Impact of technogenic transformation of northern taiga landscapes on mammalian population

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Abstract. Studies of the mammalian population in the area of operation of a large mining enterprise located in the northern taiga subzone of Yakutia have been conducted. A total of 2,334 cone-days and 3,000 trap-days are accumulated, post-hunting censuses of game species are taken. The mammalian fauna in the area affected by Udachninsky GOK is represented by 27 species. The negative impact of the mining enterprise on game species of mammals is manifested as an affected zone, for fur animals its width is 1.5–4.4 km, for the moose it is over 20 km. The study area is crossed by migration routes of the wild reindeer, and the presence of an industrial facility is a permanent threat to the well-being of the Lena-Olenek population of the species. The region is characterized by low abundance levels of small mammals even outside the anthropogenically affected areas. In technogenically transformed biotopes a decrease in capture rate and biodiversity parameters is registered, especially in open biotopes. In the forest stations forest species are being replaced by herbivorous inhabitants of open areas, which results in observable changes in the community structure. On the whole, the impact of the technogenic transformation of landscapes by the mining industry is manifested in redistribution of economically valuable species across the territory and a decrease in abundance and changes in the community structure of small mammals in the affected area.

1. Introduction

Currently, there is a trend toward an active expansion of the mining industry in high latitudes. This process has an impact on all components of ecosystems, including the population of mammals; and it is significant that the degradation of populations of game species is a source of discontent of the indigenous peoples of the North, for whom hunting is the main traditional way of use of natural resources. While the transformation of the population of game species has a direct effect on traditional use of natural resources, the changes in the population of small mammals are of interest, first of all, as an indicator of the degree of the cenosis transformation; also, one should not forget about small mammals having a high share in the energy transformation in the ecosystem. Despite the obvious relevance, this issue is not covered in literature in enough detail. The issues of transformation of the mammalian population are generally discussed in the context of urbanized territories [1-2]. There are publications on the effect of the urban environment on small mammals [3-4], analysis of the changes in the community composition in the landscape profile and along the gradient of anthropogenic pressure [5-9], and in the area affected...
by industrial enterprises [10]. Little research has been made into the impact of industrial development of virgin territories on abundance and distribution of game species.

The problem of the effect of transformation of natural landscapes on the biota is very relevant for the West Yakutia, where development of diamond deposits started in the mid-twentieth century; since the beginning of the 21st century the development of previously discovered oil and gas fields has intensified; and development of rare-earth deposits is planned as well. This issue is the most acute in case of the north taiga subzone, given the high vulnerability of northern cenoses to anthropogenic impact [17]. The impact of technogenic transformation of natural landscapes on the population of small mammals was studied in the vicinity of cities Mirny and Udachny, in the Anabar River valley [5,18,19]. There are articles that discuss the response of small mammals to technogenic impact on the population and organism levels [17,20,21], and an attempt has been made to identify the consequences of the transformation of natural landscapes for mammals that would be specific for the North-East Siberia in general [22].

Udachny, a city in the North-West Yakutia, can be taken as a typical example of the development of the north taiga landscapes by the mining industry. It is located 12 km to the south of the polar circle (66°28'N, 112°E) and administratively belongs to the Mirninsky raion of the Republic of Sakha (Yakutia).

The primary deposit of diamonds of the kimberlite pipe Udachnaya started being mined in 1971 by the open-pit method. Around this deposit Udachninsky GOK was created with all its communications and a processing factory, and Udachny city was built, with population of more than 13,000 people. Currently, there is a functioning mine located on the edge of the open pit of Udachnaya pipe. Also, there is Zarnitsa pipe, its development was started in 1999, it is located in the upper reaches of the D'yakh stream, a right tributary of the Daldyn River, there is a road connecting it to Udachny. The goal of our study was to assess the impact of the mining industry on the population of mammals of the north taiga subzone.

2. Material and methods
The material for this paper was collected in the area affected by the mining enterprise working Udachnaya and Zarnitsa deposits. They are similar in the character of the impact they have, but different in their age and the distance from the city. Udachnny mine has been operational for more than 50 years, and during that time the mining method was changed: from open pit to underground mining; the mine is practically on the outskirts of the city it shares its name with; thus, at this site one can observe overlapping effects of the mining industry and urbanization. Zarnitsa mine has been operational for just a little over 20 years and is located at a distance of 15 km from the city. In the text below we are going to address these sites as Udachny and Zarnitsa respectively.

Winter censuses of game species of mammals were taken in April 2013 in accordance with "Guidelines for Organizing, Performing, and Processing the Data of Winter Route Censusing of Game Species in the RSFSR" [23]. The works were carried out by two game estimators without using snowmobiles. The total length of census routes was 31.5 km. The data we obtained was compared with the information of the Department of Hunting of the Ministry of Nature Protection of the RS(Y) on abundance and population density of game species in the Mirninsky raion of the RS(Y) for that year. Additionally, efforts were taken to determine the width of the zone where commercial game species of fur animals were affected. Animal tracks were registered with a GPS tracker, which allowed us to determine as accurately as possible the distance from the boundaries of the impact source to the first found track of a given species.

Studies of the population of small mammals were carried out in summer of 2004 and 2013 with standard methods: capture grooves 20 m in length with a pair of cones set 5 m away from either of the groove's end; in the forest stations we used break-back traps, the traps were set for three days, in the amount of 50 per biotope, with an interval of 5 m between them, for bait we used pieces of bread soaked in sunflower oil [24]. In 2004 a total of 1,458 cone-days and 650 trap-days were accumulated; and in 2013, 876 cone-days and 2,350 trap-days. A total of 133 specimens of small mammals were collected.
Natural habitats (control) and ecotopes subjected to technogenic impact were examined concurrently. The studied biotopes are divided into three groups: natural, where anthropogenic impact is not manifested; slightly disturbed, where a transformation of vegetation is observed; and technogenically transformed, where the soil cover is destroyed or heavily polluted and natural vegetation was destroyed completely or partially. Slightly disturbed areas include firebreaks, clearings for power lines, water ducts, and sites exposed to moderate dust pollution [17]. Technogenically transformed territories are those of open-pit mines, waste-rock dumps, and tailings ponds, where the soil cover is completely destroyed or buried; and also, sites with heavy chemical pollution. Statistical treatment of the material was performed with standard methods. When analyzing the composition of the communities, Shannon's, Pielou's, and Zhivotovsky's indices were used [25,26].

3. Results and discussion

According to our own data and literature, the theriofauna of the study area includes 27 species of mammals [5,22,27,28], with most species encountered there being widespread throughout the taiga zone and fairly abundant. The main part of the biomass consists of small mammals: rodents and insectivores. Characterizing the theriofauna of the study area, it should be noted that it is poor in small mammals, not only relative to the sites lying to the south, in the vicinity of Mirny and in the Vilyuy River valley, but also to some geographically neighboring territories [29], while the composition of game species does not differ within the limits of the North-West Yakutia. Species of mammals included into the Red Book of the Russian Federation and the Red Book of RS(Y) [30,31] on the territory covered by this study were not observed.

Characteristics of the population of commercial game animals. The main commercial game species are the sable *Martes zibelina* and wild reindeer *Rangifer tarandus*, and for sport also is hunted the moose *Alces alces*. In the course of winter route censusing we have registered the presence of 8 species. The most numerous were the tracks of the mountain hare *Lepus timidus*, the stoat *Mustela erminea*, and the sable *Martes zibellina* (Table 1).

**Table 1.** Results of the post-hunting census of the main game species in forest lands (population density, ind. per 1.000 ha).

| Region, site                  | *Martes zibellina* | *Mustela erminea* | *Lepus timidus* | *Sciurus vulgaris* | *Gulo gulo* | *Canis lupus* | *Vulpes vulpes* | *Alces alces* |
|------------------------------|-------------------|-------------------|-----------------|-------------------|-------------|--------------|----------------|--------------|
| Zarnitsa, route 20.5 km²      | 2.24              | 3.80              | 3.71            | 0.0               | 0.06        | 0.16         | 0.14           | 0.0          |
| Udachny, route 10.5 km²       | 1.75              | 6.19              | 7.23            | 0.95              | 0.0         | 0.10         | 0.57           | 0.0          |
| Mirinsky raion⁵               | 1.34              | 0.33              | 0.40            | 0.24              | 0.0         | 0.09         | 0.05           | 0.21         |

* our data, ⁵ data of the Ministry of Environment, Natural Resource Management, and Forestry of RS(Ya).

It is noteworthy that in the vicinity of Zarnitsa mine we observed the tracks of the wolverine *Gulo gulo*, which on the territory of Yakutia is limited in number. Probably, this is explained by the fact that there are migration routes of *Rangifer tarandus* in this area, and preying on them provides predators with a good food supply. Both sites are also characterized by a relatively high abundance of the grey wolf *Canis lupus*, which may also be associated with the reindeer migration. Very remarkable is a high abundance of the red fox: at Zarnitsa site it is 3 times higher than on average in the area, and at Udachny site it is 11 times higher. Perhaps, this is due to the low degree of anthropophobia of the species. Colonization of the outskirts of human settlements by the red fox has been registered in many regions of the Russian Federation starting from the late 20th century [1]. Differences between the sites in population density of the squirrel, hare, and stoat can be attributed to biotopic differences: thinner forest stands are characteristic of Zarnitsa site, while at Udachny site forests are a little thicker, but because of
the long-lasting development of the territory areas overgrown with shrubs and serving as hare feeding grounds are common [27]. The tracks of the moose Alces alces on the surveyed territory have not been registered within the tract of up to 20 km away from the enterprise, despite the species being common for this region; this indicates a high pressure of sport hunting.

It is necessary to separately discuss the state of the wild reindeer population in the region. The area of operation of Udachninsky GOK is a part of the area of winter migration of the Lena-Olenek population, which extends to the south to the upper reaches of the Siligir, Alakit, and Markoka Rivers [32]. According to the results of the aerial census performed by the Department of Biological Resources of the Ministry of Nature Protection of the Republic of Sakha (Yakutia), in the 1980s the Lena-Olenek population consisted of approximately 81,000 head. At the time of performing our censuses and currently the size of the Lena-Olenek population of the wild reindeer according to the data of the Department of Biological Resources of the Ministry of Environment of the RS(Y) is estimated to be 90–95 thousand head. Apart from the Lena-Olenek tundra population of the reindeer, in this area also migrates the Popigay group (Taymyr) of this species [32]. Which population prevails in this area in winter is a debatable question. The amount of migrants varies greatly by the season and by the year.

We did not present the occurrence of Rangifer tarandus in table 1, because the censuses were performed according to the method [23], which should not be used during the migration period of the species. In both surveyed areas the routes registered numerous "old" tracks of the wild reindeer and fresh tracks indicating its migration in the last ten days of March. During the migration period the reindeer herds periodically come into the outskirts of the city, even to the industrial sites of the GOK.

Finding the width of the affected area. This parameter was assessed based on the fact that the distribution of large mammals over the territory is heavily affected by such factors as disturbance and direct hunting; therefore, the distance from the external border of the enterprise to the first observed tracks of the species can be considered as the width of the zone that the animals prefer to put between themselves and the source of disturbance and danger. Figure 1 shows the distance from the borders of the enterprises to the first tracks of animals; at Udachny and Zarnitsa sites some differences were found in the size of the zone, with the exception of the stoat. At Udachny site sable tracks were registered at a distance of 2.9 km from the object; and at Zarnitsa site, 1.6 km. It should be noted here that at the first site, as mentioned above, the impact is made not only by the mine itself, but also by the city infrastructure as a whole. The tracks of the mountain hare and the red fox at Udachny site are registered closer than at Zarnitsa; this can be explained by a better food supply due to the abundance of shrub vegetation in the Daldyn River floodplain, and, as already mentioned above, the adaptation of the fox to suburban conditions.

![Figure 1. The distance from the boundary of the impact source to the first track of the game species of mammals.](image-url)
the Ministry of Environment, Natural Resource Management, and Forestry of the RS(Y). The presence of the anthropogenic factor is indicated by the following: a complete absence of moose tracks at both sites; a higher population density of the mountain hare due to forest cutting and its replacement with shrub biotopes, and the presence of an affected area around the mining enterprises. The zone where no commercial game species are found comprises approximately 3 km for the sable, and for other fur species it varies from 1.5 to 4.4 km; which is similar to the distribution of these species at other industrial sites within the taiga zone [13,22]. The seasonal increase in the occurrence of the wild reindeer and the predators associated with it, i.e. the wolf and wolverine, are not related to anthropogenic factors, they are explained by the migration routes existing as the result of the natural history of these species. The high population density of the fox on the outskirts of Udachny city can be explained by its adaptation to urbanization.

Population of small mammals. The abundance of this group during the study period was low compared to other regions of the West Yakutia [5]. The total occurrence of small mammals according to the results of capture with cones in 2004 was 5.86 ind./100 c·d (cone-days). In 2013 it was 6.87 ind./100 c·d; and according to the results of capture with break-back traps it was 1.41 ind./100 t·d (trap-days). Some differences are noted, both in the total abundance and in the community structure, depending on the type of biotope and the degree of its disturbance. The most typical picture of the species ratio was observed in 2004 (figure 2). A relatively high abundance was registered in natural and slightly disturbed biotopes, where it was 2–10 times higher than in the transformed ones (figure 2). Forest habitats on the most of the territory of Yakutia are, as a rule, dominated by typical taiga species, first of all, by the northern red-backed vole Myodes rutilus [5]; in some years high abundance levels can also be achieved by the Laxmann's shrew Sorex caecutiens and the wood lemming Myopus schisticolor [33].

![Figure 2. Abundance and community structure of small mammals at Udachny site in 2004. FN, Natural Forests; FSD, Slightly Disturbed Forests; FTT, Technogenically Transformed Forests; MSD, Slightly Disturbed Meadows; MTT, Technogenically Transformed Meadows; SSD, Slightly Disturbed Shrubs; STT, Technogenically Transformed Shrubs.](image)

Udachny site in 2004 was dominated by the northern red-backed vole, co-dominant was the flat-skulled shrew Sorex roboratus. In open areas among rodents the dominants were generally represented by herbivorous species, i.e. voles from the Microtus group; and among shrews, by the tundra shrew S.
tundrensis and the Siberian large-toothed shrew *S. daphaenodon*. It is noteworthy that in technogenically transformed larch forests, where the natural moss and dwarf-shrub layer was disturbed due to pollution, it was replaced by herbaceous vegetation, and with that the share in the community of the root vole *Alexandromys oeconomus* has increased.

In 2013, in natural and disturbed biotopes the occurrence of small mammals was almost the same, which is unusual for the population of posttechnogenic territories. The second peculiarity of the population of small mammals in 2013 is a high evenness of the community in both natural and technogenic habitats. The latter fact is determined, in our opinion, by the low abundance of small mammals; we had observed a similar distribution in natural habitats in the North Yakutia during the periods of depression in abundance of small mammals [34]. On the whole, the dominant position of the northern red-backed vole, despite a significant decline in abundance, is noticeable; and the Laxmann’s shrew is inferior in abundance to the flat-skulled shrew, which is characteristic only for this region of Yakutia.

### Table 2. Abundance and diversity of small mammal communities at Udachny site.

| Category               | Biotope type | Year | Abundance, ind./100 cone-days | Parameters of species diversity | μ±s | E | H |
|------------------------|--------------|------|-------------------------------|--------------------------------|-----|---|---|
| Natural                | Forests      | 2004 | 24.00                         | 3.21±0.32                      | 0.72| 1.00 |
|                        |              | 2013 | 9.38                          | 5.67±0.45                      | 0.94| 1.68 |
|                        | Meadows      | 2013 | 13.16                         | 1.17±0.65                      | 0.63| 0.69 |
| Slightly Disturbed     | Forests      | 2004 | 3.91                          | 6.22±0.42                      | 0.88| 1.71 |
|                        |              | 2013 | 6.36                          | 5.40±0.48                      | 0.88| 1.57 |
|                        | Meadows      | 2004 | 18.00                         | 3.30±0.51                      | 0.72| 1.00 |
|                        |              | 2013 | 5.21                          | 2.79±0.35                      | 0.86| 0.95 |
|                        | Shrubs       | 2004 | 4.00                          | 2.91±0.25                      | 0.95| 1.04 |
| Technogenically        | Shrubs       | 2004 | 6.24                          | 2.57±0.25                      | 0.73| 0.80 |
| Transformed            |              | 2013 | 2.99                          | 3.78±0.34                      | 0.92| 1.28 |
|                        | Shrubs       | 2013 | 6.52                          | 2.40±0.65                      | 0.41| 0.57 |
|                        | Meadows      | 2004 | 4.27                          | 1.90±0.16                      | 0.86| 0.60 |
|                        |              | 2013 | 2.17                          | 1.00                          | -   | -   |

Note: *μ±s*, the Zhivotovsky index (average number of species); *H*, the Shannon's diversity index; *E*, Pielou’s evenness.

A cluster analysis of the two-year data on abundance and community structure has allowed us to reveal some common patterns. In abundance, natural larch forests in 2004 stand widely apart, as well as natural and slightly disturbed meadows; at the opposite pole are technogenically transformed meadows, characterized by low abundance and biodiversity; whereas all other biotopes are highly similar due to the evenness of the community composition (figure 3a). In community structure, a somewhat different picture is observed: there is an isolated cluster of meadow biotopes and technogenically transformed forests; the similarity of the latter with meadows is explained by the predominance of the root vole, which is related to the transformation of the herbaceous layer (figure 3b). The second cluster is biotopes with good shelter conditions: forests and shrubs characterized by predominance of typical forest species; that this cluster also includes one category of slightly disturbed meadows can be explained by the latters' proximity to forest stations, from which the dispersal of juveniles of taiga species takes place during the reproduction period.

### 4. Conclusion

Thus, the mammalian fauna in the area affected by Udachninsky GOK is represented by 27 species, with no significant change observed in the period of 2004–2013. Population density of game species, judging by the performed censuses, is on par with the regional level, and in many species it is higher in the
vicinity of Udachny than what is average for the region. The negative impact of mining enterprises on the game species of mammals is manifested in the presence of the zone within which there are no commercial game animals. For the sable this zone covers approximately 3 km; for other fur species, 1.5–4.4 km; for the moose, over 20 km. The study area is crossed by migration routes of the wild reindeer, and the presence of an industrial facility and a city poses a permanent threat to the well-being of the Lena-Olenek population of the species.

Figure 3. Similarity of the communities of small mammals at Udachny site in 2004 and 2013 in abundance (a) and community structure (b). FN, Natural Forests; FSD, Slightly Disturbed Forests; FTT, Technogenically Transformed Forests; MN, Natural Meadows; MSD, Slightly Disturbed Meadows; MTT, Technogenically Transformed Meadows; SSD, Slightly Disturbed Shrubs; STT, Technogenically Transformed Shrubs.

The region is characterized by low levels and marked fluctuations in the abundance of small mammals even outside the anthropogenically affected area. The impact of the mining industry is manifested primarily in redistribution of mammals among the biotopes and in changes in the structure
of the communities. The decrease in occurrence and in biodiversity is pronounced the most in open technogenically transformed areas, where the community can be represented by 1–3 species. The changes in the structure are evident the most in forest stations, where one can observe a replacement of forest species with herbivorous inhabitants of open areas. On the whole, the impact of the technogenic transformation of landscapes by the mining industry is manifested in redistribution of economically valuable species across the territory and a decrease in abundance and changes in the community structure of small mammals in the affected area.

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