



# Migration of mercury in the food chains of the Beloosipovo biocenosis (part 1)

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## Abstract:

**Introduction.** Mercury and its compounds are among the most dangerous toxic substances, which makes mercury pollution one of the most urgent environmental issues. The present research objective was to study the accumulation of mercury and its impact on the terrestrial ecosystems in the area of the Beloosipovo mercury deposit (Kemerovo Region, West Siberia, Russia).

**Study objects and methods.** The study used standard methods to test soil, herbs, herpetobiont insects, and small mammals. The sampling was conducted at 13 points in the cardinal directions at 0.5, 1.5, and 3.0 km from the pollution source. The method of atomic absorption was employed to measure the concentration of mercury in the samples prepared by the wet mineralization method.

**Results and discussion.** The main components of terrestrial ecosystems revealed no excessive concentration of mercury in the soil. However, the water samples from the Belaya Osipova river demonstrated an excess in the maximum permissible concentration of mercury from 5 to 20% (0.00056–0.00074 mg/L). Further up the food chains, the concentration of mercury in organisms decreased by 1–2 orders of magnitude, depending on the sampling point. The study also revealed Siberian trout lily (*Erythronium sibiricum* (Fisch. et C. A. Mey) Kryl.), which is protected at the federal and regional levels, as well as several nemoral tertiary relics.

**Conclusion.** The decreasing concentration of mercury in the food chains means the ecosystem is under no severe negative impact.

**Keywords:** Ecology, mercury, mercury-containing compounds, terrestrial ecosystems, food chains

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## INTRODUCTION

Mercury is an important safety issue in the environmental, medical, and social aspects. In fact, mercury-related issues are one of the most urgent contemporary challenges. Mercury (Hg) and mercury-containing compounds are toxic substances that pose danger to all living organisms. According to preliminary estimates, about 4700 tons of mercury is discharged worldwide every year [1–3]. Mercury-related water pollution is especially dangerous, since water-soluble toxic methylmercury [CH<sub>3</sub>Hg] accumulates in the fish as a result of activity of sediment microorganisms.

Mercury affects land and water plants, animals, fungi, and microorganisms, which constantly interact with each other in food chains, symbiosis, and etc. [4]. Many studies recognize the essential role of terrestrial plants in the biogeochemical cycle of mercury [5–7]. For instance, Leonard *et al.* tested five plant species

for absorption, distribution, and subsequent release of mercury into the atmosphere, namely *Lepidium latifolium* L., *Artemisia douglasiana* Bessin Hook, *Caulanthus* sp. Watson, *Fragaria vesca* L., and *Eucalyptus globulus* Labill [8]. The research featured various ecological and physiological profiles of plants in a mercury-contaminated area. In the arid ecosystem, mercury emissions proved dominant in the mercury cycle, while plants functioned as channels for the interphase transfer of mercury from the geosphere to the atmosphere.

Asati *et al.* also examined the effect of heavy metals, including mercury, on plants and their metabolic activity in areas with high anthropogenic pressure [9]. Heavy metals appeared to have a severe toxic effect on plants, animals, and other local living organisms. Jameer Ahammad *et al.* claimed that even low concentrations of mercury has a negative effect on plants, e.g. stunted growth and many other adverse consequences [10].

High levels of mercury in soil demonstrated various adverse effects on plant growth and metabolism, e.g. poor photosynthesis, transpiration, water absorption, chlorophyll synthesis, and high lipid peroxidation [11–15].

In plants, a high content of mercury affects most enzymes. Zhou *et al.* studied the global database for about 35 000 measurements of mercury [16]. They examined the distribution and absorption of mercury in deciduous and coniferous ecosystems. The scientists believe that an effective monitoring of the impact of vegetation on the global mercury cycle requires a better parameterization of models and more consistent observational data, while recording the exchange of mercury in the entire ecosystem is especially important.

Obrist *et al.* investigated the role of sedimentation in the global cycle of mercury [17, 18]. The precipitation of mercury compounds occurs all year round. However, it is much higher in summer because the metal is absorbed by vegetation. Absorption of gaseous mercury by the tundra increases its concentration in the soil. The authors predict an increase in the impact of mercury on various ecosystems and human life, which requires further multifaceted research.

Ranieri *et al.* discovered that phytoextraction is an effective and affordable technological solution for the removal of metals, including mercury, from contaminated soil and water [19]. Jiskra *et al.* confirmed the severe effect of mercury isotopes on mercury absorption by vegetation [20]. Greger *et al.* studied six plant species that translocate and release mercury into the air [21]. They used a transpiration chamber to monitor the absorption of mercury by the roots, its further distribution over the shoots, and the final release through the shoots. The research featured garden peas, spring wheat, sugar beets, oilseed rape, white clover, and willow. All the plants were able to absorb significant amounts of mercury from its nutrient solution (200 µg/L). However, the translocation to the shoots was rather low (0.17–2.50 %).

Juillerat *et al.* examined soil and ground litter in 15 locations covered by northern deciduous trees or mixed deciduous and coniferous forests [22]. Their research objective was to determine how mercury content depended on the tree species, forest type, and soil profile. Twelve tree species from two sites demonstrated significant differences. The research proved that the peculiarities of a particular territory are important for mercury studies. The differences in the mercury pools from ground litter correlated with the differences in carbon pools.

These global issues are relevant for Russia and the Kemerovo Region. Komov *et al.* studied the content of mercury in soil, water sediments, and animals on the banks of the Rybinsk Reservoir [23]. The recorded mercury concentrations varied by more than two orders of magnitude. As for aquatic invertebrates, the concentration of metal appeared to be high in heterotopic species: larvae and adult insects had 0.85 mg

of mercury per 1 kg of dry weight. However, homotopic species had a lower concentration of mercury, e.g. for mollusks, it was 0.11 mg per 1 kg of wet weight. As for predatory arachnids, aquatic and semi-aquatic species proved to have higher concentrations of mercury: for hydrocarina, it was  $\leq 0.68$ , and for raft spiders, it was  $\leq 0.33$  mg per 1 kg of dry weight. On the contrary, spiders that lived far from water sources revealed much lower concentrations of mercury: crab spiders  $\leq 0.07$  mg per 1 kg of dry weight. Creatures that feed on vegetation or phytophagous animals also demonstrated lower mercury concentrations.

Gremyachikh *et al.* studied the content of mercury in the muscle tissue of river perch fished in different areas of the Rybinsk Reservoir in 1997–2012 and registered an increase in mercury concentration in recent decades [24].

Gorbunov *et al.* assessed the increase in mercury in the tissues of fish caught in the Volga [25]. They focused on how the accumulation of mercury in the muscle tissues of perch, bream, and pike depended on the mass of fish. The research registered a directly proportional dependence for perch (correlation coefficient  $r = 0.881$ ,  $p = 0.018$ ) and an inversely proportional relationship for pike ( $r = -0.653$ ,  $p = 0.029$ ). For bream, no such dependence was revealed.

Komov *et al.* studied the content of mercury in five species of amphibians and seven species of leeches [26]. The average values for amphibians were 0.007–0.101, for leeches – 0.014–0.065 mg per 1 kg of wet weight. The concentration of mercury depended on the taxonomy, habitat, and tissue type. The experiment established some consequences of the alimentary mercury intake on several biological parameters, i.e. metamorphosis rate of toad larvae, behavior pattern of tadpoles of frogs and leeches, etc. The results delivered new data on the mechanisms of migration and distribution of mercury compounds in aquatic, near-water, and terrestrial ecosystems.

Golovanov *et al.* studied *in vivo* the effect of accumulated mercury on the maltase and amylolytic activity of glycosidases in tadpoles of the common toad (*Bufo bufo* L.) [27]. The research revealed changes in the activity of glycosidases depending on the level of accumulated mercury and the timing. The activity of the glycosidases decreased, whereas the sensitivity of starch-hydrolyzing enzymes to heavy metal ions (Cu, Zn, Cd, and Pb) increased.

The physicochemical properties of mercury allow it to circulate, accumulate, and redistribute in environment, depending on the particular conditions of aquatic and terrestrial ecosystems. Most of the mercury is dispersed and creates a natural global geochemical background, superimposed on man-induced mercury pollution, thus forming areas of antropogenic pollution.

Until recently, the accumulation of mercury by hydrobionts attracted most scientific attention because aquatic environment is optimal for the formation of

the most toxic organomercury compounds. Methylated mercury compounds accumulate in living organisms more intensively than inorganic ones and are slowly to excrete. As a result, the transport of mercury along the food chain is faster than in cases of direct absorption of the metal from the environment.

The content of mercury in living organisms increases at the tops of food webs and reaches maximal values in predatory fish, fish-eating birds, and mammals.

Terrestrial ecosystems attract less attention regarding the issues of mercury accumulation and distribution. More research is needed to establish the accumulation patterns of mercury compounds by living organisms in terrestrial ecosystems. The best way to establish the patterns is to determine the level of mercury accumulation in organisms of different trophic groups.

The present research objective was to study the mercury accumulation and its effect on various components of terrestrial ecosystems near the Beloosipovo mercury deposit (Kemerovo region, Russia).

#### STUDY OBJECTS AND METHODS

The research featured such components of the terrestrial ecosystem as soil, herbaceous plants, herpetobiont insects, and small mammals harvested in the vicinity of the Beloosipovo mercury deposit in the Kemerovo region, Russia (55.196730 N, 86.970065 E).

The sampling involved standard methods. Regardless of the wind pattern, all samples were taken at four cardinal points (Fig. 1) at three radii:

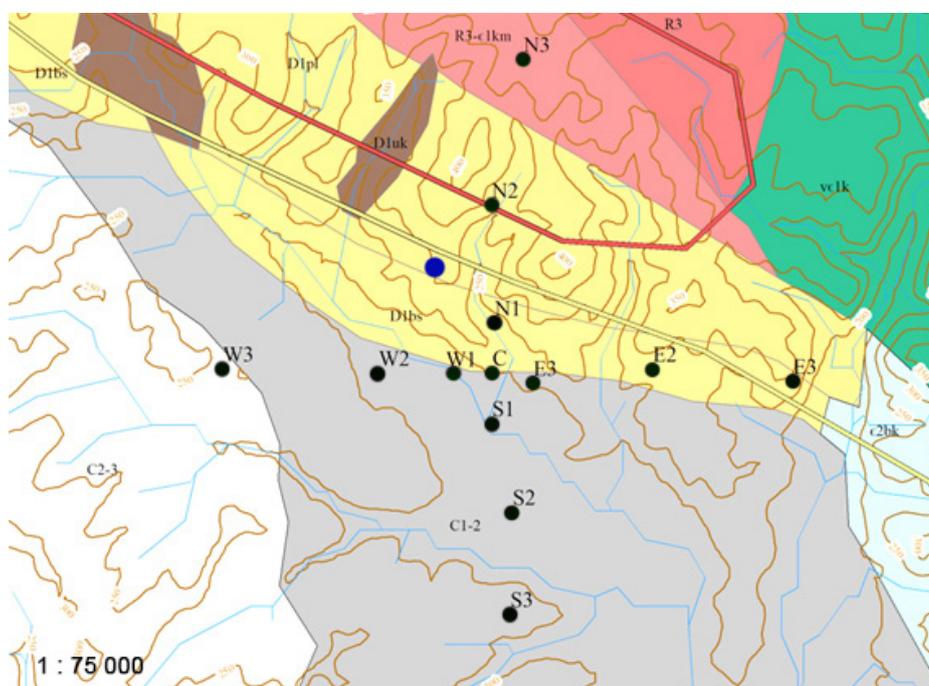
- 1) 0.5 km from the pollution source;
- 2) 1.5 km from the pollution source;
- 3) 3.0 km from the pollution source.

The sampling points:

- Point 0 (Control) – N 55°10.920', E 087°00.959'
- Point North 1 (N1) – N 55°11.180', E 087°00.980'
- Point North 2 (N2) – N 55°11.798', E 087°00.954'
- Point North 3 (N3) – N 55°12.561', E 087°01.244'
- Point South 1 (S1) – N 55°10.654', E 087°00.958'
- Point South 2 (S2) – N 55°10.189', E 087°01.146'
- Point South 3 (S3) – N 55°09.654', E 087°01.123'
- Point West 1 (W1) – N 55°10.915', E 087°00.605'
- Point West 2 (W2) – N 55°10.918', E 086°59.920'
- Point West 3 (W3) – N 55°10.940', E 086°58.496'
- Point East 1 (E1) – N 55°10.866', E 087°01.333'
- Point East 2 (E2) – N 55°10.939', E 087°02.427'
- Point East 3 (E3) – N 55°10.876', E 087°03.705'

The territory of the Beloosipovo mine was considered as the main source of pollution and marked as Point 0 (C).

The control sampling was carried out at N 55°13.291', E 086°35.294'. It was located more than 30 km away from the Beloosipovo mercury deposit, which means it had no effect whatsoever on the background indicators. The soil sampling followed State Standards R 56157-2014 and State Standards 17.4.3.01-2017 using the



**Figure 1** Sampling points and boundaries of mercury zones of the Beloosipovo deposit

Legend:

- – sampling points;
- – adit entrance;
- (red line) – border of the Beloosipovo mercury deposit;
- (yellow line) – border of the Pezass-Beloosipovo mercury ore-bearing zone.

envelope method at a depth of 0–20 cm and 30–60 cm. The total sampling weight was  $\geq 2$  kg. The soil samples were put in separate plastic containers and labeled.

The eight herb samples were taken in the same areas as the soil samples. The combined sample wet weight was  $\geq 2$  kg (natural moisture). The plants were removed together with the rhizomes, which were thoroughly cleared of soil. The samples were placed in plastic bags and labeled.

Invertebrates are the main link by which mercury from the environment enters the organisms of vertebrates. Herpetobiont insects inhabit the soil surface and are widespread in terrestrial ecosystems. They play an important role in food and soil chains.

The main group of herpetobiontic insects was represented by four families of Coleoptera (*Coleoptera* L.): dung beetles (*Geotrupidae* L.), lamellar beetles (*Scarabaeidae* L.), ground beetles (*Carabidae* L.), and istafilinids (*Staphylinidae* L.)

The herpetobiont insects were caught using Barber’s traps. At one point, 50 traps with a volume of 0.3 l were dug in one line at a distance of 1 m from each other. The traps contained 5% acetic acid solution. The insects collected at each point were packed into containers, labeled, and stored in an automobile refrigerator at  $-4^{\circ}\text{C}$ .

The small mammals were represented by insectivores (*Eulipotyphla* L.) and rodents (*Rodentia* L.). They were caught using crushers. At each point, 50 crushers were installed at a distance of 1 m from each other. The captured animals were placed in plastic containers, labeled, and stored in a car refrigerator.

The species composition of the mammals:

**Byinsectivores (*Eulipotyphla*)**

*Shrews (Soricidae L.):*

- Common shrew (*Sorex araneus* L.);
- Even-toothed shrew (*Sorex isodon* L.);
- Pygmy shrew (*Sorex minutus* L.);
- Masked shrew (*Sorex caecutiens* L.);
- Water shrew (*Neomys fodiens* L.).

**Rodents (*Rodentia*)**

*Hamsters (Cricetidae L.):*

- Red-backed vole (*Clethrionomys rutilus* L);
- Grey-sided vole (*Clethrionomys rufocanus* L.);
- Bank vole (*Clethrionomys glareolus* L.);
- Root vole (*Microtu oeconomus* L.);
- Common field vole (*Microtus agrestis* L.).

*Mice (Muridae L.):*

- Field mouse (*Apodemus agrarius* L.);
- Jerboa mouse (*Dipodidae* L.);
- Birch mouse (*Sicista betulina* L.).

The sampling of water in the Belaya Osipova river was carried out 0.5–1.0 km above the mouth (Fig. 2) in five replicates in 2018–2021. The samples were poured into two-liter vessels and were delivered to the laboratory within no more than 18 h from the moment of water intake.

The concentration of mercury in soil, plants, herpetobiont insects, and small mammals was carried out in an accredited laboratory of the Kemerovo State University (Russia). The tests followed Federal Environmental standard PNDF 16.1.2:2.2.80-2013 (M 03-09-2013) “Quantitative chemical analysis of soils. Methods for measuring the mass fraction of total mercury in samples of soils and grounds, including greenhouses, clays, and bottom sediments, by the atomic absorption method using a mercury analyzer RA-915M.”

The samples were prepared using wet mineralization and concentrated nitric acid, hydrochloric acid, and hydrogen peroxide. The samples were dried to obtain biosubstrates in an EKPS-10 electric chamber furnace at  $520^{\circ}\text{C}$ . The obtained white ash was used to determine the content of mercury.

The method for measuring the mass fraction of total mercury involved thermal decomposition accompanied by the atomization of mercury. After that, the atomic mercury was transferred to the analytical cell of the analyzer by air flow. The atomic absorption

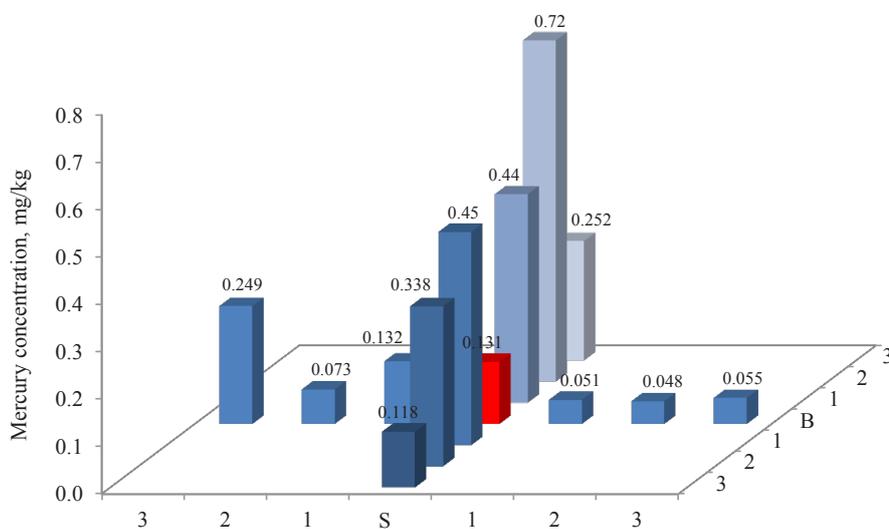


Figure 2 Concentration of mercury in the soil (horizon – 0–20 cm) in the area of the Beloosipovo mercury deposit

of mercury was measured at a resonant wavelength of 253.7 nm. The mass fraction of mercury in the sample was automatically determined by the peak area value (analytical signal). The process was based on the preset calibration characteristic using the software for the analyzer (RAPID software). The calibration was carried out using standard samples of a solution of mercury ions. It involved a calibration sample that contained mercury adsorbed on activated carbon.

## RESULTS AND DISCUSSION

According to the e-catalog of geological documents from the Russian Federal Geological Fund, the mercury deposit of 124 tons is located in the river basin of the Belaya Osipova. The ore-bearing mineral is cinnabar (HgS). Mineralization is extremely uneven, and areas of high concentration are replaced by barren ones. The deposit has a hydrothermal low-temperature origin and is confined to the zone of deep and echelon faults. The study area has manifestations and mineralization points, as well as placer and geochemical aureoles of mercury.

The deposit was developed in 1969–1975. A small plant extracted mercury from ore by evaporation. No exact information on the volume of mined mercury is available; according to unofficial data, it mined only several tens of tons.

The area under study is covered by black forests of Siberian fir (*Abies sibirica* Ledeb.), Aspen (*Populus tremula* L.), birch (*Betula pubescens* Ehrh., *Betula pendula* Roth), and tall grasses, which can reach three meters in height.

The lush undergrowth is represented by such shrubs as goat willow (*Salix caprea* L.), cranberry bush (*Viburnum opulus* L.), pea shrub (*Caragana arborescens* Lam.), Siberian mountain ash (*Sorbus sibirica* Hedl.), and bird cherry (*Padus avium* Mill.). Some areas have scarce undergrowth.

The most typical herbaceous plant species are melancholy thistle (*Cirsium heterophyllum* (L.) Hill.), millet grass (*Milium effusum* L.), dissected hogweed (*Heracleum dissectum* Ledeb.), wild chervil (*Anthriscus sylvestris* (L.) L.), Siberian cacalia (*Crepis sibirica* L.), northern wolfsbane (*Aconitum septentrionale* Koelle), black meadowsweet (*Filipendula ulmaria* (L.) Maxim.), Siberian globeflower (*Trollius asiaticus* L.), giant fescue (*Festuca gigantea* (L.) Vill.), etc.

The area has a big population of large ferns, which often dominate the herbaceous cover: adderspit (*Pteridium aquilinum* (L.) Kuhn.), male shield fern (*Dryopteris filix-mas* (L.) Schott), female fern (*Athyrium filix femina* (L.) Roth), and ostrich fern (*Matteuccias truthiopteris* (L.) Tod.).

Nemoral tertiary relics are represented by alfredia (*Alfredia cernua* (L.) Cass.), giant fescue (*F. gigantea* (L.) Vill.), whitespot betony (*Stachys sylvatica* L.), male shield fern (*D. filix-mas* (L.) Schott), sweet woodruff (*Galium odoratum* (L.) Scop.), and slender false brome (*Brachypodium sylvaticum* (Huds.) Beauv.).

The area is dominated by forest phytocenoses, mostly tall-grass forests with a forest stand of birches, aspens, and firs (2Os3B5P): drooping birch (*B. pendula* Roth.), Siberian fir (*A. sibirica* Ledeb.), aspen (*Populus tremula* L.), and Siberian spruce (*Picea obovata* Ledeb.). Siberian fir and silver birch have a good seed reproduction; as a result, the forest canopy is rich in fir undergrowth, while the open areas demonstrate a thick population of young birches. The average diameter of the birch is  $\leq 40$  cm, the average height is 25 m. The average diameter of the fir is  $\leq 30$ –40 cm, the height is 28–30 m. The average diameter of the aspen is 40–50 cm, the height is about 30 m, and the crown density can reach 0.7–0.8.

The composition of the forest stand differs in the ratio of fir, aspen, and birch: birch-fir-aspen, fir-aspen, or aspen-fir with a few birches, while some areas are entirely fir or birch forests. Some areas have a rich undergrowth: goat willow (*S. caprea* L.), cranberry bush (*V. opulus* L.), pea shrub (*C. arborescens* Lam.), red raspberry (*Rubusidaeus* L.), Siberian mountain ash (*S. sibirica* Hedl.), downy currant (*Ribes spicatum* Robson.), black currant (*Ribes nigrum* L.), and bird cherry (*Padusavium* Mill.).

In the open and birch-dominated areas, raspberries grow in lush thickets. Some forest parts have a steeply-sloping terrain with areas of higher moisture, where willow thickets proliferate. Willow patches and fir- or aspen-predominated areas also host vines, usually represented by wild hop (*Humulus lupulus* L.).

The grass stand is represented by tall grasses. The projective cover is over 85%. The maximal height of the grass stand can reach 3.5 m in cases of alfredia or hogweed, while the average height is 1.5 m. The list of tall grasses includes: melancholy thistle (*C. heterophyllum* (L.) Hill.), millet grass (*M. effusum* L.), northern wolfsbane (*A. septentrionale* Koelle), dissected hogweed (*H. dissectum* Ledeb.), meadow rue (*Thalictrum minus* L.), golden thoroughwax (*Bupleurum aureum* Fisch. ex Hoffm.), great nettle (*Urtica dioica* L.) wild chervil (*A. sylvestris* (L.) Hoffm.), meadowsweet (*F. ulmaria* (L.) Maxim.), cacalia (*Cacalia hastata* L.), and Siberian hawk's beard (*C. sibirica* L.). In some places, especially those dominated by fir trees, the thickets are formed almost entirely by nettle, infested by dodder (*Cuscuta* sp.).

Other perennial herbs also play a significant role in the composition of the phytocenosis: alfredia (*A. cernua* (L.) Cass.), four-leaved Paris herb (*Parisqua drifolia* L.), wood geranium (*Geranium sylvaticum* L.), Dahurian chickweed (*Cerastium davuricum* Fisch. ex Spreng.), Bunge chickweed (*Stellaria bungeana* Fenzl.), wood sorrel (*Oxalis cetosella* L.), Siberian globeflower (*T. asiaticus* L.), wild leek (*Allium microdictyon* Prokh.), lungwort (*Pulmonaria mollis* Wulf. ex Hornem), spurge (*Euphorbia pillosa* L.), touch-me-not (*Impatiens nolitangere* L.), Urals peony (*Paeonia anomala* L.), northern bedstraw (*Galium boreale* L.), sedge (*Carex macroura* Meins.), Greek-valerian polemonium (*Polemonium*

*caeruleum* L.), violet (*Violauni flora* L.), whitespot betony (*S. sylvatica* L.), and snakeflower (*Lamium album* L.).

Ferns make up part of some grass stand areas: female fern (*Athyrium filix-femina* (L.) Roth), adderspit (*P. aquilinum* (L.) Kuhn.), ostrich fern (*Matteuccia struthiopteris* (L.) Tod.), and male shield fern (*D. filix-mas* (L.) Schott). Adderspit and ostrich grow in thickets.

The herbaceous layer also includes species from the spring synusia, which have completed their growing season (*Corydalis*, *Anemone* s. L., etc.), including Siberian trout lily (*Erythronium sibiricum* (Fisch. et C. A. Mey) Kryl.). This flower is endemic to the Altai-Sayan ecoregion and is protected by the federal and regional law.

Herb-dominated patches appear in some open spaces, depending on the moisture and some other factors. They form tall-grass-grassland patches, grass meadows, and motley grass-grasses associations.

The tall-grass-grassland meadows consist of the same species as the herb layer in the forest: melancholy thistle (*C. heterophyllum* (L.) Hill.), northern wolfsbane (*A. septentrionale* Koelle), dissected hogweed (*H. dissectum* Ledeb.), meadow rue (*T. minus* L.), golden thoroughwax (*Bupleurum aureum* Fisch. hastata L.), wild chervil (*C. sibirica* L.), wild leek (*A. microdictyon* Prokh.), soft lungwort (*P. mollis* Wulf. ex Hornem), spurge (*E. pillosa* L.), etc.

The grass meadows and motley grass-grasses associations develop on sunlit and warm areas, e.g. forest edges. Some species grow both in the forest and in the open, e.g. meadow rue (*T. minus* L.), golden thoroughwax (*B. aureum* Fisch. ex Hoffm.), wild chervil (*Anthriscus cussylvestris* (L.) Hoffm.), meadowsweet (*F. ulmaria* (L.) Maxim.), cock's-foot (*Dactylis glomerata* L.), bluegrass (*Poa* sp.), timothy grass (*Phleum pratense* L.), common tansy (*Tanacetum*

*vulgare* L.), lousewort (*Pedicularis incarnata* L.), bladder campion (*Oberna behen* (L.) Ikonn.), etc. More humid areas are home to other kinds of bluegrass (*Poa remota* Forsell.), water forget-me-not (*Myosotis palustris* (L.), white hellebore (*Veratrum lobelianum* Bernh.), Siberian globeflower (*T. asiaticus* L.), buttercup (*Ranunculus* sp.), marsh orchid (*Dactylorhiza* sp.), wood bulrush (*Scirpus sylvaticus* L.), clump speedwell (*Veronica longifolia* L.), groundsel (*Senecio* sp.), etc.

Many meadows are gradually overgrowing with willow and birch. Willow thickets predominate in the floodplain of the river and represented by goat willow (*S. caprea* L.), woollytwig willow (*Salix dasyclados* Wimm.), basket willow (*Salixvim inalis* L.), almond-leaved willow (*Salix triandra* L.), etc. The list of herbs that proliferate in the willow patches includes fireweed (*Chamerion angustifolium* (L.) Holub), wood horsetail (*Equisetumsyl viaticum* L.), common loosestrife (*Lysim achiavulgaris* L.), sedge (*Carex* sp.), etc.

In addition to willow thickets, floodplain meadows are also widespread along the river banks, where grain grass prevails, e.g. smallweed (*Calamagrostis* sp.), cock's-foot, timothy grass, etc. The floodplain areas also include white hellebore (*V. lobelianum* Bernh.), sorrel (*Rumex* sp.), marsh orchid (*Dactylorhiza* sp.), wood reed (*S. sylvaticus* L.), clump speedwell (*V. longifolia* L.), ragged robin (*Coccyganthe flos-cuculi* (L.), dissected hogweed (*H. dissectum* Ledeb.), marsh cress (*Rorippapalustris* (L.) Bess.), lousewort (*Scrophularia* sp.), scouring horsetail (*Equisetum hiemale* L.), sedge (*Carex* sp.), common loosestrife (*L. achiavulgaris* L.) angelica (*Archangelica decurrens* Ledeb.), and coltsfoot (*Tussilago farfara* L.). Angelica grows in lush thickets. Birch and bird cherry also grow on the floodplain meadows.

In shallow water, there are thickets of butterbur (*Petasites radiatus* (J.F. Gmel.) J. Toman) and rush flower (*Butomusum bellatus* L.).

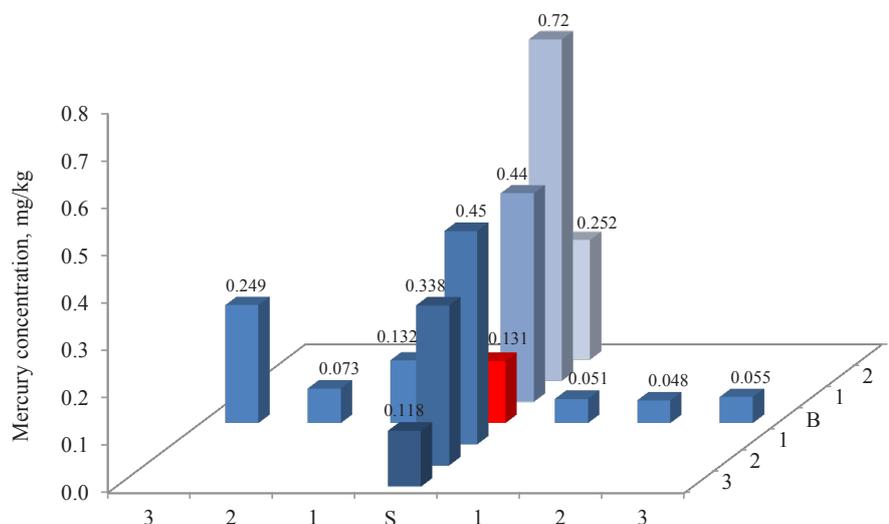
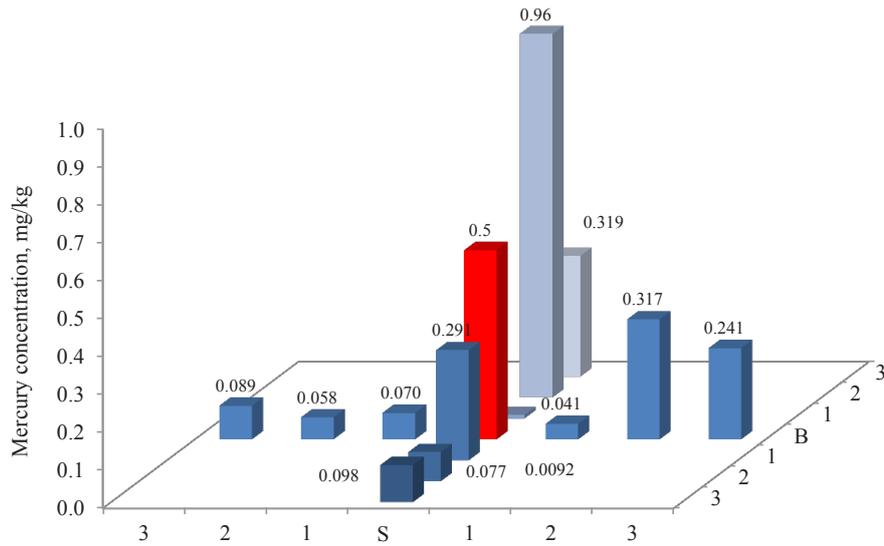
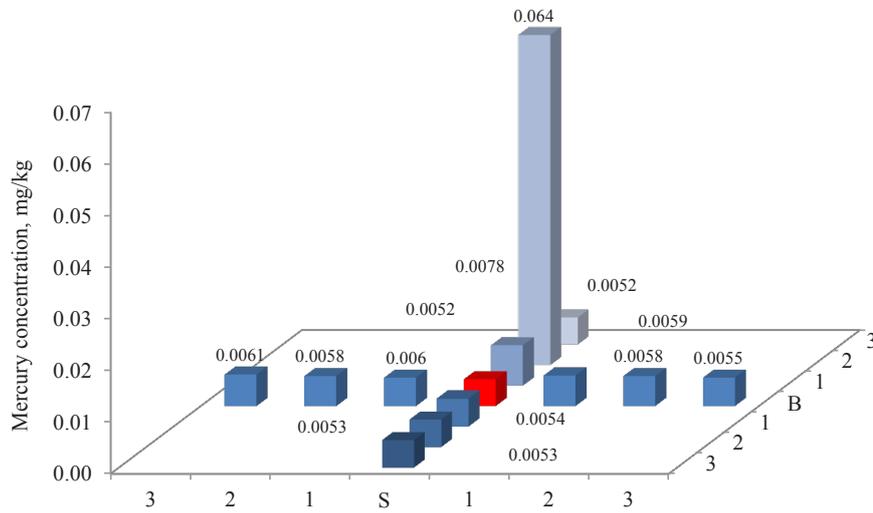


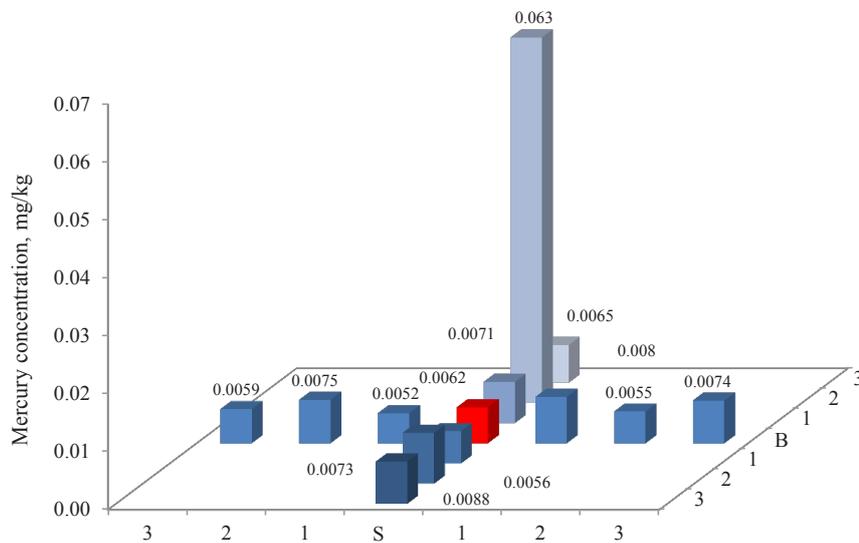
Figure 3 Concentration of mercury in the soil (horizon – 0–20 cm) in the area of the Beloosipovo mercury deposit



**Figure 4** Concentration of mercury in soil (horizon – 30–60 cm) in the area of the Beloosipovo deposit



**Figure 5** Concentration of mercury in plants in the area of the Beloosipovo deposit



**Figure 6** Concentration of mercury in herpetobiont insects in the area of the Beloosipovo deposit

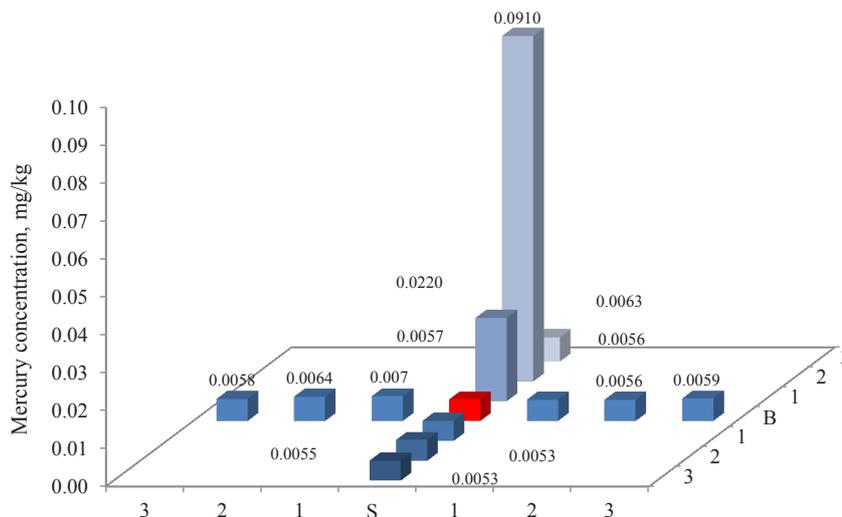


Figure 7 Concentration of mercury in rodents in the area of the Beloosipovo deposit

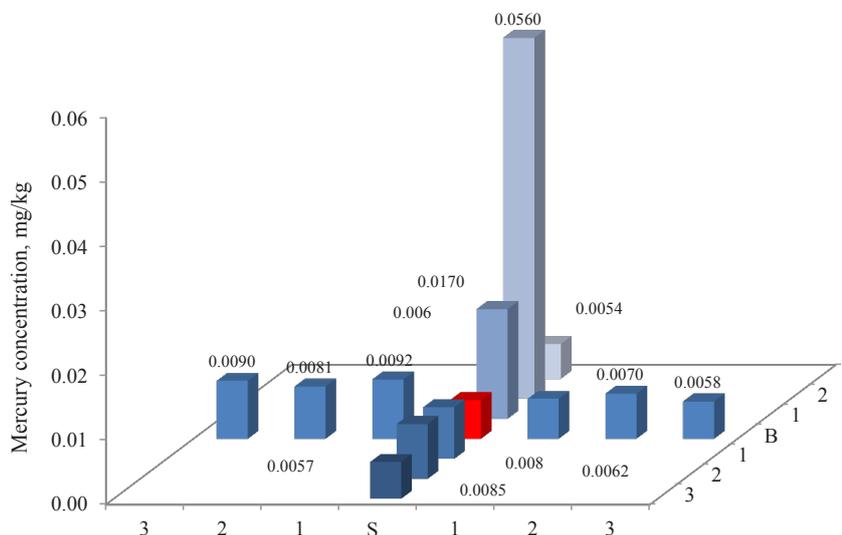


Figure 8 Concentration of mercury in insectivores in the area of the Beloosipovo deposit

Therefore, the study area boasts a significant biological diversity. In addition, it is home to a species protected at the federal and regional levels, namely Siberian trout lily (*E. sibiricum* (Fisch. Et C. A. Mey) Kryl.) and several nemoral tertiary relics, such as alfredia (*A. cernua* (L.) Cass.), giant fescue (*F. gigantea* (L.) Vill.), whitespot betony (*S. sylvatica* L.), male shield fern (*D. filix-mas* (L.) Schott), and slender false brome (*B. sylvaticum* (Huds.) Beauv.). No invasive species were registered.

Figures 3–8 demonstrate the mercury concentration in soil, plants, insects, and small mammals near the Beloosipovo mercury deposit and in the control zone. The highest concentration of mercury was observed at point North 2 (N 2), which was located at 1.5 km north of the deposit: in soil – 0.72 mg/kg and 0.96 mg/kg, in plants – 0.064 mg/kg, in insects – 0.063 mg/kg,

in rodents – 0.091 mg/kg, and in insectivores – 0.056 mg/kg.

According to regulatory documents, the maximal permissible concentration of mercury in soil is 2.1 mg/kg. As the maximal value in the soil samples was 0.96 mg/kg, it means that no dangerous concentration of mercury was detected. However, the e-catalog of geological documents specifies the average concentration of mercury in the soils of the Kemerovo Region at the level 0.16–0.22 mg/kg [28]. Thus, the concentrations of mercury in the soil near the Beloosipovo mercury deposit proved to be by 3–4 times higher than the average values, despite the fact that the mine was closed more than 40 years ago.

The high concentration of mercury in the samples taken the north was presumably related to the terrain peculiarities: the altitude decreases from north to south,

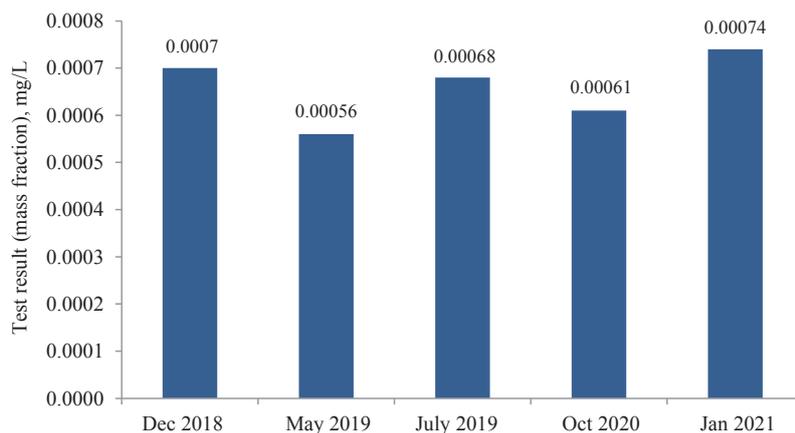


Figure 9 Concentration of mercury in the Belaya Osipova river

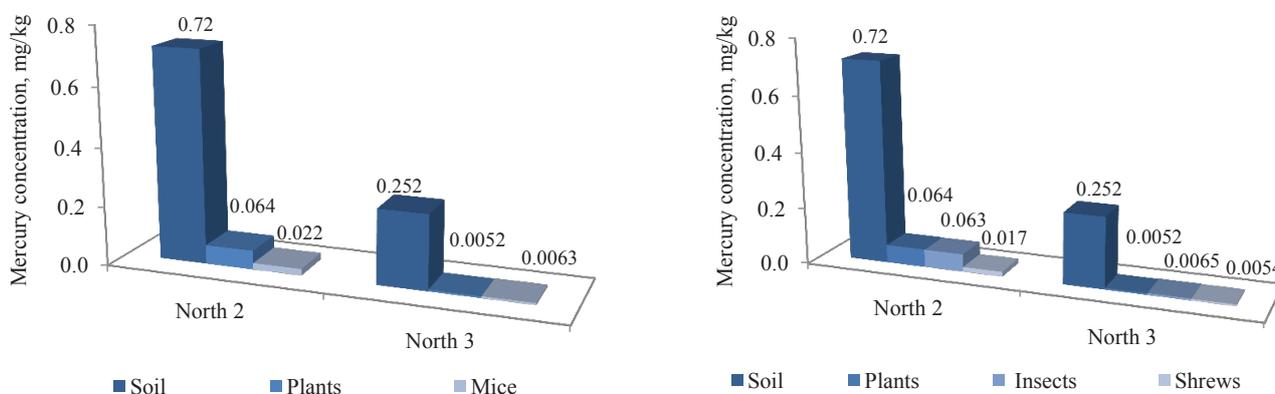


Figure 10 Changes in the concentration of mercury along the food chains

dropping from 407 to 214 m. Points North 2 (N 2) and North 3 (N3) were located directly in the deposit zone, while point North 1 (N 1) was on the borderline.

As for the control point, the concentration of mercury in all components of the ecosystem was much lower than in the area under analysis: in soil and small mammals, it was lower by 1–3 orders of magnitude; in plants and herpetobiontic insects – by 2–4 times.

While the soil samples demonstrated a permissible concentration of mercury, the samples from the Belaya Osipova river exceeded the permissible value (Fig. 9). The maximal permissible concentration of mercury for water bodies is 0.0005 mg/L. In the Belaya Osipova (2018–2021), the concentration exceeded the permissible value by 5–20% and reached 0.00056–0.00074 mg/L.

The high content of mercury in the Belaya Osipova may be associated with the Beloosipovo mercury deposit: mercury compounds might be washed out by groundwater and surface spring floods. Further studies require additional tests of the water biocenosis, which will be one of the tasks of subsequent research.

The concentration of heavy metals is believed to increase up the food chains. To test this presumption, we compared the concentration of mercury in the food

chains at points North 2 (N 2) and North 3 (N3) with the highest mercury concentration in the soil. However, it was the soil samples that demonstrated the highest concentration of mercury, and further up the food chains its concentration dropped by one or two orders of magnitude, depending on the collection point (Fig. 10). The greatest drop was observed at North 2, where the concentration of mercury in the soil was the highest: from 0.72 to 0.022 mg/kg in the soil – plants – mice chain and from 0.72 to 0.017 mg/kg in the soil – plants – insects – shrews chain.

### CONCLUSION

The mercury concentration in the soil near the Beloosipovo mercury deposit did not exceed the maximal permissible concentrations. The maximal mercury concentration in the soil was 0.96 mg/kg while the permissible value is 2.1 mg/kg. In the control zone, the research registered a decrease in the mercury concentration by 1–3 orders of magnitude for individual components of the terrestrial ecosystem, namely soil and small mammals. However, the water samples from the Belaya Osipova exceeded the maximal permissible

concentration by 5–20% in 2018–2021, which means that mercury compounds may go with groundwater and surface spring floods.

The detected mercury concentrations proved to produce no negative effect on the ecosystem, which was confirmed by the rich biological diversity. The area is home to the critically endangered species of Siberian trout lily (*Erythronium sibiricum* (Fisch. et C.A. Mey) Kryl.) and several nemoral tertiary relics, such as alfredia (*Alfredia cernua* (L.) Cass.), giant fescue (*Festuca gigantea* (L.) Vill.), whitespot betony (*Stachys sylvatica* L.), male shield fern (*Dryopteris filix-mas* (L.) Schott), and slender false brome (*Brachypodium*

*sylvaticum* (Huds.) Beauv.). The research revealed no invasive species.

The mercury content decreased up the food chains, which means that the Beloosipovo mercury deposit has no negative impact on the local ecosystems.

The present article is the first part of a series of related publications. Further publications will feature the impact of technogenic centers on the local ecosystem and its individual representatives.

#### CONFLICT OF INTEREST

The authors declare no conflict of interests regarding the publication of this article.

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