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Ichthyofauna as an Indicator of Environmental Conditions of the Ishim River: Accumulation of Heavy Metals and Bioindication

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Abstract: It is of great interest to study the processes of metal supply and migration in the natural environment. It was discovered in this study that metal content in fish is higher than that in the Ishim River water by 2–3 orders of magnitude and by an order of magnitude lower than that in the bottom sediments. Among fish tissues, the highest degree of accumulation of toxicants was observed in liver and gills. In all examined fish species, iron content was higher than the maximum allowable concentration. The physical appearance of the examined fish (fins, gills, heart) correlated with score 0, which corresponds to environmental welfare. The liver of the examined fish turned out to be the most sensitive indicating organ. The average grade for pike liver was 1.7; the roach individuals were mainly characterized by damaged liver (scores 3 and 4; very poor), a twofold reduction in the liver size and cirrhosis. Bream individuals were also characterized by poor condition of their liver (scores 2 and 3). A conclusion was drawn that the morphological parameters of the liver and muscles of the examined fish species provide the data regarding the functional state of individuals during a certain period of their life cycle; whereas gonadal condition is a crucial indicator of the reproductive potency of the species (a criterion of its adaptive plasticity).

Key words: Ichthyofauna · Heavy metals · Bioindication

INTRODUCTION

The research into the processes of supply and migration of metals in the natural environment, as well as into the transformation of heavy forms and properties of metals is of great interest. The term “heavy metals” is nowadays associated with the concept of toxic metals [1]. The greatest interest is aroused by the metals causing the most significant degree of atmospheric pollution due to the large-scale industrial use. They can be accumulated in the environment, thus being extremely hazardous in terms of their biological activity and toxic properties. These metals include cadmium, copper, arsenic, nickel, mercury, lead, zinc and chromium [2].

The supply of metals to water bodies is caused by both anthropogenic and natural processes: volcanic activity, weathering, chemical and biological degradation of rocks and vegetation degradation. The anthropogenic supply of the elements to aquatic objects is frequently higher than the natural supply [3, 4]. The sources of anthropogenic pollution of the environment with heavy metals include heat-and-power engineering enterprises, metallurgical plants, mining and chemical combines, motor transport, solid waste dampfills and sludge storage pits. Heavy metals belong to the group of non-conservative metals; i.e., their content in water, soil and ooze depends on a number of factors, such as temperature, salt content, season and pH [5]. Heavy metals can enter the rivers with sewage water of industrial enterprises, waste disposal plants, rainwater drainage systems, or from the water-shed area of the rivers [6]. Some substances participating in technogenous migration are deposited and accumulated in bottom sediments, while the others are supplied to the oceans by the river flow. An increase in concentration of heavy metals in the environment results in accumulation of significant amounts of the corresponding ions in the organisms and in disruption of the vital functions. The hazard is associated with bioaccumulation and bioamplification of heavy metals as they move along the food chains, which may cause mass poisoning of animals and humans [7].

The toxic effect is determined by concentration, type of migration and content of the other pollutants in the environment. When several heavy metals are present simultaneously, the toxic effect cannot be determined by simple addition of the toxic effects of these metals [1].

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The overall effect of heavy metals entering the aquatic environment on living organisms and the ecosystem in general depends both on properties of the metals and on water composition [8].

This work was aimed at studying the content of heavy metals in the aquatic environment and in the living organisms (fish) in order to determine the possibility of their use as bioindicators of environmental conditions.

MATERIALS AND METHODS

The Ishim River headwaters are located at an altitude of 560 m above sea level (50°30°N; 73°12°E). The Ishim River joins the Irtysh River on its left side (57°42°N; 71°12°E). The river stream is meandering; its width varies from 40 to 200 m. The bottom of the river is predominantly sandy. Its riffle depth is 0.1–0.3 m; the pool depth is 8–10 m. The width of the river valley varies from 4 to 22 km. The floodplain is wide with a large number of lakes. The river is 2450 km long; it is the world's longest second-order tributary. The water catchment area is 177 000 km^2. The total head is 513 m; the mean slope being 21 cm/km. The river flow is formed within the Kazakh Uplands.

The index of unfavorable state (IUS) was determined as the total score for all the organs, including parasite infestation and fat accumulation [9].

Water and bottom sediment samples were collected in order to analyze the level of technogenic pollution of the environment with the priority toxicants for this area (belonging to the group of heavy metals: iron, copper, zinc, cadmium, lead).

Prior to determining the heavy metal content, water samples were concentrated via evaporation during heating to 50–60°C. Soil samples were dried until constant weight was achieved at 50–60°C. The dry samples were ground in a porcelain mortar, passed through sieves with mesh size below 500 μm, quartered; weighed portions were then selected.

All the samples for determining the heavy metal content were converted into the dissolved form via wet combustion. The contents of iron, zinc, copper, cadmium and lead were analyzed by flame atomic absorption spectroscopy on an AA8-3 spectrophotometer (Carl Zeiss Jena, Germany).

The samples obtained from the pike, roach and the common carp captured in the Ishim River were also analyzed to determine the heavy metal content in various organs. The samples of muscle tissue, gills and liver of the fish were prepared using the standard procedures. The total content of iron, cadmium, lead, zinc and copper was determined in the fish samples by inversion voltamperometry using the procedure MU No 31-04/04 FR.1.31.2004.00986. Based on the analysis results, we compiled the rows of decreasing mean contents of metals in various fish organs (liver, muscles, gills) [10].

The fish for studying ichthyofauna was captured using gill nets and hook-and-line gear. The statistical analysis of the experimental data was performed using Microsoft Excel 2007 software.

RESULTS AND DISCUSSION

The contents of a number of metals (Pb, Cd, Zn, Cu, Fe) in water, bottom sediments and tissues of the fish captured in the Ishim River were analyzed. Tissues of the pike (a predatory fish) and the roach (a seston-feeder) were selected for the study.

The mean annual concentrations (mg/l) of metals in water of the Ishim River are shown in Table 1.

In general, a higher content of heavy metals was observed at sites No 3 and 5 as compared to the samples collected at site No 1.

Concentrations of heavy metals in the bottom sediments of the Ishim River differed depending on a certain area (Table 2).

The highest lead content (19.31 mg/kg) was recorded at site No 3; the lowest lead content was detected at site No 1. The highest cadmium content (0.85 mg/kg) was observed in ooze deposits at site No 5; while its content at site No 1 was twice as low. Zinc accumulation was detected at sites No 3 (24.95 mg/kg) and No 5 (20.79 mg/kg). Copper content in bottom sediments increased when moving from site No 1 to site No 5. Iron concentration was the highest at site No 3 (64935.6 mg/kg); while its content was twice as low at site No 5 and equal to 25974 mg/kg at site No 1.

Table 1: Mean annual concentrations of metals (mg/l) in water of the Ishim River (2006-2010)

Site	Pb	Cd	Zn	Cu	Fe
1	0.06±0.001	0.0015±0.0001	2.28±0.05	0.0012±0.0001	0.17±0.005
3	0.138±0.001	0.0044±0.0001	4.7±0.05	0.0013±0.0001	0.38±0.006
5	0.098±0.002	0.005±0.0001	4.98±0.05	0.002±0.0002	0.28±0.004

Table 2: Mean annual concentrations of metals (mg/kg) in the bottom sediments of the Ishim River (2006-2010)

Site	Pb	Cd	Zn	Cu	Fe
1	13.23±1.25	0.40±0.05	8.32±0.93	7.00±0.65	25974.8±93.1
3	19.31±1.36	0.79±0.09	24.95±3.16	10.39±1.05	64935.6±145.8
5	17.90±1.83	0.85±0.09	20.79±3.15	14.55±1.63	32467±86.9

Table 3: Mean annual concentrations of metals (dry weight, mg/kg) in tissues of the fish captured in the Ishim River (2006-2010) (p=0.95)

	Species, age	Sample type	Pb	Cd	Zn	Cu	Fe
1	Pike, 4+	Liver	0.21±0.01	0.04±0.02	40.20±5.15	2.06±1.35	24.48±8.13
	Site 1	Gills	3.33±0.32	0.21±0.02	116.38±14.53	0.71±0.12	34.82±7.45
		Muscles	0.1±0.04	0.09±0.01	4.12±0.50	0.41±0.04	25.49±3.10
2	Pike, 4+	Liver	0.67±0.08	0.08±0.03	58.88±6.15	5.10±0.61	64.02±4.10
	Site 3	Gills	4.10±0.30	0.26±0.04	110.52±9.24	0.88±0.06	45.79±5.64
4	Roach, 4+	Liver	1.84±0.15	0.26±0.03	45.44±6.40	6.63±0.76	47.89±5.11
	Site 1	Gills	0.56±0.19	0.25±0.02	48.33±7.62	0.23±0.01	47.39±4.93
		Muscles	0.26±0.10	0.15±0.01	2.95±0.30	0.22±0.01	12.31±1.32
5	Roach, 4+	Liver	0.82±0.06	0.11±0.01	30.37±5.58	2.70±0.15	41.74±4.86
	Site 3	Gills	1.58±0.03	0.35±0.01	68.93±6.10	0.81±0.04	40.39±4.75
		Muscles	0.91±0.01	0.22±0.01	5.71±0.45	0.21±0.01	19.90±2.02

Table 4: IUS values according to the scale of abnormalities in fish in the Ishim River [9]

	Pike	Roach	Bream
Site	Min-max, average	Min-max, average	Min-max, average
1	0-3 0.8±0.27	0-34 2.7±0.62	0-3 1.3±0.15
5	3-7 4.7±0.67	5-9 7.7±0.67	3-8 6.8±0.44

The content of heavy metals in the organs of fish captured at hydrological posts in the Ishim River was analyzed.

Accumulation of heavy metals in the fish organism was discussed using the pike and roach species as an example (Table 3).

The content of toxicant metals in the fish organism was 2–3 orders of magnitude higher than that in water of the Ishim River and an order of magnitude lower than that in bottom sediments. It was determined by analyzing the content of individual toxic elements in the environment and fish tissues that the nature of their accumulation was rather ambiguous. Lead content for the pike species at site No1 increased in the following order: water – muscles – liver – gills – bottom sediments. For the roach species, the order was as follows: water – muscles – gills – liver – bottom sediments. A homogeneous distribution of lead concentration was observed for both species at site No 3: water – liver – gills – bottom sediments.

Cadmium concentration at site No 1 increases in the following row. For the pike, water – liver – muscles – gills – bottom sediments; for the roach, water – muscles – gills –liver – bottom sediments.

Let us consider the distribution of the elements under study by an example of site No 3. At site No 3, cadmium is accumulated in the pike and roach species in a similar manner as it is in the pike species at site No 1. Zinc content in the environment–organism system is characterized by specific features. The maximum zinc content was detected in gills and liver of both species at sites No 1 and 3; it is higher than zinc concentration in the bottom sediments. Furthermore, zinc content in muscles was higher than that in water. Copper accumulation for the pike and roach species can be represented as a row: water – muscles – gills – liver – bottom sediments; for the roach: water – muscles – gills – liver – bottom sediments. Iron content increased for the pike and roach species at site No 3 as follows: water – muscles – gills – liver – bottom sediments. It is obvious that among all the analyzed components, water was characterized by the lowest content of all elements. The maximum content of the elements (except for zinc) was recorded in the bottom sediments. Among the fish tissues, toxic metals are most likely to be accumulated in liver (Fe, Cu, Zn) and gills (Pb, Cd). The maximum allowable concentration (MAC) of zinc was exceeded in liver of the roach and pike species. The MAC of lead was exceeded in liver of the roach species; the MAC of cadmium was exceeded in liver and gills of the pike species. In all the fish species under analysis, iron content was higher than the MAC value.

The fact that the relatively high concentrations of heavy metals were detected in the fish organism as a result of environmental pollution suggests metal accumulation. A number of researchers have pointed out that due to their considerable weight, fish muscles significantly contribute to accumulation of heavy metals, although not ranking first in terms of their content.

The IUS values for the pike, roach and bream species were calculated in this study. The samples consisting of 10 fish individuals of approximately the same age were selected for each species each month during the summer period for the analyzed years. Table 4 shows the ranking of the pathologies based on the score obtained.

The IUS value was determined as the total score for all the organs, including parasite infestation.

In terms of their external morphological indicators, the fish under study did not deviate from the norm typical of their species and were given score 0, which corresponds to environmental welfare. No pathologies have been identified based on the external appearance of the fins, gills and heart (hence, the fish were given score 0).

However, the liver of the analyzed fish individuals captured at sites No 3–5 turned out to be a more sensitive indicating organ. Thus, certain pike individuals were given score 2, which corresponds to the very pale and mosaic pattern and weakly reduced size. The average score given to the pike liver was 1.67±0.444. The roach individuals mostly had the pathological liver (scores 3 and 4; very poor condition) – red, with a strongly mosaic pattern and granular structure, reduced by over two times; cirrhosis. The bream individuals were characterized by poor condition of their liver, as well (scores 2 and 3).

Fish muscles were in a relatively unfavorable condition in all individuals of both the pike and roach species; they were given score 2 as the muscles could be pressed through by fingers.

Some individuals of the roach species had asymmetric gonads (one gonad was larger than the other one by 1/3 and more), which corresponds to score 1. The gonads of the other fish species exhibited no external pathologies. No pathological fat accumulation was observed in all the analyzed individuals. In some pike individuals, over two organs were infested with parasites; however, the average score for this indicator was 0.3 at sites No 1 and No 3 – 5.

As a result, the index of unfavorable state calculated for three fish species of the Ishim River was 4.7±0.67 (score 3–7) for the pike (a predatory species) and for the non-predatory fish species: 6.0±0.44 for the bream (score 3–8) and 7.7±0.67 for the roach (score 5–9).

The assessment of the condition of fish based on the IUS values has demonstrated that this index had low values near site No 1, which attested to favorable environmental conditions. The higher IUS values were observed in fish in the area affected by the urban ecosystem, which allows one to differentiate the river areas with respect to the degree of anthropogenic action. Apart from the IUS value of the carp species, the Ishim River can be regarded as the zone of relative environmental welfare according to the IUS values of the pike and bream species. The assessed condition of the indicating organs in fish inhabiting the Ishim River allows one to suggest a certain deprivation, which is particularly characteristic of the river zone in the central part of the city, where the character and degree of the abnormalities in the reproductive function of female fish and pathologies of the liver and muscles in both male and female individuals increased to some extent.

CONCLUSIONS

Thus, the relatively high concentrations of heavy metals detected in the organisms of fish inhabiting the polluted areas (although the relatively satisfactory physiological condition of the fish) attests to the fact that the organisms of hydrobionts possess specific systems that neutralize the toxic effect of heavy metals. The abnormalities detected in the organs can result from an increased content of heavy metals, organophosphate compounds, insecticides, synthetic detergents, etc. in the river water. The reproductive system becomes susceptible to the effect of toxic metals in an indirect way (via the disturbance in the hormonal status of the organism) or through blood (due to systemic intoxication). The morphological characteristics of the liver and muscles of the analyzed fish species provide the data regarding the functional state of the individuals during a certain period of their life cycle; whereas the gonadal state is the crucial indicator of the reproductive potency of a species and a criterion of its adaptive plasticity.

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