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RESEARCH ARTICLE

Environmental protection measures in mineral resource development: case study of a gold-bearing deposit in the Russian Far East

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Abstract

In the Russian mining industry, the recent social and economic processes inevitably affect environmental safety and the social security of all those affected by mining. Thus, this study aimed to evaluate the technogenic impacts of a mining company on the environment. Measures were developed and implemented to ensure ecological safety and social security during a mineral resource development project in the southern part of the Russian Far East. This study analysed global experiences in this regard and carried out field research with the aim of establishing an inventory of plants and animals (terrestrial and aquatic), showing that technogenesis produced new specific landforms, e.g. quarries and dumps that replaced natural landforms. The main ecologically negative impacts of the mining operations in the region were the movement of mountain masses, changes in forms of erosion, and destruction of mountain ranges with the formation of dispersed clastic fractions of large specific surface areas, which determine exomorphodynamic processes, e.g. deflation, suffusion, and landslides. A general assessment of the biota status and natural water quality within the boundaries of influence of the developed deposit was presented, and a set of measures was recommended for environmental protection and ensuring the rational use of natural resources during mining operations. Moreover, the necessity of creating effective mining and environmental monitoring systems was supported. A 'Map of the Ecological State of Gold Mining Development in the Albazino Territory' was compiled for the first time, pinpointing areas undergoing various degrees of environmental stress. Changes in the forested areas within the territory of the mining allotment were forecast using the forest cover of the study area as the baseline.

Keywords Mineral processing waste · Environmental safety · Ecosphere · Ecosystem · Reclamation · Technogenic apparatus

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Introduction

Intensive long-term development of mineral deposits worldwide has led to significant destruction of natural ecosystems (Trubetskoy and Galchenko, 2017). Given the nature of its environmental impact, mining is the most large-scale, multi-waste-generating, and long-term production operation (Krupskaya et al., 2017), and hence, the problems posed by pollutants from mining activities on the ecosystem are considered urgent (Oparin et al., 2017). Several negative trends are associated with mining activities: (1) the ageing and slow upgrade of mining equipment and the application of outdated technologies and processes, which contribute to the development of negative environmental impacts; (2) limited green technology investments in mining enterprises, delayed construction of new facilities (including environmental ones), and limited repair and modernisation of equipment; (3) lack of attention to environmental management issues highlighted by environmental managers and nature conservation services hired by mining enterprises; and (4) loopholes in environmental legislation and the current system of payments/fines for environment pollution (Trubetskoy, 2017; Trubetskoy et al., 2016). Moreover, in the coming years, delays in implementation of immediate effective measures to overcome the above-mentioned negative factors may further aggravate the ecological situation in mining areas (Krupskaya et al., 2016; Trubetskoy et al., 2016, 2017; Zvereva et al., 2015).

Currently, the ecosystems hosting mining activities are intensely degraded, which negatively impacts public health (Krupskaya et al., 2019). These negative effects include surface and groundwater depletion and degradation, as well as harmful impacts on soil, flora, fauna, and ultimately human health (Rastanina et al., 2018; Shul'kin et al., 2015). In the Russian mining industry, the social and economic processes recently taking place, particularly in the Far Eastern Federal District, inevitably affect environmental safety and the social security of all those affected by mining. Therefore, effective measures are needed to prevent negative technogenic impacts on ecosystems. According to Dong et al. (2020), tailings dam is an indispensable part of mining safety production and environmental sustainability. The stability, monitoring, pre-alarming, and sustainability of tailings dam are crucial for mining disaster control, environment, and human beings. As result, the conception map of disaster prevention, disaster control, and environmental sustainability for safety management and environment to enhance cleaner production work in tailings dam was presented.

Additionally, it is necessary to improve mining technologies to reduce the increase of waste that requires storage and achieve sustainable development within the mineral resource sector in Russia (Kaplunov et al., 2018). The latest advances in CO2 mineralisation technology involving natural minerals and industrial waste are summarised in the paper by Xie et al. (2015), with great emphasis on the advancement of fundamental science, economic evaluation, and engineering applications.

Globally, environmental safety concerns stemming from mineral development processes and pollution generated by mining enterprises are not new topics. For instance, Juracek and Drake (2016) reported on the effects of mining in the USA and indicated that the water bodies affected by mining operations continue to remain contaminated despite the closure of lead and zinc production facilities. In Colombian large gold mining districts, mercury compounds are the main source of technogenic environmental impacts (Carranza-Lopez et al., 2019). Given their toxicity, these compounds are responsible for a fairly large percentage of diseases in the population owing to the consumption of polluted water from gold-bearing rivers. In Australia, Ali et al. (2017) estimated the impacts of the coal industry on public health, reporting increased concentrations of Al, Fe, Mn, Ni, and Zn compounds. Moreover, the socio-economic impacts of mining enterprises have previously been investigated, such as through studies in Vietnam (Nguyen et al., 2018) and Australia (Sincovich et al., 2018).

Remote monitoring has been used by several researchers in this field of study. For example, Chinese researchers have used hyperspectral remote sensing to reveal the stressed and unstressed states of vegetation in their study area (Zhang et al., 2012). More recently, scientists have used unmanned aerial vehicles with high-resolution image transmission ability to assess geomorphological changes arising from mining (Xiang et al., 2018). Despite the advancements in monitoring environmental changes (e.g. mapping modelling), it is crucial to develop environmental and social interventions and ensure their successful implementation in mining areas. This will not only reduce the burden on environmental facilities but also improve the tapping of available natural resources. For example, Finland has proposed the concept of 'Green Mining' (Pekka, 2017), consisting of five criteria: (1) full use of resource potential, (2) conservation of mineral resources for future generations, (3) minimisation of technogenic exposure by improving control and measurement methods, (4) improvement of working conditions, and (5) long-term planning of the reclamation phase long before the start of mining operations.

Unfortunately, the available scientific information associated with the functioning of ecosystems regarding mining operations is insufficient for providing a comprehensive understanding of the state of these systems. However, having such an understanding is crucial for the forecasting, monitoring, and regulation of mining and resource development, particularly with regard to successful environmental and operations management and social security. A precondition for successful global mineral resources governance is the establishment of an International Competence left on Mineral Resources Management, as suggested by Henckens et al. (2019).

Furthermore, in the Far Eastern Federal District of Russia, there are no generic processes or methodologies for the ecological monitoring of mining operations in either closed or operational mines (Krupskaya et al., 2016, 2017, 2019). Therefore, mining companies located in areas with newly discovered deposits, such as Albazinsky in Khabarovsky Krai, experience problems regarding the monitoring of ecosystem changes due to mining. Thus, this study aimed to assess and analyse the technogenic impacts of a mining company located in the south of the Russian Far East and develop measures to ensure environmental and public health.

Materials and methods

This research followed the methodology proposed by Vernadsky (1989) for the study of the biosphere and noosphere, as well as the main provisions set forth by Kolesnikov and Motorina (1978). This study included natural and industrial technogenic systems, including quarries, tailings dumps, settling ponds, and plant and animal populations (Fig. 1).

The work was performed using generally accepted methods in environmental, zoological, mineralogical, and geochemical studies (Alexandrova, 1964; Kolesnikov and Motorina, 1978). Additionally, three articles by the authors were analysed based on the results of later studies (Shishikin, 2019; Dyukarev et al., 2000; Efremov, 1999). We conducted monitoring/field observations, thematic mapping, comparative and structural system analyses, and statistical processing (e.g. factor analysis) of the empirical data collected from the mining area. Furthermore, the study was supplemented by a thorough literature review and patent search, including all relevant legislative and normative acts, instructional, and methodical materials, as well as the data from the State Statistics Committee and the Ministry of Natural Resources and

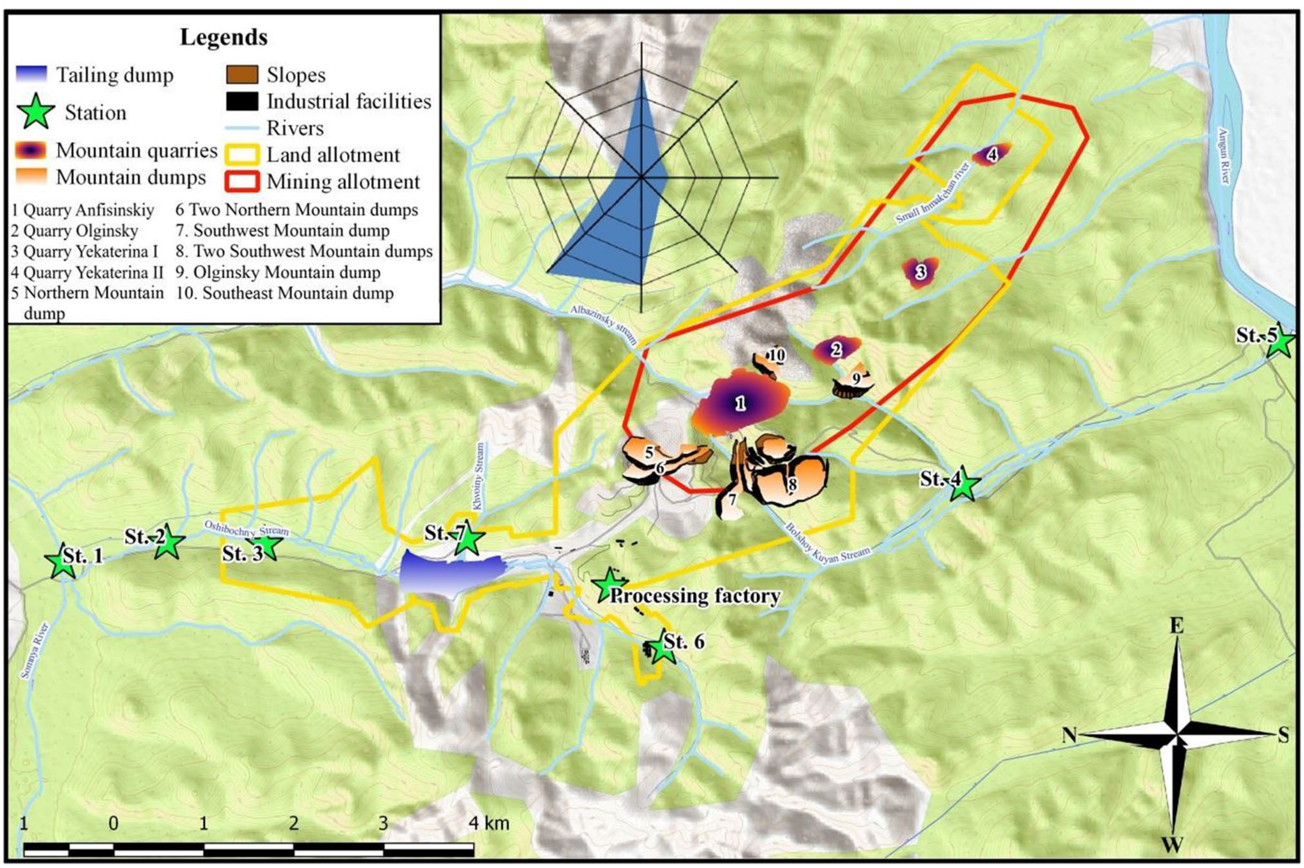


Fig. 1 Territory of the Albazinsky gold ore deposit

Ecology of the Russian Federation. Pertinent monographs, periodicals, laboratory studies, and data reported by the mining enterprises and forestry department were also reviewed.

Study area

The Albazinsky is one of the largest and most prospective gold ore deposit in the Far Eastern Federal District of the Russian Federation. This deposit is a part of the gold ore cluster of the same name and which is localised in the Nizhne-Amur zone of the Sikhote-Alin gold-bearing province on the left bank of the estuary of the Amur river of the Mongol-Okhotsk orogenic belt (Moiseenko and Eirish, 1996). The Albazinsky gold ore deposit is one of the largest objects with an approximate Au reserves (Volkov and Sidorov, 2017).

Specifically, it is located in the eastern part of the region (Polina Osipenko) of the Khabarovsk Territory in the Amgun-Somnya interfluve (Fig. 1) in the central part of the Omalsky Ridge. It has an absolute elevation of 350–800 m. According to the botanical-geographical zoning of the region, the Omalsky Ridge is located on the border of the middle-taiga and southern-taiga subzones of the coniferous forest zone (Kolesnikov, 1961, 1969). Kolesnikov (1961), who took the 'Geobotanical zoning of the USSR' (1947) as a basis, described the Omalsky ridge as part of the Amgun-Nizhne-Amur mountain-plain district consisting of fir–spruce and larch forests. This district is in the Amur-Sikhote-Alin province of the South Okhotsk dark and Eurasian coniferous (taiga) region. The Amgun-Nizhne-Amur mountain-lowland district is characterised by the predominance of ayan spruce, pochko-scaly fir (white fir), and Dahurian larch (Fig. 2).

The mining operations have generated wastewater, depleted groundwater, and required the construction of intakes and drainage systems for mining operations, transport, drilling equipment, and material processing. The land and mining allotment areas amount to 1980 and 1098 ha, respectively. Four rivers flowing into the Amur tributaries particularly the Amgun and Sonmya rivers are affected by this development.

Methods for assessing the state of forests

Forestry and taxonomic records were identified and perused, and the methodological developments reported by Alexandrova (1964), Rabotnov (1978), Yaroshenko (1969), Voronov (1973), and Sukachev and Zonn (1961) were carefully followed for scientific forecasting and classification, as well as physicochemical and biological analyses. Conditions for the renewal of the natural vegetation modified by technogenic relief forms (Dyukarev et al. 2000; Efremov, 1999; Pugachev and Tekhmenev, 2004; Rodaeva, 2004; Shishikin, 2019) were studied and referred to for this research.

Test areas were identified in the most relevant regions according to typically implemented forest survey methods (Artamonov et al., 2000; Bubnova and Ozaryan, 2016; Kalabin et al., 2016, 2018). The sources of technogenic impacts on forest communities were assessed, and the descriptions in the forest taxonomic records were used to select sampling

Fig. 2 **a** Quarry of the Anfisinskiy ore deposit; **b** overburden dumps; **c** settlement pond; **d** tailings dump

plots. Vegetation monitoring was carried out for the entire basin of the Oshibochny and Bolshoy Kuyan streams, and parts of the basins of the Maly Inmakchan and Albazinsky streams. These basins correspond to forest quarter nos. 103, 129, 130, 142, 787, 789, 801, 802, 803, 823, 824, 837, 838, and 840, which were identified by the natural boundaries recorded as per State Forestry Management and partially amended (for quarter no. 130) in 2016.

Methods for bioindication

Testing for all vegetation bioindicators was conducted in the laboratory of the Far East Scientific-Research Institute of Forestry. The level of technogenic pollution in the studied ecosystems was identified through a rapid assessment of the biosphere components using pollen sterility and growth test systems (Gorovaya, 1996).

Zoological research

Zoological research sampling and analyses were conducted for all plant groups (forest types) in the study area. Animal abundance was estimated using Kuzyakin (1962) point scales. Small mammals were counted by the trap method, with individuals being counted per 100 trap days (considering the dusk- and night-time activity of the animals). Artisan-made traps were set in the evening with white bread soaked in vegetable oil as bait, and the catches were collected in the morning. The traps were set systematically (5 m from each other). Large animals were counted visually by their tracks and encounters, and previously published data provided by specialists were used to account for large animals in the summer (traditionally regarded as a non-counting period) (Dunishenko, 2014). Additionally, bird counts were implemented according to Ravkin and Chelintsev (1990), and bird identification to species was carried out according to Nechaev and Gamova (2009). Finally, the number of species was distributed as follows: numerous or more than 10 individuals (+++), common or 9.9 to 1.0 individuals (++), rare or 0.9 to 0.1 individuals (+), and very rare or less than 0.1 individuals (+-).

Hydrobiological research

Hydrobiological studies were implemented within the area of influence of the developed Albazinsky gold ore deposit. Algal material (periphyton) and zoobenthos were collected at five hydrobiological stations from two watercourses, i.e. the Oshibochny and Bolshoy Kuyan streams. Two mountain streams, the Bolshoy Kuyan Stream, or the left tributary of Amgun River (52° 45′ N, 137° 58′ E), and the Oshibochny Stream, or the right tributary of Sonmya River (52° 56′ N, 137° 54′′E), were examined in the Albazinsky mining complex area. Both afore-mentioned streams belong to Amgun River Basin, which is part of the hydrographic network of the Low Amur River Basin. One of the stations (St. 4) of the Bolshoy Kuyan Stream was located on the boundary of the undisturbed mountainous area, and five stations were established along the longitudinal profile of the Oshibochny Stream: station 6 (St. 6), at the source; station 2 (St. 2), in the middle; station 3 (St. 3), 1.3 and 0.56 km from the first and second tailings dumps, respectively; station 1 (St. 1), at the confluence of the Oshibochny Stream with the Sonmya River, and station 5 (St. 5), at the confluence of the Bolshoy Kuyan Stream with the Amgun River (Fig. 1).

Samples of periphyton cyanobacteria and algae were collected according to standard methods (Wasser et al., 1989). All diatoms were cleaned following the technique noted by Swift (1967) and processed on to permanent microscope slides. Light microscope observations were made with an Axioskop 40 instrument (Zeiss, objective 40×/0.65 and 100×/1.25 oil) and an Alphaphot-2 YS-2 microscope (Nikon, objective 40×/0.65 and 100×/1.25 oil). Algae identification was carried out according to Dedusenko-Shegoleva and Gollerbakh (1962), Gollerbakh et al. (1953), Hartley et al. (1996), Krammer (2000), Krammer and Lange-Bertalot (1986, 1988, 1991a, b), Matvienko (1954), Moshkova and Gollerbakh (1986), and Vinogradova et al. (1980). Taxonomic nomenclature and classification for algae followed AlgaeBase (Guiry and Guiry, 2017).

To estimate the frequency of taxa occurrence at the selected stations, we used the 6-point scale suggested by Korde (1956), where 1 denotes solitary (1–5 cells on the slide); 2, rare (10–15 cells on the slide); 3, not infrequent (25–30 cells on the slide); 4, frequent (one cell in each row of the cover glass at magnification with immersion); 5, very frequent (several cells under the same conditions); and 6, bulk (several cells in each visual field under the same conditions). The taxa with Korde values of five and six were referred to as subdominants and dominants, respectively. All the algae with Korde values of four or lower were considered as secondary.

Biological methods are widely used to assess water quality based on indicator organisms (algae and invertebrates). Here, the Pantle–Buck method (Pantle and Buck, 1955) and the Sládeček modification (Sladeček, 1986) were used to ascertain the presence of periphyton communities of algae, which are indicators of organic pollution, and assess the organic pollution of the streams. We also referred to published data on the saprobic characteristics of algae (Barinova et al., 2006; Bukhtiyarova, 1999; Sladeček, 1986).

Quantitative samplings of macroinvertebrates were carried out on riffles using a modified Levanidov benthometer (Levanidov, 1977). The benthometer consisted of a rectangular frame with a capture area of 0.0729 m^2 and a height of 0.5 m. The front face of the frame was open, and the two-sided frames were tightened with gas bags with 1–1.5-m-long mesh nos. 15 and 23 attached to the fourth posterior face. The benthometer was firmly mounted on the streambed to a depth of 0.3 m. The stones inside the benthometer were removed and washed in a bucket, and the filler existing between the stones was stirred up. The fraction collected by the benthometer bag was transferred to a bucket containing previously washed stones, and the total sample was washed through the landing net and fixed. Two samples were taken at each station, resulting in a total of 10 samples. The material was stored in 80% alcohol and processed according to the generally accepted technique (Zhadin, 1960). Samples were taken at an adequate distance, and the collected aquatic insects were identified after referring to Kluge (1997), the Key to Insects of the Russian Far East (2006), Lepneva (1964, 1966), Makarchenko (2006), Makarchenko and Makarchenko (2006, 2012), and Teslenko and Zhiltzova (2009).

Assessments of water quality were carried out in terms of the ratio of Ephemeroptera, Plecoptera, and Trichoptera (EPT) and total taxon richness, considering the regional features of fauna in the Russian Far East (Vshivkova et al., 2019). Additionally, chironomid abundance distributions were compared with the structural characteristics of macroinvertebrate communities (biomass, wet weight in g/m^2, and density in individuals/m^2).

Statistical data were processed using EXCEL 2010 (Microsoft Corp., USA).

Results and discussion

The processing of mined gold ore has generated large amounts of solid and liquid waste (approximately in the ratio 1:2) containing hazardous minerals such as pyrite, arsenopyrite, sphalerite, and galena, which are dumped into a hydraulic tailings impoundment/storage area with the ability to return recycled water to the factory. The tailings dump site is located more than 1.5 km from a drinking water intake, and the absolute levels of the tailings dump site were at 250–272 m, while those of the water intake site were located at 312–318 m. Thus, the tailings dump site is located 40–68 m below the relief.

As previously shown (Krupskaya et al., 2016, 2017, 2019), the mining and processing of gold deposits leads to various environmental problems, such as forest clearance, isolation and loss of productive forest land, disturbance and/or degradation of the surrounding flora and fauna, disappearance of plant and animals populations, depletion of fish stocks, depletion of mineral reserves, disturbance of natural relief forms, intensification of adverse geomorphological processes, loss of soil fertility due to drying and pollution, changes in the hydrological regime and hydro-chemical composition of the underground and surface waters, lowering of groundwater reserves and their pollution, changes in the dynamics of air mass movement, air pollution, degradation of the landscape's recreational properties, and disruption and irretrievable loss of unique objects of cultural value.

Environmental assessments of the mining land allotment and mining background territory have revealed several negative anthropogenic impacts (Fig. 3):

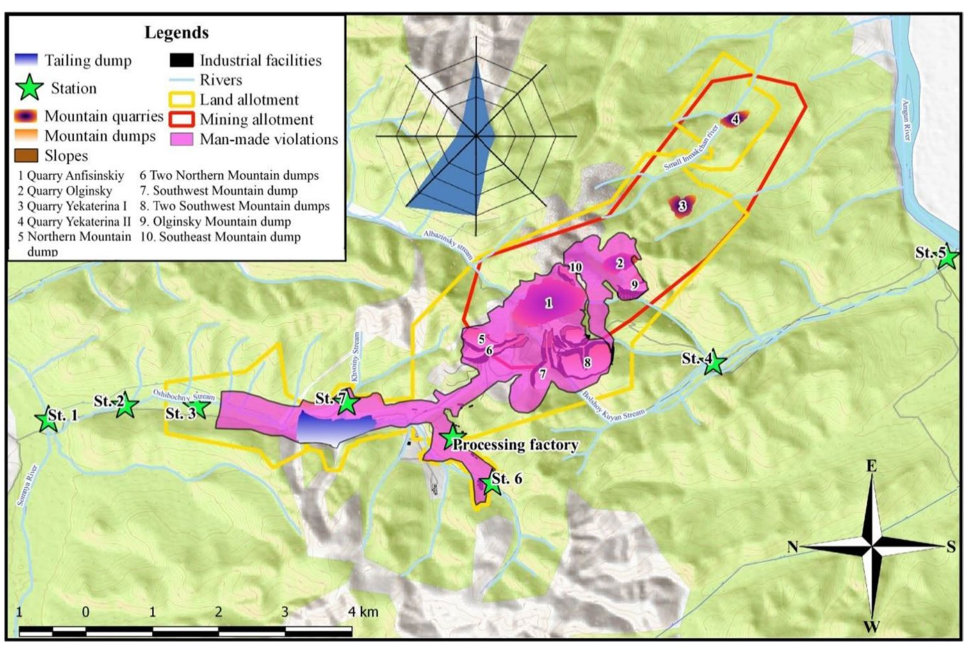


Fig. 3 Map of the ecological state of the area impacted by the Albazinsky gold ore deposit

1) The mining activities have led to several changes in the geological environment, including those in the landscape and surface runoff to water bodies. The risk of intensification of dangerous geological processes along the boundary of the territory is also serious. Notably, the total estimated mining reserve is quite high, amounting to more than 500 ha/million t of ore. Thus, the extent of environmental changes is expected to worsen in the future.
2) The landscape of approximately 70% of the territory containing the Albazinsky gold ore deposit has been anthropogenically modified (Fig. 3).
3) The soil and vegetation covers are seriously degraded, leading to changes in faunal and floral habitats and populations, as well as increased surface runoff and soil contamination in the adjacent areas.
4) The Anfisinskiy and Olginsky quarries were developed.
5) Dumps and technogenic deposits were created.
6) Tailings dump 1 is already operational, and the second dump is being constructed.
7) A road network has been constructed and has negatively impacted the local fauna.
8) Development in the areas allocated for mining and the construction of industrial facilities has contributed to changes in the flora and fauna. Animal habitats have been destroyed, forage areas have been reduced, and the mortality of nests with clutches and chicks has risen. Sedentary species that permanently inhabit the area are locally preserved, most of which may be amphibians, reptiles, and small mammals.

Future technogenic facilities include the Yekaterina 1 and Yekaterina 2 quarries, trans-shipment ore storehouse 3, settlement ponds, catchwater drain 9, and interceptor drains 4 and 5. These developments will entail cutting forests and plantations located in the study area and raise the probability of fires in the adjacent forest areas during construction. The increase in the number of vehicles visiting and departing from these sites will add to environmental pollution on account of the release of lead and other heavy metal compounds to the adjacent soil and vegetation.

Integrating the results from the above-mentioned studies, we created a map of the ecological state of the Albazinsky gold mine development (Fig. 3) using the floral and faunal changes that could be forecast in the affected area (Bubnova and Ozaryan, 2016). According to these forecasts, if the current business-as-usual trend continues, the production volume will increase by 2022, as will the volume of generated waste (60 million t), and the area occupied by rock dumps, quarries, and tailings dumps will cover approximately 200 ha. Figure 4 provides more details on the forecast changes in the forested areas due to the gold mining at the Albazinsky gold ore deposit until (and including) 2022.

Analysis of the forested area and forest cover indicators of the P. Osipenko district in Khabarovsky Krai enabled changes in the vegetation state to be forecast through 2022 (Artamonov et al., 2000; Bulgakov et al., 2003).

Soil

Changes in the habitat, flora and fauna, surface and groundwater, and pollution of adjacent territories in the study area occur under the influence of a complex of technogenic factors. Destruction of the soil cover in the mining area has led to changes in habitats, flora and fauna, and surface and underground waters, as well as pollution in the adjacent territories. Soil microorganisms (i.e. active microbial biomass levels) are a ready indicator of soil degradation. In this study, our experiments proved that the active microbial mass levels in the sampled areas (stations 1, 2, 4, 5, 6, and 7) were high compared to those in the background (Fig. 3), with slightly lower amounts of active microbial mass being registered in the tailings dump (Table 1), which indicated that the dump

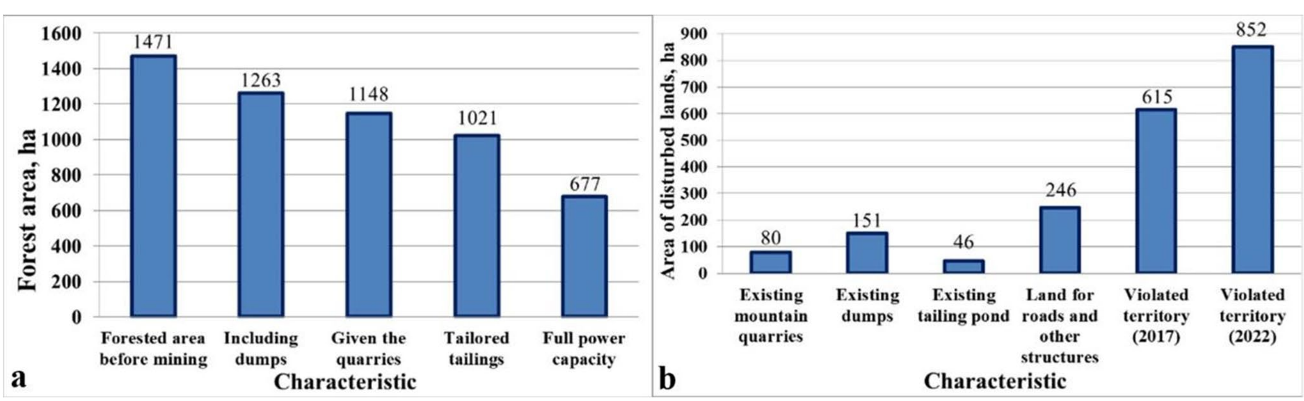


Fig. 4 **a** Changes in forested areas located within the territory of the mining allotment (until and including 2017). **b** Dynamics and forecast of changes in the forested area within the allotted land affected by the technogenic mining apparatus (2022)

Table 1 Results of microbiological analysis of soils as bioindicators of mining activity

Site name (location)	Fungi on Czapek, cfu/g	Actinomycetes on starch-ammonia agar, mln/g	Bacteria on starch-ammonia agar, mln/g	Bacteria on fish peptone agar, mln/g	Bacteria on Ashby, mln/g
St. 1 (inflow of Oshibochny Stream in Somnya River)	48.51	4.79	227.29	143.96	196.67
St. 2 (middle reach of Oshibochny Stream)	41.29	4.13	125.07	129.80	141.59
St. 3 (near tailing dump 1)	None detected	None detected	None detected	1.49	0.99
St. 4 (middle reach of Bolshoy Kuyan Stream)	21.12	4.32	32.52	50.68	127.24
St. 5 (inflow of Bolshoy Kuyan Stream in Amgun River)	15.41	1.24	8.51	23.74	10.84
St. 6 (head of Oshibochny Stream)	33.94	2.13	23.81	39.91	19.50
St. 7 (Khvoiny Stream, before tailings dump 1)	19.90	0.24	8.52	13.12	17.98

Table 2 Bioindications of environmental stress via plant pollen sterility measurements[a] at different distances from the technogenic source

Plant sampling location (distance from tailing dump 1)	Quantity of cells tested (units)	Pollen sterility (%)
Station 1 (3.3 km)	500	2.1 ± 0.23
	500	2.4 ± 0.25
	500	2.3 ± 0.22
Station 2 (2.4 km)	500	3.9 ± 0.28
	500	3.6 ± 0.22
	500	3.8 ± 0.29
Station 3 (1.3 km)	500	8.3 ± 0.34
	500	8.0 ± 0.31
	500	8.5 ± 0.36
Control/background	500	0.3 ± 0.18
	500	0.2 ± 0.18
	500	0.4 ± 0.19
Station 4 (4.7 km)	500	3.6 ± 0.21
	500	3.8 ± 0.27
	500	3.9 ± 0.29
Station 5 (8.2 km)	500	1.9 ± 0.36
	500	1.4 ± 0.33
	500	1.6 ± 0.35
Station 6; head of Oshibochny Stream (1.7 km)	500	3.9 ± 0.29
	500	3.7 ± 0.26
	500	3.5 ± 0.23
Station 7; Khvoiny Stream (0.3 km)	500	6.3 ± 0.33
	500	6.6 ± 0.35
	500	6.4 ± 0.32

[a]Rosebay Willowherb (*Epilobium angustifolium*) was used as the bioindicator at each location.

is not yet a direct threat to living organisms. This notion was confirmed by bioindication of ecological tension (Table 2).

Fauna and flora

We conducted tests on plant pollen sterility at different distances from technogenic sources and analysed the occurrence of mosses and lichens in the area impacted by the mining activities. Pollen sterility increased as the distance of the sampled area from the pollution source decreased (Table 2). Moreover, the amounts of mosses and lichens within the influence zone of the mining activities were found to increase with the distance from the tailings dump (Table 3).

At least 370 bird species have been recorded in the Low Amur Region (Babenko, 2000) of which 160 (more

Table 3 Impacts of mining activity on the presence of lichens and mosses

Distance from the tailing dump (km)	Observations	Assessment
> 5	Lichens: absent Mosses: absent	Negative impact likely due to proximity to the tailings dump
7	Lichens: present Mosses: present	No negative impact
> 10	Lichens: present Mosses: present	No negative impact
20	Lichens: present Mosses: present	No negative impact
> 20	Lichens: abundant Mosses: abundant	No negative impact

than 43%) live in the P. Osipenko municipal district (Tagirova et al., 2015). We registered 50 species belonging to 11 orders, 24 families, and 32 genera on linear routes along different plant formations (Table 4). Passeriformes comprised the greatest number of species (27), accounting for 54% of all species of the above group. We also recorded five species of Falconiformes, three species each in the orders Anseriformes, Charadriiformes, and Piciformes, two species of Galliformes and Cuculiformes, and one species each in the other five orders. Moreover, bird diversity generally decreased in the study area. For most bird species, the reproductive period ends in the second half of July. We found nests with yellow-browed bunting and mountain wagtail chicks in the third week of July, which were signs of the final summer period. The birds were preparing for their autumn migration to the south, and they were thus becoming less visually and audibly noticeable in the study area.

Table 5 reports on the diversity of rare, endangered, and specially protected terrestrial vertebrate species in the Albazino territory. Overall, from the 108 species of terrestrial vertebrates living within the territory of the Albazinsky gold deposit area, 12 of the identified species in Khabarovsky Krai appear in The International Union for Conservation of Nature (IUCN) Red List of Threatened Species, including seven mammals.

Studies of vertebrate populations in the area of development of the Albazinsky gold ore deposit have shown that technogenic factors had a negative impact on large animals in terms of their migration to other places. Migration for large animals is a huge stress. Small mammals, reptiles, and amphibians are more susceptible to negative impacts; however, the process of restoration of the fauna occurs imperceptibly due to multiple reproduction (small rodents) or local mutual substitution (distribution).

Hydrobiology

Periphyton algae

Hydrobiological studies were conducted to understand the extent of technogenic pollution due to the mining activities in the region. The first algal studies in the Lower Amur River (from Khabarovsk City to the Amursky Estuary) and its basin were conducted by Skvortzow (1917, 1918, 1931) and Khakhina (1937, 1948). Basic information on the species composition of plankton and periphyton algae in the mainstream and channels of the lower Amur River and its basin has been described in previous scientific papers (Barinova and Medvedeva, 1989; Barinova and Sirotsky, 1991; Genkal and Kukharenko, 1990; Kukharenko and Naumenko, 1990; Nikulina, 2014), as well as in review articles and general publications (Medvedeva and Nikulina, 2014; Medvedeva and Sirotsky, 2002; Nikulina and Medvedeva, 2019).

In this study, an examination of periphyton algal communities of two watercourses, the Oshibochny and Bolshoy Kuyan streams, revealed their species composition. In total, 90 algae species and varieties from six phyla and 43 genera were found (Tables 6 and 7). Most of the studied algal flora (91.1% of the total number of taxa) were diatoms. Bacillariophyceae was the most diverse class, as it included 77 species (82 infraspecific taxa) from 36 genera (Tables 6 and 7). A systematic structure analysis showed the largest number of infraspecific taxa belonged to *Eunotia*, *Nitzschia*, *Navicula*, and *Pinnularia*, with 6, 6, 7, and 7 taxa, respectively (Table 7).

The total species composition of algal flora at the four sampling stations of the Oshibochny Stream (Sts. 6, 2, 3, and 1) included 86 species and varieties from six phyla. The phylum Bacillariophyta presented the maximum number of taxa (78 species and varieties; Tables 6 and 7). Typically, diatoms prevailed in the periphyton communities of the watercourse, and their relative abundance considering occurrence frequencies was estimated as 'very frequent' or 'in bulk' (point scales: 5 and 6). Local algal floras of three of the sampling stations in the Oshibochny Stream (Sts. 6, 2, and 3) presented an equal number of species and were represented by 40–42 infraspecific taxa. Contrastingly, at the confluence of the Oshibochny Stream with Sonmya River (St. 1), the algal diversity increased to 66 species and varieties (Table 7).

In addition, the flora showed highly similar species composition among sampling stations. However, they differed in terms of the dominance structures. At St. 6, diatoms *Diatoma mesodon*, *Gomphoneis olivaceum*, and *Meridion circulare* var. *circulare* exhibited the highest occurrence frequency (4–5 or 5) in the periphyton communities of solid substrates, and the dominant species were absent. At St. 2, diatoms *Encyonema silesiacum*, *G. olivaceum*, and

Table 4. Bird species diversity at the study site.

Order and species	Formations						Abundance[a]	
	1	2	3	4	5	6	7	
Ciconiiformes								
Grey heron (*Ardea cinerea* Linnaeus, 1758)					+	+		++
Anseriformes								
Wild duck (*Anas platyrhynchos* Linnaeus, 1758)						+		++
Garhaney (*Anas querquedula* Linnaeus, 1758	+					+		++
Teal (*Anas crecca* Linnaeus, 1758)	+					+		++
Falconiformes								
Goshawk (*Accipiter gentilis* Linnaeus, 1758)							+	Rare protected species
Ern (*Haliaeetus albicilla* Linnaeus, 1758)					+			Rare protected species
Hobby falcon (*Falco subbuteo* Linnaeus, 1758)		+						+
Pigeon hawk (*Falco columbarius* Linnaeus, 1758)			+					+
Kestrel (*Falco tinnunculus* Linnaeus, 1758)	+	+			+	+		++
Galliformes								
Rock capercaillie (*Tetrao parvirostris* Bonaparte, 1856)		+						+-
Hazel grouse (*Tetrastes bonasia* Linnaeus, 1758)	+	+	+	+	+	+		++
Gruiformes								
Hooded crane (*Grus monacha* Temminck, 1835)	+							Rare protected species
Charadriiformes								
Little ringer plover (*Charadrius dubius* Scopoli, 1786)	+						+	++
Common sand piper (*Actitis hypoleucos* Linnaeus, 1758)	+		+				+	+++
Common stern (*Sterna hirundo* Linnaeus, 1758)	+							+
Cuculiformes								
Common cuckoo (*Cuculus canorus* Linnaeus, 1758)					+			+
Himalayan cuckoo (*Cuculus (saturatus) optatus* Gould, 1845)	+				+			+
Strigiformes								
Ural owl (*Strix uralensis* Pallas, 1771)				+				+
Coraciiformes								
Little kingfisher (*Alcedo atthis* Linnaeus, 1758)	+					+		+
Piciformes								
Black woodpecker (*Dryocopus martius* Linnaeus, 1758)			+					+-
Great spotted woodpecker (*Dendrocopos major* Linnaeus, 1758)					+			++
White-backed woodpecker (*Dendrocopos leucotos* Bechstein, 1803)	+				+			+
Passeriformes								
Olive-backed pipit (*Anthus hodgsoni* Richmond, 1907)	+					+		++
Richard's pipit (*Anthus richardi* Vieillot, 1818)		+				+		+-
Mountain wagtail (*Motacilla cinerea* Tunstall, 1771)	+	+	+	+				+++
White wagtail (*Motacilla alba* Linnaeus, 1758)	+					+		++
Brown shrike (*Lanius cristatus* Linnaeus, 1758)	+	+			+			++
Siberian jay (*Perisoreus infaustus* Linnaeus, 1758)				+				+-
Nut cracker (*Nucifraga caryocatactes* Linnaeus, 1758)	+			+	+	=		++
Jungle crow (*Corvus macrorhynchos* Wagler, 1827)	+	+	+	+	+	+	+	+++
Eastern carrion crow (*Corvus (corone) orientalis* Eversmann, 1841)						+	+	++
Crowned willow warbler (*Phylloscopus coronatus* Temminck et Schlegel, 1847)	+	+	+		+			+++
Pallas' warbler (*Phylloscopus proregulus* Pallas, 1811)	+		+	+				++
Dusky warbler (*Phylloscopus fuscatus* Blyth, 1842)					+	+		+
Greenish warbler (*Phylloscopus trochiloides* Sundevall, 1837)	+							+
Gildcrest (*Regulus regulus* Linnaeus, 1758)	+		+	+				+-
Siberian flycatcher (*Muscicapa sibirica* J. F. Gmelin, 1789)		+	+		+	+		+-

Table 4. (continued)

Order and species	Formations						Abundance[a]	
	1	2	3	4	5	6	7	
Taiga flycatcher (*Ficedula (parva) albicilla* Pallas, 1811)			+			+		+-
Mugimaki flycatcher (*Ficedula mugimaki* Temminck, 1836)	+	+						+-
Rufous-tailed robin (*Luscinia sibilans* Swinhoe, 1863)		+		+	+		+	++
Pale thrush (*Turdus pallidus* J. F. Gmelin, 1789)							+	+-
Grey-backed thrush (*Turdus hortulorum* Sclater, 1863)				+		+		+
Naumann's thrush (*Turdus naumanni* Temminck, 1820)	+						+	+-
Willow tit (*Parus montanus* Baldenstein, 1827)	+		+		+			++
Coal tit (*Parus ater* Linnaeus, 1758)					+			+
European nuthatch (*Sitta europaea* Linnaeus, 1758)	+	+		+			+	+++
Tree creeper (*Certhia familiaris* Linnaeus, 1758)		+						+
Pine bunting (*Emberiza leucocephala* J. F. Gmelin, 1771)				+		+		+
Yellow-browed bunting (*Ocyris chrysophrys* Pallas, 1776)			+		+			+-
Chestnut bunting (*Ocyris rutilus* Pallas, 1776)						+		+

[a]Numerous or more than 10 individuals (+++), common or 9.9 to 1.0 individuals (++), rare or 0.9 to 0.1 individuals (+), and very rare or less than 0.1 individuals (+-)

Fragilaria vaucheriae dominated the periphyton community and were accompanied by subdominants *Navicula avenacea*, *Nitzschia palea* (Bacillariophyta), and *Audouinella chalybaea* (Rhodophyta). At St. 3, i.e. in the tailings dump area, *E. silesiacum*, *G. olivaceum*, and *F. vaucheriae* were abundant in the periphyton algal community, and the diatoms *Cymbella cistula*, *N. avenacea*, and *Ulnaria ulna* as well as the filamentous Heterokontophyta *Tribonema viride* were subdominant. Significant amounts of empty diatom valves without cell contents and with damaged chloroplasts were recorded, and Heterokontophyta algae with damaged cell walls were detected at this station, probably owing to the deteriorating ecological situation in this part of the watercourse. At St. 1, the highest abundance estimates belonged to the species *E. silesiacum* and *F. vaucheriae*, while *G. olivaceum* and *N. avenacea* were subdominant.

Forty-two species of diatoms, golden algae, and cyanobacteria were found in the periphyton communities of the Bolshoy Kuyan Stream (St. 4). The species *Hydrurus foetidus* (Class: Chrysophyceae, Phylum: Heterokontophyta) was abundant and categorised as 'in bulk', while three subdominants, *D. mesodon*, *E. silesiacum*, and *M. circulare* var. *circulare*, were present in the algal community. All the other species were classified as secondary, and their frequency was estimated as 'solitary'–'frequent' (Table 7).

Water quality, i.e. the presence of organic pollution, was assessed using the Sládeček modification of the Pantle–Buck method (Sládeček, 1967). Data were used to calculate the saprobity index (S) for each stream, which varied from 1.40−1.43 for the Oshibochny Stream and was 1.27 for the Bolshoy Kuyan Stream (Table 8). The waters of the examined watercourses were categorised as oligosaprobous and oligo-betamesosaprobous, respectively, and the water purity corresponded to Class II. Thus, the streams were classified as 'clean' (Table 8).

Additionally, we suggest that the pollution at St. 3 caused the xenosaprobous and oligosaprobous algal species to die off, and a gradual replacement by algae that can withstand aquatic pollution is likely to occur in the future.

Macrozoobenthos

Degradation of the benthos communities and significant changes in their structural and functional characteristics were revealed during hydrobiological monitoring conducted in the Sikhote-Alin mountain streams, which have experienced organic and technogenic pollution (Alimov and Teslenko, 1988; Teslenko, 1986). Degradation was expressed in terms of the reduction in total species richness and replacement of stenothermic and oxyphilic stoneflies, mayflies, and caddisflies by eurythermal chironomids with wide ecological spectra. The ecological regression was accompanied by the simplification of trophic nets, particularly the disappearance of predatory aquatic insects (primarily predatory stoneflies). This transformation of the community structure led not only to changes in community organisation and dominant species, but also to a decrease in natural activities and processes, such as matter and energy utilisation, as strict quantitative links exist between the structural and functional characteristics of an ecosystem.

Benthic macroinvertebrates were monitored to assess the influence of the technogenic activities from the mining complex on the water quality of Oshibochny and Bolshoy Kuyan streams. The invertebrate species compositions in

Table 5 Terrestrial vertebrate species diversity in the area surrounding the Albazinsky deposit

Rare species	Very rare species	IUCN Red List species
Mammals		
Long-clawed shrew (*Sorex unguiculatus*)	Siberian stag (*Cervus canadensis sibiricus*)	Eurasian water shrew (*Neomys fodiens*)
Siberian weasel (*Mustela sibirica*)	Wild reindeer (*Rangifer tarandus*)	Amur bat (*Myotis bombinus*)
Elk (*Alces alces*)	Musk deer (*Moschus moschiferus*)	Fraternal myotis (*Myotis frater*)
Siberian stag (*Cervus canadensis sibiricus*)		Brandt's bat (*Myotis brandti*)
Siberian roe deer (*Capreolus pygargus*)		Long-eared bat (*Plecotus auritus*)
Eurasian otter (*Lutra lutra*)		Northern bat (*Eptesicus nilssoni*)
		Siberian tube-nosed bat (*Murina hilgendorfi* Gray, 1842)
Birds		
Hobby falcon (*Falco subbuteo* Linnaeus, 1758)	Rock capercaillie (*Tetrao parvirostris* Bonaparte, 1856)	Goshawk (*Accipiter gentilis* Linnaeus, 1758)
Pigeon hawk (*Falco columbarius* Linnaeus, 1758)	Black woodpecker (*Dryocopus martius*)	Ern (*Haliaeetus albicilla* Linnaeus, 1758)
Common tern (*Sterna hirundo*)	Richard's pipit (*Anthus richardi* Vieillot, 1818)	Hooded crane (*Grus monacha*)
Common cuckoo (*Cuculus canorus* Linnaeus, 1758)	Siberian jaw (*Perisoreus infaustus* Linnaeus, 1758)	Siberen grouse (*Falcipennis falcipennis*)
Himalayan cuckoo (*Cuculus (saturatus) optatus* Gould, 1845)	Greenish warbler (*Phylloscopus trochiloides* Sundevall, 1837)	Eurasian eagle owl (*Bubo bubo*)
Ural owl (*Strix uralensis* Pallas, 1771)	Dusky warbler (*Phylloscopus fuscatus* Blyth, 1842)	
Little kingfisher (*Alcedo atthis* Linnaeus, 1758)	Gildcrest (*Regulus regulus* Linnaeus, 1758)	
White-backed woodpecker (*Dendrocopos leucotos* Bechstein, 1803)	Siberian flycatcher (*Muscicapa sibirica* J. F. Gmelin, 1789)	
Pale thrush (*Turdus pallidus* J. F. Gmelin, 1789)	Taiga flycatcher (*Ficedula (parva) albicilla* Pallas, 1811)	
Grey-backed thrush (*Turdus hortulorum* Sclater 1863)		
Naumann's thrush (*Turdus naumanni* Temminck, 1820)		
Tree creeper (*Certhia familiaris* Linnaeus, 1758)		
Coal tit (*Parus ater* Linnaeus, 1758)		
Pine bunting (*Emberiza leucocephala* J. F. Gmelin, 1771)		
Chestnut bunting (*Ocyris rutilus* Pallas, 1776)		

Table 6 Algal taxonomic composition in the Oshibochny and Bolshoy Kuyan streams

Phylum	Class	Order	Family	Genus	Species	Species and infraspecific taxa
Cyanobacteria	1	2	2	2	2	2
Bacillariophyta	3	11	19	36	77	82
Heterokontophyta	2	2	2	2	3	3
Charophyta	1	1	1	1	1	1
Chlorophyta	1	1	1	1	1	1
Rhodophyta	1	1	1	1	1	1
Total	9	18	26	43	85	90

Table 7 Species composition of algae in the Oshibochny and Bolshoy Kuyan streams

Taxa[a]	Oshibochny[b]				Bolshoy Kuyan[c]	S[d]	s[e]
	St. 6	St. 2	St. 3	St. 1	St. 4		
Phylum Cyanobacteria Stanier ex Cavalier-Smith							
Class Cyanophyceae Schaffner							
Order Oscillatoriales Cavalier-Smith							
Family Ammatoideaceae Elenkin							
Homoeothrix varians Geitler	-[f]	1	-	1–2	1	χ-β	1.0
Order Oscillatoriales Cavalier-Smith							
Family Phormidiaceae Anagnostidis & Komárek							
Phormidium uncinatum (C. Agardh) Gomont ex Gomont	2	2	-	1–2	-	β	2.1
Bacillariophyta							
Class Coscinodiscophyceae Round & Crawford							
Order Melosirales Crawford							
Family Melosiraceae Kützing, sensu emend							
Melosira varians C. Agardh	-	1	-	2	-	α-β	2.7
Class Fragilariophyceae Round							
Order Fragilariales Silva							
Family Fragilariaceae Greville							
Diatoma hyemalis (Lyngbye) Heiberg	1	-	-	-	2	β-o	1.7
D. mesodon (Ehrenberg) Kützing	4–5	-	3	1	5	χ-β	1.0
D. tenue C. Agardh	-	1	-	-	-	β-α	2.5
D. vulgare Bory	-	-	-	-	1	β	2.4
Fragilaria capucina Desmazières	-	1	1–2	-	1	o-β	1.5
F. rumpens (Kützing) G. W. F. Carlson	-	-	-	1	-	o-β	1.5
F. vaucheriae (Kützing) J.B. Petersen	2	5–6	4–6	5–6	-	o-β	1.5
Hannaea arcus (Ehrenberg) Patrick var. *arcus*	1	1	-	1	1	χ-β	1.0
H. arcus var. *amphioxys* (Rabenhorst) Patrick	-	-	-	1	2	-	-
H. arcus var. *rectus* (Cleve) M. Idei	1–2	2	2–3	2–3	-	χ-β	1.0
Meridion circulare (Greville) C. Agardh var. *circulare*	5	5	3–4	3	5	o-β	1.5
M. circulare var. *constrictum* (Ralfs) Van Heurck	2	3	4	3	-	χ	-
Ulnaria inaequalis (H. Kobayasi) M. Idei	-	1	1	1	-	-	-
U. ulna (Nitzsch) Compère	-	3–4	5	4	2	o-α	1.9
Order Tabellariales Round							
Family Tabellariaceae Kützing							
Tabellaria fenestrata (Lyngbye) Kützing	-	-	-	-	1	χ	0.2
T. flocculosa (Roth) Kützing	1	-	-	1	-	o-α	1.9
Class Bacillariophyceae Haeckel							
Order Eunotiales Silva							
Family Eunotiaceae Kützing							
Eunotia bilunaris (Ehrenberg) Mills	1	-	-	2	1	χ-β	1.0
E. exigua (Brébisson ex Kützing) Rabenhorst	-	-	-	1	-	o-β	1.5
E. implicata Nörpel, Lange-Bertalot & Alles	-	-	-	-	1	–	–
E. incisa W. Smith ex Gregory	-	-	-	1	-	α-β	2.7
E. muscicola Krasske	1	-	-	-	-	-	-
E. praerupta Ehrenberg	1	1	1	1	1	o-α	2.0
Order Cymbellales Mann							
Family Rhoicospheniaceae Topachevskyj and Oksiyuk							
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot	2	-	1	1	1	β-α	-
Family Cymbellaceae Greville							
Brebissonia boeckii (Ehrenberg) E. O'Meara	-	-	-	1	-	-	-

Table 7 (continued)

Taxa[a]	Oshibochny[b]				Bolshoy Kuyan[c]	S[d]	s[e]
	St. 6	St. 2	St. 3	St. 1	St. 4		
Cymbella cistula (Ehrenberg) Kirchner	-	3	4–5	-	2	o	1.2
C. tumida (Brébisson) Van Heurck	-	-	1	-	-	χ	0.2
Cymbopleura naviculiformis (Auerswald) Krammer	-	-	1	1	-	β-o	1.6
Encyonema silesiacum (Bleisch) Mann	4	5–6	6	5–6	5	χ-o	0.5
Family Gomphonemataceae Kützing							
Didymosphenia geminata (Lyngbye) M. Schmidt	-	-	-	1	-	χ	0.0
Gomphoneis olivaceum (Hornemann) Dawson ex Ross and Sims	5	5–6	4–6	5	4	β-α	2.5
G. quadripunctatum (Oestrup) Dawson ex Ross and Sims	2	3	2	2–3	-	-	-
Gomphonema affine Kützing	1	-	1	1	1	o-β	1.5
G. angustatum (Kützing) Rabenhorst	2	4	3–4	2	3	o-α	2.0
G. angustum C. Agardh	1	-	-	1	1	o	1.4
G. aff. *clevei* Fricke	-	-	-	-	1	χ	0.3
G. parvulum (Kützing) Kützing	-	1	-	1	1	χ	0.1
Reimeria sinuata (Gregory) Kociolek and Stoermer	1	2	-	2	-	-	-
Order Achnanthales Silva							
Family Cocconeidaceae Kützing							
Cocconeis placentula Ehrenberg var. *placentula*	1	-	-	-	1	o	1.4
C. placentula var. *euglypta* (Ehrenberg) Grunow	3–4	3	1	2	2	-	-
Family Achnanthidiaceae Mann							
Achnanthidium exiguum (Grunow) Czarnecki	-	-	1	-	-	o-β	1.5
A. minutissimum (Kützing) Czarnecki	1	1	1	2	-	o-β	1.5
Eucocconeis aff. *laevis* (Oestrup) Lange-Bertalot	-	1	-	1	-	o-β	1.5
Planothidium haynaldii (Schaarschmidt) Lange-Bertalot	2	-	-	-	1	-	-
P. lanceolatum (Brébisson ex Kützing) Lange-Bertalot	2–3	-	-	1	-	χ-o	0.5
Order Naviculales Bessey sensu emend.							
Family Diadesmidaceae Mann							
Luticola mutica (Kützing) Mann	-	2	1	1	2	χ-β	1.0
Family Amphipleuraceae Grunow							
Frustulia amphipleuroides (Grunow) Cleve-Euler	-	-	1	-	-	-	-
F. vulgaris (Thwaites) De Toni	-	1	-	-	-	χ-β	0.9
Family Neidiaceae Mereschkowsky							
Neidium bisulcatum (Lagerstedt) Cleve	1	-	-	1	-	o-β	1.5
Family Sellaphoraceae Mereschkowsky							
Sellaphora pupula (Kützing) Mereschkowsky	-	-	-	1	-	β	2.2
Family Pinnulariaceae Mann							
Pinnularia borealis Ehrenberg	1–2	1	-	1	1	o	1.4
P. eifelana Krammer	1	-	-	1	1	-	-
P. microstauron (Ehrenberg) Cleve var. *rostrata* Krammer	-	-	-	-	1	-	-
P. neomajor Krammer	1	-	-	-	-	o-χ	0.6
P. viridiformis Krammer	1	-	-	1	-	-	-
P. viridis (Nitzsch) Ehrenberg	1	-	-	-	-	o	-
Pinnularia sp.	-	-	-	1	-	-	-
Family Diploneidaceae Mann							
Diploneis ovalis (Hilse) Cleve	1	-	-	1	1	o-α	2.0
Family Naviculaceae Kützing							
Caloneis silicula (Ehrenberg) Cleve	1	-	-	-	-	χ	0.3
Chamaepinnularia krookii (Grunow) Lange-Bertalot & Krammer	-	-	-	1	1	-	-
Navicula avenacea (Brébisson and Godey) Brébisson ex Grunow	2	4–5	5	4–5	4	o	1.4

Table 7 (continued)

Taxa[a]	Oshibochny[b]				Bolshoy Kuyan[c]	S[d]	s[e]
	St. 6	St. 2	St. 3	St. 1	St. 4		
N. cryptocephala Kützing	-	1	-	1	-	χ	0.2
N. cryptotenella Lange-Bertalot	1	-	-	1	-	o	1.4
N. radiosa Lange-Bertalot	-	-	-	1	-	o	1.1
N. rhynchocephala Kützing	-	1	1	-	-	β	-
N. slesvicensis Grunow	-	2–3	2	2	-	α-β	-
N. viridula (Kützing) Ehrenberg	-	-	1	-	1	o	1.3
Family Stauroneidaceae Mann							
Stauroneis anceps Ehrenberg	1	-	-	1	1	χ	0.3
Order Thalassiophysales Mann							
Family Catenulaceae Mereschkowsky							
Amphora ovalis (Kützing) Kützing	-	-	1	1	-	β-o	1.65
A. pediculus (Kützing) Grunow ex A. Schmidt	1	-	-	1	-	o	1.4
Order Bacillariales Hendey							
Family Bacillariaceae Ehrenberg							
Hantzschia amphioxys (Ehrenberg) Grunow	2–3	1	1	2	-	β-o	1.7
Nitzschia dissipata (Kützing) Grunow var. *dissipata*	-	4	2	2	22	χ	0.2
N. dissipata var. *media* (Hantzsch) Grunow	-	-	-	1	-	-	-
N. linearis (C. Agardh) W. Smith	1	1	1	1	-	χ	0.0
N. nana Grunow	-	-	-	1	-	α-β	-
N. palea (Kützing) W. Smith	2	5	-	3	-	α-β	2.75
N. vermicularis (Kützing) Hantzsch	-	-	2	-	-	β	2.3
Order Rhopalodiales Mann							
Family Rhopalodiaceae (Karsten) Topachevskyj and Oksiyuk							
Epithemia adnata (Kützing) Brébisson	-	-	1	1	-	β-α	2.5
Order Surirellales Mann							
Family Surirellaceae Kützing							
Surirella angusta Kützing	-	2	2	1	1	o	1.1
S. brebissonii Krammer and Lange-Bertalot var. *kuetzingii* Krammer and Lange-Bertalot	-	1	1	1	-	-	-
S. minuta Brébisson	1	1	3	2–3	2	o-α	-
S. pantocsekii Meister	-	-	-	1	-	-	-
Kingdom Plantae Haeckel							
Phylum Charophyta Cavalier-Smith							
Class Charophyceae Rabenhorst Chlorophyta							
Order Klebsormidiales Stewart and Mattox							
Family Klebsormidiaceae Stewart and Mattox							
Klebsormidium rivulare (Kützing) Morison and Sheath	-	-	-	1	-	o-β	-
Phylum Chlorophyta Pascher Chlorophyta							
Class Ulvophyceae Mattox and Stewart							
Order Ulotrichales Borzi							
Family Ulotrichaceae Kützing							
Ulothrix zonata (Weber and Mohr) Kützing	-	2–3	2	2	-	o	1.1
Phylum Heterokontophyta Moestrup							
Class Chrysophyceae Pascher [=Chrysophyta]							
Order Hydrurales Pascher							
Family Hydruraceae Rostafinsky							
Hydrurus foetidus (Villars) Trevisan	1–2	2	3	3–4	6	χ-o	0.7
Class Xanthophyceae Allorge ex Fritsch [=Xanthophyta]							

Table 7 (continued)

Taxa[a]	Oshibochny[b]				Bolshoy Kuyan[c]	S[d]	s[e]
	St. 6	St. 2	St. 3	St. 1	St. 4		
Order Tribonematales Pascher							
Family Tribonemataceae G. S. West							
Tribonema affine (Kützing) G. S. West	-	-	2	-	-	-	-
T. viride Pascher	-	-	4–5	-	-	o	1.2
Phylum Rhodophyta Wettstein							
Class Florideophyceae Cronquist							
Order Acrochaetiales Feldmann							
Audouinella chalybaea (Roth) Bory [=*Chantransia chalybea* (Roth) Fries]	-	4–5	-	-	-	χ-o	0.5

[a]Korde's (1956) 6-point scale was used to estimate the frequency of taxa occurrence at the stations: 1 – solitary (1–5 cells on the slide); 2 – rare (10–15 cells on the slide); 3 – not infrequent (25–30 cells on the slide); 4 – frequent (1 cell in each row of the cover glass at magnification with immersion); 5 – very frequent (several cells under the same conditions); and 6 – in bulk (several cells in each visual field under the same conditions). [b]*Station 6* source of Oshibochny Stream, *Station 2* middle of Oshibochny Stream, *Station 3* Oshibochny Stream close to the tailing dump area, *Station 1* confluence of the Oshibochny Stream with Somnya River. [c]*Station 4* Bolshoy Kuyan stream. [d]S (relation to saprobity of water): *χ* xenosaprobous, *χ-o* xeno-oligosaprobous, *o-χ* oligo-xenosaprobous; *χ-β* xeno-betamesosaprobous, *o* oligosaprobous, *o-β* oligo-betamesosaprobous; *β-o* beta-oligosaprobous; *o-α* oligo-alphamesosaprobous, *β* betamesosaprobous, *β-α* beta-alphamesosaprobous; *α-β* alpha-betamesosaprobous. [e]*s* the index of saprobity. [f]No data available

Table 8 Algal indicators of saprobity in the Oshibochny and Bolshoy Kuyan streams

Stream (location)	Station no.	Saprobity index (S)	Saprobity zone[b]	Degree of water saprobity[c]	Water purity class[a]
Oshibochny Stream (source)	6	1.41	o	o-β	II
Oshibochny Stream (middle)	2	1.40	o	o-β	II
Oshibochny Stream, (tailing dump area)	3	1.41	o	o-β	II
Oshibochny Stream (confluence of the stream in Somnya River)	1	1.43	o	o-β	II
Bolshoy Kuyan Stream (background station)	4	1.27	o	o	II

[a]Sládeček, V. (1967). [b]*o* oligosaprobous. [c]*o-β* oligo-betamesosaprobous.

these streams were unknown, as only a handful of studies have previously reported the overall distributions of several indicator groups, i.e. aquatic insects, in the tributaries of the Lower Amur Basin. Seventy-six species of mayflies (Order: Ephemeroptera) were recorded in the main Low Amur left-bank tributaries, of which 34 inhabited the Amur River bed (Tiunova and Gorovaya, 2011). Moreover, 66 species of stoneflies (Plecoptera) from 33 genera and 8 families were recorded in the streams and rivers of the Lower Amur Region (Teslenko, 2011). According to the results of macrozoobenthic studies, the total species richness in the 96 main Lower Amur left-bank tributaries was estimated to be 295 invertebrate taxa belonging to five types and nine classes, including chironomids (Diptera, 128), caddisflies (Trichoptera, 62), mayflies (51), and stoneflies (33) (Yavorskaya, 2016).

Our study identified a total of 93 invertebrate taxa of various ranks from 13 groups in the Oshibochny and Bolshoy Kuyan streams (Table 9). Macroinvertebrates were primarily represented by the larvae of stoneflies, mayflies, caddisflies, and Diptera, which are typical for the cold mountain streams in the south of the Russian Far East. Considering species richness, Diptera from the Chironomidae family dominated the list (34 species and groups of species), followed by mayflies (19 taxa), stoneflies, caddisflies, and other dipterans (10 taxa each), crustaceans (3 taxa), beetles, water mites, oligochaetes, nematodes, planaria, and gastropods (1 taxon).

In total, 85 and 41 taxa were identified in the Oshibochny and Bolshoy Kuyan Streams, respectively. This difference in total taxa richness was partly explained by the different numbers of samples collected from the streams. We sampled the Oshibochny Stream at four stations and the Bolshoy Kuyan Stream at one station bordering the mountainous area.

The total taxa richness in the Oshibochny Stream increased from the source to its confluence with the Sonmya River (Table 9), corresponding to the river continuum concept (Vannote et al., 1980). Our sampling and analysis revealed 29, 48, 42, 44, and 41 taxa in the upper reaches of the Oshibochny Stream (St. 6), middle course (St. 2), St. 3, St. 1, and St. 4, respectively. The total taxa richness in the

Table 9 Distribution of invertebrates and water quality in the Oshibochny and Bolshoy Kuyan streams

Taxa	Stations[a]				
	St. 6	St. 2	St. 3	St. 1	St. 4
Plecoptera					
Pictetiella asiatica Zwick and Levanodova	0[b]	1[c]	0	1	1
Arcynopteryx polaris Klapálek	0	0	0	0	1
Megarcys pseudochracea Zhiltzova	1	1	0	1	0
Amphinemura sp.	0	1	1	1	1
Nemoura sp.	1	1	0	1	1
Mesocapnia sp.	1	1	1	1	1
Megarcys sp.	1	1	0	1	1
Suwallia sp.	1	1	0	1	1
Leuctra fusca (Linnaeus)	0	1	0	0	1
Chloroperlidae	0	0	1	0	0
Ephemeroptera					
Drunella aculea Allen	0	0	0	1	0
D. triacantha Tshernova	1	0	0	1	1
D. lepnevae Tshernova	0	0	1	0	0
Ephemerella sp.	1	0	0	1	0
Ephemerella atagosana Imanishi	0	1	0	0	0
E. aurivillii Bengtsson	0	1	0	0	1
Serratella nuda Tshernova	1	1	1	1	1
Cinygmula sp. 1	0	0	0	1	0
Cinygmula sp.	1	0	1	1	1
Cinygmula hirasana Imanishi	1	0	0	0	1
Epeorus sp.	1	0	1	1	0
Iron maculatus (Tshenova)	1	0	1	0	1
I. aesculus (Imanishi)	1	0	0	0	1
Neoleptophlebia japonica (Matsumura)	0	0	0	1	0
Baetis sp.	0	0	0	1	0
Baetis bicaudatus Dodds	1	0	1	0	1
B. pseudothermicus Kluge	0	0	0	0	1
Acentrella sibirica (Kazlauskas)	1	0	0	1	0
Ameletus cedrensis Sinitshenkova	0	0	0	0	1
Trichoptera					
Brachycentrus americanus (Banks)	0	1	1	1	0
Rhyacophila sp. 1	0	1	1	1	1
Rhyacophila egijnica Schmid	0	1	1	1	1
Rhyacophila gr. *sibirica*	1	0	0	0	0
Glossosoma intermedium (Klapálek)	0	1	0	0	0
Anagapetus schmidi (Levanidova)	0	1	1	1	1
Neophylax sp.	0	0	1	0	0
Neophylax ussuriensis (Martynov) (Martynov)	0	1	0	0	1
Apatania sp.	1	0	0	0	0
Micrasema sp.	0	1	0	1	0
Megaloptera					
Sialis sp.	0	1	1	1	0
Diptera					
Chironomidae					
Diamesa tsusuii Tokunaga	0	1	1	1	1
D. gregsoni Edwards	0	0	0	0	1
Pagastia orientalis (Tshernovskij)	0	0	1	0	0

Table 9 (continued)

Taxa	Stations[a]				
	St. 6	St. 2	St. 3	St. 1	St. 4
Pseudodiamesa branickii (Nowicki)	0	0	1	0	0
Cricotopus (*Pseudocricotopus*) *tamadigitalis* Sasa	0	1	1	0	1
Cricotopus (*Isocaldius*) *sylvestris* (Fabricius)	0	0	1	0	0
Limnophyes sp.	0	0	1	0	1
Parametriocnemus boreoalpinus Gouin	0	0	0	0	1
Stilocladius intermedius Wang	0	0	0	0	1
Tvetenia bidzhanica Makarchenko and Makarchenko	1	0	0	0	1
T. tamaflava Sasa	1	0	0	0	0
Tanypodinae indet	0	1	0	0	0
Corynoneura sp.	0	1	0	0	0
Diplocladius cultriger Kieffer	0	1	1	0	0
Eukiefferiella gr. *claripennis*	1	1	1	1	0
Eukiefferiella gr. *brevicalcar*	0	0	1	0	0
Hydrobaenus sp.	0	1	0	0	0
Krenosmittia halvorseni Cranston and Sæther	0	1	0	1	0
Orthocladius (*Euorthocladius*) *rivicola* Kieffer	0	1	1	1	0
Orthocladius (*Euorthocladius*) sp.	1	0	0	0	0
Orthocladius (*Euorthocladius*) *saxosus* (Tokunaga)	0	0	0	1	0
Orthocladius (*Eudactylocladius*) sp.	0	0	1	0	0
Orthocladius (*Mesorthocladius*) *frigidus* (Zetterstedt)	0	1	1	1	0
Orthocladius (*Orthocladius*) aff. *defensus* Makarchenko and Makarchenko	0	0	0	1	0
Orthocladius (*Orthocladius*) *pedestris* Kieffer	0	0	1	1	0
Orthocladius (*Orthocladius*) sp. 1	0	1	1	0	0
Orthocladius (*Orthocladius*) sp. 2	0	0	1	0	0
Parakiefferiella bathophila (Kieffer)	0	1	0	0	0
Parametriocnemus sp.	0	1	0	0	0
Smittia controversa Makarchenko and Makarchenko	0	0	0	1	0
Thienemanniella sp.	1	1	0	1	0
Micropsectra sp.	1	1	1	0	0
Rheotanytarsus pentapodus (Kieffer)	0	1	0	0	0
Rheotanytarsus sp.	1	0	1	1	0
Other Diptera	1	0	0	1	1
Simuliidae	1	1	1	1	1
Limoniidae gen. sp.	0	1	0	0	0
Dicranota sp.	0	1	0	1	1
Pedicia sp.	0	0	1	0	0
Blephariceridae	0	1	1	1	1
Ceratopogonidae	0	0	0	1	1
Empididae	0	1	0	0	0
Phoridae	0	1	0	0	0
Psychodidae	0	1	1	0	0
Coleoptera					
Elmidae	0	1	1	1	1
Crustacea					
Gammarus sp.	1	1	1	1	1
Bathynella sp.	0	0	0	0	1
Ostracoda	1	1	1	0	1
Acarina	1	1	1	1	1

Table 9 (continued)

Taxa	Stations[a]				
	St. 6	St. 2	St. 3	St. 1	St. 4
Oligochaeta	0	1	1	1	1
Nematoda	0	1	1	1	0
Planariidae	0	1	0	0	0
Gastropoda	0	0	0	0	1
Total taxa richness	29	48	42	44	41
EPT[d] taxa richness	17	18	14	22	22
EPT/total taxa richness (%)	58	37	33	50	53
Water quality classification	Good	Fair	Fair	Good–fair	Good–fair

[a]Same as Notes b and c in Table 7. [b]0 denotes the absence of the taxon. [c]1 denotes the presence of the taxon. [d]EPT stands for Ephemeroptera, Plecoptera, and Trichoptera

Oshibochny Stream at St. 3 was attributed to a decrease in the number of stoneflies, i.e. a minimal number of stonefly species (3) were recorded, which serve as indicators in clean mountain streams. Simultaneously, the maximum value of chironomid species richness (17 species) was recorded at this station, possibly owing to a decrease in the diversity of invertebrate fauna sensitive to pollution caused by the mining company. Thus, the species with low resistance to pollution were eliminated. Notably, the total taxa richness at St. 4 in the Bolshoy Kuyan Stream (41) was lower than that in the Oshibochny Stream near the tailing pond, but a significantly large number of stoneflies (8) and mayflies (18) resistant to various types of pollution were observed here.

Further analysis in terms of the EPT/total taxa richness ratio indicated significant differences in the ecological status of stations along the Oshibochny Stream. Station 6, which marked the source of the Oshibochny Stream, was the only station with ‘Good’ water quality. The tailings dump area (St. 3) recorded the smallest ratio (33%), corresponding to ‘Fair’ water quality (Table 9). The negative technogenic impacts of the tailings dump could also be observed in the middle reach of the Oshibochny Stream (St. 2) located upstream of the tailings dump, as the water quality there was also rated as ‘Fair’ despite this location exhibiting the highest total species richness. Water quality in the downstream reach of the Oshibochny Stream, at its confluence with the Sonmya River (St. 1), was assessed as ‘Good–Fair’. Thus, it can be assumed that the invertebrate richness in the lower reaches of the Oshibochny Stream was restored to a certain extent despite anthropogenic impact, or the impact was short-lived or not intense. This is supported by the fact that water quality in the undisturbed reaches of the Bolshoy Kuyan Stream (St. 4) was also categorised as ‘Good–Fair’.

The biomass levels of invertebrate communities in the Oshibochny and Bolshoy Kuyan streams ranged from 4.97 to 17.32 g/m^2 (Table 10), corresponding to the values expected in cold, mountain streams (Levanidov, 1981; Tiunova et al., 2007; Tiunova et al., 2010). The maximum biomass value (17.32 g/m^2) was recorded at the Bolshoy Kuyan Stream (St. 4), where the larvae of mayflies, caddisflies, chironomids, and gammarids comprised significant proportions of the total biomass (Table 10). The number of invertebrates increased from the source to the mouth of the Oshibochny Stream, with biomass varying from 4.97 to 10.05 g/m^2 in the upper reaches (St. 6) and the mouth (St. 1), respectively (Table 10). Moreover, the anthropogenic impact of the tailings dump located near the Oshibochny Stream (St. 3) led to not only a reduced number of aquatic insects, which act as bioindicators, but also noticeable changes in the community structure.

The upper reaches of the Oshibochny Stream (St. 6) were characterised by undisturbed biotopes, the maximum density of mayflies (43.7%), of which the larvae of *Baetis bicaudatus* and *Cinygmula hirasana* were the most numerous, and a community structure dominated by chironomids and *Gammarus* sp. (Table 11). Moreover, results for the middle reach of the Oshibochny Stream evidenced the impact of the tailings dump as a potential pollution source at St. 2, where chironomids from the subfamily Orthocladiinae displaced the mayfly as the dominant category, while caddisflies (mainly *Anagapetus schmidi* and *Brachycentrus* sp.) occupied the subdominant position. According to sampling results, the community structure at St. 3 significantly differed from that at other stations, with prevalence of chironomids over other invertebrates, i.e. chironomid density exceeded 96% of the total community. In the lower reaches of the Oshibochny Stream (St. 1), water quality improved relative to that at St. 2 and St. 3, which were situated upstream. However, chironomids still dominated (76%) at this location, while *Gammarus* sp. was a subdominant group. Compared to the community structure in the upper reaches of the Oshibochny stream (St. 6), that of the undisturbed Bolshoy Kuyan Stream (St. 4) revealed similar trends in the dominance of mayflies (*B. bicaudatus*) and chironomids. Contrastingly, chironomid density (53.6%) was higher than mayfly density (33.6%) at this station.

Table 10 Biomass (B, g/m^2) and density (N, ind./m^2) of invertebrates in the Oshibochny and Bolshoy Kuyan streams

Taxa	St. 6[a]		St. 2		St. 3		St. 1		St. 4	
	N[b]	B[c]	N	B	N	B	N	B	N	B
Ephemeroptera	833	1.88	144	0.35	182	1.30	307	0.24	2,898	2.04
Plecoptera	69	1.35	305	0.22	34	0.004	302	0.54	230	0.80
Trichoptera	38	0.16	1,149	2.97	103	0.62	504	2.30	254	2.53
Chironomidae	357	0.05	7,040	0.68	21,752	3.07	9,733	0.53	4,617	7.40
Simuliidae	106	0.30	99	0.013	48	0.07	233	0.12	55	0.03
Other Diptera	14	0.01	56	0.05	175	0.19	38	0.07	22	0.03
Megaloptera	0[d]	0	41	0.91	3	0.02	7	0.003	0	0
Gammaridae	350	1.21	309	1.72	14	0.003	1,684	6.08	511	4.48
Ostracoda	99	0.001	41	0.001	17	0.000	0	0	10	0.001
Coleoptera (larvae)	0	0	89	0.01	21	0.02	21	0.001	7	0.002
Oligochaeta	0	0	0	0.07	0	0.08	0	0.16	0	0.001
Nematoda	0	0	161	0.001	62	0.001	3	0.000	0	0
Planariidae	0	0	3	0.05	0	0	0	0	0	0
Acarina	41	0.008	377	0.03	106	0.03	27	0.003	14	0.005
Gastropoda	0	0	0	0	0	0	0	0	3	0.001
Total	1,907	4.97	9,814	7.08	22,517	5.41	12,858	10.05	8,621	17.32

[a]Same as Notes b and c in Table 7. [b]Density (units: individuals/m^2). [c]Biomass (units: g/m^2). [d]0 denotes the absence of the taxon

Table 11 Density of invertebrates in the Oshibochny and Bolshoy Kuyan streams

Taxa	St. 6[a]	St. 2	St. 3	St. 1	St. 4
	N[b] (%)	***N*** (%)	***N*** (%)	***N*** (%)	***N*** (%)
Ephemeroptera	**43.68**[c]	1.47	0.81	2.39	**33.62**
Plecoptera	3.62	3.11	0.15	2.35	2.67
Trichoptera	1.99	11.71	0.46	3.92	2.95
Chironomidae	**18.72**	**71.73**	**96.60**	**75.70**	**53.56**
Simuliidae	5.56	1.01	0.21	1.81	0.64
Other Diptera	0.73	0.57	0.78	0.30	0.26
Gammaridae	**18.35**	3.15	0.06	13.10	5.93
Others	7.34	7.28	0.93	0.44	0.39

[a]Same as Notes b and c in Table 7. [b]N denotes density. [c]Dominant groups marked in bold

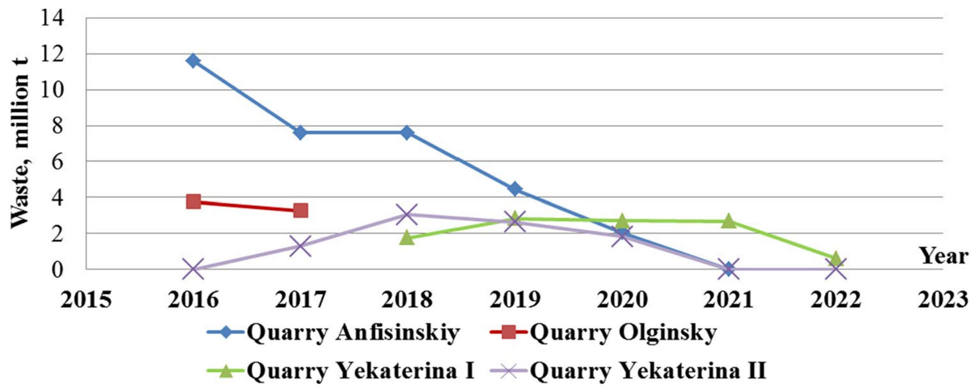
Therefore, invertebrate community structures in both streams revealed a range of 18.7−96.6% for chironomid dominance, with the maximum value being observed in the area affected by tailings in the Oshibochny Stream. The natural seasonal density fluctuations and the timing of mass flights are important for the interpretation of this chironomid metric. High chironomid quantities in July are associated with their abundance before mass flights. Regarding the undisturbed biotopes in the Oshibochny Stream (St. 6) and the Bolshoy Kuyan Stream (St. 4), chironomid larvae abundance was accompanied by a good representation of the EPT complex. The Oshibochny Stream area affected by the tailings dump (St. 3) showed an increase in chironomid dominance alongside a decrease in EPT representatives in the invertebrate community, which resulted not only from the natural flight period of the chironomids, but also the influence of potential pollution sources.

Environmental remediation activities

Strict compliance with environmental protection measures during mining development in the Albazinsky area will significantly reduce the damage caused to the ecosphere (Fig. 5). Using the collected ecological information, we successfully produced a novel 'Map of the Ecological State of Gold Mining Development in the Albazino Territory' (scale, 1:200,000), showing the areas affected by mining operations as well as the different degrees of ecological stress. The forecast change of forested areas (74.3%) in technogenic facilities (territory of mining allocation) was made using the forest cover index of the P. Osipenko District, Khabarovsky Krai, and the area covered with forest. The developed map showed that the mining activity impacts on several ecosystem components do not exceed the standards provided by the current legislation. However, given the significant extent of land degradation, conducting timely reclamation is necessary.

This should be done using novel but proven approaches, such as bioremediation (e.g. Krupskaya et al. (2015) issued by the Federal Institute of Industrial Property, Russia) and the implementation of ecological monitoring for ecosphere changes.

Fig. 5 Mining waste stockpiled in the Anfisinskiy and Olginsky dumps and from the Yekaterina I and Yekaterina II allotments



Conclusions

This study revealed the status of the ecosystem impacted by the development in the Albazinsky gold ore deposit (southern part of the Russian Far East). Soil experiments revealed some extent of degradation; however, in overall terms, the soil status in the studied area can be considered as 'satisfactory', probably due to the short period of mining activity at the Albazinsky gold ore deposit at this time.

In ecological terms, the Oshibochny and Bolshoy Kuyan streams were in good condition, as the extent of pollution was low and the waters were clean at the time of this study. Their S values ranged from 1.27 to 1.43, and the waters were categorised as belonging to the oligosaprobic zone of self-purification (class II water quality). However, additional observations and monitoring at St. 3 (in the tailings dump area) are recommended.

The tailings dump near the Oshibochny Stream acts as a source of pollution. Although the corresponding water quality was 'Fair', the lowest value of EPT/total taxa richness was observed at this station. The negative technogenic impact of the tailings dump can also be traced in the community structure, which was significantly different from those at the other stations, given the almost complete prevalence (> 96%) of chironomids over other invertebrates, while species less resistant to pollution were almost eliminated. As the downstream water quality of the Oshibochny Stream was assessed as 'Good–Fair', it appears that the invertebrate community tends to recover from anthropogenic impacts, or the influence of the pollution was short-term and/or not intense. However, habitat restoration for vertebrates, i.e. birds, mammals, and partially cold-blooded amphibians and reptiles, appears to be less intensive. The limitation for our study was the observed decrease in the reproductive period of birds.

Based on the above results, we successfully produced a novel 'Map of the Ecological State of Gold Mining Development in the Albazino Territory' (scale, 1:200,000). We also provided recommendations for decreasing the negative impacts of the mining activities on the environment. A new method for reclamation of tailings has been proposed, in which phototrophic bacteria are used as a bioactivator, which helps to reduce the negative impact of toxic waste on the environment and increase the efficiency of recultivation (Krupskaya et al. 2015). To suppress dust on the surface of tailings, we have experimentally developed a composition that includes biochar, adsorbents in the form of zeolites, and humic acids (Krupskaya et al. 2018). In 2019, a composition for dust suppression and reclamation of the tailings surface was developed (Krupskaya et al., 2019), containing biochar, zeolites and biohumus obtained from spent blocks of oyster mushroom (Pleurotus ostreatus). Technogenic components are represented by ore processing waste. The technical result consists in reducing the negative impact of toxic waste from mineral processing on the objects of the ecosphere and ensuring their environmental safety, as well as the possibility of using them in biological reclamation. Given that a significant area of the land surface has undergone degradation, establishing and implementing stringent environmental monitoring in the area is crucial. We recommend developing a research programme for 2021−2023 to study the technogenic pollution from the tailings dumps and other facilities, to plan for the ecologically safe processing of mineral wastes from mining activities.

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Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflict of interest The authors declare no competing interests.

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