Formation of phytocenoses on lands disturbed by oil extraction in the Udmurt Republic

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Abstract. The Udmurt Republic is a region in which the oil extraction industry occupies a leading place in the economy along with metallurgy and mechanical engineering. Oil exploration work has been carried out here since the 40s of the XX century. Today, there are over 120 oil fields in the territory of Udmurtia. Every year, geological exploration of the subsoil contributes to the identification of new territories in which work on hydrocarbon raw materials' extraction is planned in the future. A significant part of these territories is located on the lands of the forest fund. To characterize the dynamics of environmental conditions and predict measures for the rational formation of post-technogenic territories, it is important to study the overgrowing processes of disturbed lands. The study of technogenic landscapes makes it possible to assess the disturbance degree of the vegetation, living ground cover. The article shows the features of phytocenoses formation, their species diversity in the conditions of oil production on the territory of the Udmurt Republic. The growth and development of living ground cover, natural regeneration of tree species depending on the age and degree of pollution have been investigated. It was found that with an increase in the technogenesis age, an increase in the proportion of forest species in phytocenoses takes place. Therefore, when forecasting for a longer period, one can expect the formation of plant communities mainly from forest tree and shrub species.

1. Introduction
Direct production of hydrocarbon raw materials on the territory of the republic began in 1967. In terms of the initial extracting reserves, the group of large ones includes the Chutyrsko-Kiengopskoye, Mishkinskoye, Vyatskaya area of the Arlanskoye field. Gremikhinskoe, Elnikovskoe, Krasnogorskoe oil fields are classified as medium group [1, 2]. According to the reported data in the region, work on search, exploration and development of oil and gas fields is carried out by 25 organizations, the largest of which are PJSC Udmurtneft and PJSC Belkamneft [3]. At oilfield facilities, it is possible to distinguish: mechanical destruction of landscapes; geochemical transformation and subsequent destruction of natural ecosystems. Mechanical skyline destruction is due to the physical impact - transport, boring machines, bulldozers. Geochemical transformation occurs when emergencies occur as a result of oil production, storage and transportation. Among the main pollutants formed as a result of oil production, it is customary to isolate oil, oilfield waters and their various mixtures - oil-water-salt emulsions. The soil as a heterogeneous system determines the nature of their fractionation. In it, oil flows are stratified into oil components and retained in the upper soil horizons, and saline waters, which, being heavier and less viscous, deepen into the lower horizons [4, 5]. The relief largely determines the gravitational mechanism of the spread of technogenic flows - towards the slope of the terrain.
The functioning of the oil industry is associated with global environmental pollution by hydrocarbons that are toxic to plants, animals and humans [6, 7]. In case of accidental spills, oil products cause depression of the functional activity of flora and fauna. In addition, the oil produced in the republic is heavy, viscous with a high content of sulfur, paraffin and tar in its composition. In most cases, its effect on biocenoses is indifferent and depends on the degree of pollution (concentration), exposure duration. There are 4 degrees of soil pollution with oil: low (up to 1%), medium (1-3%), strong (more than 5%), very strong (more than 7%) [8].

In some cases, when a weak concentration of this hydrocarbon enters the soil, the growth and development of plants is stimulated. Several scientists suggest that the following factors may take place here: the effect of plant growth stimulants contained in oil; improving plant nutrition through the decomposition of petroleum organic matter; reduction of competition between plants due to herbage thinning under the influence of oil [4, 9, 10]. In the literature, conflicting information is presented about the impact of oil products on plants and the resistance of various types of flora to oil pollution. The current situation is explained by the variety of physical and geographical conditions of the territories and their characteristic type of vegetation. Thus, according to the observations of T. Savkina (1970), monocotyledonous plants have the highest sensitivity to the oil content in the soil [11]. On the contrary, Shilova I.I. (1986) classifies such plants as the most resistant and notes the manifestation of the stimulating effect of oil on perennial cereals in enhancing tillering and increasing plant vigor [12]. The proportion of cereals, sedges, and rushes increases with an increase in petroleum products' concentration in the soil in the total projective cover. It has been proven that as a result of severe soil pollution, natural plant communities are completely destroyed and groups of weeds appear in their place: knot grass (Polygonum aviculare L.), barnyard grass (Echinochloa crus galli L.), quack grass (Elytrigia repens L.), Canadian thistle (Cirsium arvense (L.) Scop.), corn bindweed (Convolvulus arvensis L.). The most adapted of them are rhizome and creeping-rooted species [13, 14]. Among the most resistant wild plants are also narrow-leaved bluegrass (P. angustifolia L. (P. pratensis L. subsp. Angustifolia (L.) Arcang.), common chickweed (Stellaria media (Linn.) Cyrill.), lady grass (Phalaris arundinacea L.), bush grass (Calamagrostis epigejos (L.) Roth.).

When studying the degradation and restoration dynamics of forest phytocenoses and living ground cover after oil pollution, the presence of green mosses and lichens in technogenic areas was not observed even after 9 years. The duration of phytocenoses restoration largely depends on the degree of pollution and disturbance of the territory. The purpose of this work was to study renewal processes in areas that have undergone mechanical destruction and geochemical transformation during oil production in the taiga zone.

2. Materials and methods

The studies were carried out in the taiga zone on the territory of Balezinsky, Igrinsky, Yakshur-Bodkinsky forestries within the Turetskoye, Krasnogorskoye, Tukmachevskoye oil fields, respectively. The objects of study are distinguished by intensive oil production and are characterized by a high degree of geological knowledge and a large territorial coverage. A brief description of the objects is given in Table 1.

| Forestry (field) | TP No. | FST, type of forest | Creation year of forest crops | Pollutant, other negative effect | Year of contamination/violation |
|-----------------|--------|---------------------|-----------------------------|-------------------------------|-------------------------------|
| Igrinskoe       | TP 1   | B2, Fb              | 2003                        | oil                           | 2000                          |
| Forestry (field) | TP No. | FST, type of forest | Creation year of forest crops | Pollutant, other negative effect | Year of contamination/violation |
|-----------------|--------|---------------------|------------------------------|---------------------------------|--------------------------------|
| (Krasnogorskoie) | TP 2   |                      |                              | temporally abandoned production drilling site | 1998 |
| Igrinskoe       | CTP 1  | B3, Fb              | 2003                         | no pollutant                    | - |
| (Krasnogorskoie) | CTP 2  |                      |                              | no pollutant                    | - |
| Balezinskoe     | TP 3   | C3, Fcc             | 2001                         | temporally abandoned production drilling site | 1996 |
| (Turetskoye)    | TP 4   |                      |                              | oil                            | - |
|                  | CTP 5  |                      |                              | no pollutant                    | - |
|                  | CTP 6  |                      |                              | no pollutant                    | - |
| Yakshur-Bodyinskoe | TP 5   | D3, Fwg             | 1999                         | temporally abandoned production drilling site | 1998 |
| (Tukmachevskoe) | CTP 5  |                      |                              | no pollutant                    | - |
|                  | CTP 6  |                      |                              | no pollutant                    | - |

Note: FST – forest site type; B3- moist subor, Fb - bilberry spruce forest; C3- moist complex subor, Fss - wood sorrel spruce forest; D3 - moist ramen, Fwg - wide grass spruce forest.

The work is based on the trial plots method. A total of 12 test plots were laid, of which 6 test plots were on reclaimed lands (TP 1 - 6), 6 - on clearances not exposed to oil pollution (CTP 1 - 6). At the same time, oil spill pollution was noted at TP 1, 4 and 5; TP 2, 3 and 6 are areas that have undergone mechanical destruction (temporally abandoned areas production drilling sites). In the areas that underwent geochemical transformation (TP 1, 4, 5), the contaminated soil layer was removed by a bulldozer. At TP 2, 3 and 6, the technical stage of reclamation consisted of equipment dismantling, garbage collection and surface leveling.

The anthropogenic impact on TP 3 and TP 4 was 18 years old, on TP 2, 6 - 16 years, on TP 1, 5 - 14 years. On all test plots (TP 1 - 6), biological reclamation was carried out by creating pure forest stands of spruce.

Control test plots (CTP 1 - 6) were laid in forestry conditions similar to the contaminated plots with the same year of forest stands planting.

Methods used in forest inventory and geobotanical studies [15, 16, 17, 19] were used to describe and assess the state of vegetation and renewal processes in oil-polluted and control plots. On each trial plot, a geobotanical description of the living ground cover and natural regeneration was given. The assessment of natural regeneration was carried out using the enumeration method by dividing the trial plot into record plots of 10 × 10 m, on which a continuous recalculation of self-seeding and undergrowth was carried out [15]. When recording natural regeneration, the composition of natural regeneration, the amount of undergrowth, its origin (seed, coppice), the qualitative state of the undergrowth, factors that promote and impede regeneration were determined.

To account for the living ground cover, 10-15 record plots with a size of 1 × 1 m were laid along the diagonal of the trial plot. When studying herb-shrub and moss-lichen vegetation, the floristic composition of phytocenoses and projective cover were considered. The projective cover was assessed using the Brown-Blanquet scale.
The assessment of biological diversity and the identification of the factors' significance that determine the species diversity of plant communities were carried out using cluster analysis of the obtained values. The indices of Jaccard and Chekanovsky-Sørensen were used to compare the species composition of the floras of individual objects; they were expressed in relation to the number of common species to the arithmetic mean in two lists [18]. The analysis of similarity matrices was graphically depicted using dendrograms. Unification of objects into clusters was carried out by the method of single attachment or by the "nearest neighbour method". Clusters were formed according to distance measures and coefficients of the maximum value of similarity between objects.

3. Results

The development of a plant grouping from the settlement stages of individual specimens to grouping with a certain closeness degree and clearly expressed phytocenotic relations characterizes the formation of a phytocenosis. Living ground cover is one of the main structural components. In the study of the living ground cover in the experimental plots, 1 species of fern, 2 species of mosses and 2 lichens, 26 representatives of angiosperms were identified. The overgrowth of the plots is slow, the plants grow in clumps. The species composition is not rich. The studied areas are better overgrown with representatives of embryophytes of the families: *Fabaceae* (red and white clover), *Asteraceae* (coltsfoot), *Poaceae* (tufted hairgrass, bushgrass). All sample plots were characterized by the predominance of the number of species of the family *Asteraceae*. Of the mosses, disturbed areas are best inhabited by a representative of the family *Hylocomiaceae*, red-stemmed feathermoss; from lichens - filamentous cladonia (*Cladonia nemohuna* Ach.).

Species diversity is largely determined by the influence of pollution long standing of the studied areas. Thus, the proportion of weed species decreases from 50 - 60% (TP 1, TP 5) to 42% (TP 4), respectively, with an increase in the time elapsed since the technogenic impact. An increase in forest species also occurs with an increase in the period of technogenic intervention from 11% to 38%, respectively, Figure 1. The amount of weed species is determined by the degree of plant communities' formation decreasing with an increase in the density of the forest canopy. The emerging plant communities are represented mainly by weed-ruderal (TP 1, TP 2, TP 3, TP 5) and meadow-weed species (TP 4, TP 6).

The living ground cover on the control test plots (CTP 1-6) is formed mainly due to forest species.

![Figure 1. Fractional participation of plant species by landscape-zonal attribute.](image)

When studying natural regeneration, it was revealed that in all types of forest growing conditions, the goat willow (*Salix caprea* L.) is the predominant species. In areas that underwent geochemical transformation, deciduous species predominated in the bilberry and wood sorrel spruce forest types.
Conifers were dominated by spruce and pine. The fir was represented mainly by unreliable undergrowth. On the control sample plots, goat willow predominates as part of natural regeneration like technogenically disturbed plots. In the composition of natural regeneration, weeping birch (*Betula pendula ‘Gracilis’*) and European spruce (*Picea abies* L.) also occupy a dominant position, table 2.

| Table 2. The number of preserved self-seeding and undergrowth of tree species on the test plots. |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| TP 1 | European spruce | Pine common | Siberian fir | Weeping birch | Silver willow | Aspen | Speckled alder | Long standing of contamination/violation | FST, forest type | Year of conifers’ appearance after pollution/violation |
| 1.5 | 1.5 | - | 0.15 | 3.0 | - | - | - | 14 years |
| TP 2 | 0.25 | 0.25 | 1.5 | 6.5 | 3.5 | 33.5 | - | - | 16 years | B3, Fb by the 12th year |
| CTP 1 | 10.0 | - | - | 17.5 | - | 5.0 | 165.0 | - | no pollutant |
| CTP 2 | 10.0 | - | - | 18.0 | - | 7.5 | 150.0 | - | - |
| TP 3 | 17.0 | 1.5 | 66.5 | - | - | - | 50.0 | 0.1 | 18 years | C3, Fcc by the 8th year |
| TP 4 | 25.0 | 0.05 | - | 16.5 | 7.5 | 75.0 | 162.5 | 0.25 | by the 11th year |
| CTP 3 | 7.5 | - | - | 15.0 | - | 2.25 | 150.0 | - | no pollutant |
| CTP 4 | 10.0 | - | - | 17.5 | - | 5.0 | 150.0 | - | - |
| TP 5 | 6.5 | 3.5 | 0.25 | 1.5 | 1.65 | - | - | - | 14 years | D3, Fwg by the 11th year |
| TP 6 | 16.5 | - | 25.0 | 50.0 | 12.5 | 41.0 | 12.5 | - | 16 years | by the 6th year |
| CTP 5 | 2.5 | - | - | 10.0 | - | - | 120.0 | - | no pollutant |
| CTP 6 | 5.0 | - | - | 15.0 | - | 5.0 | 100.0 | - | - |

A comparative assessment of the species diversity on the studied areas indicates that the species richness in the control plots (3-4 species) is lower than in the areas subjected to mechanical destruction (5-7 species) and geochemical transformation (4-7 species). The regeneration on the control sample plots includes goat willow, weeping birch, European spruce, and aspen. In the areas that have undergone geochemical transformation and mechanical destruction, in addition to the above-mentioned species, the
regeneration includes silver willow (*Salix acutifolia* Willd.), Siberian fir (*Abies sibirica*), Baltic pine (*Pinus sylvestris* L.), grey alder (*Alnus incana* (L.) Moench), table 3.

**Table 3.** Composition of natural regeneration of tree species on sample plots.

| Object | Composition | Object | Composition |
|--------|-------------|--------|-------------|
| TP 1   | 5Wis1B2Sp2P | CTP 3  | 9Wig1B+Sp,As|
| TP 2   | 7As2B1Sp+Wis,F,P,Sp | CTP 4  | 8Wig1B1Sp+As|
| CTP 1  | 8Wig1B1Sp+As | TP 5   | 5P3Sp1Wis1B+F|
| CTP 2  | 8Wig1B1Sp+As | TP 6   | 3B3As2F2Sp+Wis,Wig|
| TP 3   | 5F4Wig1Sp+P,Gal | CTP 5  | 9Wig1B+Sp|
| TP 4   | 6Wis3As1Sp+B,Wig,Gal,P | CTP 6  | 8Wig2B+Sp+As|

Conifers' renewal in areas that have undergone geochemical transformation is represented by self-seeding, small and medium undergrowth of spruce, pine, and fir. It should be noted that spruce and pine undergrowth was characterized as reliable, and fir undergrowth was almost completely attributed to unreliable undergrowth.

The factors that hinder the process of natural renewal or impede its progress on technologically disturbed lands include:

1. the absence of a close location of natural phytocenoses - sources of seed material and, as a consequence, the difficulty of renewal from the adjacent forest edges (TP 1, TP 5);
2. violation of soil and hydrological conditions (waterlogging).
3. the development of a powerful living ground cover represented by synanthropic and meadow plant species, mosses, which contributes to soil drying and sodding, as well as damping the seedlings and self-seeding of conifers.

**4. Discussion**

When assessing the formation of phytocenoses on disturbed lands, the following stages of syngenesis were considered:

1. ecotypic grouping (projective cover 0.1%);
2. simple grouping (projective cover 0.1-5%);
3. complex grouping (projective cover 6-50%);
4. phytocenosis (projective cover more than 50%).

Judging by the abundance of species, the studied communities represent simple (0.1-5%) and complex (6-50%) groups.

According to the introduction of species, the following were identified:

- typical for "young communities" groups (technogenesis long standing - 14 years): white clover, bushgrass;
- indifferent species present regardless of the age of the communities: red-stemmed feathermoss (*Pleurozium schreberi*), wild strawberry (*Fragaria vesca*), red clover (*Trifolium pratense*);
- characteristic of the group of "old communities" (technogenesis long standing - 18 years) - forest hawkweed (*Hieracium murorum*), meadow buttercup (*Ranunculus acris*).

On all test plots, a productivity decrease of the stages of phytocenoses restoration was noted. The stage of introduction is characterized by high phyto-diversity (up to 15 years). At the second stage, ecotopic selection is observed - the displacement of weed-ruderal species and the formation of herbaceous layers. The intensification of the phyto-diversity restoration in most cases is due to anthropogenic regulation. Since all sites were cultivated, semi-natural phytocenoses are formed. On plots older than 15 years (TP 5, 6), the closeness of the forest crops' tree canopy in the rows creates conditions for the dominance increase of forest plants' role. Small plots (up to 1 hectare) also contribute to faster overgrowth.
When forecasting for a longer period, individual options with the dominance of meadow and forest species can be expected. In young communities with a technogenic long standing of 14 years (TP 1, TP 5), the species composition is expected to be predominated by forest hawkweed and meadow buttercup. According to these stages, TP 1 and TP 5 are at the stage of species “introduction”; TP 2, TP 3, TP 4, TP 6 go through the stage of ecotopic selection.

A high degree of species commonality at the level of 0.6 and higher is shown by the flora of closely located and similar in the influence degree of anthropogenic load on the landscape (TP 5, TP 6). In terms of floristic composition, TP 3 was the closest to the control area. It is characterized by a longer long-standing period of technogenic interference and the absence of pollution, Figure 2.

According to the research results, the low resistance of conifers to technogenic disturbance is noted. The emergence of sprouts and self-seedings of fir and pine in these areas is noted only in the 10-11th year after the oil spill and the 6-8th years after mechanical destruction, Figure 3. Perhaps an additional negative factor is the absence of a tree canopy, and, consequently, sun damage to young coniferous seedlings. With an increase in the time elapsed since the technogenic impact, the floristic composition of the test plots approaches the indicators of the control test plots.

![Figure 2. Dendrogram of cluster analysis of living ground cover on test plots.](image2)

![Figure 3. Dendrogram of cluster analysis of tree species' natural regeneration.](image3)
5. Conclusions
Thus, the studies confirm that higher plants are the first to settle in technologically disturbed territories. TP 1, TP 5 are at the stage of species "invasion", TP 2, TP 3, TP 4, TP 6 are at the stage of ecotopic selection and growth of species with vegetative reproduction.

In phytocenoses of areas subjected to mechanical destruction and geochemical transformation, communities are formed with a predominance of simple and complex groups of weed-ruderal and meadow-weed plant species in the living ground cover, as well as deciduous tree species in natural regeneration. The species richness of herbaceous plants increases in the following order: control plots, areas subjected to mechanical destruction, subjected to geochemical transformation. With an increase in the technogenesis long standing, there is an increase in the proportion of forest species in the ecosystem. Therefore, when forecasting for a longer period, the formation of forest species' communities can be expected.

In mechanically destroyed forest areas, the process of natural overgrowth with tree species develops more favorably, in contrast to areas that have undergone geochemical transformation. In the absence of a pollutant, the first seedlings of conifers appear in 6-8 years after the disturbance, and on contaminated substrates - in 10-11 years.

The natural regeneration of tree species in areas subjected to mechanical destruction and geochemical transformation is dominated by: deciduous - silver willow, conifers - fir and pine. A high degree of species commonality at a level of 0.6 and higher is shown by the flora of areas closely located and similar in the influence degree of anthropogenic load on the landscape.

References
[1] Artemieva A A 2008 Territorial analysis of oil extraction in the Udmurt Republic Bulletin of UdSU 6-1 105-114
[2] Shabanova E E 2008 Optimization of landscapes and reforestation processes in the conditions of oil fields of the Udmurt Republic: Thesis abstract of the diss. for the Candidate of Agricultural Sciences Yekaterinburg 19
[3] On the state and protection of the environment in the Udmurt Republic in 2014: State report 2014 Izhevsk 261
[4] Pikovsky Yu I 1981 Geochemical transformation of soddy podzolic soils under the influence of oil flows Technogenic matter flows in landscapes and ecosystems' condition Moscow 149
[5] Shorina T S Rusanov A M Suleimanova A M 2010 Influence of oil on the physical properties of common chernozem in the steppe zone of the Urals Bulletin of OSU 6 (112) June 137-140
[6] Arellano P Tansey K Balzter H Boyd D S 2017 Field spectroscopy and radiative transfer modelling to assess impacts of petroleum pollution on biophysical and biochemical parameters of the Amazon rainforest Environ. Earth Sci. 76 217 doi: 10.1007/s12665-017-6536-6.
[7] Varjani S J Gnansounou E Gurunathan B Pant D Zakaria Z 2018 Polycyclic aromatic hydrocarbons from petroleum oil industry activities: effect on human health and their biodegradation Waste bioremediation. Energy, environment and sustainability Singapore 185-199 doi: 10.1007/978-981-10-7413-4_9.
[8] A V Lednev 2002 Practical guidelines for reclamation of lands contaminated by accidental oil spills and oilfield waters Izhevsk: GNU UGNIISKH 80
[9] Nesterov A L 2009 Characteristics of phytocenoses near oil-extracting units of the Elowitz district of the Perm krai Perm agrarian bulletin: collection of sci. art. of the XIX All-Russian scientific and practical. conf. of young scientists, graduate students and students "Youth Science: Technologies, Innovations" (Perm, March 10-11, 2009) 1 113-114
[10] Sedykh V N 2004 Problem's state of the drilling wastes' impact on the natural environment Plants response to drilling wastes influence Novosibirsk Ch. 1 7-17
[11] Savkina T 1970 Soil damage caused by oil pollution Mater. of the symp. on reclamation issues of areas disturbed by industry - Leipzig 1 199-205
[12] Shilova I I 1986 Impact of environmental pollution during oil production on some components of biogeocenoses of the Middle Ob region General problems of biogeocenology: II All-Union. meeting: abstracts' report Moscow 2 57-59

[13] Gasheva M N 1990 State of vegetation as a criterion of forest biocenoses' disturbance due to oil pollution Ecology 2 77-78

[14] Gashev S N 2012 Influence of oil on terrestrial ecosystems: from degradation to restoration on the example of oil-contaminated middle taiga biogecenoses in the Middle Ob region of the Tyumen region: monograph LAP LAMBERT Acad. Publ., 64 URL: https://znanium.com/catalog/product/1072518 (access date: 15.08.2021).

[15] OST 56-69-83. Trial forest inventory areas 20

[16] Mirkin B M 1983 Explanatory dictionary of modern phytocenology Moscow 134

[17] Chibrik T S 2014 Study of technogenic landscapes' phytocenoses Yekaterinburg 166

[18] Magarran E 1992 Ecological diversity and its measurement. Translated from English by the Cand/ of Bio. sci. N V Matveeva, ed. by Yu I Chernova Moscow 181

[19] Chibrik T S 2007 Restoration of phyto-diversity at disturbed technogenic objects of the taiga zone of the Urals Biological reclamation and monitoring of disturbed lands: materials of the Intern. scientific Conf., Yekaterinburg, 4-8 June 2007 743-762