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Original Research

Biogenic and Metalic Element Accumulation in the European Perch (*Perca fluviatilis*) in the Largest Dam in Slovakia

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Abstract

Our study focuses on the European perch (*Perca fluviatilis*) regarding differences in concentrations of the biogenic (P, S, Cl, K, Ca, Mn, Zn) and metallic (Sr, Sb, Rb, Pb, Mo, Cr, Fe) elements relative to perch morphology and environmental factors at the largest dam in Slovakia. The juvenile perch were sampled at four capture sites from June to October. The highest concentration of biogenic elements and metals was found in perch caught in the site disposed to wastewater effluent (WWE). The concentrations of biogenic elements in perch decrease with the size of the fish; at most the perch affected by WWE had the smallest size. The concentration of biogenic elements in perch increased with the date from June to October and with water temperature for all sites. Lead accumulated by the perch in all sites exceeded more than five times the maximum permissible limits provided by international institutions.

Keywords: heavy metal, biogenic elements, wastewater effluent, *Perca fluviatilis*

Introduction

Aquatic organisms are exposed to a complete mix of elements. The accumulation of elements in organisms often reflects the amount of these elements in the surrounding environment, especially in the water environment, where the elements are easily spread [1, 2]. In studies where the concentration of metals in different lakes increased in gradient, the accumulation of metals increased in the juvenile perch transplanted up the gradient and the opposite down the gradient [3]. The accumulation of elements in fish depends on environmental factors such as temperature, pH, dissolve organic matter, and salinity [4-6]. These physico-chemical parameters often change with the season, and thus season affects the bioavailability and accumulation of elements in fish [1]. Biological factors such as age, size, and weight of individuals, sex, reproduction cycle, feeding, and habitat use also play an important role in the accumulation of elements [2, 7-10]. The accumulation and the beneficial or toxic effects of elements depend on element properties. In general, elements are categorized into biologically essential and non-essential. Biogenic elements are integral components to support the function of an organism [11]. However, the concentration and accumulation of these elements account for the

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beneficial or harmful effects [11]. With respect to essential elements, there are symptoms of deficiency at low concentrations and toxicity at high concentrations. However, as to the nonessential elements, there is only the tolerance level [12]. Over the essential elements the fish have some homeostatic control, and their uptake and elimination is regulated by physiological mechanisms [11]. The non-essential elements are controlled by fish through acclimatization and detoxification [12]. They are detoxified to a certain threshold concentration by decreasing their uptake or by increasing their elimination rate [12]. But for fish chronically exposed to contaminants there is no threshold concentration, and chronic exposure to even a low concentration could yield stress and other adverse effects [3].

With the rising concentration of contaminants in water comes heightened toxicity for fish [11-13]. The toxicity of various elements has an effect on the structure and functionality of organs, and the endpoint is often connected with averse changes in survival, morphology, reproduction, and behaviour [11-12, 14]. Additionally, the majority of elements interact and actin synergy [15-16]. Metals could even mimic the pathways of essential elements and thus inhibit their influx [12]. Fish are at the top of the food chain in fresh water and therefore they could accumulate the highest amount of elements [17]. So the accumulation of elements in fish could also determine the pollution of the whole ecosystem [14].

Waters affected by anthropogenic activities are a good source to study the effect of human development on the environment. The perch is widely distributed across the northern hemisphere in waters disposed to anthropogenic pressure. As a sedentary species and being relatively tolerant of environmental contaminants, in recent decades perch has attracted the attention of researchers [18]. They study the uptake and accumulation of inorganic and organic contaminants and their effects on perch — especially the investigation of metals. Anthropogenically driven metals, in comparison to natural ones, are released at a higher rate and make up half of all metal fluxes in the environment [19]. The concentration of metals in various tissues is studied, and often in relation to the accumulation, biometrics are measured [1]. The great source of nutrients, metals, and organic contaminants are wastewater treatment plants (WWTPs) [20-22]. Released municipal effluents cause eutrophication and the complete change of biota [23], and effects on the health of various fish species exposed to the wastewater contaminants were found [24-26]. Heavy metals present an especially serious threat to fish because of their long persistence, bioaccumulation, and biomagnification in the food chain [27].

The major aim of this research was to specify the influence of environmental and morphological factors on the accumulation of biogenic elements and metals in *Perca fluviatilis*. We also wanted to detect sites with potential contamination.

Material and Methods

Study Area

In 1975, after the displacement of 4,000 people, the construction of the Liptovská Mara Dam (49°.06 N, 19°.32 N) in central Slovakia ended. Liptovská Mara is

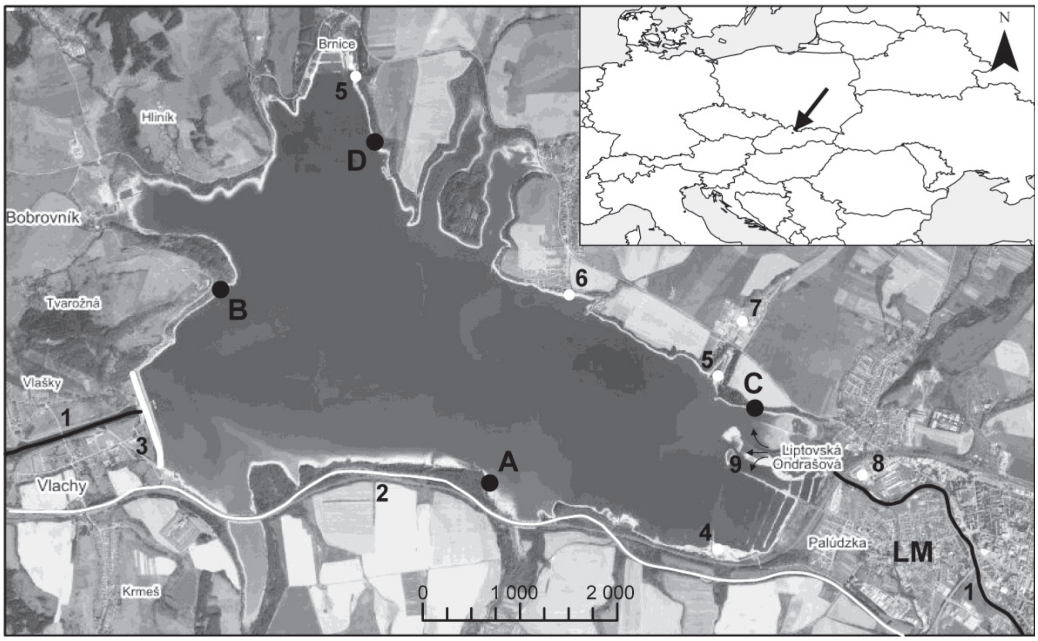

Fig. 1. Map of the study area: A-D represent capture sites, LM - the town Liptovský Mikuláš, 1 - river, 2 - highway, 3 - flood barrier, 4 - quarry, 5 - harbour, 6 - campsite, 7 - aquapark, 8 - wastewater treatment plant, 9 - wastewater effluent (source of aerial imagery: Eurosense 2015).

the largest dam in Slovakia, with a volume of 361,9 mil. m^3, an area of 21,6 km^2, and maximum depth of 45 m. The dam is home to about 30 fish species and a very popular holiday destination often called the "Slovakian Sea." This dam is also popular for recreational fishing. The eastern side is on the edge of the town of Liptovský Mikuláš with a population of around 32,000. On the southern side, along the shore, there is a heavy traffic highway. The shore is bordered by groves, agriculture lands, and scattered small villages. The average temperature for the summer season (June-September) is 16,4°C, and the average annual precipitation is 676,4 mm. We determined four equally spaced fish capture sites (Fig. 1). The first site (A) is situated near the major highway. The next site (B) is situated in the fishing area – the same side as the dam barrier. The third site (C) is near the town where the wastewater treatment plant (WWTP) is situated. Close to this site, there is a small harbour and a popular aquapark. The last site (D) is in a bay, which is also a very popular fishing area.

Sample Collection

The fish samples were collected from June to October 2016. We sampled juvenile (≤ 2 years) *Perca fluviatilis* using a fishing rod with bait of bone worms. We also simultaneously used a dip fishing net (1x1 m) with bait of mixed breadcrumbs with strawberry aroma. The sampling interval was every fourteenth day from the beginning of June, so there were two samplings per month (except for October, when there was only one sampling day). On the sampling day we captured fish at all the sites. At every site we spent 90 minutes. We put each sample into an individual plastic bag marked with the number of the site, date, time, and air temperature. Air temperature was measured as an average of three measurements in 90 minutes at every site. Water temperature was acquired from the Slovak Aquaculture Company as an average per sampling day. After the sampling day, we transported the samples to the laboratory and measured the length and weight of every fish. Afterward the sample was frozen at -40ºC.

Sample Preparation

After defrosting the sample at room temperature we put every fish in a Petri dish and dried the sample using a Memmert Universal Oven UF160 Plus. The time of drying was 12 hours at 75ºC and 70% ventilation. We milled the dried sample using the CryoMill Retsch GmbH 2015, and set the frequency of milling on 30/s; the time of milling was 2 minutes. For larger samples we set the milling time at 5 minutes with the same frequency. After the sample was milled we used x-ray fluorescence spectrochemical analysis with the XRF DELTA Classic spectrometer. The analysis was repeated three times and an average was calculated. Concentrations of the following elements were measured: P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Zr, Mo, Ag, Cd, Sn, Sb, Ba, Hg, and Pb. The chemical elements were measured in mg kg^{-1}.

Statistics

The elements Ti, Co, Ni, Cu, As, Se, Zr, Ag, Cd, Sn, Ba, and Hg were below the detection limit. All statistical analysis were conducted in IBM SPSS Statistics 23 using a critical value for each test set at $p = 0.05$. Seven biogenic elements (P, S, Cl, K, Ca, Mn, and Zn) with no missing data were selected for principal component analysis (PCA). The sample included 240 cases of juvenile *Perca fluviatilis*. We deleted two univariate outliers. The variables in the correlation matrix had all correlations above 0.7. The measure of sampling adequacy of every element was greater than 0.6, and the overall was 0.87. The Barlett Test of Sphericity was significant as well. We reran the PCA ($N = 238$) with varimax rotation. The PCA extracted only one component with eigenvalue greater than one. The single component had all loadings above 0.8. The lowest communality was 0.75. The single extracted component had a high positive correlation with all seven elements, which explained 81% of the variance.

A standard multiple regression was performed to identify the relationship between the morphometric and environmental factors and the accumulation of biogenic elements in *Perca fluviatilis*. The PCA component of biogenic elements was a response variable and the length of an individual, water temperature, air temperature, and date of a sample were used as predictors. The variables were measured at the scale level and had no missing values. The size and air temperature were log-transformed for normal distribution. Three univariate outliers in the biogenic elements and one in the size variable were deleted. The analysis was rendered with $N = 234$.

To find the difference in the accumulation of biogenic elements between the four capture sites, multinomial logistic regression was applied on the dataset from PCA ($N = 238$). The response variable was the site (A-D), and the predictors were the length of an individual, air temperature, water temperature, date, and the PCA component of biogenic elements.

The elements Sr, Sb, Rb, Pb, Mo, Cr, and Fe had some amount of data below the detection limit. These elements were used to render a series of the separate one-way analysis of variance (ANOVA) to test the difference of element concentrations between the capture sites (A-D) with the Tukey post hoc. The outliers for elements Sr (4), Cr (4), and Fe (11) were deleted. The log-transformation of Cr and Fe was used for normal distribution. The Levenes test of homogeneity revealed unequal variances for Fe ($F(3, 198) = 3.43$, $p = 0.018$) and for Rb ($F(3, 234) = 5.68$, $p = 0.001$). We conducted Welch's ANOVA with the Games-Howell post hoc test for Fe and Rb.

Table 1. Mean concentrations (g.kg^{-1}) of elements in the whole body mass of *Perca fluviatilis* in different capture sites (A-D).

Element	N	A	B	C	D	Average
P	238	2.19±0.518	2.081±0.606	2.769±0.492	2.16±0.646	2.292±0.63
S	238	5.187±0.616	5.01±0.795	5.697±0.683	4.931±0.794	5.194±0.785
Cl	238	5.05±0.716	5.039±1.029	5.653±0.802	4.788±0.965	5.121±0.943
K	238	23.727±2.912	22.765±3.399	25.475±2.429	21.972±3.206	23.423±3.279
Ca	238	50.29±9.137	49.525±11.841	60.022±7.679	52.825±13.449	53.104±11.569
Mn	238	0.035±0.01	0.032±0.013	0.051±0.013	0.035±0.010	0.038±0.014
Zn	238	0.227±0.054	0.205±0.061	0.261±0.034	0.203±0.061	0.223±0.059
Sr	236	0.079±0.012	0.08±0.013	0.087±0.012	0.08±0.012	0.081±0.013
Sb	104	0.013±0.002	0.012±0.002	0.014±0.002	0.013±0.002	0.013±0.002
Rb	238	0.025±0.004	0.023±0.004	0.028±0.003	0.021±0.005	0.024±0.005
Pb	165	0.008±0.002	0.007±0.002	0.008±0.002	0.007±0.002	0.008±0.002
Mo	230	0.004±0.001	0.003±0.001	0.004±0.001	0.003±0.001	0.004±0.001
Cr	197	0.009±0.003	0.008±0.004	0.013±0.005	0.009±0.003	0.01±0.004
Fe	202	0.131±0.084	0.138±0.108	0.279±0.148	0.184±0.125	0.183±0.132

Results

The mean concentrations of fourteen elements in the whole body mass of *Perca fluviatilis* are given in Table 1. The standard multiple regression revealed that there is a significant relationship between the concentration of biogenic elements (P, S, Cl, K, Ca, Mn, Zn) in perch and the length of the perch, water and air temperature, and date ($F(4, 229) = 45.22$, $p<0.001$, with R^2 at 0.44 (95% CI = 0.35 to 0.53), adjusted $R^2 = 0.43$). Altogether, 44% of the variability in concentrations of biogenic elements was predicted by the length of the perch, water and air temperatures, and date. The four predictors in combination contributed only 0.03 in the shared variability, and the unique variability was 0.41. The size and direction of relationships suggest that the accumulation of biogenic elements is decreasing with the length of fish and increasing with the air and water temperature (Table 2). In addition, the accumulation increases with the date from June to October. The length of fish ($sr^2 = 0.31$) is the most important predictor, and the other three predictors explain a very small proportion of variance.

The multinomial logistic regression revealed a significant relationship between the four capture sites (A-D) and the length of the perch, air and water temperature, date, and the concentration of biogenic elements in the perch (Deviance χ^2 = , $\alpha = 0.999$, Pearson χ^2 = , $\alpha = 0.384$; correct overall classification = 43,3%, A = 7,3%, B = 43,5%, C = 75,4%, D = 45,3%; R = 0.295 (95% CI = 0.16, 0.36). The length of the perch and the concentration of biogenic elements significantly distinguish the four categories of capture sites. Perch caught at site D had the largest size, followed by the perch at sites A and B; the smallest were caught at site C. Among all the sites, perch caught at site C had the highest concentrations of biogenic elements (Table 3).

Table 2. Results of multiple regression with biogenic element (P, S, Cl, K, Ca, Mn, Zn) concentrations in *Perca fluviatilis* grouped in one principal component as a response variable and four predictors; log transformation of fish length (Length_log), water temperature, log transformation of air temperature (Air temp._log), and date of capture.

Predictor	β	Std. Error	OR	t	95 % CI	sr^2 (unique)
Constant	0.457	.957		.478	-1.428, 2.342	
Length_log	-4.877**	.431	-.568	-11.325	-5.726, -4.029	0.31
Water temp.	0.098*	.035	.174	2.813	0.029, 0.167	0.02
Air temp._log	0.412*	.144	.168	2.868	0.129, 0.695	0.02
Date	0.007**	.001	.301	5.641	0.005, 0.01	0.08

* $p<0.05$, ** $p<0.001$.

Table 3. Results of the multinomial logistic regression comparing the four categories (A-D) of the response variable capture site from the predictors; fish length (Length) and concentrations of biogenic elements (P, S, Cl, K, Ca, Mn, Zn) in *Perca fluviatilis* were grouped in one principal component (Bio_elements).

Predictor	Comparison of sites	*β*	SE	Wald	OR	95 % CI OR
Length	A vs D[a]	-0.246*	0.12	4.177	0.782	0.62, 0.99
Bio_elements	A vs D[a]	-0.055	0.273	0.04	0.947	0.55, 1.62
Length	B vs D[a]	-0.219*	0.112	3.840	0.803	0.65, 1
Bio_elements	B vs D[a]	-0.271	0.274	0.975	0.763	0.45, 1.31
Length	C vs D[a]	-0.86**	0.206	17.420	0.423	0.23, 0.63
Bio_elements	C vs D[a]	0.759*	0.294	6.683	2.136	1.2, 3.8
Length	A vs C[a]	0.614*	0.205	8.994	1.848	1.24, 2.76
Bio_elements	A vs C[a]	-0.814*	0.29	7.868	0.443	0.25, 0.78
Length	B vs C[a]	0.641*	0.204	9.909	1.898	1.27, 2.83
Bio_elements	B vs C[a]	-1.030**	0.301	11.714	0.357	0.2, 0.64
Length	A vs B[a]	-0.027	0.121	0.049	0.974	0.77, 1.23
Bio_elements	A vs B[a]	0.216	0.28	0.595	1.241	0.72, 2.15

* $p \le 0.05$, ** $p \le 0.001$; [a] the reference category

ANOVA results showed that perch caught at site C had the highest concentrations of Sr among all the sites ($F(3, 232) = 5.109$, $p = 0.002$). Perch at site C had higher concentrations of Sb than perch in site B ($F(3, 100) = 3.004$, $p = 0.034$). Perch in site C had higher concentrations of Pb relative to sites B and D ($F(3, 161) = 4.413$, $p = 0.005$). Perch in site C had higher concentrations of Cr among all the sites ($F(3, 193) = 15.442$, $p<0.001$). Perch in site C had higher concentrations of Fe among all the sites ($F(3, 108.89) = 18.687$, $p<.001$). Perch in site C had higher concentrations of Rb among all the sites, and perch in site A had higher concentrations of Rb relative to sites B and D ($F(3, 128.86) = 37.496$, $p<.001$). Perch in sites A and C had higher concentrations of Mo relative to sites B and D ($F(3, 226) = 13.736$, $p<.001$) (Table 4).

Discussion

The size difference of perch between the capture sites was observed. The perch at site D had the greatest size, followed by the perch at the sites A and B, and the smallest perch were at site C. This diversification could be due to phenotypic plasticity and genetic variation. Genetic studies of the perch in the last twenty years have suggested that perch within one lake do not form a single panmictic population, but create genetically different subpopulations [28, 29]. Yet in small-scale waters there exist some cryptic barriers to dispersal [28]. The genetic differences between subpopulations correlate with the changes in environmental parameters, such as the temperature at time of spawning [30]. The other cause of differentiation into subpopulations could be a philopathric behavior to spawning sites, kin recognition, and kin preference [31, 32]. The morphometric difference in size may suggest the existence of three subpopulations in the dam. If individuals are philopatric to the capture site and create subpopulations, we can assume that a different accumulation of elements between sites is a manifestation of local and diversified environmental chemistry in the dam.

Site C, with the smallest perch, correspond with the highest accumulation of biogenic elements grouped in one component (P, S, Cl, K, Ca, Mn, Zn) and other elements (Sr, Sb, Pb, Cr, Fe) between all sites. This site also relates to the greatest amount of pollutant sources. To the west of this site lie the aquapark and the harbour (250 m), while to the east there is the edge of the urban area (250 m) where the WWTP is located. The purified wastewater is discharged into the river, which flows into the dam. The river current is diffused almost directly in the area of this site. The source of contamination could also be the agricultural land that borders the shore. Agricultural lands are often responsible for excess emissions of nutrients and metals [33, 34]. Higher concentrations of biogenic elements and contaminants in fish exposed to wastewater effluent (WWE) is commonly reported [25, 35, 36]. WWE mainly increases the input of nutrients in fresh water [22]. The fish exposed to the wastewater contamination derive part of their nutrition from these effluents [35]. As the smallest perch were captured in this site, we assume some chronic effects of elevated concentrations of contaminants on perch growth. WWE is a mixture of environmental contaminants, and its discharge may lead to a complex change of aquatic biota [23, 37]. Endocrine disruptive chemicals, ammonia, and metals are present in WWE

Table 4. Post-hoc comparisons (ANOVA) of the concentrations of SR, Sb, Pb, Cr, Fe, Rb, and Mo in *Perca fluviatilis* between the capture sites (A-D).

Element	*N*	Comparison of sites	Mean accumulation difference	Std. Error	95% CI
Sr[a]	236	C vs A	7.9560*	23.553	1.86, 14.05
Sr[a]	236	C vs B	7.0834*	22.837	1.17, 12.99
Sr[a]	238	C vs D	6,9707*	22.746	1.09, 12.86
Sb[a]	104	C vs B	1.688*	0.58	0.17, 3.2
Pb[a]	165	C vs B	1.125*	0.428	0.01, 2.24
Pb[a]	165	C vs D	1.290*	0.448	0.13, 2.45
Cr_log[a]	197	C vs A	0.13298**	0.03205	0.05, 0.22
Cr_log[a]	197	C vs B	0.20361**	0.03242	0.12, 0.29
Cr_log[a]	197	C vs D	0.16464**	0.03223	0.08, 0.25
Fe_log[b]	202	C vs A	0.32494**	0.04856	0.2, 0.45
Fe_log[b]	202	C vs B	0.35950**	0.0588	0.21, 0.51
Fe_log[b]	202	C vs D	0.21460**	0.05521	0.07, 0.36
Rb[b]	238	A vs B	2.3179*	0.7019	0.49, 4.15
Rb[b]	238	A vs D	4.326**	0.8305	2.16, 6.49
Rb[b]	238	C vs A	2.9713**	0.6740	1.21, 4.73
Rb[b]	238	C vs B	5.2892**	0.6433	3.61, 6.97
Rb[b]	238	C vs D	7.2973**	0.7817	5.26, 9.34
Mo[a]	230	A vs B	0.53372*	0.19796	0.02, 1.05
Mo[a]	230	A vs D	0.75987**	0.19478	0.26, 1.26
Mo[a]	230	C vs B	0.88494**	0.19443	0.38, 1.39
Mo[a]	230	C vs D	1.11108**	0.19119	0.62, 1.61

* $p \leq 0.05$, ** $p \leq 0.001$; [a]Tukey HSD test, [b]Game-Howell test.

[38-40]. These contaminants were proven to affect the growth of fish [41, 42]. Tetreault [25] reported longer white stickleback collected downstream of the WWTP, but fatheads from the same site were shorter. Generally increased condition and growth is referred to fish exposed to WWE [26, 43, 44]. The increase in fish condition is explained by the enhanced productivity of waters affected by urban effluents [37]. However, the enhance growth refers mainly to older fish classes [26, 43, 44]. In juveniles, the toxic effect may have a greater impact than the benefits of nutrient enlargement [45]. WWE often contains a variety of metals [37, 40, 46].

Many studies have shown reduced growth in fish exposed to metal contaminants [11, 12, 47]. Pyle et al. [48] studied yellow perch in lakes with the metal contamination gradient. The perch grew slower along the gradient of high concentration. The reduced growth was reported for contamination of Pb, Fe, Cr, Zn, Sb, P, and Cl [47, 49-54]. Fish studies recognize direct effects of elements on fish growth and indirect effects through the negative impact on the food web and habitat [11, 12]. The direct effects of metals on bioenergetics of fish could potentially reduce growth. Metals were reported to reduce aerobic and biosynthetic capacity, feeding activity, swimming speed, and resting [18, 55]. Metals increase energy demands, metabolic cost, and impair the endocrine functions [55-57]. The metabolic rate of fish in metal-contaminated waters tends to decrease [55], which could lead to lower uptake of mass and smaller size of fish in the most contaminated site. Fish exposed to metal contaminants try to reduce the impact through detoxification [11, 12], which should be reflected by the reduction of growth [58]. Some indirect factors could be responsible for the smaller individuals in the most exposed site. Fish exposed to metal contamination exhibit delayed spawning and delayed hatching [12, 59]. The delayed spawning is referred also to fishes exposed to WWE [25]. Metal contamination could also result in a change of habitat use, predator-prey interactions, and competition with subsequent changes in fish morphology [11, 60, 61]. The attribution of reduced growth could be due to decrease diversity and abundance of invertebrates as a response to metal contamination [62].

We found higher concentrations of biogenic elements in smaller individuals. Biogenic elements are structural components of enzymes, and enzymes such as nucleoside diphosphokinase were associated with fish growth [63]. Most of the biogenic elements grouped in one component were metals (Cl, K, Ca, Mn, Zn). Many studies found higher concentrations of biogenic metals in smaller fish [1, 64]. For the negative relationship between metal concentrations and growth, the difference in metabolic activity between younger and older fish could be responsible [64]. Younger, smaller fish, due to their excessive growth, development, and higher metabolic rate, have higher energy requirements and thus need to accumulate higher amounts of biogenic elements. Younger individuals have higher uptake of elements and older one have a higher elimination rate. [1]. The juveniles are also more sensitive (especially to heavy metals) than the mature stages [45, 65]. Various metals show different bioconcentrations in accordance with metal properties and the properties of target tissue [11, 12]. Liang et al. [66] found that the hepatic Cu concentrations in several fish species decreased with the size of the fish, the contrary hepatic Zn concentration increased with the size of the fish, but the Zn content in the muscles decreased. Such differences in concentrations of metals in relation to fish growth are commonly reported even for one element. Başyğit and Tekin-Özan [1] determined a positive relationship between fish weight and Mn levels in muscles and gills, and a negative relationship between fish length and Mn levels in the liver and gills. Fish accumulate most of the metals in the metabolically active tissues like liver and gills [67, 68]. The concentrations of heavy metals in gills and liver tends to increase with age and size of the fish [2], but the muscles proved to be an inactive tissue and the metals there are degrading [67, 69]. In our study, we did not use individual organs for analysis, but the whole body mass – and therefore muscles – was the most important part in the resulting concentration.

There was a higher accumulation of biogenic elements during the sampling time, and the concentration was increasing from June to October. Seasonal variations in the concentrations of metals and biogenic elements are commonly reported [1, 70-72]. These elements often do not vary together, and there are seasonally different peaks and falls for different elements [71]. Many causes have been demonstrated to affect seasonal tissue element concentrations. Diet-borne concentration of elements in fish is changing with food diversity, food abundance, change in diet, and feeding rate [11, 72, 73]. Yellow perch tissue metal concentration peaked in summer with the increase in food uptake [74]. Kraemer et al. [75] reported seasonal variations in the hepatic Cu concentration in yellow perch. As the perch change diet during the season, the tissue concentration decreased, but the total burden increased. The biogenic elements concentrations in fish often reflect the ambient concentrations of these elements in water [72, 76]. The concentration of elements in the water column depends on physicochemical parameters such as temperature and dissolved organic matter, and these parameters influence the bioavailability of elements across the season [77, 78]. Thus the abiotic factors like the photoperiod indirectly affect the accumulation of elements in fish [79].

We have statistically found that the accumulation of biogenic elements in perch increased with water temperature. The highest temperature in the dam was from July to September. Higher temperature in summer tends to raise pH, evaporation, photosynthesis, conductivity, and inorganic substances, and decrease CO_2 [80]. These changing parameters influence the bioavailability of biogenic elements. Most of the studies report the highest concentrations of biogenic elements in fish in the summer, and they mostly relate these concentrations to water temperature [59, 71, 81, 82]. Fish with increasing ambient temperatures increase their metabolic rate [83]. Zayed and Eldien [81] found the highest metal contents in fish during the summer, which suggested that it was due to a higher rate of breathing and lower oxygen content in water. The metabolic rate was responsible for the highest concentrations of Cd, Cu, Pb, Fe, and Zn during the summer in marine fish [82]. Also, the growth rate of perch is highest in summer and therefore the perch could demand higher amounts of nutrients [84]. The precipitation was reported as being responsible for the highest concentrations of tissue metal during the wet season in various fish species [85, 86]. The highest precipitation in the area of the dam were in July and August. Precipitation could splash the biogenic elements from surrounding agricultural lands, and thus elevate their content in the dam. Also, the amount of water flow could affect the element concentrations in the dam. Johansson et al. [87] reported the increased metal concentrations in the lake during the rainy season due to high precipitation and high river flooding. The discharge of the river feeding the dam was highest in the summer. The other factors affecting the tissue element concentrations could be the population activities as reproduction. Mzimela et al. [88] found low values in hepatic Zn concentrations during spawning, followed by an increase during the post-spawning season. For the European perch, the spawning season ends in June and even the one-year-old perch could associate in spawning [18]. The lowest concentrations of biogenic elements in perch in the dam were found in the middle of June (following the increase in July), and the highest concentrations were in September and October. We suggest that the biogenic element concentrations in the perch cumulate over the summer and thus reach the highest concentrations in the whole body mass in autumn. Başyiğit [1] found the highest concentrations of biogenic elements in the muscle of pikeperch in autumn. These highest concentrations could be induced by various environmental factors and biological factors of the perch, acting in synergy.

From the studied elements, the maximum permissible levels are set only for Pb. According to the European Commission (EC), the Food and Agriculture Organization of the United Nations (FAO), and the World Health Organization (WHO), the maximum level for Pb in fish for human consumption is 0.3 mg/kg of wet weight [89, 90]. In order to compare the data obtained in this study with prescribed limits, concentrations of Pb were recalculated to wet weight according to the conversion factor of 0.246 for *Perca fluviatilis* [91]. Concentrations of Pb in wet weight were 1.968 mg/kg in sites A and C, and 1.722 in sites B and D. The concentrations of Pb in perch highly exceeded the limit.

Conclusions

This study was carried out to provide information on biogenic and metal element concentrations in *Perca fluviatilis*. As expected, the highest concentrations of biogenic elements and metals were found in perch caught in the site disposed to WWE. This site also saw the smallest perch captured, and higher concentrations of biogenic elements were found in smaller individuals. The concentrations of biogenic elements increased from June to October, corresponding to increased water temperature. Regular monitoring of heavy metal concentrations should be conducted in the future since the levels of Pb exceeded the limit values for fish in all sampling sites.

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Conflict of Interest

The authors declare no conflict of interest.

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