Monitoring of meadow biocenosis after oil spill rehabilitation measures in subtaiga subzone

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Abstract. This article presents results of long-term monitoring of meadow biocenosis restoration after an oil spill and subsequent rehabilitation procedures at southern subtaiga territories of the Tyumen Region, Russia. The data obtained show that the measures taken fostered development of vegetation with high abundance and diversity of species. There passed 25 years after rehabilitation, and the succession stage of phytocoenosis at the affected area is not any more determined by pollution, but by bogging, a process characteristic of the unaffected biocenoses of the area under study. Secondary succession is also evidenced by more than a two-fold decrease in diversity and abundance of decomposer fungi species in a forest biocenosis adjacent to the area of oil spill. Such a decrease is conditioned by a reduced amount and variety of forest litter, that had been formed after the accident and was later humified by the fungi. In 2020, the ratio of the fungal species used as indicators of forest stand health prompted that the impacted forest was nearing its original condition. The terrestrial vertebrates communities have almost recovered over the period of monitoring, although there have appeared synanthropes, and the proportion of anthropophilic species has gone up.

1. Introduction

Having a substantial share in Russian budget revenue, the oil industry is a key economic sector in Russia, but at the same time it is the most hazardous industry from the point of view of ecology [1]. Accidents involving crude oil and its refined products entail not only a loss of an amount of strategical asset, but also negative outcomes for polluted ecosystems [2-4]. Most hazardous accidents are those at big diameter oil pipelines, when significant amounts of pollutant are simultaneously released into the
environment. The current research presents results of 25-year-long monitoring of meadow biocenosis restoration after an oil spill in December, 1994, and its subsequent rehabilitation. The affected area is situated 100 km to the South-East of Tyumen City, Russia, along Ust'-Balyk–Al'met'yevsk major pipeline.

2. Materials and methods
The area under study is located in the parvifoliate forests subzone (subtaiga) of forest latitudinal zone of the West-Siberian Plane [5]. The oil spill occurred within the pipeline corridor through a herb-lidum birch forest. The polluted biocenosis is a moist tallgrass meadow with marshy low areas, and patches of thick shrubs. The oil spill impacted an area over 3 hectares (7.4 acres). The mean concentration of oil in the soil was 60% w/w, which is a strong pollution [6]. In 1995, rehabilitation measures were taken at the impacted area, these included: making clay soil berms around the spill area, pumping the oil from ditches dug to that end, filling in the area with clean fertile soil taken from fields, adding organic and mineral fertilizers to the soil. These measures decreased the concentration of the oil in the surface soil down to 0.5%. The last step was sowing ameliorant grass mix of 2 cereal and 4 pulse species.

Before rehabilitation procedures took place, the authors performed a complex assessment of the biocenosis: its botanical, zoological, and mycological examination. We explored two sites: polluted by the oil, and clean, situated near the former and having a similar biocenosis, but not affected by the spill. The latter served as control. Over the years following the oil spill, both sites were monitored.

3. Results and discussion
Table 1 presents results of vegetation cover monitoring. The control is the 2020 data obtained during the last monitoring of the clean site. They show the evolution of the phytocoenosis over the period under study.

| Indices             | Polluted Site, Monitoring Years | Control 2020 |
|---------------------|--------------------------------|--------------|
|                     | 1995  | 1996  | 1997  | 2000  | 2009  | 2020  | 2020  |
| Number of Species   | 9     | 53    | 56    | 53    | 59    | 45    | 51    |
| Projective Cover, % | 5     | 80    | 90    | 90    | 100   | 100   | 95    |

The oil spill led to near-total wipeout of forest live cover at the polluted site. It was only at the fringe of the site that individual live plants were registered. But in 1996, a year after the rehabilitation procedures, there already was a permanent grass stand consisting of sown grass, weeds brought with fertile soil, and local plant species that spread to the site from the neighbouring territories. From the beginning of the monitoring, the projective cover of the grass stand grew steadily, and since 2009 has been at the level of 100%. Species diversity (number of species) of the phytocoenosis after rehabilitation was not very different from year to year, without any clear-cut increasing or decreasing trend. Apparently, this value depends on actual weather conditions of the vegetation season. At present, the species diversity is close to the control. Over the monitored time, Gramineaea, Fabaceae, and Asteraceae families were dominant at both sites. They are characteristic of meadow biocenoses of the area under study. Nevertheless the rehabilitated site and the control differ considerably in terms of species registered at each of them; in 2020, the Czekanowski similarity index was at the level of 46%.

Over the period of investigation, floristic composition of the developing phytocoenosis has undergone a considerable transformation, the correlation between different ecological and cenotic groups has changed both in terms of the total number of species (figure 1a), and in terms of their abundance (projective cover) (figure 1b).
At the early stages of the secondary succession, weed species, that were brought to the site with the new soil, like *Atriplex hortensis*, *Cannabis sativa*, *Artemisia vulgaris*, etc., were numerous. These species can quickly spread over a vacant territory due to high seed productivity. By 2000, the share of weeds in the community has considerably shrunk; it is meadow mesophytes that holds the first place both in the number of species and in abundance (projective cover).

In 2009, both sites showed proliferation of meadow-swamp vegetation. At the rehabilitated area, this group prevails in terms of abundance, and in 2020 it dominates even more strongly. Natural processes of swamp formation are common in the region and explain such a dominance.

By now, a tallgrass hydrophytic meadow has formed at the rehabilitated patch of land, the grass reaching 120 cm (3.9 ft) tall. The aspect of the phytocenosis is determined by *Calamagrostis langsdorffii*, *Phragmites australis* and several sedge grass species. Mesophyte species are mostly found at fragmented elevations, that are the remaining parts of clay berms. Along the ditches, there grow shrubs, and at the border with the forest there is deciduous undergrowth.

Terrestrial vertebrates population showed its reaction to the oil pollution in the first summer after the spill. At the studied area there were no amphibians, nor reptiles, but they were rather common in the control. The bird population is restricted to shrub dwellers. These are the following genera: *Sylvia* (with *Sylvia communis* dominating), *Acrocephalus* (with numerous *Acrocephalus agricola*) and *Emberiza* (*Emberiza schoeniclus*), but there were no ground nesting species of *Phylloscopus* genus, numerous in the control. The number of species at the polluted territory decreased by more than 2.5 times, their abundance dropped threefold (table 2). Mammal count was extremely low. Only some mouse-like rodents from the control were registered, namely *Microtus oeconomus* and *Microtus agrestis*.

A year after, in summer of 1996, at the polluted site no amphibians were registered, but as for reptiles, there appeared separate individuals of *Zootoca vivipara* and *Vipera berus*. The bird population underwent understandable changes [7]: the number of species went down, but at the same time, there appeared a typical synanthropic species, *Passer montanus*, missing on the control site. *Phylloscopus trochilus*, *Luscinia svecica*, *Emberiza citrinella* emerged at the polluted area, but species from *Sylvia* disappeared. This fact can be accounted for by new grassland vegetation, especially cane and sedge, together with an on-going shrub defoliation. Relative abundance of birds grew to some extent (table 2). Species composition of small mammals at the polluted site was enriched by *Apodemus uralensis*, that can easily climb shrubs and avoid contacting the polluted surfaces, although there was no succession of dominant species yet, but the general abundance fell by half. Summer of 1997 did not bring any significant changes to the situation. The number of species and abundance of terrestrial vertebrates...
showed insignificant growth. In birds, there was an increase in the share of *Acrocephalus* and *Emberiza*, and in small mammals – in the share of *Apodemus uralensis*.

**Table 2. Bird Population Dynamics at 707 km of Ust'-Balyk–Al’met’evsk.**

|                      | Clean Site (Control) | Polluted Site |
|----------------------|----------------------|---------------|
|                      | 1995 | 1996 | 1997 | 2020 | 1995 | 1996 | 1997 | 2020 |
| Number of Species    | 16   | 19   | 16   | 17   | 6    | 4    | 5    | 16   |
| Relative Abundance, individual per 1 km of the route | 46   | 54   | 59   | 55   | 15   | 20   | 23   | 51   |
| Synanthropic Species Abundance, % | 0    | 0    | 0    | 0    | 0    | 30   | 22   | 6    |

The 2020 study of the terrestrial vertebrates fauna showed that the species composition and relative abundance have almost reached the levels of the clean site. In shallow bodies of water, *Rana arvalis* of amphibians have become common. The number of *Zootoca vivipara* is the same as at the control site, and *Vipera berus* is common, too. In the bird population, the number of species has grown threefold, and relative abundance has increased by 3.3 times, almost equalling the value of the control (table 2). In the bird population at the polluted area, species of *Phylloscopus* genus dominate (especially *Phylloscopus trochilus*), with species of *Sylvia* genus subdominating (*Sylvia communis* being numerous) and *Emberiza* (*Emberiza schoeniclus* dominating among them). Species of *Acrocephalus* genus are also numerous. But the synanthropic *Passer montanus* is still registered at the polluted territory although its share has gone down to 6%. The community of small mammals is almost identical to the same in the control. Aquatic and semi-aquatic species (*Arvicola amphibius* and *Ondatra zibethicus*) that disappeared right after the oil spill, have returned to the site. The pits, dug as a part of rehabilitation procedures, are now inhabited by a high density micropopulation of *Castor fiber*. This species has not been registered before at the control site.

Fungi are an intrinsic part of biogeocenoses, they decompose detritus. In forest biogeocenoses, wood-destroying fungi have the highest value, their species and communities (xylomycocenoses) are a reliable indicator of forest health [8-10]. One of the bioindication methods is analysing mycocenoses in the ecological matrix showing connection of certain fungi species with forest degradation stage [11]: 1) a closed forest, 2) an open forest, 3) a drying-up forest, 4) a mechanically disintegrated open forest, 5) a mechanically disintegrated forest (figure 2). This scale takes into account hydrothermal valence of fungi as well.

![Figure 2. The Distribution of forest health indicator fungi (of birch trees) in the impacted woodland.](image-url)
Several fungus censuses were conducted over the monitoring period: in May, 1995 (showing the condition of the forest stand before the oil spill, in autumn 1994), and in autumn 1995, in 1996 and 2020. Fungi species were registered in a herbaceous birch forest 50 m (54 yd) away from the oil spill territory. There were 198 conditional individuals registered in 1996, and up to 40 in 2020. If there were several fruit bodies of a species on a tree trunk, one individual was registered irrespective of their actual number.

In 1994, we registered 21 fungus species; after the spill, in 1995, the number of species grew to 26, in 1997 – to 27 species. 2020 monitoring showed a decrease to 14 species. This dynamics corresponds to an increased amount and diversity of dead wood produced by the oil spill. For the next 23 years after it, the bulk of the dead wood was humified by the abundant fungi; along with this process, the forest community was restoring, and when it neared the initial state, the decomposer fungi abundance and diversity went down. Over the whole period of time, a typical forest species, decomposing a major part of birch stemwood, *Fomes fomentarius* was dominating. The share of the species dropped from 33% to 26% in 1995 and to 20% in 1996. In 2020 it went up to 36%. *Stereum subtomentosum* is characteristic of forest-steppe open forests after fires. And its share has significantly grown over the years of the research from 1.8% prior to the spill to 4.0%, 5.1%, and 12.8% after it, correspondingly. Such an indicator of disturbed drying-up forests as *Merulius tremellosus* was not registered before the spill; in 1995, its share was 1.6%, in 1996 – 5.1%; in 2020 it was not registered again. *Cerrena unicolor* fungus is common at forest-steppe and forest-tundra open forests; its share prior to the oil spill was 0.9%, in 1995 it grew to 3.2%, and to 5.1% in 1996; in 2020 the species was not registered. A fungus infesting trees through wounds, *Bjerkandera adusta*, is an indicator of mechanically disintegrated forests; it had the following dynamics over the period of monitoring: 5.4 – 9.6 – 15.3 – 7.7 %, that is by 2020 its share has almost gone down to the baseline level.

The generalized distribution of the number of xylomycocenosis species in the ecological matrix shows a similar, but steadier trend of the impacted forest's biocenosis degradation after the oil spill and its further rehabilitation. Each cell of the matrix shows several indicator species. After the spill, the share of hydrophylous species has gone down from 0.5% in 1994 to 0% in 2020. At the same time, if we speak about fungi infesting trees through wounds and common at fellings, the share of thermophylous species, as compared to eurybionts, first decreased from 10.8% to 3.1%, and in 2020 it reached 14.4% exceeding the baseline values. This dynamics again shows that the forest community has rehabilitated. Figure 2 shows overall dynamics of indicator species. The share of indicator fungi of undisturbed forests and open forests after the oil spill decreased from 69% in 1994 to 49% in 1996, but restored to 66% in 2020, with open forest features getting stronger. The share of indicator fungi of drying-up forest grew from 2.7% to 12.2% in 1996, but went down to 5.8% in 2020. The share of fungi infesting trees through wounds, common at mechanically disintegrated forests, grew from 28% to 38% in 1996, but returned to 28% in 2020 (one should note that 2020 data include fungi that developed after beavers' biting trees).

4. Conclusion
The findings of the research show that the rehabilitation measures at the oil polluted site have promoted formation of meadow phytocoenosis with high species diversity and abundance. In 25 years after the rehabilitation, vegetation cover successional changes depend on natural bogging, characteristic of the biotic communities of the area under study. In the impacted forest adjacent to the oil spill, the species abundance and diversity of decomposer fungi reduced by more than two times. This decrease is indicative of secondary succession and shows a decrease in the amount and diversity of forest litter formed by the accident and humified by the fungi. The ratio of forest health indicator fungi in 2020 shows that the impacted forest has almost returned to its original state. Over the period of monitoring, terrestrial vertebrates communities have almost recovered, although the synanthropes have joined the community, and the share of anthropophilic species has increased.

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