Short thesis for the degree of Doctor of Philosophy (PhD)

Bioaccumulation of Trace Elements in the Maros and Szamos Rivers: Fish as Bioindicators of Aquatic Pollution

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1. Introduction

Freshwater ecosystems are under increasing pressure from pollution, habitat degradation, and overexploitation. In Europe, 65% of freshwater fish species are threatened, primarily due to water pollution, water abstraction, and invasive species (Kottelat & Freyhof, 2007; Vié et al., 2009). Fish play vital ecological and economic roles, however population trends remain unknown for 76% of species, suggesting that biodiversity loss may be underestimated (Gozlan et al., 2019).

In Hungary, the Maros River and Szamos river are vulnerable to heavy metal pollution, particularly from upstream industrial and mining activities. The 2000 Baia Mare cyanide spill severely impacted the Szamos River, killing over 1,200 tonnes of fish (Koenig, 2000; WWF, 2002). Despite signs of ecological recovery (Antal et al., 2013), heavy metals persist in the environment matrices (Sandu & Bloesch, 2006).

Fish are effective bioindicators of aquatic pollution, reflecting long-term environmental conditions and contaminant accumulation through both dietary intake and waterborne exposure (Sandu & Bloesch, 2008; Subotić et al., 2013). However, knowledge remains limited regarding how trace elements accumulate in fish according to age, tissue type, and feeding habits in the Maros and Szamos Rivers. Few studies in Hungary have evaluated species-specific contamination risks in relation to human consumption.

This study addresses these gaps by analysing trace element concentrations in juvenile and adult fish tissues to inform food safety assessment, strengthening the use of fish as bioindicators, and supporting conservation and management strategies.

2. Objectives

This study aims to achieve the following primary objectives, designed to address specific research questions:

(i) *To analyse the concentrations of macroelements (calcium, potassium, magnesium, and sodium) and microelements (cadmium, chromium, copper, iron, manganese, lead, strontium, and zinc) in different fish tissues (gills, liver, and muscle) to assess tissue-specific bioaccumulation patterns:* (a) Which macroelements and microelements exhibit the highest accumulation in gill, liver, and muscle tissues? (b) How do tissue-specific bioaccumulation patterns vary among fish species within each river system?

(ii) *To evaluate the influence of environmental conditions and species-specific traits on trace element bioaccumulation in juvenile fish from the Szamos River and adult fish from the Maros River*: (a) How do trace element accumulation patterns differ in juvenile Szamos River fish and adult Maros River fish? (b) How do water and sediment quality parameters influence trace element accumulation within each river system? (c) How do species-specific traits, including habitat preference, feeding habits, and species-level trophic position, contribute to observed bioaccumulation patterns? (d) Which fish species serve as the most reliable bioindicators of trace element pollution? (e) Do heavy metal concentrations in fish muscle exceed food safety thresholds and pose potential health risks to consumers?

3. Materials and Methods

3.1. Sampling area and sample collection

The Szamos and Maros Rivers, both major tributaries of the Tisza River have been significantly impacted by industrial activities, particularly mining. The Szamos River has a history of severe pollution, from mining operations in Romania, making it one of the most polluted rivers in Europe (Kraft et al., 2006; Simon et al., 2017a). Notably, it shows elevated levels of strontium and other metals such as lead, cadmium, copper, and zinc (Málnás et al., 2014). The sampling was done in autumn November 2013 and sampling location was in the Csenger area, close to the border between Hungary and Romania (47°50'17.89"N, 22°41'37.48"E) as shown in Figure 1A.

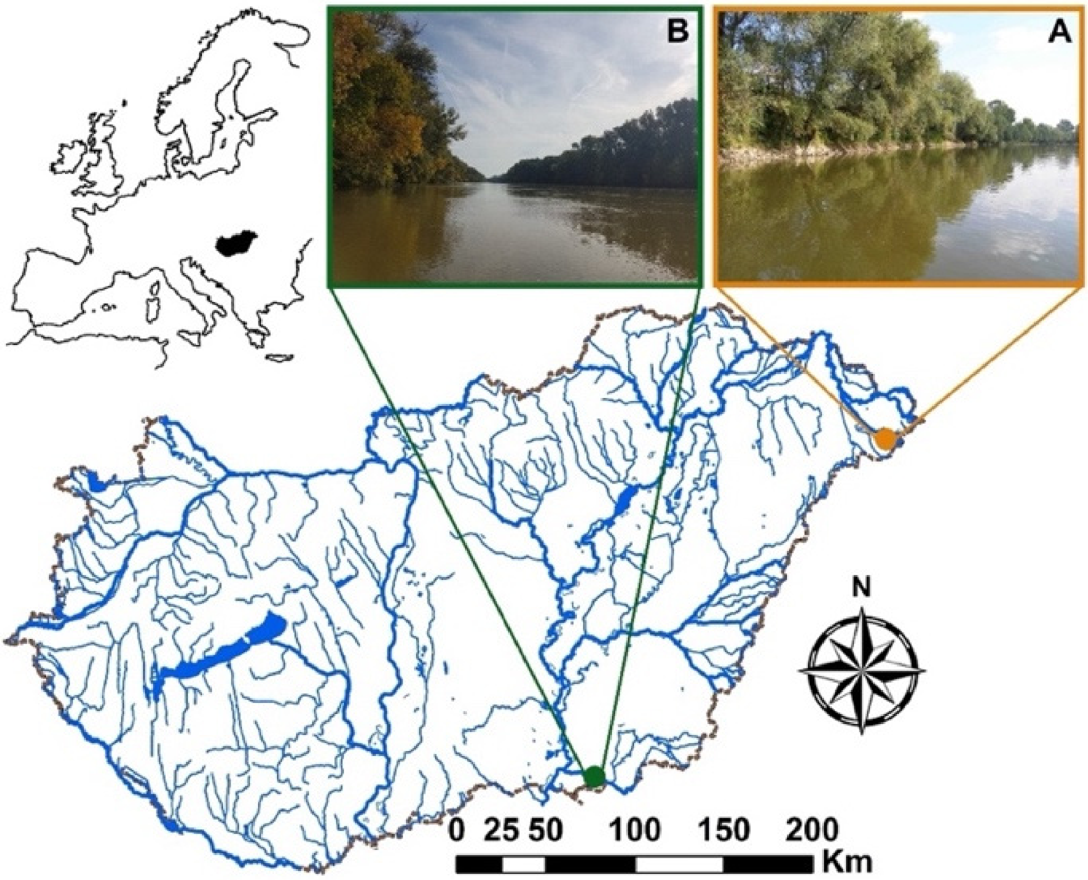

Figure 1. Map of the sampling sites. A: Szamos/Someş river near Csenger, B: Maros River near Makó.

Similarly, the Maros River, one of the largest in the Tisza basin, also shows signs of recent pollution (Málnás et al., 2014; Nyeste et al., 2019). Its ecological significance, combined with contamination concerns, makes it a critical site for environmental monitoring. The sampling work was done during autumn, October

2020 for two days along the Maros River near Makó, near the Romanian border (46°12'12.45"N, 20°27'14.11"E), as shown in Figure 1B.

Fish were captured using an electrofishing device (Hans Grassl IG200/2b). The captured fish were euthanised on-site immediately after capture using clove oil and brought to the laboratory, where the samples were refrigerated at -18 ºC. Ethical approval for the experimental protocol and endpoints was granted by the Workplace Animal Experiments Committee of the University of Debrecen (approval number: HBH/01/00971-2/2013). All procedures were conducted following appropriate national and international protocols and regulations. The study adhered to the principles as detailed in the Animal Research: Reporting of In Vivo Experiments (ARRIVE) guidelines.

3.2. Fish biological characteristics

Juvenile fish

Fifteen cyprinid fish were examined (n = 15), with five individuals per species. The standard length and body weight (mean ± standard deviation) for the juveniles were determined as follows: barbel (*Barbus barbus*) (52.1 ± 2.4 mm; 2.56 ± 0.32 g), chub (*Squalius cephalus*) (60.6 ± 5.1 mm; 4.06 ± 1.23 g), and nase (*Chondrostoma nasus*) (72.3 ± 3.8 mm; 5.57 ± 1.10 g). Based on these measurements, the fish were classified as belonging to the 0+ age group, indicating juveniles (Epler et al., 2009; Vegh et al., 2020).

Adult fish

One hundred adult specimens were collected (n = 100), with ten individuals per species. The species examined were asp (*Leuciscus aspius*), barbel (*Barbus barbus*), catfish (*Silurus glanis*), chub (*Squalius cephalus*), carp (*Cyprinus carpio*), nase (*Chondrostoma nasus*), silver carp (*Hypophthalmichthys molitrix*), bream (*Abramis brama*), white-eye bream (*Ballerus sapa*), and zander (*Sander lucioperca*).

3.3. Sample Processing and Element Analysis

As preparation, beakers are cleaned with nitric acid and distilled water to avoid contamination, and the weight of the dry beakers was recorded. The samples were thawed, and the standard length (SL), total length (TL), and mass (M) of each fish were recorded. Following that, plastic instruments and gloves were used to extract the tissue samples to prevent any contamination by metals. The left side of each fish was prepared for tissue sampling by carefully removing scales and skin along the dorsal region above the dorsal line. A cube-shaped section of muscle tissue (approximately 1–2 cm^3) was excised. Liver samples of similar dimensions (1–2 cm^3) were also collected. Gills were sampled by removing part of the branchial system (gill filament and gill arch) and extracting the second gill arch on the left side.

Before the weighing process, the dissected samples were rinsed with double-deionised water (Milli-Q) and then placed into glass beakers on an analytical balance (Precisa 240A). They were left to dry overnight at 105 °C until they reached a consistent weight, and then the dried samples were measured from the dry mass. In the same container, samples were digested for 4 hours at 80 °C on an electric hot plate with 4.0 mL of 65% nitric acid (m/m, reagent grade, Merck) and 1.0 mL of 30% hydrogen peroxide (m/m, reagent grade, Merck). The samples, once digested, were transferred into volume-calibrated plastic centrifuge tubes and diluted to a final volume of 10 mL containing 1% nitric acid (m/m, reagent grade, Merck) and Milli-Q water (Braun et al., 2009).

The trace element (Al, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, and Zn) in the samples were analyzed with an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES 5100, Agilent Technologies). The setup included an autosampler (SPS 3, Agilent Technologies), a Meinhard-type nebulizer, and a double-pass spray chamber. A five-point calibration approach was applied based on The ICP multi-element standard solution IV (Merck). The measurement process involved the use of certified reference material (ERM-BB422, fish muscle). The metal recoveries were found to be within 10% of the certified values, and the wavelengths and measuring parameters were selected according to the software of instrument (MP EXpert) guidelines. All element concentrations were presented as mg kg^{-1} wet weight (ww).

3.4. Statistical Analysis

The bioconcentration factor (BCF) refers to the ratio of the concentration of a chemical in an organism (or a specific tissue) compared to its concentration in the water or sediment (Ivanciuc et al., 2006; Nyeste et al., 2019, 2024):

$$BCF_{\text{water or sediment}} = C_{\text{fish}} / C_{\text{water or sediment}}$$

where C_{fish} refers to the concentration of the chemical in the organism's whole body or tissue (mg kg^{-1} wet weight), C_{water} is the concentration in the water (mg L^{-1}), and C_{sediment} is the concentration of the trace element in the sediment (mg kg^{-1} dry weight).

Data on trace element concentrations in sediments and water were sourced from the National Environmental Information System of Hungary (OKIR in Hungarian) database. The concentrations were evaluated against the chronic concentration criteria (CCCs) for freshwater set by the National Recommended Water Quality Criteria (USEPA, 2017).

Metal pollution index (MPI) was assessed to compare the total content of trace elements excluding the macro elements (Cd, Cr, Cu, Fe, Mn, Pb, Sr, Zn) for the different tissues of each specimen. The following formula represents the MPI (Ju et al., 2017; Nyeste et al., 2019; Usero et al., 1997):

$$\mathrm{MPI} = (C_1 \times C_2 \times C_3 \times \ldots C_n)^{1/n}$$

where C_n indicates the mean concentrations of trace element n in the examined tissue (mg kg-1 wet weight).

The statistical analysis was conducted using IBM SPSS Statistics (Version: 28.0.11 (14)) for Mac (*IBM*, 2011) and Past 3.03 (Hammer et al., 2001) software with the Shapiro-Wilk test applied to test for normal distribution. Levene's test (Levene, 1960) was used to assess the homogeneity of variances. Due to the lack of normality in the data (Shapiro-Wilk test, $p < 0.05$), the non-parametric Kruskal-Wallis's test was applied to compare the concentrations and BCF values of elements in the muscle, gills, and liver of each juvenile species (Habib et al., 2022; Nyeste et al., 2019). As a post hoc test, the Mann-Whitney U test was used to investigate the significant differences between the groups. With the macroelements excluded, principal component analysis (PCA) was utilised to examine the differences between species based on the concentration of trace elements (Cd, Cr, Cu, Fe, Mn, Pb, Sr, Zn) in various fish tissues. The potential health risks of consuming these fish species were assessed, and the concentrations of trace elements in muscle tissue were compared with the maximum acceptable concentrations (MACs) established by the European Union (EU, 2008) and the Food and Agriculture Organization of the United Nations (Nauen, 1983)

4. Results and Discussion

4.1. Analysis of Trace Element Concentrations in Sediments and Water

The analysis of trace element concentrations in sediments and water from the Szamos and Maros Rivers reveals both persistent and emerging contamination issues. In the Szamos River, sediment data suggest ongoing pollution, with Cr at moderate levels and Cu, Mn, and Zn at heavily polluted levels (Málnás et al., 2014; Simon et al., 2017b). Water samples in 2013 showed that Cu, Cd, Pb, and Zn exceeded the EPA's freshwater criteria (CCCs) by 2–10 times, indicating recent contamination (EPA, 2018), likely driven by domestic sewage, agro-industrial processes, and agricultural runoff (Koh et al., 2015). These results align with previous studies on chub and dragonfly larvae, showing significant contamination linked to industrial (mining) and agricultural activities (Málnás et al., 2014; Nyeste et al., 2019; Simon et al., 2017b). In contrast, the water chemistry data of Maros River in 2020 revealed iron (Fe) levels exceeding CCCs by 10 times (EPA, 2018), while other elements like Cd, Cu, Mn, Pb, and Zn were below thresholds. The elevated Fe, possibly resulting from fertilizer use, pesticides, and increased runoff during warmer, wetter winters, reflects trends observed in Northern Europe and North America (Björnerås et al., 2017; Riise et al., 2023; Sarkkola et al., 2013; Viana et al., 2021). While Fe is a natural sorbent, excess levels can cause genetic mutations and bone disorders in vertebrates and pose risks to human health (Chandrapalan & Kwong, 2020; Rahmani et al., 2018). However, a lack of studies on local lithology in both rivers limits the understanding of natural contributions to trace metal loads.

4.2. Assessment of Bioaccumulation in Juveniles from the Szamos River

This study reveals that juvenile fish are effective bioindicators of heavy metal pollution due to their distinct macroelement and trace element accumulation patterns, which are shaped more by habitat preference than trophic level. Macronutrient accumulation patterns (e.g., K>Ca>Na>Mg in muscle) reflect their physiological roles (Khawar et al., 2024; Ustaoğlu et al., 2024), while trace elements like Cr, Cu, Fe, and Zn correlate with trophic level only in muscle tissues. Higher Cu levels in the liver of nase, a low-trophic herbivore, contradict this trend, suggesting a stronger link to dietary intake of benthic algae (Djikanović et al., 2016; González-Dávila et al., 2000). Cd accumulation in chub, a pelagic species, highlights the impact of gill respiration exposure, while Pb accumulation in benthic juveniles' liver suggests uptake via ingestion (Jia et al., 2017; Subotić et al., 2015). Despite high Cd in water, its absence in sediment and higher levels in pelagic species suggest habitat-driven accumulation, not diet (Llamazares Vegh et al., 2022; Milošković et al., 2016). Zn and Cu were elevated in both sediment and water in the Szamos River, aligning with higher gill accumulation in pelagic chub (Harkabusová et al., 2012). Moreover, Cr and Mn accumulation in benthic juveniles (barbel and nase) corresponds with sediment data showing moderate to heavy pollution. Juveniles showed greater sensitivity to contamination than adults, likely due to faster growth, higher metabolic rates, and less-developed detox systems (Jia et al., 2017; Nikolić et al., 2021). These findings support the use of species-specific habitat preferences in early life stages as a powerful tool for biomonitoring, as microhabitat differences cause diverse bioaccumulation patterns even within the same river stretch. Thus, employing both pelagic and benthic juvenile species offers a more comprehensive approach to assessing ongoing and long-term pollution in aquatic ecosystems.

4.3. Assessment of Bioaccumulation in Adults from the Maros River

The distribution of macroelements in adult fish from the Maros and Szamos Rivers revealed clear tissue- and species-specific patterns. Potassium (K) was most abundant in muscle tissues, particularly in omnivorous species like bream, likely due to its role in muscle contraction and cellular function. Conversely, calcium (Ca), sodium (Na), and magnesium (Mg) were predominantly concentrated in the gills, especially in piscivorous species such as asp and catfish. This is consistent with the gills' key function in osmoregulation and ion exchange, making them primary sites for physiological adaptation to environmental conditions. The sequence of macroelement concentrations—K > Ca > Na > Mg in muscle; Ca > Na > K > Mg in gills; and K > Na > Ca > Mg in liver, supports this functional differentiation. These observations reflect the active role of the gills in regulating ionic balance in response to external stressors like salinity, temperature, and pollutants (Marshall, 1995; Perry, 1997; Uchida et al., 2000). Moreover, the variation across species further emphasizes how feeding behavior and habitat preferences influence elemental uptake.

For trace elements, iron (Fe), zinc (Zn), and copper (Cu) dominated across all tissues, with higher concentrations observed in the liver and gills of species like asp and silver carp. The liver, being the central organ for detoxification and metal storage, naturally showed elevated levels, especially of Cu and Fe, which play essential roles in enzymatic processes. The gills, continuously exposed to the aquatic environment, accumulated reactive metals such as Mn and Cr, especially in pelagic species like asp, suggesting waterborne exposure and possibly biomagnification via contaminated prey (Das Pinkey et al., 2024; Jia et al., 2018). The highest Cd and Zn concentrations were found in the livers of omnivorous bream and carp, likely due to benthic foraging, which increases contact with contaminated sediments and enhances uptake through bioturbation (Burada et al., 2014; X. Zhang et al., 2016).

Filter-feeding species like silver carp had higher levels of Cu and Fe in their liver, a likely result of constant water filtration and ingestion of suspended particles, which increases exposure to dissolved and particulate-bound metals (Calkins et al., 2012; Xia et al., 2022). It is consistent with the liver's central role in metal regulation and detoxification. However, both Fe and Cu are redox-active transition metals that can catalyse the formation of reactive oxygen species (ROS) through Fenton and Fenton-like reactions when present at elevated concentrations, potentially leading to oxidative stress if cellular antioxidant defences are overwhelmed (Lushchak, 2011; Valko et al., 2005). Experimental studies have shown that copper exposure can disrupt antioxidant defence systems in fish, altering enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), while increasing lipid peroxidation and causing tissue damage (Atli & Canli, 2010; Lushchak, 2011). More recently, copper-induced oxidative stress has also been linked to transcriptomic changes, intestinal microbiota alterations, and histopathological damage in common carp (*Cyprinus carpio*), indicating that elevated Cu burdens may have systemic physiological consequences beyond simple storage (L. Zhang et al., 2022).

Similarly, excessive iron accumulation has been shown to induce hematological disturbances, oxidative imbalance, and histological alterations in freshwater fish such as *Labeo rohita*, demonstrating that Fe overload can result in sublethal toxic effects (Singh et al., 2019). Taken together, these findings suggest that the elevated hepatic Fe and Cu concentrations observed in silver carp in the present study may reflect not only physiological regulation but also the potential for oxidative and tissue-level stress. Therefore, further assessment of antioxidant biomarkers, haematological parameters, and histopathological endpoints would help clarify whether the observed metal burdens represent adaptive detoxification or early toxicological effects.

In conclusion, species-specific ecological traits such as habitat use and feeding strategy strongly affect bioaccumulation patterns more than the trophic level. It also confirms that fish gills and liver are reliable tissues for environmental monitoring of trace elements, with asp, bream, carp, white eye-bream and silver carp emerging as strong bioindicator candidates for metal pollution in Maros River (Canli & Atli, 2003; Kareem et al., 2022; Subotić et al., 2013).

4.4. Human Health Implications

According to the Food and Agriculture Organization (FAO) and Commission Regulation (EC), the Maximum Allowable Concentrations (MACs) for toxic elements in fish muscle are established to protect public health: Cd (0.05 mg/kg ww), Cr (1.0 mg/kg ww), Cu (30.0 mg/kg ww), Fe (43.0 mg/kg ww), Mn (1.0 mg/kg ww), Pb (0.30 mg/kg ww), and Zn (40.0 mg/kg ww) (European Union, 2008; Nauen, 1983). In the Szamos River, juvenile chub exceeded the MACs for Cd (0.10 ± 0.17 mg/kg ww) and Pb (0.36 ± 0.31 mg/kg ww) in muscle tissue, while Cr, Cu, Fe, Mn, and Zn remained below the safety thresholds. This is particularly concerning as these elevated levels in fish tissues directly reflect the elevated concentrations of Cd and Pb in the water, highlighting active, ongoing waterborne pollution. The absence of these metals in sediments suggests that pelagic fish such as chub are more vulnerable to direct water contamination than benthic species like barbel and nase. Moreover, the mean concentrations of multiple elements (Cu, Fe, Mn, Pb, Zn in gills; Cd, Cr, Fe, Mn, Pb, Zn in liver) exceeded the MACs, indicating that these organs are unsafe for human consumption. Although regulations in Hungary prohibit the harvesting of juvenile cyprinids, the presence of hazardous levels of Cd and Pb in these young fish presents potential health risks in cases of unauthorised fishing. These findings underscore the need for additional investigations into trace element accumulation in adult fish from the Szamos River to better evaluate the health risks (European Union, 2008; Nauen, 1983).

In contrast, adult fish species from the Maros River had muscle tissue concentrations of all examined elements below the MACs, suggesting that their flesh is safe to consume. However, several elements, particularly Mn and Zn in gills, and Cd, Fe, Mn, and Zn in livers, exceeded MACs across multiple species. This indicates that while muscle may be consumed safely, gill and liver tissues should be avoided due to potential toxicity. Interestingly, muscle pollution index (MPI) values were lowest in piscivorous catfish and zander despite their high trophic positions, which suggests that trophic level alone does not always predict heavy metal bioaccumulation. In contrast, common carp and silver carp exhibited the highest MPI values in gills and liver, respectively, likely due to their benthic feeding and filter-feeding habits that increase exposure to sediment-associated and waterborne contaminants. However, further studies are needed to fully understand the mechanisms behind their sensitivity and to validate their potential as reliable sentinel species. Ongoing biomonitoring efforts are essential to ensure the safety of fish consumption and protect public health in these two major tributaries of the Tisza River.

5. Conclusion

This study confirms that the Szamos and Maros Rivers are contaminated with various trace elements in both water and sediments. Fish at different life stages proved effective as bioindicators, revealing that feeding habits and habitat preference have a greater influence than trophic level on metal accumulation. Juvenile fish showed high sensitivity to heavy metals, especially in muscle tissue, making them reliable indicators of contamination. Chub was the best juvenile bioindicator, while adult asp, silver carp, common carp, common bream, and white-eye bream were key adult indicators based on their trace element affinity and accumulation patterns. Muscle tissue of juvenile chub contained cadmium and lead above food safety limits, posing potential health risks, whereas adult fish muscle remained within the established safety limits. Continued monitoring of adult fish in the Szamos River and regular assessment in the Maros River are essential to protect ecosystem health and ensure long-term food safety

6. New Scientific Findings

Szamos River (Juvenile)

- Elevated waterborne Cd, Pb, and Zn were linked to higher accumulation in pelagic juvenile chub, especially in muscle and gills, indicating dominant waterborne exposure.
- Sediment-associated Cr, Cu, and Mn accumulated more in benthic juveniles such as nase and barbel, reflecting habitat-driven uptake.
- Juveniles showed higher bioconcentration of Cd, Cr, Cu, and Pb in the liver and of Fe, Mn, and Sr in the gills, demonstrating clear tissue-specific accumulation at early life stages.
- Cd and Pb in juvenile chub muscle exceeded maximum allowable concentrations, posing potential health risks.
- Juvenile chub was identified as the most sensitive and reliable bioindicator of pollution in the Szamos River

Maros River (Adult)

- Fe and Zn were the most abundant trace elements across adult fish tissues.
- Feeding strategy and habitat preference influenced metal accumulation more strongly than trophic level.
- The piscivorous asp showed the highest Cr and Sr levels in the gills, likely linked to pelagic exposure.
- Planktivorous silver carp accumulated the most Cu and Fe in the liver due to filter-feeding and high water intake, warranting further investigations.
- Omnivorous common bream had the highest Cd in the liver, indicating sediment-related accumulation.
- Carp showed elevated Zn in the liver, associated with benthic feeding and physiological demand.
- Adult fish muscle concentrations remained below maximum allowable limits, indicating safe consumption.
- Gills and liver are not recommended for consumption due to consistently higher metal accumulation.

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7. References

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List of publications related to the dissertation

Foreign language scientific articles in international journals (2)

1. Nyeste, K. J.*, **Zulkipli, N.***, Uzochukwu, I. E., Somogyi, D., Nagy, L., Czeglédi, I., Harangi, S., Baranyai, E., Simon, E., Nagy, S. A., Velcheva, I., Yancheva, V., Antal, L.: Assessment of trace and macroelement accumulation in cyprinid juveniles as bioindicators of aquatic pollution: efects of diets and habitat preferences.
   Sci. Rep. 14 (1), 1-14, 2024. EISSN: 2045-2322.
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2. Yancheva, V., Georgieva, E., Velcheva, I., Iliev, I., Stoyanova, S., Vasileva, T., Bivolarski, V., Todorova-Bambaldokova, D., **Zulkipli, N.**, Antal, L., Nyeste, K. J.: Assessment of the exposure of two pesticides on common carp (Cyprinus carpio Linnaeus, 1758): are the prolonged biomarker responses adaptive or destructive?
   Comp. Biochem. Physiol. C-Toxicol. Pharmacol. 261, 1-17, 2022. ISSN: 1532-0456.
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List of other publications

Hungarian scientific articles in Hungarian journals (1)

3. Tóth, R., Bíró, Z., Farkas, G. B., **Zulkipli, N.**, Somogyi, D., Antal, L., Nyeste, K. J.: A Rakamazi-Nagy-morotva halközösségének vizsgálata eltérő mintavételi protokollok alapján = Investigation of the fish fauna of Rakamazi-Nagy-morotva with different sampling protocols.
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4. Somogyi, D., Erős, T., Mozsár, A., Czeglédi, I., Szeles, J., Tóth, R., **Zulkipli, N.**, Antal, L., Nyeste, K. J.: Intraguild predation as a potential explanation for the population decline of the threatened native fish, the European mudminnow (Umbra krameri Walbaum, 1792) by the invasive Amur sleeper (Perccottus glenii Dybowski, 1877).
   NeoBiota. 83, 95-107, 2023. ISSN: 1619-0033.
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5. Sharir, S., **Zulkipli, N.**, Mohamad, A., Farinordin, F. A., Zakeyuddin, S., Samat, A., Md. Sah, A. S. R., Md., N. S.: Surgical Implantation of Acoustic Transmitters in Neolissochilus soroides and Channa lucius and Post-Surgical Wound Observation to Study Fish Telemetry.
   Pertanika J. Trop. Agr. Sci. 45 (4), 853-866, 2022. ISSN: 1511-3701.
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Hungarian abstracts (1)

6. Nyeste, K. J., **Zulkipli, N.**, Uzochukwu, I. E., Somogyi, D., Nagy, L., Czeglédi, I., Harangi, S., Baranyai, E., Simon, E., Nagy, S. A., Velcheva, I., Yancheva, V., Antal, L.: Eltérő táplálkozású és habitatpreferencájú halivadékok indikátorszerepe a fémszennyezés kimutatásában.
   Halászatfejlesztés. 40, 30-31, 2023. ISSN: 1219-4816.

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