitoring data of 2003 (Kj,t = 0.45, Kj,g = 0.35, Kj,u,g = 0.08), an increase in the similarity of the floristic composition of old and middle-aged terraces, as well as early-age terraces and background, was found. Reducing the similarity of old-age terraces and background ecotope is associated with the suppression of the life potential of zonal species in conditions of high toxicity of the substrate and, as a result, weak germination of seeds and / or loss of the ability to form them. A number of authors have noted an increase in the frequency of mutations and anaphase anomalies, a change in the mitotic index of the root meristem cells and a delay in cell division at the stages of mitosis under the influence of tungstates, molybdenum and other heavy metals [18, 19].

A characteristic feature of the primary succession on a technogenic substrate is the regular changes in the dominant life forms – from terophytes to hemicryptophytes [20]. The initial stages of vegetation restoration on the terraces of TTMCP are mainly formed by hemicryptophytes and terophytes. With an increase in the duration of succession, the proportion of terophytes decreases by 23.17 %, and that of chamephytes – by 2.5 %, hemicryptophytes and phanerophytes – increases by 14.3 and 6.45 %,
respectively (table 2).

**Table 2.** Characteristics of plant cover of phytocenoses at different stages of succession

| Life form          | 35–50 years (Tl) | 25–34 years (Tm) | 15–24 years (Tu) |
|--------------------|------------------|------------------|------------------|
|                    | pcs. | %          | pcs. | %          | pcs. | %          |
| Phanerophytes      | 4    | 6.45      | 2    | 3.77      | 0    | 0.00      |
| Chamephytes        | 5    | 8.06      | 4    | 7.55      | 2    | 10.53     |
| Geophites          | 3    | 4.84      | 2    | 3.77      | 0    | 0.00      |
| Hemicryptophytes   | 35   | 56.45     | 29   | 54.72     | 8    | 42.10     |
| Terophytes         | 15   | 24.20     | 16   | 30.19     | 9    | 47.37     |
| Species richness   | 62   | 100.00    | 53   | 100.00    | 19   | 100.00    |

The flora of the ground area and the pioneer communities of the terraces is represented by 17 geo-elements. Extensive ranges (Pluriregional, Holarctic and Palaearctic) have more than a third of species (34.95 %). The most widespread in the vegetation cover are the Palaearctic, Caucasian and South Siberian geo-elements (26.52; 21.70 and 14.47 %, respectively). The participation of species with a wide ecological amplitude (46.67 and 42.31 %, respectively) increases in the plant communities of Tu and Tm compared with more favorable conditions of Tl (35.49 %). In the pioneer communities of Tm and Tu, the depletion of the geographic spectrum of species was observed, represented by 13 and 8 geo-elements, respectively.

In the succession age series, mesobiont and hemieubribo species are most prevalent. The proportion of species with a low potential ecological valency (SB, HSB) during succession increases from 9.5 to 32.2 %, while species with a wide range of adaptation to adverse edaphic conditions (HBB, EB) decreases from 40 to 31 %. The specific weight of mesobionts with intermediate ecological valence is highest in the early stages of succession (50.6 %), in the later stages its decrease to 35 % was noted.

The proportion of species with deviations from environmental comfort factors increases in the age succession series. The greatest deviation from comfortable conditions at all levels of the terraces is marked by edaphic factors (table 3).

**Table 3.** The proportion of species with deviations of environmental factors from comfort, %

| Environmental factors | Tl  | Tm  | Tu  |
|-----------------------|-----|-----|-----|
| Thermal mode          | 14.5| 9.4 | -   |
| Continentality        | 12.9| 5.7 | -   |
| Soil moisture         | 12.9| 13.2| 10.5|
| Soil acidity          | 41.9| 30.2| 15.8|
| Soil nitrogen availability | 45.2| 35.8| 15.8|
| Soil salt regime      | 45.2| 41.5| 42.1|

Species with no deviations from ecological regimes (Artemisia scoparia Waldst., Cichorium intybus L., Taraxacum officinale F.H. Wigg., I. germanica L., Phleum phleoides (L.) H. Karst., Plantago major L., P. media L., Ambrosia artemisiifolia L., Melilotus officinalis (L.) Pall., Scabiosa bipinnata K. Koch, Ephedra procera Fisch. et Mey., Echium vulgare L.), noted in the plant communities of middle-aged and early-age terraces, show no visible signs inhibition of ultrahigh Mo and W concentrations in the substrate.

In the tailing substrate, the average content of Mo and W was 112 and 230 µg/g, respectively. The translocation coefficients of the species studied with respect to Mo and W (CT>1) indicate the triggering of the protective function of the roots, which accumulate most of the elements entering them. The ability of plants to the biological absorption of Mo (CBA-1) indicates the possibility of their use in phytoremediation of soils contaminated with molybdenum. Biological absorption of W does not depend on the gross content of the element in the substrate (Table 4). High concentrations of tungsten in the roots indicate that the element is easily accessible to plants in alkaline environmental conditions, favorable for the transition of tungsten into mobile and easily accessible forms of migration for plants.
[21].

In general, in the succession age series of technogenic ecotopes with a toxic substrate, a regular change of the abiotic S-model of plant community organization (patients of extreme conditions) at the initial stage of succession (young terraces), R-model (segetal and ruderal groups) on middle-aged terraces and transition is observed to CRS models on lower terraces [22]. However, the speed of this process is strongly inhibited.

According to the results of monitoring of vegetation cover, it was established that the dam overgrowth proceeds according to the type of primary succession. In accordance with the polyvariant model of primary succession [4], the pioneer stage (first stage) still continues at the upper level of terraces (Tu), which is characterized by the settlement of pioneer plants (one- and two-year grasses with short root system, one- and two-year grasses with perennial long root system), low species diversity and general projective cover. On the terraces of the middle level (Tm), the second stage of pioneer succession continues (transitional “cereal” stage). In the transition transeluvial ecotope of the middle part of the slopes, grass-forb and forb-grass communities are noted, they contain long-grass grasses, high-grain cereals; species diversity and total projective cover increase. In the transeluvial-accumulative ecotope of the lower old-age terraces, a third (transitional “shrub” stage) is observed, which is characterized by the gradual formation of natural phytocenoses and shrub layer, which contributes to the accumulation of leaf litter and the formation of litter. The rate of transition from initial to subsequent stages of primary succession is constrained mainly by the high toxicity of the substrate.

Table 4. Content in aboveground (a) and underground (u) plant phytomass (C, µg / g dry matter), biological absorption (CBA) and translocation (CT) of Mo and W

| Indicators | Artemisia scoparia | Phleum phleoides | Melilotus officinalis | Taraxacum officinale | Inula germanica | Echium vulgare |
|------------|-------------------|------------------|----------------------|---------------------|----------------|----------------|
| Ca (Mo)    | 32.12±0.12        | 37.94±4.01       | 74.08±7.83           | 43.66±4.62          | 49.11±3.08     | 53.23±4.75     |
| Cu (Mo)    | 63.46±0.30        | 84.72±4.73       | 118.47±10.25         | 94.46±6.44          | 132.56±11.47   | 87.54±10.61    |
| CT (Mo)    | 1.96              | 2.23             | 1.60                 | 2.16                | 4.55           | 2.23           |
| CBA (Mo)   | 1.18              | 1.11             | 1.76                 | 1.35                | 11.73          | 12.38          |
| Ca (W)     | 0.34±0.11         | 0.46±0.05        | 0.51±0.07            | 0.29±0.05           | 0.43±0.08      | 0.38±0.09      |
| Cu(W)      | 0.59±0.08         | 0.63±0.09        | 0.94±0.10            | 0.67±0.05           | 0.84±0.30      | 0.96±0.85      |
| CT (W)     | 1.73              | 1.37             | 1.24                 | 2.31                | 1.95           | 2.53           |
| CBA (W)    | 0.008             | 0.007            | 0.006                | 0.005               | 0.011          | 0.010          |

According to the results of monitoring the vegetation cover of the TTMCP tailing dump, it was established that the dam overgrowth proceeds according to the type of primary succession, aimed at the gradual replacement of ruderal plants with species of natural flora and increase in species diversity. With an increase in the succession, changes in the dominant life forms, a decrease in the proportion of species with wide ranges, an increase in the number of hemievribionts and mesobionts were noted. Species with no deviations from ecological regimes growing in ecotopes of young and middle-aged terraces are characterized by indifference to chemical pollution of the habitat and are promising for phytoremediation of soils contaminated with molybdenum. Due to the extremely low self-healing potential of vegetation on the toxic substrate of the TTMCP tailing dump, it is necessary to carry out both biological and technical reclamation for the restoration of vegetation cover.

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