Sustainable Aquaculture in the Baltic Sea Region of Russia: 
Ecotoxicological Issues of Restocking Wild Salmon and 
Whitefish Populations

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Abstract. It is widely recognized that aquaculture plays an important role in rural development, contributing significantly to food availability, household food security, and income generation in particular. In developing sustainable aquaculture in the Baltic Sea region of Russia, it is essential to strike a balance between the need for aquaculture development and the need for natural resource conservation, especially in the case of Atlantic Salmon and Whitefish—the most valuable object of fishery, which almost lost their native spawning areas due to negative anthropogenic impacts. Without sufficient information about the accumulation of dangerous pollutants in fish tissues it is hard to develop a sustainable strategy for restocking populations of wild Salmonids and Whitefish in their natural habitats. In this paper, the accumulation of heavy metals in the tissues of wild Salmonids and Whitefish caught for artificial reproduction and their fry from the state hatcheries of northwest Russia was studied with the use of voltammetry, X-ray fluorescence analysis, and capillary electrophoresis. Analysis of the obtained data showed that significant bioaccumulation of heavy metals happens during growth and feeding after Salmon fry are released into the wild. This study demonstrates the necessity of improving state hatcheries with automatic control systems for ecological parameters.

1. Introduction

Rapid world population growth (predicted to reach over 9 billion people by the middle of the 21st century) causes an increasing need for high-quality animal protein and essential nutrients. According to the United Nations 2030 Agenda, rural development and agriculture are key to achieving the entire set of Sustainable Development Goals (SDGs), and many SDGs are directly relevant to fisheries and aquaculture [1, 2].

Rural development has various directions, but it is particularly the development of the agricultural sector which is the main driving force for reducing poverty and hunger and ensuring food security for all. Various types of aquaculture form an important component within agricultural and farming systems development.

Nowadays, aquaculture is an integral part of the multifunctional agricultural sector which is currently expanding, becoming more diverse, dynamic, and technically and technologically developed. Aquaculture consists of the diverse systems of farming plants and animals in inland and coastal areas, and FAO (Food and Agriculture Organization) defines aquaculture as the “farming of aquatic
organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated [3]. Aquaculture is becoming an attractive and important component of rural development due to increasing population growth, environmental degradation or loss of access limiting catches from wild fisheries, health, and nutrition. Aquaculture provides high-quality animal protein and essential nutrients, especially for nutritionally vulnerable groups such as pregnant and lactating women, infants, and pre-school children [4].

The Russian Federation has the world’s largest water fund of inland waters and coastal waters, including 20 million hectares of lakes, 120 thousand rivers with a length of more than 10 km each, 4.5 million hectares of reservoirs, more than 150 thousand hectares of ponds, and over 300 thousand square meters of ponds and pools that create tremendous opportunities for aquaculture development [5, 6]. However, for the purpose of aquaculture development, the listed reservoirs are used poorly. Therefore, the Russian Federation officially recognizes aquaculture as a high-priority type of fishery and one of the key points of rural development and economic growth [7].

Salmonid fishes and Whitefish have always been the most valuable products of fisheries in the Baltic region of Russia. The population growth in Baltic region and the demand for fish products have resulted in overfishing and the impoverishment of many fishing areas. Most of the wild types of fish are losing their native spawning areas because of anthropogenic transformation of their key habitats: hydrotechnical constructions, reduction of the quality of spawning areas due to the transformation of the landscape in the river basins, water eutrophication and the associated change in fish communities, and chemical pollution of the aquatic environment in the spawning and feeding areas of fish.

Atlantic Salmon and Whitefish are important for providing the population of the northwestern part of Russia with high-quality fish products. This task is currently being accomplished by growing aquaculture of domesticated trout and Norwegian Salmon in open-water cage farms [8].

Cage farming is one of the most common methods of aquaculture production worldwide. The widespread use of this technology is due to the simplicity of the design and low cost, and there is also no need for mechanical water supply—when placing the cages, lakes, reservoirs, quarries, rivers [8], etc., are used. Carrying cage farms is one of the fastest ways to fill the market with fish products, but it has significant drawbacks in terms of fish quality and negative effects on the ecosystem; these include differences in the nutritional properties of domesticated fish from wild types (high fat content; high content of antibiotic and antifungal agent decay products used in the artificial cultivation of fish for accelerated growth to marketable size), a negative impact on the aquatic environment (water pollution by nutrients and chemicals), and high environmental risks (fish parasites typical for foreign producers but not typical for Russian regions entering into water bodies [9] and the associated increase in the number of pathogenic organisms, penetration of domesticated fish into the natural environment, and their hybridization after escaping from cages [10, 11]).

The biodiversity of aquatic genetic resources—genetic diversity among different species, populations, and even individuals—is a valuable part of the “building blocks” that support sustainable production and trade of fish in both capture fisheries and aquaculture. Maintaining biodiversity is critical to meeting the objectives of the three pillars of sustainability: environmental, social, and economic [4].

The most favorable way to maintain both the ecological conditions in the aquatic environment and biodiversity is to restore the populations of wild fish species with their inherent beneficial nutritional and genetic qualities.

Heavy metals are considered the main toxicants in the production of fish products [12, 13]. Bioaccumulation of these toxicants in fish tissues has a significant negative impact on the physiological and reproductive quality of fish, as well as reducing the quality of the fish products [14]. According to investigations in this field, bioaccumulation of heavy metals in fish and subsequent distribution in organs is greatly inter-specific [15-18]. In addition, many factors can influence their uptake, like sex, age, size, reproductive cycle, swimming patterns, etc. [19-22]. Therefore, without sufficient information about the accumulation of dangerous pollutants in fish tissues it is impossible to
develop an adequate strategy to maintain fish farming, restock wild fish populations, and follow the principles of “sustainable aquaculture”.

This article is devoted to the study of heavy metal accumulation in the tissues of wild Atlantic Salmon and Whitefish caught for artificial reproduction and in the juveniles of Atlantic Salmon and Sea Trout from the State hatcheries of the northwestern part of Russia to identify future aquaculture development directions.

2. Materials and methods

2.1. Study area and research materials

According to Federal Fishery Agency (FFA) statistics, 238.65 thousand tons of aquaculture were produced in the Russian Federation in 2018, which is 27 percent higher than that in 2014. The northwest region of Russia, which includes the Baltic Sea region, is the second most productive area in aquaculture production and is therefore a key region for aquaculture development (Figure 1).

![Figure 1. Volumes of aquaculture production in the Russian Federation (Data source: Federal Fishery Agency (FFA) of the Russian Federation).](image)

The Atlantic Salmon and Sea trout have almost completely lost their natural spawning areas, and their populations in rivers are partially maintained by artificial reproduction in state hatcheries. The Whitefish from Ladoga Lake is listed in the Red Book of the Russian Federation, and its populations are fully maintained by artificial reproduction in the Volkhov State hatchery [23].

The replenishment of wild fish populations with juveniles, grown from wild spawners for release into the wild, is one of the key actions undertaken to preserve favorable ecological conditions in the aquatic environment and biodiversity. This action is carried out to restore populations of Atlantic Salmon, Sea trout, and Whitefish in State hatcheries in the rivers and lakes of the Baltic Sea region of Russia (Ladoga Lake and the Neva, Narva, Luga, Svir rivers, etc.) which are directly “built” into the ecosystem and meet the requirements of the ecosystem approach to aquaculture (EAA) promoted by FAO [1, 2, 4].

According to the latest FFA statistics, the total amount of released smolts in 2014 was higher than the 2013 figures by 7 percent; however, the release volumes of Salmonid fry decreased to 42 percent and Whitefish rates were lower by 45 percent (Figure 2). These volumes are not sufficient to restore their populations in rivers which were previously rich in fish.
Figure 2. Release volumes of juveniles (million units) of aquatic biological resources in the 2013–2014 period in the northwestern part of Russia (Source: FFA).

There are significant difficulties associated with the environmental quality of the waters and with the efficiency of artificial reproduction. The main spawning rivers of the region are experiencing significant chemical anthropogenic impact. One of the threats to the water ecosystem is heavy metals. The accumulation of heavy metals in aquatic ecosystems causes pollutants to concentrate in the food chain of the ecosystem, leading to the highest accumulation on the top of the food chain—that is, in the large predatory fishes, which include Atlantic Salmon and Whitefish.

The subject of the research was the accumulation of heavy metals in the valuable aquatic bioresources of northwestern Russia: Atlantic Salmon and its fry (Neva and Narva rivers), Sea trout fry (Svir river), and Whitefish (Volkhov river).

Wild fish caught for artificial reproduction and its fry from “Sevzaprybvod” fish hatcheries (state hatcheries on the Neva, Narva, Volkhov, and Svir rivers) authorized by the FFA in 2018 were used (Figure 3).

Figure 3. Map of the selected hatcheries with their locations.
The main focus of study when determining the concentrations of heavy metals in fish tissues was given to the internal organs that are key to the physiological and reproductive states of living organisms: the biliary system (liver), excretory system (kidneys), and reproductive system (gonads, eggs).

The conducted research involved 10 specimens of spawning adult fish from each studied species: Whitefish from the Vokhov State Hatchery (51-53 sm) and Atlantic Salmon from the Neva (70-74 sm) and Narva (75-78 sm) state hatcheries provided by “Sevzaprybvod”, and samples of liver, kidneys, gonads, and eggs were taken.

For determining the accumulation of heavy metals in the Atlantic Salmon fry (10 specimens) and Sea trout fry (10 specimens), samples of mixed tissues (liver, kidneys, muscles) from one-year-old fry (6–10 centimeters in length) and separate samples of liver, kidneys, gonads, and muscles from two-year-old fry (10–20 cm) were taken.

Atlantic Salmon and Sea trout fry are grown in the “Sevzaprybvod” state hatcheries (Neva and Svir rivers) for subsequent release into the rivers for restocking wild fish populations in their natural habitats. Their growth stage takes place in pools with open river water flow, ensuring painless adaptation of young fry during release into the wild.

2.2. Methods and equipment
The study obtained data about heavy metal accumulation in research materials (samples of liver, kidneys, and gonads of studied fish) by carrying out three different methods of analysis: X-ray fluorescence (XRF) analysis [24], voltammetry [25], and capillary electrophoresis [26].

The analysis of samples was carried out using equipment at the Environmental Monitoring Laboratory of ITMO University in two stages: the preparation of the sample and its subsequent analysis.

The X-ray fluorescence (XRF) analysis for the quantitative determination of the heavy metal concentrations in the studying samples was carried out by using a Max GF2E X-ray spectrometer [27]. Selected samples were subjected to dry mineralization—slow heating in air to a temperature of 350 degrees Celsius. Next, the sample was pulverized into powder (fraction yield: 70 microns not less than 95%); then the powder was formed into a tablet using a hydraulic press [28] to prepare it for analysis on a spectrometer by a standardized method for determining heavy metal concentrations [29, 30].

Studies to quantitatively determine the copper, lead, and cadmium content in the samples by a voltammetry method of analysis were carried out on an ABC-1.1 polarograph [31, 32]. This analyzer is designed to measure the mass concentration of various elements such as copper, lead, cadmium, zinc, mercury, nickel, bismuth, arsenic, iodine, etc., in drinking, natural, and waste waters, food, metals, and other materials according to certified or standardized measurement procedures.

Sample preparation for the quantitative analysis of the copper, lead, and cadmium content in the samples by a voltammetry method of analysis were carried out on an ABC-1.1 polarograph [31, 32]. This analyzer is designed to measure the mass concentration of various elements such as copper, lead, cadmium, zinc, mercury, nickel, bismuth, arsenic, iodine, etc., in drinking, natural, and waste waters, food, metals, and other materials according to certified or standardized measurement procedures.

Sample preparation for the quantitative analysis of the copper, lead, and cadmium content on the ABC-1.1 analyzer was carried out using the MC-6 microwave sample preparation system [33], in which the samples under study were subjected to wet mineralization. The MC-6 microwave sample preparation system is used to decompose samples of food products, food raw materials, soils, environmental materials, biological fluids, etc., when analyzing the chemical composition of samples by various methods. The principle of the system is to use microwave energy for rapid heating of samples with the addition of oxidizing agents. The prepared sample was then analyzed by the standard addition method and processed according to the standardized measurement procedure [34].

In the conducted studies to determine the content of strontium and calcium in the samples of Salmonid fry tissues using capillary electrophoresis methods, the Kapel-103RT capillary electrophoresis system was used [35]. This system is intended for the qualitative and quantitative determination of the composition of samples of substances in aqueous and aqueous–organic solutions. The capillary electrophoresis method is implemented in capillaries and is based on differences in the electrophoretic mobilities of charged particles in both aqueous and non-aqueous buffer electrolytes.

Sample preparation for the quantitative analysis of the content of strontium and calcium was carried out using a microwave sample preparation system MC-6 (subjected to wet mineralization).
Then, prepared samples were analyzed by recording electropherograms according to a standardized, approved methodology [36].

3. Results

3.1. Heavy metal accumulation in Whitefish tissue samples
This research covers the analysis of tissues of Whitefish wild spawners caught for artificial reproduction at the Volkhov State hatchery (Volkhov river); samples of the liver, kidneys, and gonads were taken.

According to the data obtained (Table 1), the accumulation centers for each heavy metal were found using a normalized distribution diagram (Figure 4). The accumulation center for zinc, arsenic, and cadmium was the kidneys. For strontium and lead, the accumulation center was gonads, and the liver was the accumulation center for copper.

| Tissues        | Heavy metal concentrations, mg/kg |
|---------------|-----------------------------------|
|               | liver    | kidneys  | gonads   |
| Copper (Cu)   | 0.78±0.06 | 0.22±0.019 | 0.20±0.018 |
| Cadmium (Cd)  | 0.02±0.003 | 0.07±0.006 | 0.05±0.0046 |
| Lead (Pb)     | 0.21±0.01 | 0.43±0.035 | 0.59±0.043 |
| Strontium (Sr)| 19.00±0.93 | 10.00±0.89 | 27.00±1.86 |
| Arsenic (As)  | 4.00±0.39 | 5.00±0.47 | 2.00±0.19  |
| Zinc (Zn)     | 148.00±11.25 | 905.00±74.25 | 79.00±7.01 |

±SD, standard deviation.

The decreasing series of metal concentrations in the internal organs of the Whitefish is arranged as follows: Zn > Sr > As > Cu > Pb > Cd.

Figure 4. Normalized distribution diagram of heavy metals in the tissues of Whitefish.

High levels of zinc accumulation (with abnormally high accumulation observed in the kidneys), arsenic, and strontium were found in the samples of Whitefish tissues.
3.2. Heavy metal accumulation in Atlantic Salmon tissue samples

Sampling of Atlantic Salmon tissues was carried out from wild spawners caught for artificial reproduction in the Nevsky State hatchery (Neva River) and Narva State hatchery (Narva River). Samples of liver, kidneys, gonads, and eggs were taken in this study.

Based on the data obtained on the accumulation of heavy metals in the internal organs of the Atlantic Salmon caught for artificial reproduction from Neva River (Table 2), the accumulation center of zinc, arsenic, and copper was the liver. For strontium and lead, the accumulation center was the gonads; for cadmium, it was the kidneys (Figure 5a).

When comparing concentrations of heavy metals in the centers of accumulation and their levels in the reproductive system (eggs), practically all studied heavy metals (except strontium and zinc) in Atlantic Salmon presented the greatest concentration in the eggs. This indicates that the general state of heavy metal concentration in the organism of a producer affects the level of their accumulation in the offspring (eggs), and in most cases, the content of heavy metals in eggs was several times higher than the quantitative content in the centers of accumulation.

Table 2. Heavy metal accumulation in the tissues of Atlantic Salmon from the Neva river.

| Heavy metal concentrations, mg/kg | Liver | Kidneys | Gonads | Eggs |
|----------------------------------|-------|---------|--------|------|
| Copper (Cu)                      | 2.98 ± 0.18 | 0.36 ± 0.029 | 0.50 ± 0.047 | 14.81 ± 1.59 |
| Cadmium (Cd)                     | 0.10 ± 0.012 | 0.39 ± 0.032 | 0.01 ± 0.0013 | 0.53 ± 0.048 |
| Lead (Pb)                        | 0.15 ± 0.014 | 0.19 ± 0.017 | 0.30 ± 0.027 | 20.83 ± 2.15 |
| Strontium (Sr)                   | 18.00 ± 1.54 | 22.00 ± 2.18 | 31.00 ± 2.94 | 12.00 ± 1.31 |
| Arsenic (As)                     | 6.00 ± 0.57 | 5.00 ± 0.51 | 3.00 ± 0.28 | 6.00 ± 0.57 |
| Zinc (Zn)                        | 220.00 ± 20.59 | 183.00 ± 17.84 | 56.00 ± 5.49 | 104.00 ± 9.88 |

±SD, standard deviation.

Notable cases were observed for arsenic and lead accumulation in the salmon eggs: arsenic had the same distribution in the center of accumulation (liver) and in the eggs, while lead accumulation in the salmon eggs was at a concentration 10 times higher than that in the center of accumulation (gonads).

Figure 5. Normalized distribution diagram of heavy metals in the tissues of Atlantic Salmon from different spawning rivers: (a) Neva river; (b) Narva river.
The quantitative content of heavy metals and their accumulation centers in the tissue samples of the Atlantic Salmon caught for artificial reproduction in the Narva River (Table 3) were different from those in the samples of Atlantic Salmon from the Neva River.

Table 3. Heavy metal accumulation in the tissues of Atlantic Salmon from the Narva river.

| Tissues       | Heavy metal concentrations, mg/kg |   |   |   |   |   |   |   |
|---------------|-----------------------------------|---|---|---|---|---|---|---|
|               | liver                             | kidneys | gonads |   |   |   |   |   |
| Copper (Cu)   | 5.25 ± 10%                        | 0.21 ± 10% | 0.46 ± 10% |   |   |   |   |   |
| Cadmium (Cd)  | 0.62 ± 10%                        | 0.35 ± 10% | 0.20 ± 10% |   |   |   |   |   |
| Lead (Pb)     | 0.60 ± 10%                        | 0.43 ± 10% | 0.33 ± 10% |   |   |   |   |   |
| Strontium (Sr)| 25.00 ± 10%                       | 26.00 ± 10% | 36.00 ± 10% |   |   |   |   |   |
| Arsenic (As)  | 5.00 ± 10%                        | 7.00 ± 10% | 4.00 ± 10% |   |   |   |   |   |
| Zinc (Zn)     | 119.00 ± 10%                      | 126.00 ± 10% | 70.00 ± 10% | ±SD, standard deviation. |

It was shown that the zinc and arsenic accumulation center in the Atlantic Salmon caught for artificial reproduction in the Narva River, in the contrast to the Atlantic Salmon from the Neva river, was the kidneys, while the lead and cadmium accumulation centers moved to the liver (Figure 5b). The strontium and copper accumulation centers (gonads and liver, respectively) in the two observed populations converged.

The identified differences between the distribution and accumulation centers of heavy metals in the same species of Atlantic Salmon caught in two different rivers can be explained by the fact that the species has a complex intraspecific structure and high genetic diversity [37, 38].

To study the deviation of the accumulation of certain types of heavy metals from the spawning and accumulating tissue types, one-way analysis of variance (ANOVA) was carried out [39]. The ANOVA analysis was performed based on the obtained data on heavy metal accumulation in Atlantic Salmon caught for artificial reproduction (Table 4).

Table 4. ANOVA analysis of heavy metal accumulation in the tissues of the Atlantic Salmon.

| Factor       | Me | df  | F    | p     | F crit. | Me | df  | F    | p     | F crit. |
|--------------|----|-----|------|-------|---------|----|-----|------|-------|---------|
| spawning river Cu | 1  | 3.093 | 0.153 | 4.96  | Sr      | 1  | 102.311 | 0.001 | 4.96 |
| tissues      | 1  | 0.166 | 0.692 | 4.96  | Sr      | 1  | 102.311 | 0.001 | 4.96 |
| spawning river Cd | 1  | 10.911 | 0.030 | 4.96  | As      | 1  | 64.286 | 0.001 | 4.96 |
| tissues      | 1  | 12.529 | 0.038 | 4.96  | As      | 1  | 64.286 | 0.001 | 4.96 |
| spawning river Pb | 1  | 54.871 | 0.002 | 4.96  | Zn      | 1  | 23.973 | 0.008 | 4.96 |
| tissues      | 1  | 15.457 | 0.029 | 4.96  | Zn      | 1  | 23.973 | 0.008 | 4.96 |

ANOVA analysis of heavy metal accumulation in the Atlantic Salmon with respect to two factors (spawning river, tissue) showed significant results (p > 0.5) for the accumulation characteristics of copper depending on the accumulation in the internal organs. The accumulation of the other studied heavy metals within one species, according to the result, does not depend on the spawning river or the type of tissue.

3.3. Heavy metal accumulation in Atlantic Salmon and Sea trout fry tissue samples

In recent decades, in connection with the development of industrial enterprises, ports, and residential areas along the Svir river and the Neva river, the intensification of navigation on the river and the pollution of the Svir river and Neva river have increased and may pose a risk to aquaculture.
In this study, we examined the heavy metal accumulation in the muscles of the Atlantic Salmon and Sea trout fry to determine the levels of heavy metal content, evaluate their toxic effect, and establish patterns of accumulation of individual heavy metals.

The accumulation of heavy metals was studied in the muscles and internal organs of one- and two-year-old Salmonid fry (Atlantic Salmon, Sea trout) grown for later release into the wild at “Sevzaprybvod” State hatcheries (Neva and Svir rivers).

In the muscle samples of Atlantic Salmon fry, the highest values of heavy metal accumulation were noted for strontium and zinc (Table 5).

**Table 5. Heavy metal content in the muscles of the Atlantic Salmon fry (mg/kg, dry weight).**

| River | Length, cm | Sr      | Pb     | As      | Zn      |
|-------|------------|---------|--------|---------|---------|
| Neva  | 8          | 193.00 ± 19.2 | 3.00 ± 0.31 | 9.00 ± 0.87 | 145 ± 14.43 |
|       | 13         | 37.00 ± 3.65   | 8.00 ± 0.78   | 104.00 ± 10.39 | 104 ± 10.37  |
| Svir  | 6          | 62.00 ± 6.18   | 5.00 ± 0.53   | 16.00 ± 1.60   | 97.00 ± 9.71  |
|       | 17         | 17.00 ± 1.66   | 4.00 ± 0.44   | 4.00 ± 0.45    | 54.00 ± 5.38  |

±SD, standard deviation.

An in-depth study of heavy metal accumulation in tissues and muscles was carried out for one-year-old (6–10 centimeters) Sea trout fry (Table 6) using XRF analysis.

**Table 6. Copper, arsenic, and zinc concentrations in the tissues of the Sea trout fry (mg/kg, dry weight).**

| Samples       | Sr      | As     | Zn      |
|---------------|---------|--------|---------|
| Muscles       | 62.00 ± 6.20 | 16.00 ± 5.00 | 97.00 ± 11.50 |
| Internal organs | 65.00 ± 8.90 | 16.00 ± 3.00 | 160.00 ± 20.05 |

±SD, standard deviation.

The obtained data showed a slight difference between the accumulation of strontium and arsenic in muscles and internal organs. At the same time, the zinc concentration in the internal organs was 1.6 times higher than that in the muscles.

**Table 7. Ratio of magnesium, strontium, and calcium in the tissues of Sea trout fry.**

| Samples       | Concentrations, mg/dm³ | Ratio |
|---------------|------------------------|-------|
|               | Mg   | Sr      | Ca     | Ca/Sr | Ca/Mg | Mg/Sr |
| Internal organs | 5.43 ± 0.91 | 0.21 ± 0.02 | 65.25 ± 8.31 | 307.06 | 12.03 | 25.53 |
| Muscles       | 8.00 ± 1.02 | 0.16 ± 0.01 | 60.25 ± 9.43 | 387.46 | 7.53 | 51.45 |

±SD, standard deviation.

Study of the ratio of magnesium, strontium, and calcium in the tissues of Sea trout fry showed relatively large accumulation of strontium in the internal organs and of calcium and magnesium in the muscles (Table 7). The content of calcium in both cases was more than 300 times higher than the accumulation of strontium, which indicates a positive situation in the place of growing juveniles in relation to the presence of mobile forms of strontium.
3.4. Relationship analysis of heavy metal accumulation in Salmonid fry muscle samples with respect to the age group and water body

Analysis of the relationship of heavy metal accumulation in the muscles of Salmonid fry (Atlantic Salmon, Sea trout) with the age group and water body (Neva and Svir rivers) was carried out using the method of pair correlation of average values [40] at the level of reliability $p = 0.95$.

The analysis showed that the accumulation of lead and arsenic is practically not related to the age group of the fry, while the content of strontium and zinc shows an inverse correlation with the length of the fry (Table 8). The latter means that the accumulation of zinc and strontium is much stronger in the early stages of fry growth (one year old, 6–10 cm) than in the older age group (two years old, 13–20 cm), which can be attributed to the much greater vulnerability of the young fry to these toxicants. This may be caused by weaker integments of the body (skin, scales), the sensitivity of the gills, and the ability of organisms to eliminate these toxicants.

| Correlation Coefficients                        | Sr  | Pb  | As  | Zn  |
|------------------------------------------------|-----|-----|-----|-----|
| Fry length/heavy metal concentration           | −0.64 | 0.20 | 0.18 | −0.72 |
| River/heavy metal concentration                | −0.04 | 0.32 | 0.59 | 0.62 |
| Fish species/heavy metal concentration         | 0.32 | 0.24 | 0.55 | 0.75 |

Significant association was shown of the accumulation of arsenic and zinc in the muscles of young fish with the water body in which they were raised and with the species of the fry.

4. Discussion and conclusions

The world’s aquatic ecosystems are structurally and functionally highly biodiverse, forming a vital web of thousands of interconnected species which support fisheries and aquaculture, contributing to the nutritional, economic, social, cultural, and recreational betterment of human populations [2, 4, 7].

Aquaculture is an integral part of the multifunctional agricultural sector and it plays a significant role in rural development [4, 7]. In light of the negative ecotoxicological aspects of cage farming in terms of the quality of fish products (high fat content, high content of antibiotic and antifungal agent decay products, etc.) and high ecological risks (risks due to water pollution by nutrients and chemicals, parasites of fish typical of foreign producers entering water bodies, etc.) [21-23], the alternative case of replenishing the populations of wild Salmonids and Whitefish is reasonable in relation to the current water pollution in the Baltic Sea region of Russia due to chemical anthropogenic impacts [41-43].

The results on the heavy metal accumulation showed that greatest accumulation in the internal organs of Salmonids and Whitefish was indicated for zinc, strontium, and lead. The heavy metal accumulation centers in the internal organs of each studied fish were identified. All studied fish expressed organ-specific accumulation [44-46] of copper and lead and showed a statistically significant relationship of heavy metal accumulation: a significant relationship with the habitat was observed for the accumulation of copper in the internal organs of the Atlantic Salmon.

In the juveniles of the studied Salmonids (Sea Trout, Atlantic salmon) grown at the State hatcheries of northwest Russia, the highest values of heavy metal accumulation in muscles were noted for strontium and zinc. Significant calcium levels were found in the internal organs and muscles of the studied Salmonid fry compared with strontium levels, which indicates a prosperous situation at the place selected for juvenile rearing in terms of the presence of mobile forms of strontium. The accumulation of lead and arsenic is practically not related to the age group of the fry, while the content of strontium and zinc shows a high inverse correlation with the length of the fry, which indicates a much greater vulnerability of young fry to heavy metals [47, 48].
With regard to the role of aquaculture in rural development and FAO initiatives in achieving SDGs [1-4] of maintaining both favourable ecological conditions and biodiversity in the aquatic environment, the results of this study indicate the acceptability and feasibility of restoring the studied populations of wild Salmonids and Whitefish in their native habitat to commercial values; the hatcheries used for this purpose are directly “built” into the water ecosystem and meet both the requirements of the ecosystem approach to aquaculture (EAA) and “sustainable aquaculture” principles [1, 4, 7, 49].

We suggest several actions to be undertaken to maintain and improve the current system of restocking wild Salmonids and Whitefish populations in northwest Russia:

- enhancing hatcheries with automatic control systems of environmental parameters, especially in the territories with high anthropogenic pressure, to increase the survival chances of young fry;
- introducing track control of spawners in order to choose individuals with the best reproductive quality.

The obtained dependences in the accumulation and distribution of heavy metals within the studied objects (Salmonids and Whitefish) can serve as a scientific basis for more effective control on the safety of fish products in northwest Russia and ensure its high quality. We plan to continue research on studying the impact of pollutant bioaccumulation in the tissues of Salmonids and Whitefish and their effects on biochemical aspects.

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