Feature of Syngenetic Succession in Technologically Disturbed Landscapes of Kabardino-Balkaria

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Abstract. The article presents the results of monitoring syngenetic succession on a toxic substrate of the tailings of the Tyrnyauz tungsten-molybdenum plant in 2001 and 2018. According to the features of succession processes on terraces of different ages, 3 types of ecotopes were distinguished: 1 - automorphic (eluvial) upper slopes; 2 - transit transeluvial of the middle part of the slopes; 3 - transelyuvial-accumulative foothills of the slopes. The delay in the beginning of the phases of succession and the duration of the stages of syngenesis grows in the series 3 → 2 → 1. In 2018, the state of vegetation cover corresponded to the initial stages of syngenesis and was characterized by a high level of synanthropization and apophytization of the flora. On the lower and middle terraces of the tailing, weeds and intruders dominate, not typical of the zonal flora. On the upper terraces ruderal and pioneer plants are found sporadically. The succession process on the technogenic substrate of the tailings takes place spontaneously and under extreme conditions, the onset of the final stages of natural demutation is problematic. In order to stabilize the technogenic ecotope, it is necessary to carry out the technical stage of recultivation (application of fertile layer on the ground) with the sowing of multi-species grass mixtures, the wild-growing components of which are most tolerant of the extreme substrate (Cirsium vulgare, Centaurea kubanica, Taraxacum officinale, Echium vulgare, Jurinea ciscaucasica, Inula germanica).

1. Introduction
The processes occurring during the restoration of the plant cover of mining landscapes play an important role in formation of sustainability, ensuring regeneration of ecosystems, preserving biological diversity and improving the quality of the environment. Knowledge of the mechanisms for restoring disturbed lands allows improving technologies and techniques of their phytoreactivation [1–7].

The most dangerous in terms of environmental pollution and one of the most difficult for biological reclamation types of man-made ecotopes are dumps formed by waste from concentrating industries of non-ferrous metallurgy enterprises. Their negative impact on the environment is associated with pollution by toxic substances entering the biosphere as a result of denudation processes and biogeochemical migration of mobile elements that make up the composition of the dumps substrates. Technogenic ecotopes of tailings of non-ferrous metallurgy enterprises are characterized by a combination of specific plant-negative properties and factors: highly alkaline or strongly acidic
solutions, the absence of humus, nitrogen and poorness by other nutrients, phytotoxicity, the presence of physiologically harmful salts, flotation agents, structurelessness and negative water-physical properties [2, 8, 9]. According to the classification of rocks according to their suitability for crops, the substrates of tailings of non-ferrous metallurgy enterprises belong to the group of rocks that need fundamental improvement. Ecologically plastic cosmopolitan species that propagate with volatile seeds and grow vegetatively [4, 10–14] become pioneers of the overgrowing of technogenic dumps. Therefore, phytorecovery of waste dumps of non-ferrous metal ores is possible only by creating on its surface a culture phytocenosis from those few plants that are able to adapt to extremely specific and unfavorable conditions for their life. Criteria for diagnosing the stages of the primary plant succession are the total projective cover: the number of species settling on the dumps, the ratio of species of zonal and ruderal flora, the number of tiers of the vertical structure of the phytocenosis [11].

In the North Caucasus Federal District there are repositories for industrial waste from the Tyrnyauz (W, Mo, Sb, Bi), Sadonsky (Pb, Zn, Cd, Ag), Fiagdonsky (Pb, Zn, Cd), Urupsky (Cu, As, Pb, Zn) and Lermontov (U, B) mining and processing plants, which, due to higher concentrations of a number of toxic elements, may pose a threat to the ecology of nearby territories [15]. In the tailings of the Tyrnyauz tungsten-molybdenum plant (TTMP), the average content of ore elements is (g / t): Mo ~ 111, W ~ 375, Pb ~ 22, Zn ~ 241, Cu ~ 37, Ni ~ 28, Co ~ 11. Content of useful (W, Mo, Zn, Pb are economically valuable when they are extracted) and ecologically harmful (W, Mo, As, Zn, Pb, S, etc.) elements significantly exceed the MPC. The estimated reserves of metals in tailings are: W ~ 200 thousand tons, Mo ~ 60 thousand tons, Cu ~ 15 thousand tons, Bi ~ 4 thousand tons, Au from 1 to 5 tons, Ag from 4 to 20 t [16]. The negative impact of industrial waste dumped at tailing dumps of the processing plant TTMP on the ecological situation in the National Park in the National Park “Priel’brus’e” has been proven. It is expressed in the pollution with heavy and carcinogenic metals of modern soils with turf on pastures and farmlands of the village of Bylym, which are closed to the tailings of TTMP. Soil pollution occurs due to the separation of fine dust from the surface of tailings by winds [15, 17, 18]. In the 80s. of the last century, reclamation of tailings was carried out by filling rocky soil and landing on the oldest terraces of sea buckthorn (Hippophae rhamnoides L.). However, numerous violations of the integrity of the protective layer and the massive drying of shrubs indicate the ineffectiveness of reclamation.

In connection with the foregoing, the purpose of the study was to study the features of syngenetic succession in the restoration of vegetation cover under conditions of high extremes of the substrate in order to assess the potential for self-restoration of the ecosystem of the TTMP tailings, to select plant species adapted to unfavorable edaphic conditions, to form a culture of phytocenoses for phytorekultation.

2. Research methods
Evaluation of the edaphic conditions of the study area included the determination of the moisture by the thermostatist-weight method, the pH of the aqueous extract, the concentration of Mo, Cu, Pb, Zn, Mn, Cr, Ni by the atomic absorption method with electrothermal atomization. Geobotanical studies on the terraces of the TTMP tailings house No. 1 were carried out in 2001 and 2018. Research methods. Evaluation of the edaphic conditions of the study area included the determination of the moisture by the thermostatist-weight method, the pH of the aqueous extract, the concentration of Mo, Cu, Pb, Zn, Mn, Cr, Ni by the atomic absorption method with electrothermal atomization. Geobotanical studies on the terraces of the TTMP tailings house N 1 were carried out in 2001 and 2018. The terraces of the tailings were divided into groups: T1 - terraces of the lower part of the tailing dam (50 years old); T2 - terraces of the middle part (age 39 years); T3 - upper terraces (29 years old) [19]. The phytocenoses of the anthypogenically undisturbed landscape of the Bylym valley served as a background (F). On each terrace, 10 test plots measuring 1x10 m² were laid. The description of vegetation on the terraces of the TTMP tailings included an assessment of the projective cover. The synanthropic level of the flora was estimated by the coefficient of anthropogenic transformation (Cₜₚ) [20, 21]. The occurrence of synanthropic species and species of hemerophobia (plants that have disappeared as a result of
anthropogenic impact) was calculated from the totality of geobotanical descriptions within each group of terraces. According to the lists of plant species, the Jaccard generality coefficient of the species composition of terraces and background plants was calculated.

3. Results

The restoration of the vegetation cover of the terraces of the tailings and its structure is affected by unfavorable moisture conditions and high phytotoxicity of the substrate. On the upper and middle terraces of the tailings dam, moisture provision is low (8 and 15% respectively), on the lower ones - sufficient, in some places excessive (20-30%). The substrate of the tailings has an alkaline pH (pH = 7.9-8.9). On the shore of the settling pond, the pH rises to 9.4. In the profile of the substrate of the middle terrace there is a formed soil layer of 1-2 cm, below is a layer of ash deposits of dried pulp (5 cm), beneath there is a layer of stony-sandy soil (10-15 cm). On the lower terrace, the substrate is represented by stony-sandy soil. The substrate is characterized by a high content of molybdenum (62-102 mg / kg), lead (up to 19 mg / kg), zinc (100-230 mg / kg), copper (14-40 mg / kg). The content of molybdenum in the substrate of the tailings (more than 40 mg / kg) is more than 20 times higher than its content in the clean zone. The content of copper and lead exceeds the background by 3 or more times. The concentrations of chromium and nickel (3-5 mg / kg) and manganese (480-500 mg / kg) in chemozem are comparable to concentrations in soils in the background and adjacent areas.

On the technogenic neolandscapes, the composition of the flora is in the stage of formation and far from completion. This is evidenced by the fact that about 50% of the flora falls on ruderal plants. Restoration of the plant cover proceeds slowly, the penetration of the plants of the former natural flora into the neophytocenosis is insignificant. In addition, due to the reduction of moisture sea buckthorn shoots die. During geobotanical research, it was established that the restoration of vegetation on the upper terraces is at the initial stage of succession. The introduction of ruderal and pioneer species, the formation of monodominant ruderal communities Tussilago farfara L., Cirsium vulgare (Savi) Ten., Centaurea kubanica Klokov, Anisantha tectorum (L.) Nevski., Echium vulgare L. are noted. The projective cover is low (about 12%). There has been a massive drying of the Hippophae rhamnoides L. bushes.

On medium terraces in conditions of better moisture, dense thickets of Hippophae rhamnoides, grass-wormwood and wormwood-grass-forb phytocenoses dominated by Artemisia scoparia Waldst., A. campestris L., Avenella flexuosa (L.) Drejer, Melica nutans L. and Koeleria macrantha (Ledeb.) Schult are formed. The projective cover is about 20%. Herbs are represented by ruderal species Centaurea kubanica Sosn., Echium vulgare L., Cichorium intybus L., Achillea millefolium L., Verbascum thapsus L., Scabiosa bipinnata C. Koch. On the lower terraces in conditions of sufficient moisture provision, herb-wormwood, grass-wormwood, grassy-paniculate-wormwood phytocenoses with projective cover up to 60% are formed. Under conditions of increased moisture, a more dense vegetation cover with the dominance of Calamagrostis pseudophragmites (Haller f.) Koeler. develops. Hygrophiles (Phragmites australis (Cav.) Trin. ex Steud., Typha laxmannii Lepech., Lythrum salicaria L., Juncus inflexus L., Carex vulpina L.) are found in the places of drainage waters.

The participation of grass species in the formation of the plant community is unequal. Some species can be found from the lower to the upper terrace (Cirsium vulgare (Savi) Ten., Centaurea kubanica Klokov., Taraxacum officinale Wigg., Echium vulgare L., Jurinea ciscaucasica (Sosn.) Iljin, Pyrethrum partenifolium Wild., Achnatherum caragana (Trin.) Nevski, Anisantha tectorum (L.) Nevski, Calamagrostis pseudophragrames (Haller f.) Koeler.). These species exhibit the highest tolerance to chemical pollution of the substrate, low heat and moisture supply.

More than half of the flora of the tailing terraces falls on ruderal plants. The coefficient of synanthropization of private flora terraces of different ages varies from 64.0 on the upper terraces to 90.2% on the lower terraces (Table 1).
Table 1. Synanthropic and anthropogenic transformation of the flora of the terraces of tailing TTMP.

| Stages of anthropogenic transformation | Phases                  | $C_{AT} \%$ | Terraces group |
|---------------------------------------|-------------------------|-------------|----------------|
| Stage V is very strong transformations | a - first phase         | 86.9-90.2   | T1             |
| Stage IV strong transformations        | a - first phase         | 64.0-65.2   | T2             |

The synanthropization of the terraces flora, corresponding to the IV and V stages of anthropogenic transformation, indicates the process of severe degradation of vegetation, slowing down the reverse process of de-mutation of its initial state after the anthropogenic load is removed.

The biodiversity of the flora on the terraces of the tailings of different ages and in the background phytocenosis is represented by 27 families and 92 plant species. 68 are on the lower terraces, 54 are on the middle terraces, 16 are on the upper, and 41 species are on the background plot. The most numerous are the Asteraceae, Poaceae and Lamiaceae families. The lower terraces have the greatest similarity in floristic composition with medium ($K_j = 0.54$) terraces and background ($K_j = 0.31$). The smallest similarities with the background plant community are upper terraces ($K_j = 0.14$) (Table 2).

Table 2. Jacquard community coefficients between the types of communities on the terraces of the tailing dump of different age groups and the types of background landscape.

| Plant species communities | T1 2001 | 2018 | T2 2001 | 2018 | T3 2001 | 2018 | Background 2001 | 2018 |
|---------------------------|---------|------|---------|------|---------|------|-----------------|------|
| T1                        |         |      |         |      |         |      |                 |      |
| T2                        | 0.45    | 0.54 | -       |      | 0.25    | 0.25 | 0.25            | 0.23 |
| T3                        | 0.12    | 0.15 | 0.25    | 0.25 | -       | -    | 0.08            | 0.14 |
| Background                | 0.35    | 0.31 | 0.25    | 0.23 | 0.08    | 0.14 | -               | -    |

According to the data of the monitoring conducted in 2001, old-age terraces have the greatest similarity in floristic composition with middle-aged (0.45) and types of communities of the background landscape (0.35). The smallest similarity (0.08) with species of communities of the background landscape was observed in early-age terraces. There was a tendency of increasing similarity between species of communities on the terraces of the tailings storage, as well as between the species composition T3 and the background. However, unfavorable conditions of the technologically disturbed ecosystem of the TTMP tailings site cause extremely slow self-overgrowing of the substrate and sparseness of vegetation cover.

According to the features of succession processes on terraces of different ages, 3 types of ecotopes were distinguished: 1 - automorphic (eluvial) upper slopes; 2 - transit transeluvial of the middle part of the slopes; 3 - transelyuvial-accumulative foothills of the slopes. The delay in the beginning of the phases of succession and the duration of the stages of syngenesis increases in the series $3 \rightarrow 2 \rightarrow 1$.

4. Conclusion

The mechanism of sygenetic succession on the toxic substrate of the TTMP tailings corresponds to the general patterns of regenerative endogenous changes of vegetation according to the type of primary succession in mining landscapes. At the time of monitoring (2018), the state of vegetation cover corresponds to the initial stages of syngenesis and is characterized by a high level of synanthropization and apohytization of the flora. On the terraces of the lower and middle parts of the tailing dam, weed and invasive plants, not characteristic of the zonal flora, predominate; On the upper terraces, ruderal and pioneer plants are found sporadically. The succession process on groundwater mixtures of TTMP man-made dumps occurs spontaneously and under extreme conditions, the selection of plant species and the formation of serial microgroups are limited by a specific substrate
and unfavorable climatic factors, which leads to an indefinitely long-term nature of succession. Under the conditions of a technogenic substrate, the onset of the final stages of natural demutation is problematic. In order to stabilize a technogenic ecotope, it is necessary to carry out the technical stage of recultivation (with a fertile layer applied to the soil) with sowing of multi-grass mixtures, the wild-growing components of which are most tolerant to the extreme substrate (Cirsium vulgare, Centaurea kubanica, Taraxacum officinale, Echium vulgare, Jurinea ciscaucasica, Inula germanica).

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