

# METAL POLLUTION AS HEALTH INDICATOR OF LAKE ECOSYSTEMS\*

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**Abstract.** As part of a long-term monitoring study of the anthropogenic pollution of the Lake of Balaton (Hungary) the concentrations of toxic metals ( $\text{Cd}^{2+}$ ,  $\text{Hg}^{2+}$ ,  $\text{Pb}^{2+}$ ), as well as of bioelements ( $\text{Cu}^{2+}$  and  $\text{Zn}^{2+}$ ) were measured in the muscle, gill and liver of bream (*Abramis brama L.*) collected in the open water during the autumn of 1999. The highest Cd, Cu, Pb and Zn concentrations were detected in the gill and liver of fish, whereas the highest Hg concentrations were measured in the muscle. The maximum metal concentrations measured in the muscle of bream were generally below maximum permissible levels for human consumption established by the Hungarian Food Directorate. Depending on the sampling site, significantly higher Cd, Hg and Pb concentrations ( $p < 0.05$ ) were detected in the muscle of fish samples collected from the Western basin, while no significant differences were observed for Cu and Zn. In the muscle and gill an increasing trend of heavy metal (Cd and Cu) load characterizes the individuals of the 2–4 calendar age group ( $p < 0.05$ ), while for the older specimens the concentration of these elements decreased significantly ( $p < 0.05$ ). Positive relationships on the whole age scale were found for Cd in the liver, for Pb in the gill, and for Hg both in the muscle and the liver of fish.

**Key words:**

Metal pollution, Lake ecosystems, Bream (*Abramis brama L.*)

## INTRODUCTION

Lake ecosystems are increasingly affected by various anthropogenic impacts, like the excess of nutrients causing eutrofication, toxic contamination of industrial, agricultural and domestic origin, heat pollution, reaching the lakes through their catchment area and the atmosphere. Typical results of the human activities proved to be elevated levels of heavy metals present in fresh waters, and among these microelements lead (Pb), cadmium (Cd), mercury (Hg) and zinc (Zn) are most specific [1].

The arousal of anthropogenic pollution in the environment evoked the necessity to develop the pollution impact management strategies. Management of toxic substances in the environment consists of two basic parts: 1) the risk assessment of target toxic substances in the specific

ecosystem; and 2) the development of a control method for target toxic substances based upon the results of the ecosystem assessment [2].

One of the most efficient methods of assessing chemical pollution in aquatic ecosystems is the determination of the accumulated pollutant loads in organs of different animals populating the site of interest [3–5]. In such biological monitoring studies the fish proved to be the most appropriate indicator organisms, due to their longer life span and top position in the aquatic food chain. In the assessment of anthropogenic pollution of aquatic ecosystems, using the fish as biological indicators, it has become apparent that three major aspects must be taken into consideration:

■ the fish as the indicator organisms for the heavy metal pollution of their environment and their possible risk for

\* The paper presented at the conference “Metal in Eastern and Central Europe: Health effects, sources of contamination and methods of remediation”, Prague, Czech Republic, 8–10 November 2000

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**Table 1.** Heavy metal concentrations measured in the water of Lake Balaton

Measurements	$\mu\text{g Me l}^{-1}$				
	Cd	Cu	Zn	Pb	Hg
Tóth (1976)		2–8	10–50		
Kovács et al. (1984–85)		0.36–1.0	0.21–0.43	1.6–2.1	
Salánki et al. (1982) [15]	0.8	<5	57	<2	0.7
Hlavay et al. (1996)	<0.1–0.33	0.1–0.7	0.5–40	<0.1	<0.5

human consumption from the toxicological point of view [6]. It is mainly the muscle, which should be investigated in this context;

■ the fish to study the physiological behavior of heavy metals. The most important factors are: distribution of heavy metals in individual organs and the respective affinity of these organs for metals, uptake kinetics, regulatory mechanisms (especially for essential metals), effects on the metabolism evoked by heavy metals, the synergism of metals and their uptake [7–10];

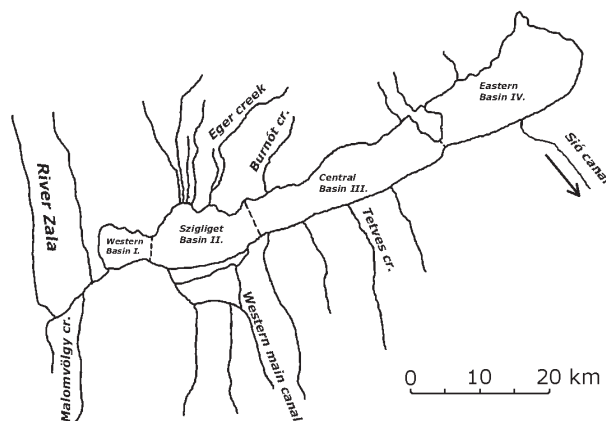
■ the fish as the end consumers in the aquatic food chain and thus their use as an indicator of heavy metal enrichment. Knowledge of biological factors such as age and size, life cycle and life history, seasonal and local variations of heavy metal content in the animal, and the trophic level of the species, as well as of the biological half-life of the metal are essential [11,12].

In view of the above-mentioned facts, as part of a long-term monitoring study of the anthropogenic pollution of the Lake of Balaton (Hungary), the heavy metal load of fish species populating the lake and the main inflows was investigated in the last two decades [13–16]. In the present paper the results of the study of the toxic metal pollution of a common bream (*Abramis brama L.*), inhabiting Lake Balaton, performed in the autumn of 1999, are presented with the special reference to the correlation of the accumulated heavy metals with age and condition of the fish. Lake Balaton is the largest shallow lake in central Europe. At the mean level the surface area is 596 km<sup>2</sup>, the mean depth 3.25 m and the volume 1.9 10<sup>9</sup> m<sup>3</sup>. The inflow waters and the processes taking place within the lake control the composition of the lake water. Limestone and dolomitic rocks predominate in the catchment area, so that the waters discharged to the lake carry Ca<sup>2+</sup>, Mg<sup>2+</sup>

and HCO<sub>3</sub> in high concentrations. Owing to CO<sub>2</sub> exchange with the atmosphere and to photosynthesis, large volumes of CaCO<sub>3</sub> are present in the lake. The pH is normally 8.4. Due to its high alkalinity and carbonate content the lake water does not contain heavy metals in ionic form. However, in unfiltered water, detectable toxic heavy metal concentrations are measured from time to time (Table 1).

The lake and its watershed are loaded by a moderate heavy metal pollution, caused besides natural and geological sources, mainly by industrial and agricultural works located at the catchment area [17,18]. A significant input originates from local municipal sources, waste deposits, heavy road and railway traffic along the lakeshore 210 km long, boating and atmospheric deposition [19].

On average, the concentrations of dissolved heavy metals of inflow waters, which provide more than half of the water budget of the lake, vary in the following ranges: Cd 0.1–2.8; Cu 1.1–8.9; Hg 0.06–0.26; Pb 0.5–8.3; Zn 12–74 ng/m<sup>3</sup>, while the total heavy metal concentrations of aerosols in

**Fig. 1.** Lake Balaton. Main inflows and basins.

the catchment area measured in 1997 were: Cd 0.55–0.74; Cu 3.8–4.9; Pb 26.4–29.8; Zn 8.7–37 ng/m<sup>3</sup>.

The aim of the study was to assess (a) water pollution in Lake Balaton; (b) potential hazard of heavy metal to fish consumers; (c) distribution of metals in the fish organs and tissues; and (d) the effect of various factors, such as age, size and seasonal variations on the concentrations of metals in the fish meat, being the final link of the nutrition chain in lake water.

## MATERIALS AND METHODS

Common bream were collected from the two outlying basins of the Lake of Balaton (Western and Eastern) basins (Fig. 1) from the open water area (1500 m off the shore) by using multi-mesh gillnets consisting of mesh sizes 18, 24, 30, 40, 50, 65 and 80 mm. After one to two hours of fishing, fish were removed from the nets, and transferred immediately to the laboratory in cool boxes. Total body length (mm), total body weight and net weight (eviscerated) of each individual fish were recorded prior to dissection in order to analyse the correlation between the size and heavy metal concentrations accumulated in organs. The age of each fish was determined from scale samples.

Ten to fifteen scales were removed from each fish from the right side of the body above the lateral line and below the insertion of the dorsal fin, and age was determined from projections of scale images on a 10 to 20 x magnification profile projector according to the annual ring structure of scales. The average length, total body weight and net weight (innards excluded) of the age classes collected from the two sampling sites are given in Table 2.

The concentration of the toxic metals (Cd, Hg, Pb), and bioelements (Cu, Zn) were measured in the mid-dorsal muscle (filleted and skinned) in the gill and liver of fish. To determine non-volatile elements, tissues were dried at 105 °C for 48 h and preserved in exsiccators until subjected to wet digestion with a mixture of 65% HNO<sub>3</sub> and 30% H<sub>2</sub>O<sub>2</sub> [20,21]. The metal concentrations were determined with a Perkin Elmer-5100 atomic absorption spectrophotometer equipped with a HGA 60 graphite furnace and using deuterium arc background correction. Measuring cadmium, lead and zinc the mixtures of 50 µg PO<sub>4</sub><sup>-2</sup>; 3 µg Mg (NO<sub>3</sub>)<sub>2</sub>; and 4 µg of Mg(NO<sub>3</sub>)<sub>2</sub>, respectively were used as matrix modifiers. The samples for mercury determinations were stored in polyethylene containers frozen at -30°C and were decomposed with the mixture of 65% HNO<sub>3</sub> and 98% H<sub>2</sub>SO<sub>4</sub> [22]. The mercury concentrations in samples were measured by the cold-vapor technique, using SnCl<sub>2</sub> as reductant. The determination was performed according to Hatch and Ott [23]. A four-point calibration curve was run for each metal at the beginning of each analysis, using Perkin Elmer pure atomic spectroscopy standards. To ensure the continuation of acceptable performance, calibration verification and procedural calibration blank were run at every 10th sample. Each metal concentration was measured at least in two replicates in different sample batches and different calibrations.

The accuracy of the analytical procedure was checked by analyzing the standard reference materials (National Research Council of Canada; dogfish muscle and liver), DORM 2 and DOLT 2, in four replicates for each batch of 50 samples digested. The metal concentrations were expressed as mg kg<sup>-1</sup> dry tissue weight. Although accuracy was variable, the precision of the analyses proved to be

**Table 2.** Mean and standard deviation of metal concentrations determined in the international standards: DORM2 and DOLT2 (mg Me kg<sup>-1</sup> dry weight)

Metal	Measured values DORM2, n = 36	Certified values DORM2	Measured values DOLT2, n = 36	Certified values DOLT2
Cd	0.047 ± 0.004	0.043 ± 0.008	18.3 ± 1.2	20.8 ± 0.5
Cu	2.41 ± 0.2	2.34 ± 0.16	24.9 ± 0.9	25.8 ± 1.1
Hg	4.52 ± 0.35	4.64 ± 0.26	2.01 ± 0.07	1.99 ± 0.10
Pb	0.051 ± 0.01	0.065 ± 0.007	0.20 ± 0.05	0.22 ± 0.02
Zn	26.2 ± 3.1	25.6 ± 2.3	81.3 ± 3.2	85.8 ± 2.5

**Table 3.** Average length, total body weight and net weight of fish collected from Lake Balaton calculated by age classes, autumn 1999

Sampling site	Age class	No.	Length [mm] (mean ± SD)	Weight (g) (mean ± SD)	Net weight (g) (mean ± SD)
Western basin	2+	7	145 ± 6	67 ± 9	63 ± 9
	3+	8	163 ± 12	93 ± 21	87 ± 20
	4+	16	192 ± 12	154 ± 26	143 ± 22
	5+	9	224 ± 9	245 ± 28	222 ± 26
	6+	18	252 ± 9	336 ± 45	301 ± 39
Eastern basin	2+	5	133 ± 7	51 ± 11	48 ± 11
	3+	2	148 ± 1	70 ± 7	66 ± 7
	4+	5	181 ± 10	135 ± 30	126 ± 27
	5+	13	210 ± 7	199 ± 17	191 ± 51

high (Table 3.). The measured Cu, Hg and Zn concentrations were within the certified values of both standards. The Cd values in DORM 2 were above, while those of Pb in both standards, were below the certified values, but within acceptable limits (95% confidence limits).

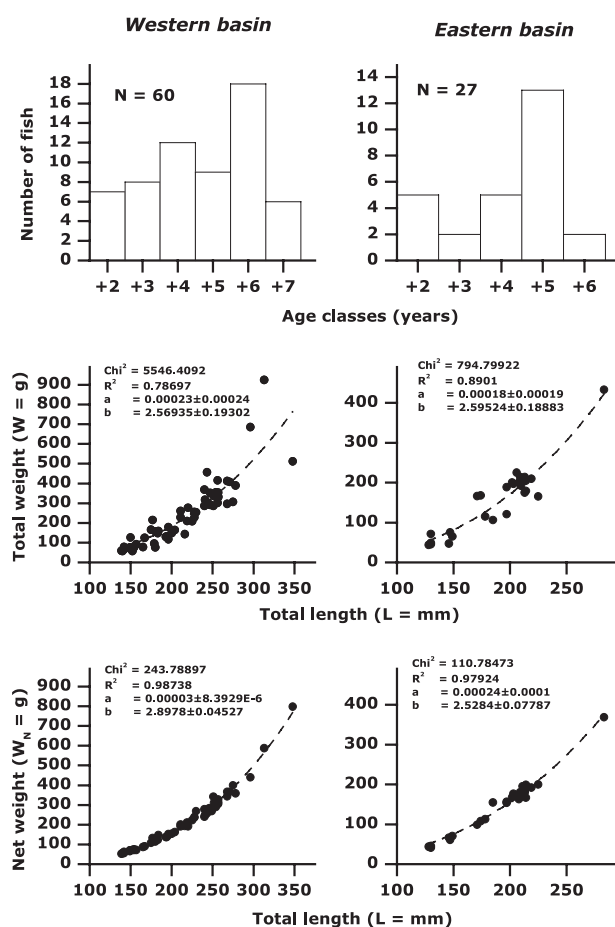
For the measurement of cadmium in the muscle tissue and of lead in all the three organs a preconcentration of the samples in the graphite tube was performed by repeated injections before atomisation (Perkin Elmer: Furnace Autosamplers – Operator’s Manual, 1988) [24].

**RESULTS**

As the heavy metal load in the fish organs strongly depends on the age and growth of specimens, the age-distribution and length-weight relationship, which characterizes the increase in length and weight of the fish population inhabiting the site of interest, were studied to ensure the correct interpretation of heavy metal measurement data. The two fish sample groups differed significantly in both their age-structure and length-weight relationship (Fig. 2). The material collected from the Western basin was much abundant (n = 60) with a much uniform age distribution, while in the Eastern basin in similar conditions only 27 fish could be caught, with only two specimens from the 3+ age class and no older fish than the 5+ age class were found. The length-weight relationship, according to Bagenal and Tesch [25] was represented by the following allometric function:

$$w = aL^b$$

where b is an exponent usually between 2 and 4. The classical Freundlich model was used in the study of allometry for both the total body length-total body weight and total body length-net weight relationships. In the first case no



**Fig. 2.** Age-structure and length-weight relationship of bream samples collected from the two basins of Balaton.

**Table 4.** Heavy metal concentrations in the organs of bream, autumn 1999

Sampling site	Element	Mg kg <sup>-1</sup> dry weight (average ± standard deviation)		
		muscle	gill	liver
Western basin	Cd	0.71 ± 0.55	1.3 ± 1.24	2.27 ± 1.15
	Cu	2.24 ± 0.49	5.26 ± 1.88	58.8 ± 17.1
	Hg	0.11 ± 0.06	0.03 ± 0.01	0.08 ± 0.04
	Pb	1.58 ± 0.56	3.35 ± 1.53	3.19 ± 1.46
	Zn	14.5 ± 2.7	40.6 ± 9.9	78.8 ± 22.9
Eastern basin	Cd	0.35 ± 0.29	0.87 ± 0.54	1.93 ± 0.85
	Cu	1.78 ± 0.75	4.96 ± 1.34	42.5 ± 15.5
	Hg	0.06 ± 0.03	0.02 ± 0.01	0.05 ± 0.02
	Pb	0.85 ± 0.5	2.97 ± 1.58	2.64 ± 1.59
	Zn	14.7 ± 2.9	41.2 ± 6.2	77.2 ± 14.4

significant differences between the two sample groups were found (Western basin:  $b = 2.569$ ; Eastern basin:  $b = 2.595$ ), but the total body length-net weight relationship showed a significantly better condition of the fish originating from the Western basin (Western basin:  $b = 2.898$ ; Eastern basin:  $b = 2.528$ ).

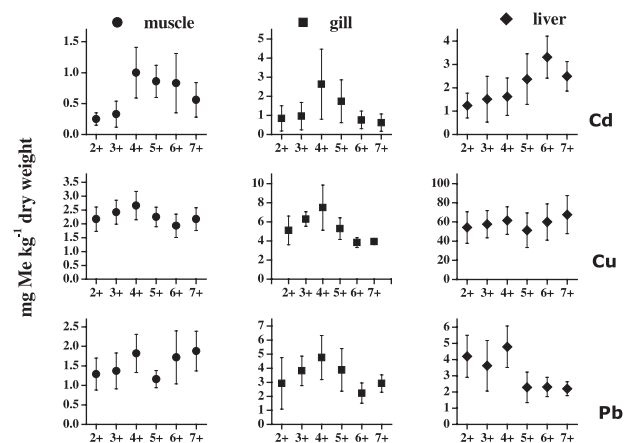
The metal concentrations in the organs of the bream varied considerably. The highest Cd, Cu, Pb and Zn concentrations were detected in the gill and liver, whereas the highest Hg concentrations were measured in the muscle (Table 4.). Depending on the sampling site, significantly higher Cd, Hg and Pb concentrations ( $p < 0.05$ ) were detected in the muscle of the fish samples collected from the Western basin, while Cu was higher both in the muscle and the gill of these fish.

At both sampling sites, the average metal concentrations measured in the muscle of bream were below the maximum permissible levels for human consumption established by the Hungarian Food Directorate. Nevertheless, in the muscle of 6 samples collected from the Western basin, Cd concentration exceeded this limit. Three of the fish samples belonged to the 4+ age class and three to the 6+ age class. In these samples the average muscle Cd concentration exceeded by 33% the maximum permissible level for human consumption, while compared to the average Cd levels, calculated for the remainder of fish samples, it proved to be 3.55 times higher. Elevated cad-

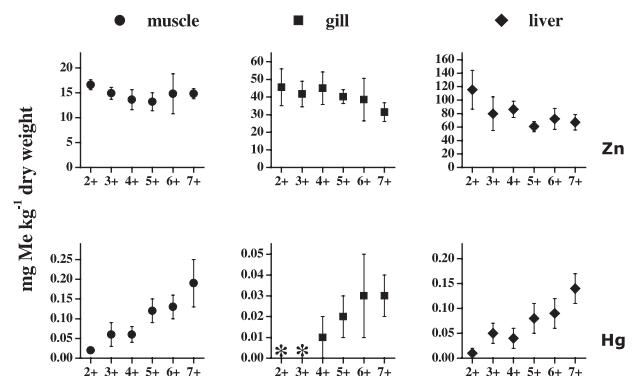
mium loads in these samples were also found to be higher in the gill (79%) and the liver (30%).

As fish samples belonging to a wider age scale could be caught only in the Western basin, the relationship

a) cadmium, copper, lead



b) zinc, mercury

**Fig. 3.** Average metal concentrations calculated per age classes in the organs of bream collected from the Western basin.

between the metal concentrations in the organs of common bream and their age was studied only in these samples. While plotting the average metal concentrations of organs of each age class (Fig. 3), it could be observed that an onward trend in Cd and Cu load in the muscle and gill of fish characterized the individuals belonging to the 2+ to 4+ age interval, while for the older specimens the concentrations of these elements decreased significantly, and a similar variation could also be observed for Pb concentration in the gill. In the liver, a different metal concentration-age relationship could be observed for these elements: for Cd and Cu an onward trend is characteristic on the whole age scale, and for Pb a significant downward trend could be observed. Negative metal concentration-age relationships were characteristic of Zn in the gill and liver of bream, while for Hg positive correlations were found on the whole age scale in all investigated organs.

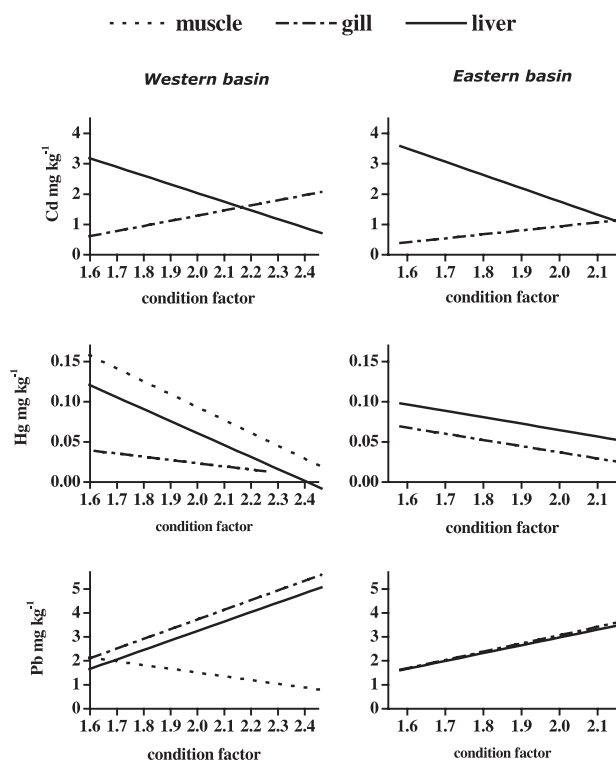
As the higher lipid content of tissues in fish samples of better physical condition caused a relative dilution of micropollutants accumulated in the fish organs, the relationship between heavy metal concentrations in organs and the condition factor of fish samples was also analyzed. Condition factors are used to compare the "condition", "fatness" or "well being" of fish, and are based on the hypothesis that the heavier fish of a given length are in better condition. The condition of fish samples were determined with Fulton's Condition Factor [25]:

$$K = 100 w/l^3$$

where  $w$  and  $l$  are the observed total weight and total length of a fish.

The relationship between heavy metal concentrations and the condition of fish was studied for both fish sample groups. Least-squares linear regression analysis between metal concentrations vs condition factor data was applied (Fig. 4).

Significant correlation between metal concentrations in organs and the condition factor of fish specimens were found especially for the gill and liver and only for the toxic metals (Cd, Hg and Pb). Positive relationships were characteristic in the gill of bream for Cd and both in the gill



**Fig. 4.** Regression plots of heavy metal concentrations vs the condition factor of fish (significance level  $p < 0.05$ ).

and liver for Pb, while for Hg a downward trend was found in all organs investigated.

## DISCUSSION

The concentration of toxic metals measured in bream of the Lake of Balaton can be considered low or moderate, showing that the heavy metal contamination of the lake and its biota is not significant. It is in agreement with earlier results obtained in the studies of fish [13], molluscs, chironomids and crustacea plankton [15] and sediment [18]. Nevertheless, the elevated Cd loads in some specimens caught in the Western basin may indicate the existence of point source pollution in the area.

The data show a higher rate of contamination of fish living in the Western basin, which may depend partly on the differences in the age-structure and condition of fish at the two sampling sites beside the higher pollution impact of the Western basin of the lake.

It is generally accepted that the concentrations of heavy metals in the organs of fish determined primarily by the pollution level of the water and food depend significantly

on the characteristic uptake, detoxification and storage of trace elements. Within a population, the differences between heavy metal concentrations in fish belonging to different developmental stages could be related first of all to the significant changes in their feeding habit, but they also depend on the metal content in food and the age, characteristic feeding rate and growth of fish. Therefore, the negative relationship between heavy metal concentrations and age of fish observed in the developmental and mature stages of common bream are the result of significant changes in the composition of the diet and a downward trend in the heavy metal intake with increasing body size. The significant correlation found between heavy metal concentrations in organs and the physical condition of fish led us to conclude that in the comparative studies of the anthropogenic pollution of different sampling sites, using fish as biological indicators, the condition factor of fish samples should also be taken into consideration.

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Received for publication: January 25, 2001

Approved for publication: May 15, 2001