The influence of mining wastes from the Russia’s Arctic zone on the plants development

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Abstract. This paper contains an integrated phytotesting-based assessment of the impact on the biota of the mining waste generated in Arctic zone of the Russian Federation (Murmansk Region, Russia). In order to collect as unbiased as possible data on plant growth and development, a number of test cultures of various classes were used, including monocotyledonous and dicotyledonous plants (Avéna satíva L., Lepidium sativum, Tríticum aestivum L., Trifolium praténse L.). Concentration tailings of apatite-nepheline, complex and loparite ores were studied using eluate and contact methods. Eluate phytotesting showed different levels of response in the test cultures when exposed to the native extracts of the concentration tailings. In the most sensitive cultures, the root length inhibition effect (of loparite ore concentration tailings) was less than 15%, which does not exceed the threshold inhibition value required for the phytotoxic effect to be established. When testing diluted extracts, manifestations of the hormetic (stimulating) effect were observed in some of the test cultures. Hazard class V was experimentally confirmed in the examined plant species. It was found that oats and wheat are more sensitive compared to watercress and clover — both when exposed to aqueous extracts and when germinating seeds in a substrate. The greatest plant inhibition effect was observed in loparite ore concentration tailings, which supports the conclusion that the likelihood of spontaneous revegetation of mining waste dumps is minimal and that comprehensive land remediation methods need to be developed. The results of contact phytotesting indicate the good prospects of tailings dump reclamation by mixing the top layer of the tailings with fertile soil in different ratios.

1. Introduction
The largest volume of production and consumption waste generation in 2018 fell on the type of economic activity "mining" - 6.85 billion tons, and this volume is increasing every year [1]. The mining and processing industry is developed in the Murmansk region, in particular, among the largest enterprises, one can single out Apatit mining plant company, Kola mining plant company, Kovdorsky mining plant company, Lovozersky mining plant company, which develop deposits of apatite-nepheline, copper-nickel, magnetite, loparite ores, niobium and tantalum, etc. According to the reports of the enterprises of the mining and manufacturing industry of the Murmansk region in 2018, the generation of waste (tailings, overburden and tunneling rocks, etc.) increased compared to 2017 and amounted to...
229.1 million tons [2]. The total volume of waste accumulated in the region reaches 8 billion tons: off-balance and associated ores (2.4%), overburden, penetrations (72.4%), tailings of various ores (24%), slag and ash (up to 1.5%).

The main approaches to assessing the impact of pollutants on the environment currently consist in comparing the concentrations of individual substances with background concentrations, maximum and approximate permissible concentrations specified in the relevant regulatory documents. Considering that MPCs, for example, of chemicals in soils are set for a very narrow list of indicators, this approach is not always effective due to the existence of a huge amount of pollutants that can affect the ecological state of biota. Also, the calculation method does not take into account the combined effect of several pollutants, which can have both synergistic and antagonistic effects. Therefore, based on analytical data alone, it is problematic to conduct a comprehensive assessment of the impact of mining waste on the environment. An experimental method for the integral assessment of toxicity is biotesting, which makes it possible to draw a conclusion about the degree of toxicity of a sample, but not about the qualitative and quantitative composition of its components - pollutants [3]. This method has a number of advantages: rapidity, availability, ease of implementation, reproducibility of results, sensitivity.

Phytotesting is a special case of biotesting. In Russia and abroad, several methods have been developed that make it possible to experimentally determine the hazard class of waste [4], the degree of pollution of soils and technogenic soils [5], chronic phytotoxicity [6] and others, but only a few of them are included in the register of methods for state environmental control. In a number of works, to assess the impact of industrial waste on biota, author's methods are used. Thus, in [7], to assess the toxicity of ash and slag waste (the effect of ash cake), the method of biotesting was used; microorganisms and oats of seed *Avena sativa* L. were used as test cultures. In the article the possibility of remodeling of phosphogypsum dumps with using the *Poaceae* family herbaceous plants seeding was considered. On the basis of determination of growth parameters [8].

The purpose of this work was to study the influence of the stored waste of the mining complex of the Murmansk region on the growth and development of higher plants.

2. Objects and methods
The objects of study were the tailings of apatite-nepheline ores (AMPC), complex (KMPC) and loparite (LMPC) ores (figure 1).

![Figure 1. Schematic map of the study area.](image)

Mineral composition of apatite-nepheline ore dressing wastes (according to [9]), %: nepheline - 61.42, aegirine - 12.94, feldspar - 7.41, apatite - 5.43, sphene - 3.19, etc.

Mineral composition of tailings of complex ores, %: forsterite - 30, carbonates - 25, phlogopite - 14, apatite - 12, magnetite - 12, etc. - 7 [10].
Tailings of loparite ore concentration are mainly represented by the following minerals, %: nepheline - more than 50, feldspar - up to 25, amphibole - 11.8, aegirine - 5.3, loparite - 1.1, eudialyte - 0.5 [11].

Phytotesting was carried out in laboratory conditions in two ways - eluate (on water extracts of the enrichment tailings) and contact (directly in the substrate). Representatives of different classes were selected as test cultures - monocotyledonous (common oat *Avena sativa* L., soft wheat *Triticum aestivum* L.) and dicotyledonous (watercress *Lepidium sativum*, meadow clover *Trifolium pratense* L.).

The first method was carried out in accordance with the Fitotest method [4]: the seeds of the selected crops (oats and watercress) were germinated in Petri dishes on paper filters moistened with an aqueous extract from waste (S: W 1:10) in different dilutions, in distilled water was used as a control, and the test function was inhibition of seed root growth. According to the results of measuring the length of the roots of seedlings, the effect of inhibition was calculated by the formula: $E_t = \frac{(L_{c} - L_{op})}{L_{c}} \cdot 100$, where $E_t$ is the effect of inhibition, %; $L_c$ - the average length of the roots in the control, mm; $L_{op}$ - average root length in the experiment, mm.

The phytotoxic effect is considered proven if the calculated indicator exceeds 20%. If only the native extract has a toxic effect, the waste is automatically assigned a IV hazard class.

The second method - contact - seeds of wheat and clover were germinated in the tailings of the enrichment. There is no approved methodology for assessing the toxic effect of ore dressing tailings and, in general, mining waste based on contact phytotesting. Accordingly, there are no approved criteria for establishing a hazard class in this way. Since the aim of the study was to identify the toxic effect of waste on the growth and development of higher plants, in addition to the previously selected test function (inhibition of seed root growth), the length of the shoots was measured. In this case, the study was also carried out with the aim of assessing the possibility of self-overgrowing of the surface of the tailing dumps of the considered objects. In addition, a series of experiments was carried out simulating the process of remediation in one of the most common ways - the introduction of different amounts of fertile soil to the investigated tails.

All experiments were carried out in three repetitions, the results were processed statistically (confidence level $p = 0.95$).

3. Results and discussion

3.1. Eluate phytotesting

When carrying out eluate phytotesting, *Avena sativa* L., *Lepidium sativum* were selected as test cultures, the toxic effect was assessed by the test function - inhibition of root growth of seeds germinated in water extracts, relative to the control (distillate). The results are presented in table 1. A decrease in root length for both oats and watercress was noted for the native extracts of all studied objects.

| Dilution of the extract | Phytoeffect (*Avena sativa* L.), % | Phytoeffect (*Lepidium sativum*), % |
|-------------------------|-----------------------------------|-----------------------------------|
|                         | LMPC     | AMPC     | KMPC     | LMPC     | AMPC     | KMPC     |
| Control                 | 0        | 0        | 0        | 0        | 0        | 0        |
| 10                      | 3.71     | -2.53    | 7.73     | -9.95    | 3.08     | -4.85    |
| 5                       | 10.19    | 3.2      | 11       | 7.49     | 4.41     | -4.41    |
| 2                       | 12.81    | 4.04     | 14.76    | 13.83    | 2.64     | 2.2      |
| 1 (native)              | 15.42    | 4.89     | 11.83    | 13.99    | 8.08     | 3.08     |

The maximum effect was recorded for the water extract from the tailings of loparite ores, while the inhibition of root length is about 15% for both test cultures. For watercress, unlike oats, when the extract is diluted tenfold, the manifestation of hormesis is noted, that is, the stimulating effect of moderate or
low doses of pollutants. Hormesis is also observed in oat seeds germinated in the extract of apatite-
nepheline ore tailings with a tenfold dilution. The stimulating effect of the extraction of magnetite ore
tailings on the growth of watercress is noted already starting from a fivefold dilution of the native extract.
The limiting value of the inhibition effect for the recognition of the phytotoxic effect in accordance with
the classification of "Phytotest" in the experiment with aqueous extracts was not reached.
Phytotesting of water extracts on oats makes it possible to arrange the tailings in a row according to
the degree of increase in the negative effect on the root length AMPC < KMPC < LMPC; on watercress
KMPC < AMPC < LMPC. Overall, watercress was found to be less sensitive.

3.2. Contact phytotesting
Since phytotesting of aqueous waste extracts may show underestimated results due to the transition to
the extract of only water-soluble pollutants [12], the second series of experiments consisted of
germinating seeds of selected test crops (wheat _Triticum aestivum_ L., meadow clover _Trifolium praténse_
L.) directly into substrate.

In plastic containers with a diameter of 11 cm, weighed portions of the studied tailings were
introduced in equal amounts. In each container, 25 seeds were sown, the experiment was carried out
separately for each of the test cultures in triplicate. The exposure time was 7 days (figure 2). For
comparison, the figure shows clover shoots in fertile soil.

![Figure 2. Clover in the tailings (from left to right): loparite, complex, apatite-nepheline ores, soil.](image)

In this case, the results of contact phytotesting can also be interpreted to assess the potential for
natural and artificial overgrowing of the tailing dump surface. Based on the results of germination of
seeds of test cultures in the substrate, it can be concluded that natural overgrowth of the surface is
unlikely for the tailing dump of LMPC, and the implementation of artificial seeding of plants must be
accompanied by reclamation measures. The simplest and most frequently used method in this case is
the introduction of fertile soil to the surface of the tailing dump, or mixing it with the upper tailings
horizon.

In laboratory conditions, we carried out modeling of reclamation measures with the addition of fertile
soil to the investigated tailings in different ratios (1: 1; 1: 5). Watering was carried out as the substrate
dries up with settled tap water.

Evaluation of the toxic effect of the tailings on the growth and development of plants and the
effectiveness of reclamation measures was carried out on the basis of measurements of test parameters:
root length, sprout length. The results are shown in table 2.

| Test parameter - average root length, cm |
|----------------------------------------|
| Substrate | Test-culture - _Triticum aestivum_ L. | Test-culture - _Trifolium praténse_ L. |

Table 2. Results of contact phytotesting of enrichment tailings.
The greatest negative influence on the growth of the roots of the test cultures under study is exerted by the tailings of the enrichment of loparite ores, which corresponds to the results of the eluate phytotesting. At the same time, the introduction of fertile soil has a greater positive effect in comparison with the tailings of the concentration of apatite-nepheline and complex ores in proportion to the proportion of the introduced soil.

For the test parameter, the length of shoots, a similar dynamics was noted: the greatest negative effect is exerted by the tailings of the dressing of loparite ores. A significant increase in the length of the shoots of both test cultures with the introduction of fertile soil occurs already at a soil: tailings ratio of 1: 5.

In addition to changing the above test parameters when applying fertile soil, figure 3 shows an increase in the degree of development of the root system and an increase in the amount of green biomass, which varies depending on the type of enrichment tailings and the amount of applied soil, on the example of a test culture of meadow clover *Trifolium pratense* L.

**Figure 3.** Red clover in the tailings, from left to right: soil, soil: tails 1: 1, soil: tails 1: 5, tails.
4. Conclusion
The work carried out a comprehensive study of the effect of the enrichment tailings of a number of mining and processing enterprises of the Murmansk region on the growth and development of higher plants (common oats *Avena sativa* L., soft wheat *Triticum aestivum* L., watercress *Lepidium sativum*, meadow clover *Trifolium pratense* L.) according to methods of eluate and contact phytotesting. The fifth hazard class of all studied tailings of enrichment by the eluate method was experimentally confirmed. It should be noted that in this case, monocotyledonous plants turned out to be more sensitive.

In general, within the framework of the V class, ore dressing waste from enterprises of the Murmansk region according to the integral level of negative impact on plant growth and development can be arranged in the following sequence: apatite-nepheline (AMPC) < complex (KMPC) < loparite ores (LMPC).

Contact phytotesting made it possible to draw a conclusion about the potential for self-overgrowing of the surface of the tailing dumps of KMPC and AMPC. According to the results obtained, both natural and artificial overgrowth of the surface of the LMPC tailing dump is unlikely without a significant amount of reclamation work.

The use of fertile soil as a remediator in different ratios has shown that this method is promising. However, work in this direction continues and the goal of further research will be the selection of the optimal remediator (sawdust, peat, vermiculite) for the storage of loparite ore dressing waste and the most tolerant plants for planting. The best options after the stage of laboratory research are planned to be tested in open areas of the tailing dump itself.

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