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An Ecotoxicological Survey of Tributaries of the Selenge River, Mongolia, August 2010

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An ecotoxicological survey of tributaries of the Selenge river, Mongolia, August 2010

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Abstract

The biodiversity of the Selenga river basin and the receiving waters of the lake Baikal, are among the greatest in the world with over 1,700 known endemic species of plants and animals. Mining activities along the Selenga river and its tributaries pose a major threat of chemical contamination, potentially reducing habitat quality and suitability for aquatic species. Moreover, the Selenga river serves as a major water source for the lake Baikal. Little information exists on the chemical contaminant concentrations in the Selenga river basin. Thus, the objectives of our study were to evaluate the concentrations of metals in soil, sediment, and fish in the Selenga. The concentrations of the metals were then compared to thresholds for toxicity to aquatic organisms. We sampled at 16 locations in the Tuul, Selbe, Khangal, Boro, Orkhon, and Selenge rivers in Mongolia in 2010. Concentrations of copper, chromium, nickel, lead and mercury were above predicted thresholds for toxicity at selected locations; however, most metals were below threshold values at the majority of stations sampled. Copper concentrations were elevated in sediments from the river Khangal downstream of Erdenet, Mongolia. Boro river sediments, at a location downstream from historic gold mining operations contained elevated concentrations of arsenic, lead, nickel, and mercury. Fish from this location also contained mercury at concentrations hazardous to both the fish and predators, including humans. The river Selbe in Ulaanbaatar had sediments with elevated concentrations of lead and zinc. The concentrations of metals in soil, and sediments from the Selenga and its tributaries in Mongolia were largely below thresholds for toxicity to fish and aquatic invertebrates. A few exceptions existed in which the concentrations of selected metals would pose a threat to aquatic fauna and potentially biodiversity in those regions.

Key words: rivers, heavy metals, mercury, water, bottom sediments, soils, fish

Introduction

The river Selenga and its tributaries are the major rivers contributing to the drainage basin providing source water to the lake Baikal, Russia. The predominant portion of the river Selenga drainage basin is situated on the territory of Mongolia. This territory abounds in gold deposits. In Mongolia, 1083 goldfields are known to exist, while 419 of these mines are actively mined according to license contracts (SHIRAPOVA & TSYRENDORZIEVA 2010).

The mining industry is one of Mongolia's most important industries when it comes to the country's economy. Gold and copper, as well as coal, fluorite, iron ore, tin, uranium, and even a small amount of oil are just a few of the natural minerals that this country has to offer (MINING & MANUFACTURING 2008).

The presence of alluvial gold in the Selenga river basin and the extraction of those resources using amalgamation methodology (STECKLING et al. 2011), suggests the release of mercury into the environment may occur in this region. Mercury contamination of the environment in gold mining areas of other parts of the world have been well documented (TELMER 2008). Accumulation of mercury in the biota, including fish of gold mining regions, has led to exposure concerns for top predatory species in those ecosystems such as fish-eating wildlife and humans. However, no comprehensive investigations of mercury contamination in the aquatic ecosystems of the Selenga river basin have been conducted. In particular, we are not aware of any studies in the Selenga river which evaluate metal accumulation in fish muscle (the terminal link in the trophic chain) from gold mining portions of the basin. Therefore, the objectives of our research study were: 1) to measure the mercury content of muscle tissue from fish collected in various gold mining and non-gold mining areas within the Selenga river basin of Mongolia; and 2) to measure metals in soil and sediment samples at key locations along the tributaries of the Selenga river in Mongolia.

Materials and methods

All samples were collected at 16 locations along tributaries of the Selenga, Mongolia, during the period from 24.08 to 01.09.2010 (fig. 1). Sub-surface soil and sediment samples were collect at each location in triplicate. The samples were placed in plastic containers for transport to a laboratory in Ulaanbataar, operated by the Joint Mongolian-Russian Expedition. The samples were dried at 100 °C overnight and then sieved through a 2 mm stainless steel sieve. Analysis of the dried samples was done by XRF according to specifications of the manufacturer (Niton model 794 XLt, Thermo Scientific Instruments, Waltham, MA, USA) while on-site, and later by ICPMS in Columbia, Missouri according to the previously described methods (BRUMBAUGH & MAY 2008).

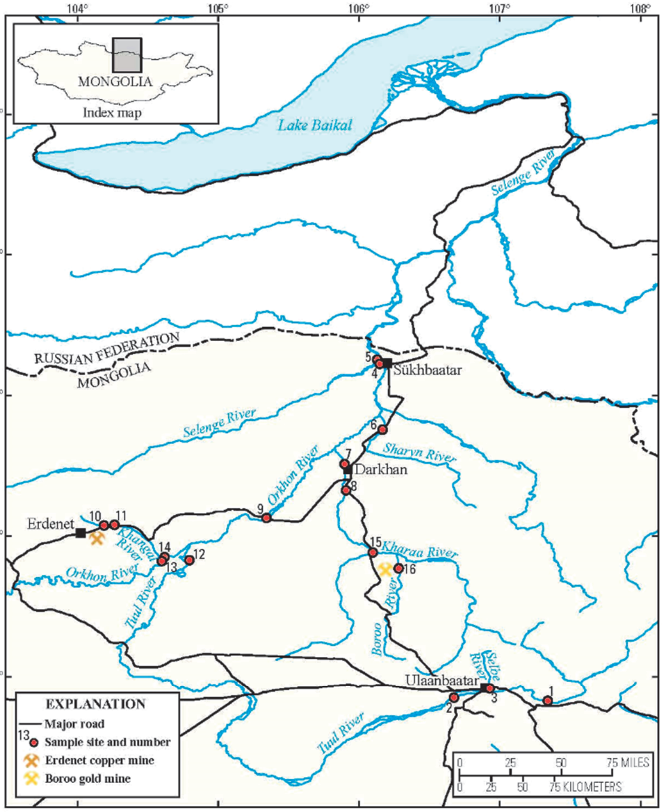

Fig. 1: Sample collection locations along the tributaries of the river Selenga, Mongolia.

Dace (*Leuciscus leuciscus*, L.) were collected from 10 locations on five tributaries of the Selenga, Mongolia during the same period. Totally 89 fish were collected and analyzed. Col-lections were made with hand nets (cast nets). Individual fish mass and length were recorded for each fish and muscle samples were taken from the dorsal portion of the fish. Samples were initially air-dried in the field and then they were dried in a thermostatically controlled oven at a temperature up to 40 °C. The dried muscle samples were then kept refrigerated until further processing for mercury analysis. The measurement of mercury content in fish muscles tissue was conducted using atomic absorption spectroscopy (Mer-cury Analyzer RA-915+ with PIRO-915+ device, Lumex) at I.D. Papanin Institute of Bio-logy of Inland Waters (IBIW), Russian Academy of Science (RAS), Borok, Russia.

Methodological control of data has been carried out using the certified biological material, Dorm-II (shark muscles) with the standard metal content taken from Institute of Environmental Chemistry, Canada [NRCC, 1993]. The determination of mercury in fish muscles in fresh or frozen samples was not possible due to logistical reasons. Since water makes up 80 % of muscle weight, the reported mercury concentration in samples is approximately five times greater than when the mercury content is normalized to fresh weight (HAINES et al. 1992). Values in this report are given on dry weight basis.

Mercury content in the fish were organized by collection site and presented as mean values with standard errors (x ± se), if not specified otherwise. Statistical treatment was done by analysis of variance (ANOVA, LSD-test) with significance level $p \leq 0.05$ (SOKAL & ROHLF 1995).

Results

Concentrations of metals in the sediment samples and soils were relatively low in most locations. But there were three sites with exceptions which contained elevated concentrations of metals in the soil and sediment (see fig. 4). The soil and sediment samples collected at the site on the Selbe river (in Ulaanbaatar), site 3, contained elevated concentrations of zinc and lead. The sites 10 and 11 along the Khangal river, just downstream from Erdenet contained copper at concentrations that were much greater than any of the other locations on the Selenga river tributaries, and indeed were greater than toxicity thresholds established for copper to protect freshwater aquatic invertebrates and fish (MacDONALD et al. 2000). The other site that contained metal concentrations in soil and sediment samples that exceeded other locations, as well as safe levels, were the samples from site 16 on the Boroo river. Samples from site 16 contained elevated arsenic and mercury. Here the values were higher than in any of the other sites we sampled.

The concentrations of mercury in fish muscle from all the locations varied over a wide range; the difference between minimal and maximal values were more than an order of magnitude. The lowest concentrations of mercury (0.20 mg/kg of dry weight, which is 0.04 mg/kg of wet weight) were observed in the muscle tissues of dace from station 6 (Sharyn river, see table 1, fig. 2). The highest concentrations (2.99 mg/kg of dry weight or 0.6 mg/kg of wet weight) were found in the muscle tissues of fish from Station 16 (Boroo river, see table 1, fig. 2).

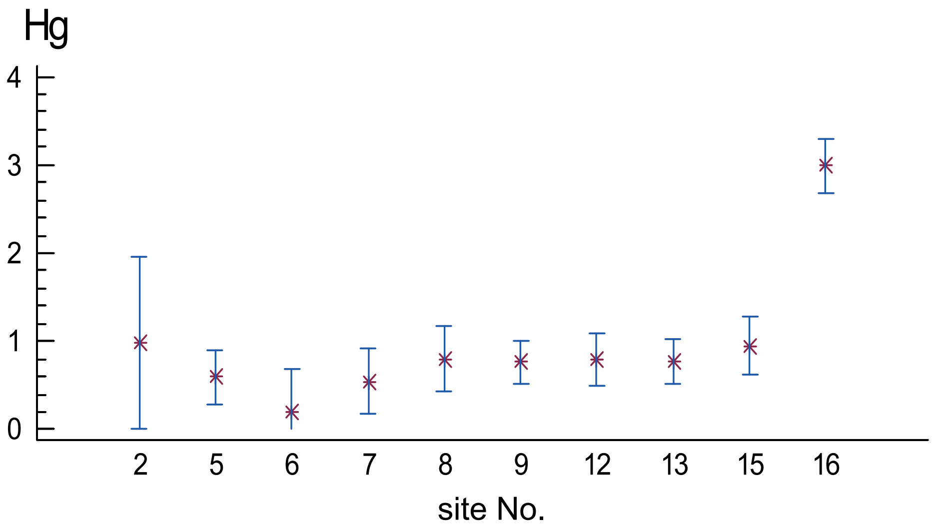

Fig: 2: Mercury content (Hg mg/kg dw) in muscle of dace (*Leuciscus leuciscus, L.*) collected from tributaries of the Selenga River. Mean values and confidence intervals are presented.

The mercury content in the muscle tissue of dace caught in the upper river reaches of the Selenga river tributaries were higher than in the lower reaches. This pattern is expressed more in the fish from the rivers Boroo, Kharaa, Tuul, and observed to a lesser extent in the fish from the Orkhon river. As a rule, the mercury concentration in muscles showed a positive correlation with fish length (fig. 3). This correlation of mercury concentrations and fish length was most apparent in dace from the Boroo River, but the correlation was not significant, and absent in dace from the river Kharaa.

Table 1: Mercury content (mg/kg, dw) in muscles and Total Length (mm) of Dace (*Leuciscus leuciscus, L.*) collected in the Selenga river tributaries, Mongolia, 2010. Mean and standard deviations are presented, followed by the number of replicate samples (n).

Site No.	Hg (mg/kg, dw)	total length (mm)
Tuul		
2	0.98 (1)	160
12	0.79 ± 0.21 0.54–1.05 (11)	135 ± 15 70-205
Orkhon		
13	0.77 ± _0.19 0.25–1.47 (14)	136 ± ±13 70-210
9	0.76 ± 0.17 0.4–1.33 (16)	121 ± 13 60-200
5	0.60±0.22 0.45–0.76 (10)	160 ± ±16 100-210
Boroo		
16	2.99 ± 0.22 0.89–8.03 (10)	160 ± 4 145-180
Kharaa		
15	0.95 ± 0.23 0.73-1.41 (9)	109 ± 7 90-145
8	0.80 ± 0.26 0.68–1.15 (7)	114 ± 14 90-180
7	0.55 ± 0.26 0.36–0.91 (7)	114 ± 17 65-180
Sharyn		
6	0.20 ± 0.34 0.15-0.25 (4)	

The correlation between fish length and mercury concentration was significant for fish taken from the Tuul and Orkhon rivers (fig. 3). No statistically significant correlations were observed between mercury concentrations in fish muscles and water quality characteristics (pH, dissolved oxygen content, electro conductivity) were shown (data not presented).

Discussion

The concentrations of metals in soil and sediment samples were near background concentrations in most of the sites along the tributaries of the river Selenga. The three exceptions were observed in situations that were not unexpected.

The city of Ulaanbaatar, the capital of Mongolia, is the largest urban centre in the country with a population of approximately 1.2 million people. The Selbe river runs through the centre of the city and elevated concentrations of zinc and lead are consistent with the urban setting and pollution common to larger cities. Chromium in sediments was elevated at two locations, the Tuul river downstream of Ulaanbaatar and in the river Selenga before the confluence with the Orkhon river. These values should be confirmed with further sampling and analysis.

The Erdenet copper-molybdenum mine (upstream from sites 10 and 11) is one of the largest in the world, producing one-half a million metric tons of copper annually, along with two thousand metric tons of molybdenum (GANBOLD et al. 2006). Copper concentrations were 700-900 mg/kg (dry weight).

Copper concentrations were 700-900 mg/kg (dry weight) in the sediment collected from the Khangal river just downstream from the mining operations, a factor of 70-fold greater than observed median values from other locations along the Selenga river tributaries in this study. The concentrations of copper in the soils and sediments of the Khangal river at these locations were well above established toxicity thresholds for freshwater aquatic invertebrates and fish (MacDONALD et al. 2000).

The Boroo river is in the vicinity of the Boroo gold mine. Concentrations of mercury in the sediments collected from site 16 on the Boroo river contained an average of 2.5 mg/kg (dry weight). The elevated concentration of mercury in these sediments is consistent with historical amalgamation gold recovery methods, which used liquid mercury. The concentration of mercury observed in fish from this site was also elevated compared to concentrations for other locations (fig. 2); again, consistent with the elevated sediment concentrations of mercury found at this site. Another metal that was above background concentrations in sediments from the site 16 on the Boroo river was that of arsenic. The observed sediment concentrations of arsenic, 45 mg/kg (dry wt.), are below thresholds considered to be ecologically relevant for toxicity to freshwater aquatic organisms.

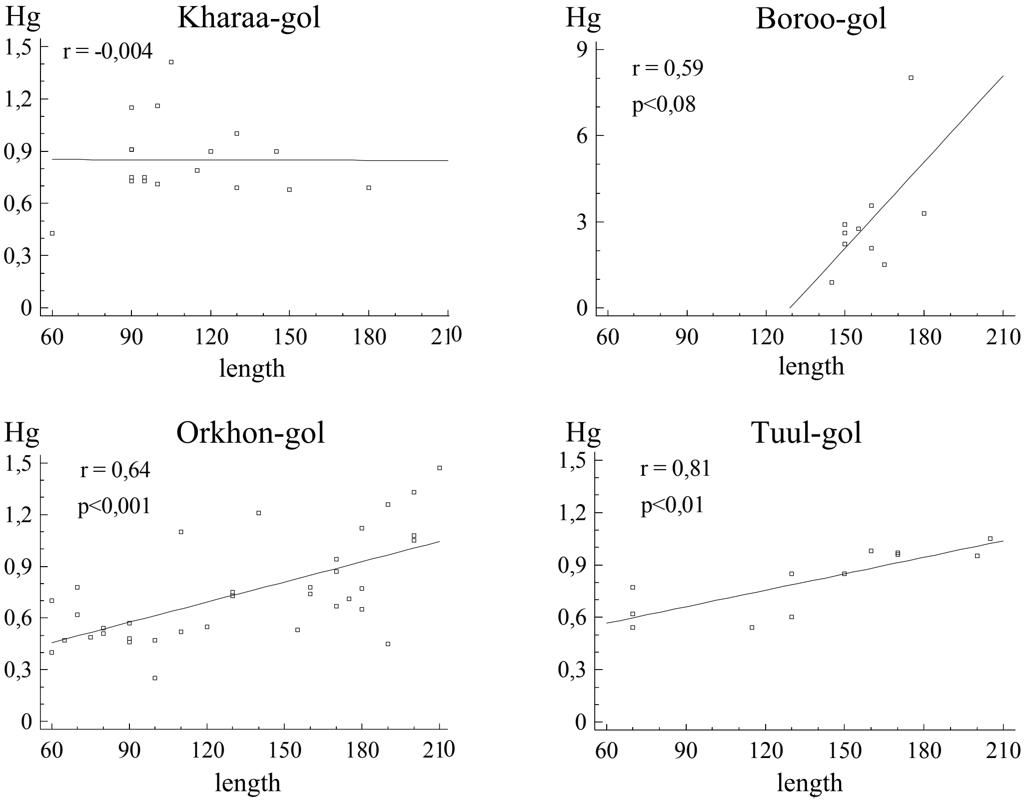

Fig. 3: Relationship between total length (mm) and mercury content (Hg, mg/kg, dw) of dace (*Leuciscus leuciscus, L.*) collected in tributaries of the river, Mongolia in 2010. Correlation coefficient and significance (p value) are presented for each collection location.

The mercury content in muscles of dace from the Mongolian rivers we studied is comparable to that measured in fish from the Russian water bodies, which are not experiencing heavy anthropogenic influences, such as industry or mining. Thus, in muscle of perch (a predator) with the masses up to 20 g from the various reaches of Rybinsk Reservoir (Russia), the mercury concentration does not exceed 0.20 mg/kg of dry weight, up to 20-200 g – 0.85 mg/kg of dry weight, up to 200-600 g – 2.30 mg/kg of dry weight (KOMOV & STEPANOVA 2001). The mercury content in muscle of non-predatory species (roach) from the Rybinsk Reservoir does not exceed 0.20 mg/kg dry weight. Similar levels of mercury accumulation are typical for the fish from rivers and reservoirs of Central Vietnam (LOBUS et al. 2011).

In the muscle of fish from all the stations (except Station 16, Boroo river) the mercury concentrations were lower than concentrations observed in the muscle of perch from acidic lakes situated in the upland bogs of Darvin (2.80 - 4.65 mg/kg of dry weight) and Rdeysky (2.35 - 3.50 mg/kg of dry weight) natural reserves in the European part of Russia (HAINES et al. 1992). Atmospheric precipitation is the only source of mercury to the ecosystems of these lakes. Mercury concentrations, which are anomalously low for the waterlogged territories (0.1 - 0.3 mg/kg of dry weight), were detected in the muscle of fish (including predators) from the delta of an African river (BLACK et al. 2011). Similar low concentrations were detected only in the muscle of fish from Station 6 (Sharyn river) in this study (table 1).

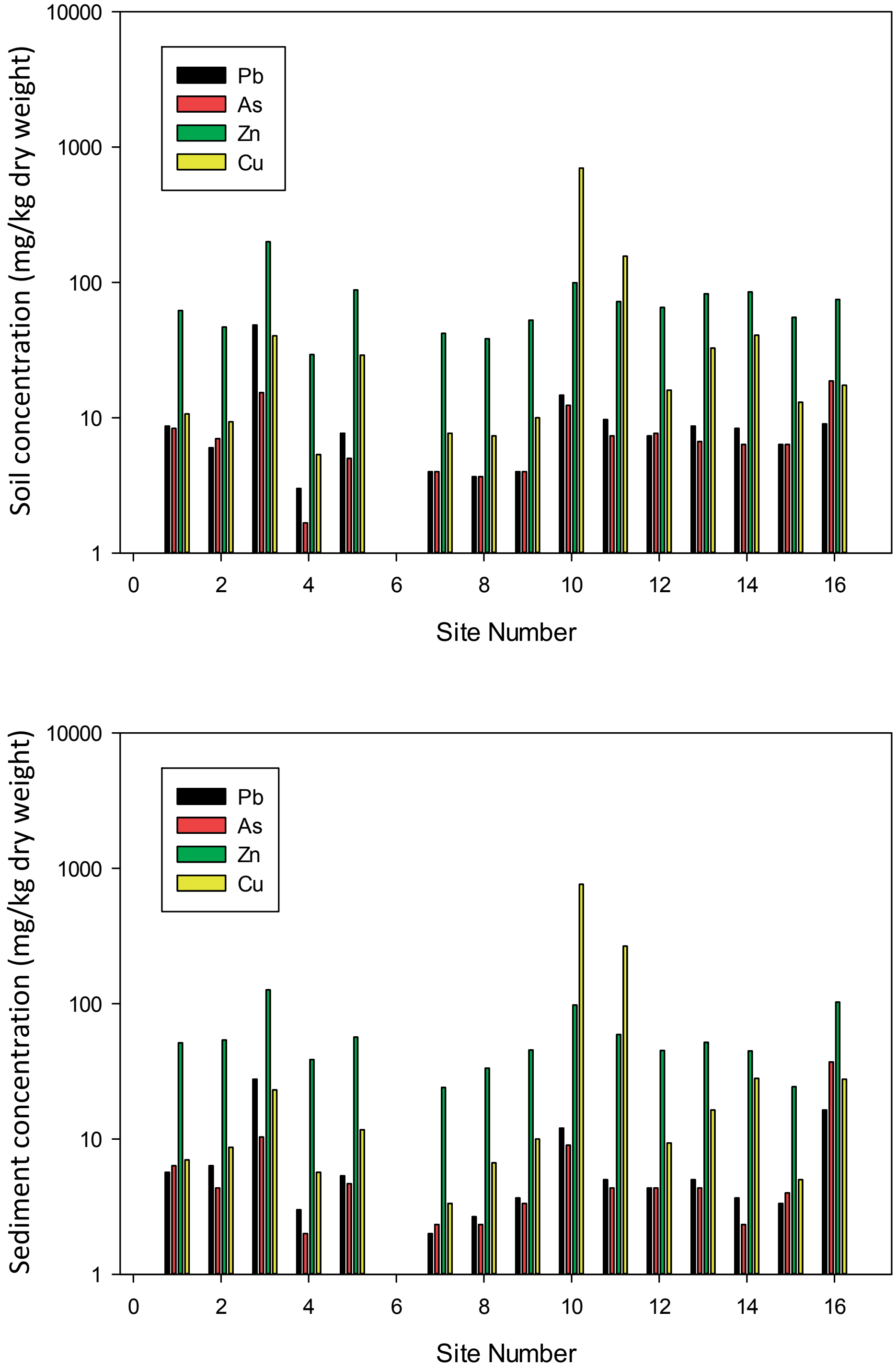

Fig. 4: Soil (above) and sediment (below) concentrations of lead (Pb), arsenic (As), zinc (Zn), and copper (Cu) in samples collected from the 16 sites along the tributaries of the river Selenga, Mongolia in 2010 (see fig. 1 for locations).

In some regions of Brasilia, where the gold mining is executed using amalgamation methods, the mercury content in the muscle of large predatory fishes reaches almost 20 mg/kg of dry weight (3.82 mg/kg of wet weight) (BERZAS NEVADO et al. 2010). The concentration of mercury in fish at these locations decreases with increasing distance downstream from the gold-mining sites. The tendency of increased mercury concentrations in dace muscle from the stations situated in the upstream of the rivers Tuul, Orkhon and Kharaa to the stations situated in the lower reach (table 1), suggests the presence of the local sources of mercury entering the rivers above the upstream collection locations. The sources may be natural (increased geochemical background) or anthropogenic. Further sampling upstream of these locations would help identify if indeed there were potential sources and if those sources of mercury were anthropogenic in nature.

The greatest concentrations of mercury accumulation are found in fish from reservoirs with industrial activities in the drainage basin. For example, in the muscle of dace collected in 1992 - 1996 from the upper part of Bratsk Reservoir (Angara river, springing from the lake Baikal, Russia), mercury concentrations reached 1.5 - 2.2 mg/kg wet weight (7.5 -11.0 mg/kg dry weight) (LEONOVA et. al. 2006). Only in the muscle of one specimen of dace from station 16 (Boroo river) such a high content of mercury was observed in this study.

Conclusions

The concentrations of metals in soil and sediments from the Selenga river and its tributaries in Mongolia were largely below thresholds for toxicity to fish and aquatic invertebrates. A few exceptions existed in which the concentrations of selected metals would pose a threat to aquatic fauna and potentially biodiversity in those regions. However, the results obtained show slightly increased levels of mercury accumulation in the muscle of the dace, a non-predatory fish. The greatest concentrations of mercury accumulation were observed in the muscle of fish from the Boroo river. These measured concentrations do not correspond with normal background levels and are therefore evidence of river contamination.

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