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Assessment of ecological safety of fish from anthropogenically polluted freshwater reservoir

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Abstract. The content of heavy metals in fish of different ecological groups in the conditions of the Argazinsky reservoir (Russia) has been studied, its ecological safety when used as a product nutrition was given. The material of the study was “local” fish (bream, pike, perch, roach, whitefish) caught by fishermen. The content of heavy metals was determined by atomic absorption method. Compared to muscular tissue, bone tissue has been found to accumulate more manganese, zinc, cadmium, lead, cobalt, nickel, iron (except for roach), copper, except for perch. The value of the metal pollution index (P_i) is greater than one in bream muscles in nickel, lead and cobalt; pike — nickel. The multifactor index of metal contamination (MPI) in the muscular tissue of fish are located in the following order: bream > pike > roach, whitefish > perch. P_i >1.0 value in skeletal tissue of bream in lead, nickel, cobalt, manganese, cadmium, zinc, iron; pike — lead, nickel, cadmium, zinc, manganese; perch — lead, cadmium; roach — zinc, cobalt, lead, cadmium; whitefish — manganese, lead, cadmium. By the magnitude of MPI, the skeletal tissue is ranked in the following order: pike > bream > whitefish > roach > perch. Pike MPI=3,85, bream MPI=3,10. The following row is formed by the value of fish fatness: perch > roach > whitefish > bream > pike. The fatness amount in the body of pike and bream is affected by excessively accumulated metals (nickel, cobalt and lead in bream, nickel, cadmium, and lead in pike), and in perch, roach, and whitefish - essential (iron, cobalt, copper and zinc in perch, manganese, iron and copper in roach, manganese, cobalt and zinc in whitefish).

1 Introduction

In the industrialized regions of most world countries, most contaminated are surface water bodies used for commercial fishing, recreational and household purposes [1-3]. At the same time, the most common pollutants of aquatic ecosystems are heavy metals and metalloids, which are included in the cycle of substances and food chains posing a serious threat not only to hydrobionts, but also human. This is a consequence of the long period of their decomposition and high migration activity [3, 4]. Heavy metals are characterized, firstly, by spatial distribution in the water bodies' components; secondly, are mainly of anthropogenic origin and have various potential toxicity for aquatic organisms, as, for

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example, shellfish and crabs, which are more prone to metals' bioaccumulation than fish and shrimp [5, 6]. To date, there are very few studies concerning the distribution, accumulation, and assessment of the potential risk of heavy metals for humans, which is relevant to the topic under consideration.

According to [6], the content of metals in aquatic ecosystems has purely regional features. Their quantity can vary greatly between sampling sites even within one water reservoir since its water area contains various biotopes with a specific composition of hydrobionts and biological productivity [7]. The rivers are most highly affected by heavy metals contamination, they can circulate in their food chains for a long time [8]. Research [9] found that aquatic organisms are distributed in the following order for bioaccumulation capacity: phytoplankton < zooplankton < fish < shrimp < shellfish. At the same time, the bioconcentration coefficients for most heavy metals in phytoplankton are lowest, and on the contrary, highest in shellfish.

As in many countries of the world, an important product in the human diet in Russia is fish, its biodiversity in all water bodies is associated with geographical, biotic, and abiotic factors [10] whose ratio and changes affect the number of fish in certain populations. First, the ecological safety of fish is associated with water quality, since all pollutants migrate through food chains with its participation. In the study [3] it is noted that there are two main ways of heavy metals entering the fish body. The first way involves the absorption of dissolved contaminants in water through the gills or by means of ionic transport through biological membranes. The second way is alimentary due to the ingestion of pollutants into the body in the composition of feed or sediment particles. According to [11], in conditions of anthropogenically polluted reservoirs, fish body can accumulate a significant amount of heavy metals, which becomes dangerous not only for the fish themselves, but also for humans. Bioaccumulation of metals is facilitated by the fact that they are practically non-biodegradable in biotic and abiotic components of aquatic ecosystems and accumulate in their composition [8]. Therefore, the fish body serves as a reliable bioindicator for monitoring metals accumulation in the environment [12-14].

Accumulating in the tissues of food fish, metals can have a negative effect on the human body when eating it up to acute and chronic poisoning [Castro-Gonzale M.I., 2008]. Especially dangerous is the presence of highly toxic heavy metals, such as lead, cadmium, mercury, arsenic in fish [8], which can accumulate in it even when ingested in microquantities due to low metabolic activity and long excretion period. In the fish body, metals are deposited not only in muscle, but also in fatty, bone, connective tissues, liver, bladder, intestines [15]. Eating various edible fish tissues is more associated with a potential toxic risk to the human body than muscular tissue [3]. According to [16], the ability to metals' bioaccumulation is not interrelated with the method of fish cultivation (natural, industrial), but depends on their species affiliation. So, toxic elements accumulate more actively in the bodies of crucians, grass carps, carps.

Based on the fact that being not only part of the food chain of aquatic ecosystems but also humans, heavy metals deposited in the body of fish pose a serious threat to its health; therefore, we studied their content in the tissues of various ecological groups' fish in the conditions of the Argazinsky reservoir (Chelyabinsk region, Russia) and assessed its ecological safety when used as a food product.

2 Materials and methods

2.1 Characteristics of research object

Argazinskoye reservoir was created in 1946 on the Miass river (Ob River basin) by the dam construction during the construction of a hydroelectric power plant. It is located in the north-western part of Chelyabinsk region, belongs to the Karabash city district and Argayash municipal district. The surface area of the reservoir is 102.4 km^2, the volume of concentrated water is 966.1-980.0 million m^3. The area of the catchment basin is 2750,00-2800,00 km^2, it is associated with the rivers Miass, Aktus and Kamennaya flowing into it, collecting water from the foothill part of the Ural Mountains. The average depth of the reservoir varies from 8.6 to 11.5 m. The reservoir is fluviolacustrine, filling type - retaining. It is currently used for water supply of the city of Chelyabinsk in the cascade mode [17], as well as for regulating the flow of the Miass river, especially during spring floods. The climate in the area of the reservoir is extremely continental, characterized by a long, cold winter with a stable snow cover (the coldest month - February), as well as a short but warm summer with a maximum of precipitation in July. Frosts are observed in the transitional seasons of the year (spring, autumn).

The Argazinsky reservoir has recreational and commercial fishing importance. Reservoir's biodiversity is represented by the following "local" fish species: pike, roach, gudgeon, verkhovka, loach, common perch, ide, burbot, whitefish, zander, bream, ruffe, common dace, crucian carp (silver, gold), vendace. There are also both trout, carp (European carp), and sturgeon in it [17].

According to [18], water in the Argazinsky reservoir in terms of heavy metals content belongs to the 4th class (very dirty), which is due to the wastewater discharge from Karabash copper smelting plant (JSC "Russian copper company") into the Miass river flowing into it. In the composition of water, there is significant MPC exceeding of copper, zinc, manganese, iron, lead [17].

2.2 Characteristics of research material

The material of the study was "local" fish (bream, pike, perch, roach, whitefish) caught by fishermen. Fish samples were packed in plastic bags and thermal containers holding the temperature in the range from 0 to -4° C and delivered to the laboratory of FSBEI of HE South Ural State University. Before the tests, fish age was determined according to growth rings on scales [1, 7]. Then it was washed with distilled water, cut while separately collecting muscle and bone tissue, crushed using stainless steel tools. The resulting biomaterial was dried with filter paper. During the period of 2017-2020, 250 samples were selected for the determination of heavy metals, 500 studies were performed.

2.3 Methods of research

Before determining metals, samples of muscle and bone tissue weighing 10.0 g were prepared for the mineralization process in accordance with GOST 26929-94 [19]. The determination of heavy metals and metalloids was carried out by atomic absorption method using a spectrophotometer (AAS-1, Jena, Germany) in accordance with GOST 30178-96 [20] and methodical instructions [21]. The concentration of manganese, iron, cobalt, nickel, copper, zinc, lead, cadmium was determined in fish tissues and the result was expressed in mg/kg of raw tissue.

To assess the ecological safety of fish by the content of individual metals, the single-factor pollution index (P_i, conv. units) was calculated according to the following formula [15]:

$$P_i = \frac{A_i}{PL_i} \tag{1}$$

where A_i is the average concentration of a separate heavy metal in the sample (mg/kg of raw tissue); PL_i- the permissible level of a separate metal in fish from fresh water bodies (mg/kg of wet weight) in accordance with the regulatory documents [22, 23], according to which the allowable level of cadmium (Cd) is 0.2; lead (Pb) — 1.0; copper (Cu) — 10.0; zinc (Zn) — 40.0; iron (Fe) — 30.0; nickel (Ni) — 0.5; cobalt (CO) — 0.5; manganese (Mn) — 10 mg/kg of raw tissue.

In addition to the single-factor index, the multifactor index of metal pollution was calculated (MPI, conv. units) [15]. Its value reflects the total fish contamination level with heavy metals and metalloids. The equation for its calculation is as follows:

$$MPI = \sqrt[n]{A_1 \cdot A_2 \cdot A_3 \cdot \ldots A_n} \tag{2}$$

where A is the average concentration of each heavy metal (mg/kg of raw tissue).

The "meatiness (fatness)" of fish was judged by the coefficient of fatness calculated according to the formula by T. Fulton [24]:

$$C_f(f) = \frac{W \cdot 100}{L^3}$$

where: W is the weight of fish (g), L -body length (cm).

The results of the research were statistically processed in Microsoft Office Excel 2007 when using the Data Analysis Package application. To identify the most general regularities of individual elements' connection with the fish fatness level, the analysis of the main components was applied [25]. Spearman correlation coefficients were used as a measure of similarity, the number of main components was determined by Cattell's scree [26]. The connections were considered statistically significant at $P \leq 0.05$. Calculations were made in the PAST package [27].

3 Results

The results of individual heavy metals determination in the muscular and skeletal tissues of fish are presented in Tables 1 and 2. Fish aged 2+ were selected for research. The species of fish influenced the proneness to deposit certain metals in the bone tissue. Thus, breams accumulated manganese, cobalt, copper, and lead at the highest amount in myocytes. Pike dominated in the ability to deposit zinc, nickel and lead, roach — iron. Perch and whitefish possessed the lowest proneness to metals' bioaccumulation in muscle tissue (Table 1).

Table 1. The content of heavy metals and metalloids in fish muscular tissue.

Fish type	Metals, mg/kg of raw tissue							
	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
Bream 2+	4.80± 0.48	12.57± 0.62	0.56± 0.26	0.60± 0.26	1.69± 0.03	13.12± 1.11	0.10± 0.01	1.15± 0.23
Pike 2+	1.44±	4.21±	0.27±	0.83±	0.86±	18.47±	0.16±	0.81±

	0.07	0.33	0.04	0.04	0.01	1.17	0.01	0.06
Perch 2+	1.27± 0.14	7.15± 0.52	0.16± 0.01	0.12± 0.03	1.14± 0.05	5.55± 0.67	0.08± 0.01	0.54± 0.04
Roach 2+	1.19± 0.08	20.61± 0.44	0.13± 0.01	0.09± 0.01	1.31± 0.16	15.93± 0.52	0.07± 0.01	0.41± 0.03
Whitefish 2+	1.07± 0.22	10.77± 0.70	0.19± 0.02	0.10± 0.01	1.37± 0.06	6.80± 0.64	0.27± 0.01	0.33± 0.05

In addition to muscle tissue, the concentration of metals was also determined in the bones of the skeleton, which is one of the main places of their deposit in the body. First, the amount of heavy metals and metalloids in the skeletal tissue of the studied fish species was much higher than in muscles (Table 2).

Table 2. Contents of heavy metals and metalloids in fish bone tissue.

Fish type	Metals, mg/kg of raw tissue							
	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
Bream 2+	25.51± 2.13	46.00± 3.72	1.35± 0.08	8.54± 0.82	5.06± 0.28	81.39± 3.95	0.41± 0.03	22.11± 2.47
Pike 2+	13.55± 0.70	11.17± 0.62	4.35± 0.21	6.51± 0.26	7.60± 0.38	121.08± 2.00	1.75± 0.12	42.08± 0.92
Perch 2+	5.30± 0.53	9.22± 0.26	0.43± 0.03	0.28± 0.04	0.94± 0.05	10.74± 0.25	0.44± 0.04	2.05± 0.21
Roach 2+	4.66± 0.22	2.56± 0.23	0.72± 0.22	0.27± 0.03	1.64± 0.21	47.93± 5.30	0.45± 0.02	1.40± 0.08
Whitefish 2+	11.61± 1.80	15.05± 1.62	0.25± 0.02	0.24± 0.03	1.66± 0.09	19.14± 2.00	0.42± 0.04	2.10± 0.15

Secondly, the species of fish determined their specificity to metals' accumulation in skeleton bones. Thus, the greatest tendency to deposit manganese, iron and nickel was revealed in bream. Cobalt, copper, zinc, cadmium, and lead were actively accumulated in the bone tissue of pike. The concentration of metals in the bones of perch, roach and whitefish was much less than that of bream and pike (Table 2).

Consequently, the muscular and skeletal tissue of fish contains varying amounts of metals. In addition, fish also showed species' specificity in the accumulation of various elements in their body.

To assess the ecological safety of fish meat and bone tissue, we compared their content with the amount of permissible levels regulated by normative documents in Russia [22, 23]. For this, we have calculated two indices: a single factor pollution index (P_i) and a multi-factor pollution index (MPI). The results are presented in Tables 3 and 4.

Thus, bream meat contained cobalt, nickel and lead in quantities exceeding the permissible level, pike - nickel (P_i, > 1.0). The muscular tissue of perch, roach and whitefish was environmentally safe with respect to all the elements defined. When ranking fish based on MPI values, they arranged in the following order:

Bream > pike > roach, whitefish > perch

Table 3. Single-factor and multi-factor indices of fish muscle tissue contamination with heavy metals and metalloids.

Fish type	P_i, con. unit								MPI, con. unit
	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	
Bream 2+	0.48	0.42	1.12	1.2	0.17	0.33	0.50	1.15	0.55
Pike 2+	0.14	0.14	0.54	1.66	0.09	0.46	0.32	0.81	0.34
Perch 2+	0.13	0.24	0.30	0.24	0.11	0.14	0.16	0.54	0.20
Roach 2+	0.12	0.69	0.26	0.18	0.13	0.40	0.14	0.41	0.24
Whitefish 2+	0.11	0.36	0.38	0.20	0.14	0.17	0.54	0.33	0.24

Consequently, considering the total toxicity of all metals (manganese, iron, cobalt, nickel, copper, zinc, cadmium, lead), the most environmentally safe was perch meat, and the most contaminated - bream. At the same time, the MPI value of any fish species did not exceed 1.0, that is, according to the total estimate of fish meat contamination level with metals, it met the “safe” criterion.

Similar calculations were performed for fish bone tissue (Table 4).

Table 4. Single-factor and multi-factor indices of fish skeletal tissue contamination with heavy metals and metalloids.

Fish type	P_i, con. unit								MPI, con. unit
	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	
Bream 2+	2.55	1.53	2.70	17.08	0.51	2.03	2.05	22.11	3.10
Pike 2+	1.36	0.37	8.70	13.02	0.76	3.03	8.75	42.08	3.85
Perch 2+	0.53	0.31	0.86	0.56	0.09	0.27	2.20	2.05	0.55
Roach 2+	0.47	0.09	1.44	0.54	0.16	1.20	2.23	1.40	0.61
Whitefish 2+	1.16	0.50	0.5	0.48	0.17	0.47	2.10	2.10	0.69

Bream bones contained manganese, iron, cobalt, nickel, zinc, cadmium, and lead exceeding the allowable level; pike — manganese, cobalt, nickel, zinc, cadmium and lead; perch — cadmium and lead; roach — cobalt, zinc, cadmium; whitefish -manganese, cadmium and lead. It should be noted that the level of toxic metals (lead, cadmium) regulated by the requirements of normative documents [22, 23] was exceeded in the bone tissue of all the fish species studied. In assessing the ecological safety of skeletal bones by total metal concentration, the following ranked series was obtained in which the MPI value decreased:

Pike > bream > whitefish > roach > perch

Consequently, like muscular tissue, bone tissue was least contaminated in perch, and most strongly - in pike. At the same time, the MPI value in bream and pike significantly exceeded the value of 1.0, reflecting a high level of risk to human health when consuming it.

The heavy metal content in the muscular and bone tissues of fish reflects the aquatic ecosystem contamination degree by these compounds, since fish tend to be the last link in the trophic chain of the reservoir [1, 7]. Therefore, we assumed that the level of metal accumulation in the fish body has an impact on their growth processes. Linked to fatness formation (Table 5).

Table 5. Indicators of fish growth depending on their species.

Age	Length, cm	Weight, g	Fatness (as per Fulton)
Bream 2+	21.50±0.59	148.94±10.71	1,49±0.11
Pike 2+	26.36±0.35	222.16±8.34	1.21±0.09
Perch 2+	11.18±0.25	29.11±0.57	2.08±0.15
Roach 2+	11,17±0.37	27.20±1.04	1.95±0.17
Whitefish 2+	17.32±0.29	80.35±1.19	1.55±0.12

Table 5 data show that fish retained specific growth and development characteristics for each species in the conditions of the reservoir under study. This reflected the quantitative severity of such indicators as body length and its weight. However, there was a significant variation by the size of the integrating "fatness" parameter, the level of which reflects the combination of abiotic and biotic factors' effects on the fish body. When ranking fish species by fatness value, the following series were obtained:

Perch > roach > whitefish > bream > pike

At the same time, having the lowest MPI value both in muscle and bone tissue, perch was characterized by the highest fatness; on the contrary, pike and bream were characterized by the highest MPI values but had a minimal "fatness". Consequently, the content of heavy metals in the fish body influenced their growth rate under the conditions of an anthropogenically polluted aquatic ecosystem.

To test this conclusion, we tried to identify the priority metals of muscle tissue, which most strongly affect the formation of fish fatness using the principal component method. At the same time, we proceeded from the fact that the content of metalloids and toxic elements in myocytes is the most metabolically active part of them in the fish body, which is actively involved in biochemical processes. To highlight the principal components, we applied the graphical "scree plot" criteria by R. Cattell [26]. This allowed to distinguish 2-3 factors in each fish species, of which only the first component had statistical significance. Therefore, the information on it was analyzed further (Table 6).

Table 6. Metals' factor loads per principal component 1.

Indicators	Bream 2+		Pike 2+		Perch 2+		Roach 2+		Whitefish 2+	
	Load	*P*	Load	*P*	Load	*P*	Load	*P*	Load	*P*
Mn	-0.19	0.63	-0.12	0.66	0.44	0.31	0.79	<0.05	0.87	<0.05
Fe	-0.07	0.78	-0.16	0.64	-0.93	<0.05	-0.71	<0.05	-0.90	<0.05
Co	0.78	<0.05	0.32	0.47	0.81	<0.05	-0.45	0.30	-0.44	0.31
Ni	0.80	<0.05	0.87	<0.05	0.17	0.63	-0.49	0.29	-0.54	0.18
Cu	-0.02	0.79	0.02	0.77	0.84	<0.05	0.82	<0.05	0.47	0.38
Zn	-0.24	0.59	0.38	0.43	-0.90	<0.05	0.64	0.10	-0.79	<0.05
Cd	0.23	0.60	0.88	<0.05	0.33	0.46	-0.39	0.44	-0.24	0.61
Pb	0.84	<0.05	0.90	<0.05	-0.48	0.28	0.28	0.53	0.18	0.64
MPI	0.88	<0.05	0.92	<0.05	0.54	0.18	0.61	0.09	0.51	0.20
Explained variance, %	85.10		90.12		78.70		80.50		82.30	
P	<0.05		<0.05		<0.05		<0.05		<0.05	

The principal components method revealed the following features of the 'metal bond - fatness' in muscle tissue (Table 6). In pike and bream, the principal component explained 90.12 and 85.10% of the total variability of metals determined in muscle tissue. At the same time, statistically significant factor loads on it were typical for such metals as nickel, cobalt, and lead in bream; nickel, cadmium and lead in pike, the levels of which were excessive in meat of these fish species. In addition, there was a statistically significant connection for the MPI index. In perch, roach and whitefish, statistically significant factor loads were identified in essential metals: iron, cobalt, copper and zinc in perch, manganese, iron and copper in roach, manganese, cobalt, and zinc in whitefish. At the same time, there was no statistically significant connection to the MPI index.

Thus, the level of heavy metals' accumulation in the fish body affects not only its ecological safety as a human food but is also interconnected with the speed of growth processes estimated by the fatness value.

4 Discussion

The heavy metals' content in the components of the aquatic ecosystem is associated with their level in the fish body, which vital processes involve direct or indirect contact with water, bottom sediments, plankton, and plants due to its location in the water food chain in the upper trophic level [15]. Therefore, in the conditions of commercial fishing reservoirs subject to constant anthropogenic effects resulting in containing excess metals in water bodies, it is necessary to perform monitoring of their content in different fish species on a regular basis, as this will allow to reduce the risks to human health when consuming it to get acute or chronic food intoxication [28].

Fish have different abilities to bioaccumulate heavy metals, which depends on the way they are fed. In studies [29], it was noted that demersal fish living near sediments and predatory fish accumulate the largest amount of metals in their bodies. Depositing specificity of elements is determined not only by the fish species, but also by the tendency of some tissues to accumulate them. Priority target organs are liver, bone tissue, gills, intestines [15, 30]. At the same time, muscle tissue (meat) has a minimum level of metal accumulation, which allows it to be used in human nutrition without restrictions. Similar conclusions were drawn in the studies [15, 28. 30].

Based on the fact that fish is included in the human diet, providing the body not only with easily digestible protein, but also essential fatty acids and fat-soluble vitamins, it is necessary to monitor its safety for health including the level of heavy metals. In case of their excess content, fish can be considered as an “ecological toxicant” [31].

To assess the ecological safety of fish, the heavy metals' level in it is compared with the values of permissible levels for each metal, which are determined by the relevant regulatory documents of the country. If its value exceeds 1.0, then such fish consumption can harm human health, especially with its constant inclusion in the diet. The results of our studies showed that in the conditions of the Argazinsky reservoir, both in muscle and bone tissues of bream and pike there were metals exceeding the P_i value 1. Particularly alarming is the dominance of such metals as lead and nickel by P_i , which are among the most toxic to living organisms. It is likely that the excessiveness of these elements in fish tissues is associated with longer contact with metal-contaminated bottom sediments, which ensures their absorption and accumulation [32]. Besides, pike is a predatory fish, and this nutrition method also contributes to the flow of metals into its body. [29, 30] came to similar conclusions in their studies. The authors noted that differences in metal bioaccumulation are associated with fish nutritional features, preferred habitat, and lifestyle.

When assessing the safety of muscle and skeletal tissue of the studied fish species by MPI, it can be noted that the total metals toxicity in fish meat did not exceed 1.0, determining the possibility of its inclusion in the diet. However, MPI value amounted to 3.10 and 3.85 conv. units in the bone tissue of bream and pike, reflecting its high toxicity to the human body. Consequently, it is necessary to exclude the skeletal bones of these fish species from the human diet as much as possible.

Being practically non-decomposing compounds, heavy metals in natural waters and included in trophic chains have a negative effect on the fish body. In our studies, we have assessed their impact on the growth and development of different fish species by the fatness value, which directly relates both to the availability of food resources and the degree of their accessibility in the digestive tract []. In the conditions of the studied reservoir, perch had a higher fatness level, in the tissues of which the least amount of heavy metals has accumulated. On the contrary, pike and bream muscle and bone tissues actively deposited metals and had a ratio between length and body weight determining lower fatness values compared to perch. Consequently, the amount of accumulated metals in the fish body influenced their linear and mass growth, as well as proportionality between them. At the same time, the variability of growth processes had species' specificity [33]. According to [34], in the conditions of excess content of various pollutants in the fish body, conditions are created in which the metabolism level changes due to increased expenses on their detoxification, affecting provision of growth processes with energy and plastic material. In addition, the assimilation of feed with excess metal content is reflected on the activity of digestive enzymes [34].

When identifying the relationship between the heavy metals' concentration in muscle tissue and fish fatness by the principal component method, it was revealed that only the principal component 1 has statistical significance, which explains between 78.70 and 90.12% of metals' variability in myocytes. In fish species such as pike and bream with differing MPI values of 0.34 and 0.55, the fatness formation is associated with metals, the amount of which exceeds the requirements of the regulatory documents [22, 23]: nickel, cobalt and lead in bream, nickel, cadmium and lead in pike. Consequently, a decrease in fish fatness is associated with the manifestation of toxic effects of metals in their bodies. In perch, roach, and whitefish with significantly higher fatness at 2 years than that of pike and bream, statistically significant factor loads were characteristic of trace elements that provide optimal rate of biochemical reactions in the fish body, both independently and as part of catalytic proteins, and metalloproteins [34].

5 Conclusions

Results reflecting data on the content of heavy metals and metalloids in muscle and bone tissues of 5 fish species caught in the Argazinsky reservoir (Chelyabinsk region, Russia), make it possible to make the following conclusions:

1. In the bodies of bream, pike, perch, roach, and whitefish in comparison with muscular tissue, bone tissue accumulates 3.91-10.85 times more manganese, 1.29-3.65 times - iron, except for roach, 1.32-16.11 times — cobalt, 2.33-14.23 times -nickel, 1.21-8.83 times - copper, except for perch, 1.93-6.55 times - zinc, cadmium - 1.55-10.93 times, and lead - 3.41-51,95 times.

2. The single-factor metal contamination index (P_i) exceeds 1.0 only in muscle tissue of bream in Ni (P_i=1.20), Pb (P_i=1.15) and Co (P_i=1.12), in pike - Ni (P_i=1.66). In terms of the multi-factor index of muscular tissue metal contamination (MPI), fish species can be ranked in the following order: bream > pike > roach, whitefish > perch.

3. The value of the single-factor metal pollution index (P_i) exceeds 1.0 in skeletal tissue of bream in Pb (P_i=22.11), Ni (P_i=17,08), Co (P_i=2.70), Mn (P_i=2.55), Cd (P_i=2.05), Zn (P_i=2.03), and Fe (P_i=1.53); in pike - Pb (P_i=42.08), Ni (P_i=13.02), Cd (P_i=8.75), Zn (P_i=3.03) and Mn (P_i=1.36); in perch - Pb (P_i=2.05) and Cd (P_i=2.20); in roach - Zn (P_i=1.20), Co (P_i=1.44), Pb (P_i=1.40) and Cd (P_i=2.23); whitefish - Mn (P_i=1.16), Pb (P_i=2.10) and Cd (P_i=2.10) . By the magnitude of the multi-factor metal contamination index (MPI), the skeletal tissue of fish by species can be ranked in the following order: pike > bream > whitefish > roach > perch. Pike MPI=3,85, bream MPI=3,10.

4. The following row is formed by the value of fish fatness: perch > roach > whitefish > bream > pike. Analysis of the relationship of muscular tissue metal - fatness by the principal components method indicates that in the body of pike and bream the level of excess accumulated metals (nickel, cobalt and lead in bream, nickel, cadmium, and lead in pike) reduces the rate of linear and mass growth. In perch, roach and whitefish, fatness is associated with essential metals content (iron, cobalt, copper and zinc in perch, manganese, iron and copper in roach, manganese, cobalt and zinc in whitefish).

The results of the studies determine the need to identify heavy metals in the body of “local” fish species of the reservoir in the age aspect, as well as other fish species to assess their environmental safety for the human body.

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