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Determination of metals in fish and mussel species by inductively coupled plasma-atomic emission spectrometry

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Abstract

The concentrations of cadmium, iron, lead, zinc, copper, manganese, nickel, chromium and cobalt were determined by ICP-AES in muscles, livers, gills and skins of two fish (*Clarias gariepinus* and *Carasobarbus luteus*), and in muscles and gills of two mussel species (*Unio terminalis* and *Potamida littoralis*) sampled from the Lake Gölbaşı. Iron showed the highest levels in all examined tissues of both fish species. Following Fe; Zn showed the second highest levels in all examined tissues of both fish species except Mn levels in muscle and gill of *C. luteus*. In both mussel species, to the contrary fish, manganese showed the highest levels in examined tissues, and followed by Fe. In both fish species, the all metal concentrations in livers were higher than those in muscles. Concentrations in tissues of the analyzed metals were significantly affected by species. There were differences between the metal levels in the similar tissues of the different species ($p < 0.05$). At the same time, there was also the differences between the metal concentrations in different tissues of the same species ($p < 0.05$). Metal levels in tissues were compared with national and international permissible limits. Metal concentrations in both edible and other tissues of the sampled species were within the permissible safety levels for human uses.

Keywords: Metals; Lake Gölbaşı; Fish; Mussel; Various tissues; Turkey

1. Introduction

Metals are introduced into the aquatic ecosystems such as lakes, rivers and seas in a number of ways. They may be accumulated by aquatic organisms such as fish and mussels and may be a potential risk for ecosystem health and organisms. Industrial wastes, geochemical structure and mining of metals create a potential source of heavy metals pollution in the aquatic environment (Gümgüm, Ünlü, Tez, and Gülsün, 1994; Lee and Stuebing, 1990). Metals such as iron, copper, zinc and manganese, are essential metals since they play an important role in biological systems, whereas mercury, lead and cadmium are non-essential metals, as they are toxic, even in traces. The essential metals can also produce toxic effects when the metal intake is excessively elevated. Fish and mussels are the major part of the human diet and it is not surprising that numerous studies have been carried out on metal accumulation in different fish and mollusc species (Alam et al., 2002; Altındağ and Yiğit, 2005; Camusso, Balestrini, and Binelli, 2001; Farkas, Salánki, and Specziár, 2003; Gundacker, 2000; Mendil et al., 2005; Rutkze, Gutenmann, Lisk, and Mills, 2000; Türkmen and Türkmen, 2005; Türkmen, Türkmen, Tepe, and Akyurt, 2005; Wagner and Boman, 2004).

Lake Gölbaşı is a natural lake located in the south eastern Mediterranean region of Turkey. Total area of this lake is about 1200 ha which consists of 400 ha with marshy area. The lake is fed by underground water and used for agricultural irrigation, and recreational facilities. Flow rate of underground water is about 2.5–3 m^3/sn. In summer, the maximum depth of the lake becomes 4.0 m by irrigation and evaporation at about 1–1.5 m in depth. On the other hand, in winter, maximum depth becomes 6 m with average depths of 3.5 or 4.0 m in depth. The lake includes a number of economically valuable fish species such as

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Clarias gariepinus, *Cyprinus carpio*, *Leuciscus lepidus*, *Anguilla anguilla*, *Tilapia* sp., *Carasobarbus luteus*, *Mugil saliens*, and mussel species such as *Unio terminalis* and *Potamida littoralis*. These are important species for local people as food and also sport fishing. This lake has a great importance for the local fisheries activities. Besides being an important area for local fisheries, Lake Gölbaşı is also stated as the wild life protection area because of its biodiversity such as various fish, birds and other aquatic organisms. Due to heavy agricultural activities in the region, the lake may be affected directly or indirectly. Present study provides primary information on the distribution of metal concentrations in these species from the lake. Our specific objectives were to determine the distribution of metals in various tissues of economically important fish and mussel species such as *Clarias gariepinus*, *Carasobarbus luteus*, *Unio terminalis* and *Potamida littoralis* from Lake Gölbaşı, to evaluate the differences between the metal levels of species and tissues, and to compare the results with national and international permissible concentrations for human uses.

2. Materials and methods

Fish and mussel samples were collected from Lake Gölbaşı, located at the south eastern area of Turkey, in October 2003 and January, April (except *C. luteus*) and July 2004 (Fig. 1). During the sampling period, 38 specimens of *C. gariepinus*, 23 *C. luteus*, 40 specimens *U. terminalis* and *P. littoralis* were sampled from the lake and brought to laboratory on ice at the same day. Total length and weight of the samples were measured to the nearest millimeter and gram before dissection. Approximately 1 g sample of muscle and skin, two gill racers and whole liver from each fish, and 1 g of muscle and gill from each mussel were dissected, washed with distilled water, weighed, packed in polyethylene bags and stored at −18 °C prior to analysis. To prevent metal contamination of the samples by the laboratory equipments, special care was taken and tissues were dissected by plastic knife and all laboratoryware was soaked in 2 M HNO_3 for 48 h, and rinsed five times with distilled water, and then five times with deionized water prior to use. All tissue samples were transferred into 100 ml Teflon beakers. There after, 10 ml ultrapure concentrated nitric acid was added slowly to the sample. The Teflon beaker was covered with a watch glass, and heated at 200 °C on a hot plate for 3 h, until the solution evaporate slowly to near dryness. Two milliliters of 1 N HNO_3 was added to the residue and the solution was evaporated again on the hot plate. By repeating the additional digestion twice, all organic materials in each sample were

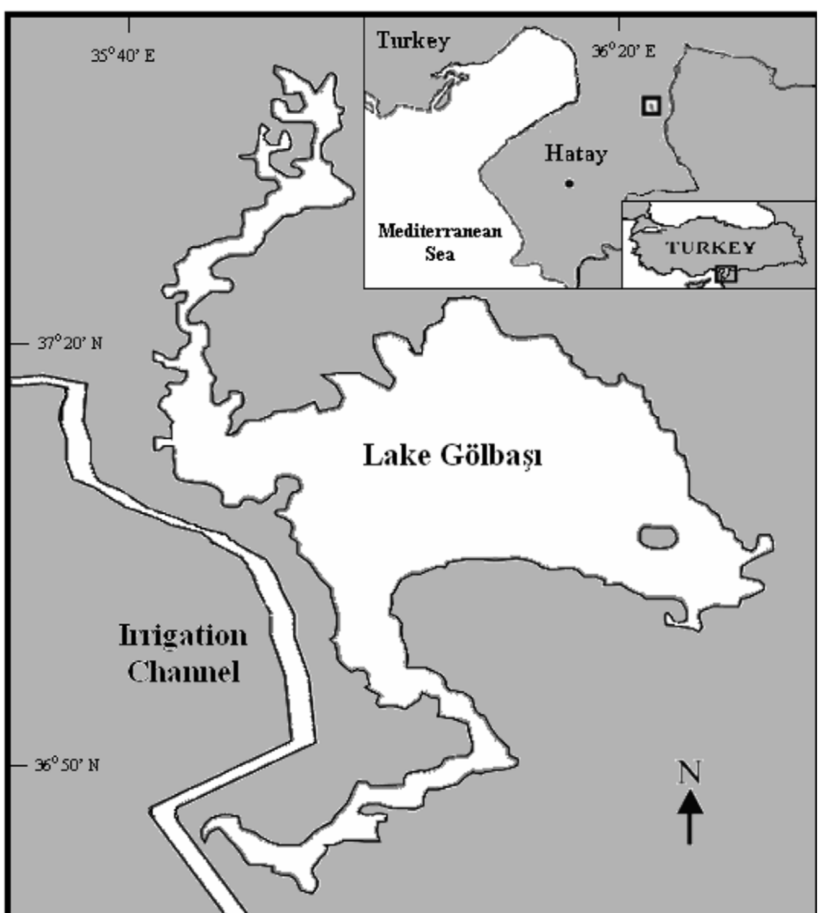

Fig. 1. Map of Lake Gölbaşı.

Table 1
Concentrations of metals found in Certified Reference Material DORM-2 (dogfish muscle) from the National Research Council, Canada (all data as means ± standard errors, in μg g^{-1} dry wt)

Value	Cd	Cu	Cr	Pb	Zn	Ni	Mn	Fe	Co
Certified	0.043	2.34	34.7	0.065	26.6	19.4	3.66	142	0.182
SE	0.008	0.16	5.5	0.007	2.3	3.1	0.34	10	0.031
Observed[a]	0.047	2.41	33.6	0.070	24.8	20.9	3.48	131	0.173
SE	0.007	0.14	1.51	0.009	1.82	0.97	0.51	11	0.024
Recovery (%)	109	103	97	108	93	108	95	92	95

[a] Each value is the average of ten determinations.

completely digested. After cooling, 2.5 ml of 1 N HNO_3 was added to digested residue and was transferred to 25 ml volumetric flasks, then diluted to level with deionized water. Before analysis, the samples were filtered through a 0.45 μm nitrocellulose membrane filter. Sample blanks were prepared in the laboratory in a similar manner to the field samples (Alam et al., 2002). Metal contents were expressed as μg g^{-1} wet weight for tissues.

All samples analysis were repeated three times for Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn by ICP-AES Varian Liberty Series-2. Standard solutions were prepared from stock solutions (Merck, multi element standard). The accuracy and precision of our results were checked by analyzed certified reference material (CRM, Dorm-2). The results showed good agreement between the certified and the analytical values (Table 1), the recovery of elements being partially complete for most of them. The absorption wavelengths for Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were 228.8, 238.9, 267.7, 324.8, 259.9, 257.6, 231.6, 220.4, and 213.9 nm, respectively.

A logarithmic transformation was done on the data to improve normality. To test the differences between the concentrations in tissues of fish and mussels, one way ANOVA was performed. Post hoc test (Duncan) was applied to determine statistically significant differences following ANOVA. Possibilities less than 0.05 were considered statistically significant ($p < 0.05$). All statistical calculations were performed with SPSS 13.0 for Windows.

3. Results

The mean metal concentrations in different tissues of the sampled fish species, *Clarias gariepinus* and *Carasobarbus luteus* from Lake Gölbaşı are given in Table 2. In both fish species, iron showed the highest levels in examined tissues, and followed by Zn except Mn levels in muscles and gills. In both species, the concentrations Cd and Co in all tissues were generally lower than those of other metals. Besides, Cd in all tissues and Co in muscle were below 0.001. In general, the metal concentrations in liver were higher than those in other tissues except Cd and Mn levels in gill for *C. luteus*. Gills showed second highest levels except Cu, Ni and Zn in skin for *C. gariepinus*, and except Cu and Zn in skin for *C. luteus*. There were differences between

Table 2
The metal concentrations in different tissues of two fish species from the Lake Gölbaşı

Metals	Tissue metal concentrations, Mean ± SE[a] (μg g^{-1} wet wt)			
Clarias gariepinus				
$N = 38$	Muscle	Liver	Gill	Skin
Cd	<0.001	<0.001	<0.001	<0.001
Co	<0.001	0.003 ± 0.000^{a}	0.001 ± 0.000^{a}	<0.001
Cr	0.013 ± 0.003^{a}	0.097 ± 0.025^{b}	0.042 ± 0.008^{a}	0.015 ± 0.002^{a}
Cu	0.079 ± 0.014^{a}	1.463 ± 0.313^{b}	0.115 ± 0.015^{a}	0.126 ± 0.018^{a}
Fe	1.485 ± 0.292^{a}	19.47 ± 2.930^{b}	2.981 ± 0.454^{a}	2.159 ± 0.710^{a}
Mn	0.068 ± 0.025^{a}	3.320 ± 1.735^{b}	0.292 ± 0.038^{a}	0.095 ± 0.028^{a}
Ni	0.009 ± 0.002^{a}	0.070 ± 0.021^{b}	0.011 ± 0.002^{a}	0.012 ± 0.005^{a}
Pb	0.014 ± 0.005^{a}	0.052 ± 0.015^{b}	0.035 ± 0.014^{ab}	0.021 ± 0.006^{a}
Zn	0.456 ± 0.098^{a}	4.392 ± 0.837^{c}	0.921 ± 0.154^{ab}	1.774 ± 0.249^{b}
Carasobarbus luteus				
$N = 23$				
Cd	0.002 ± 0.000^{a}	0.002 ± 0.000^{a}	0.003 ± 0.000^{a}	0.002 ± 0.000^{a}
Co	0.002 ± 0.000^{a}	0.015 ± 0.003^{b}	0.007 ± 0.000^{a}	0.006 ± 0.000^{a}
Cr	0.023 ± 0.004^{a}	0.125 ± 0.028^{b}	0.053 ± 0.007^{a}	0.046 ± 0.006^{a}
Cu	0.110 ± 0.019^{a}	0.521 ± 0.067^{b}	0.010 ± 0.011^{a}	0.118 ± 0.016^{a}
Fe	3.682 ± 0.960^{a}	21.56 ± 4.493^{b}	6.343 ± 1.011^{a}	3.397 ± 1.829^{a}
Mn	0.450 ± 0.263^{a}	0.891 ± 0.320^{a}	0.917 ± 0.097^{a}	0.513 ± 0.046^{a}
Ni	0.011 ± 0.002^{a}	0.102 ± 0.021^{b}	0.035 ± 0.005^{a}	0.020 ± 0.003^{a}
Pb	0.008 ± 0.001^{a}	0.058 ± 0.014^{b}	0.017 ± 0.002^{a}	0.012 ± 0.003^{a}
Zn	0.286 ± 0.018^{a}	1.363 ± 0.086^{b}	0.685 ± 0.020^{a}	2.167 ± 0.102^{b}

[a] Horizontally, letters a, b and c show differences among tissues. Means with the same letter are not statistically significant, $p > 0.05$.

the metal levels in the similar tissues of the different species ($p < 0.05$). In addition, the differences between the metal concentrations in different tissues of the same species were statistically significant ($p < 0.05$). In general, the levels in tissues of *C.luteus* were higher than those of *C. gariepinus* except Pb and Zn in muscle, Cu, Mn and Zn in liver, Cu, Pb and Zn in gill, and Cu and Pb in skin (Table 2).

The mean metal concentrations in the muscles and gills of the sampled mussel species, *Unio terminalis* and *Potamida littoralis* from Lake Gölbaşı are given in Table 3. The levels of Cd and Co in muscles and gills were generally lower than those of other metals. In both mussel species, to the contrary fish, manganese showed the highest levels in examined tissues, and followed by Fe. Except Cu in *U. terminalis*, the metal levels in different tissues of both species were statistically significant ($p < 0.05$). In both species, the metal concentrations in gills were higher than those in muscles. When compared the similar tissues of different mussel species, Cd, Mn, Ni, Pb and Zn levels in tissues of *P. littoralis* were higher than those of *U. terminalis*, however, Cr, Co and Fe levels in tissues of *U. terminalis* were higher than those of *P. littoralis*. On the other hand, Cu level in muscle of *U. terminalis* was higher than that of *P. littoralis*, whereas, the level in gill was lower. In general, the concentrations of metals in similar tissues of mussel species were higher than those of fish species, especially Mn (Tables 2 and 3).

4. Discussion

Present study examined the concentrations of Cd, Fe, Cu, Zn, Cr, Co, Mn, Ni and Pb in the muscle, liver, gill and skin of *C. gariepinus* and *C. luteus*, and in muscle and gill of *P. littoralis* and *U. terminalis* from Lake Gölbaşı. Iron showed the highest levels in all examined tissues of both fish species. Zn showed the second highest levels in all examined tissues of both fish species except Mn levels in muscle and gill of *C. luteus* (Table 2), in agreement with the results of many researchers (Karadede et al., 2004; Mendil et al., 2005; Türkmen et al., 2005). In both fish species, liver had the highest concentrations of examined metals except the levels of Cd and Mn in gill, and Zn in skin of *C. luteus*. Gill had the second highest concentrations of examined metals except the levels of Cu, Ni and Zn in skin of *C. gariepinus*, and Cu and Zn in skin of *C. luteus*. On the other hand, the lowest concentrations of examined metals in both species were found in the muscles. Many studies showed that metals accumulate mainly in metabolic organs such as liver that stores metals to detoxificate by producing metallothionein-like proteins (Carpene and Vasak, 1989; Karadede et al., 2004).

Table 4 compiles the data on concentrations of metals in the muscles of fish from Lake Gölbaşı with other studies, Turkish permissible concentrations (TPCs) and tolerable concentrations in fish according to the Turkish Fisheries Law and Regulations. As can be seen, the concentrations of Cd, Cr, Cu, Pb and Ni in *C. gariepinus* and *C. luteus* from Lake Gölbaşı were much lower than those in UN FAO Codex for fish and Turkish Fisheries Law and Regulations (Nauen, 1983; TKB, 2002). When our results were compared with other studies, the concentrations found in *C. gariepinus* and *C. luteus* were lower than those found in fishes of Lake Kasumigaura (except Fe and Mn for *C.luteus*), Lake Balaton and Lake Beyşehir, seven different lakes in Tokat and İskenderun bay (Alam et al., 2002; Altındağ and Yiğit, 2005; Farkas et al., 2003; Mendil et al., 2005; Türkmen et al., 2005).

In both mussel species, similar to fish species the concentrations of metals in gill were higher than those in muscles. Gundacker (2000) reported the levels of metals in gills were higher than those in muscles for *Anodonto* sp. and *Unio pictorum* from urban river habitats in Vienna. Manganese had the highest concentrations in both gills and muscles of *P. littoralis* and *U. terminalis*. Mn was followed by Fe as second highest levels. Wagner and Boman (2004) found the similar results for *P. swinhoei* from Duy and An Thin in the northern part of Vietnam. On the other hand, Cd and Co generally were lower than other metals or under detection limits, especially Cd. Camusso et al. (2001) reported that the levels of Cd and Co in *D. polymorpha* were lower than those of other metals. For Cd in mussels, similar results were reported by some researchers (Gundacker, 2000; Wagner and Boman, 2004).

The concentrations of Mn, Ni, Pb and Zn in muscles and Cd, Cu, Mn, Ni, Pb and Zn in gill of *P. littoralis* were higher than those of *U. terminalis*. It is very difficult to compare the metal concentrations even within the similar tissues of two different species because of different feeding habits, the differences in the aquatic environments concerning

Table 3
The mean metal concentrations in the muscles and gills of two mussel species from the Lake Gölbaşı

Metals	Tissue metal concentrations, Mean ± SE[a] (μg g^{-1} wet wt)	
Unio terminalis, $N = 40$	Muscle	Gill
Cd	<0.001	0.001 ± 0.000
Co	0.002 ± 0.000[a]	0.009 ± 0.001[b]
Cr	0.027 ± 0.006[a]	0.079 ± 0.016[b]
Cu	0.098 ± 0.019[a]	0.154 ± 0.025[a]
Fe	6.799 ± 0.807[a]	12.05 ± 1.383[b]
Mn	10.21 ± 1.498[a]	37.40 ± 4.103[b]
Ni	0.012 ± 0.002[a]	0.038 ± 0.006[b]
Pb	0.008 ± 0.003[a]	0.022 ± 0.004[b]
Zn	0.587 ± 0.043[a]	1.376 ± 0.090[b]
Potamida littoralis, $N = 40$		
Cd	0.006 ± 0.000[a]	0.008 ± 0.001[b]
Co	0.002 ± 0.000[a]	0.007 ± 0.002[b]
Cr	0.010 ± 0.002[a]	0.025 ± 0.006[b]
Cu	0.093 ± 0.008[a]	0.725 ± 0.531[b]
Fe	5.091 ± 0.742[a]	11.63 ± 2.261[b]
Mn	10.67 ± 1.390[a]	49.23 ± 4.437[b]
Ni	0.016 ± 0.002[a]	0.050 ± 0.007[b]
Pb	0.010 ± 0.002[a]	0.055 ± 0.025[b]
Zn	0.911 ± 0.107[a]	2.510 ± 0.184[b]

[a] Horizontally, letters a and b show differences between tissues. Means with the same letter are not statistically significant, $p > 0.05$.

Table 4
Comparison of the overall metal concentrations in the muscles of fish species from Lake Gölbaşı with other studies and guidelines

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
This study (μg g^{-1} wet wt)									
C. gariepinus	<0.001	<0.001	0.013	0.079	1.485	0.068	0.009	0.014	0.456
C. luteus	0.002	0.002	0.023	0.110	3.682	0.450	0.011	0.008	0.286
Altındağ and Yiğit (2005)[a]	0.54–0.64	–	0.24–0.31	–	–	–	–	0.30–0.68	–
Farkas et al., 2003)[b]	0.42–0.61	–	–	1.77–2.22	–	–	–	0.44–1.63	10.9–14.5
Alam et al. (2002)[c]	0.009	0.005	0.067	0.249	2.729	0.307	0.041	0.031	5.433
Türkmen et al. (2005)[d]	0.95	1.42	1.69	1.57	10.2	1.71	2.90	2.32	4.36
Mendil et al. (2005)[e]	0.1–1.2	–	0.6–1.6	1.1–4.1	64.3–197	11.1–72.9	1.2–3.4	0.7–2.4	11.9–37.1
TKB (2002)[f]	0.1	–	–	20	–	–	–	1.0	50
Nauen (1983)[g]	0.05–5.5	–	1.0	10–100	–	–	–	0.5–6.0	30–100

[a] Lake Beyşehir, Turkey (*Leuciscus cephalus*, *Cyprinus carpio*, *Tinca tinca*, *Lucioperca lucioperca*).
[b] Lake Balaton, Hungary (*Abramis brama*), (μg g^{-1} dry wt).
[c] Lake Kasumigaura, Japan (*Cyprinus carpio*), (μg g^{-1} dry wt).
[d] Iskenderun Bay, Mediterranean Sea (*Saurida undosquamis*, *Sparus aurata*, *Mullus barbatus*) (μg g^{-1}dry wt).
[e] Seven different lakes in Tokat, Turkey (seven fish species).
[f] Turkish Permissible Concentrations.
[g] The ranges of maximum permissible concentrations for different countries (FAO), (μg g^{-1} wet wt).

the source and level of water pollution (Papagiannis, Kagalou, Leonardos, Petridis, and Kalfakaou, 2004), growing rates of the species, types of tissues analyzed and some other factors. Thus, the differences between metal accumulations in similar tissues of different species are probable.

Table 5 compiles the data on the concentrations of metals in the muscles of mussels from Lake Gölbaşı with other studies, some guidelines for mollusks. As can be seen, when compared with those, the concentrations of all examined metals in *U. terminalis* and *P. littoralis* were much lower than TPCs and tolerable concentrations in mollusks (Nauen, 1983; TKB, 2002). On the other hand, if our results were compared with other studies, the concentrations of all metals analyzed in *U. terminalis* and *P. littoralis* from Lake Gölbaşı were lower than those found in mussels of urban river habitats, lakes Erie and Ontario, Italian subalphine lakes, the northern part of Vietnam (Gundacker, 2000; Camusso et al., 2001; Rutkze et al., 2000; Wagner and Boman, 2004).

5. Conclusion

Present study provides primary information on the distribution of metal concentrations in tissues of *C. gariepinus*, *C. luteus*, *P. littoralis* and *U. terminalis* from the Lake Gölbaşı. Although Lake Gölbaşı is surrounded by agricultural lands, the levels of analyzed metals in the tissues of examined species in the present study were found much lower than legal limits. Being a natural lake, supported by underground water and has no inflow might be the reason for these low metal levels. Based on the samples analyzed, the values for cadmium, cobalt, chrome, copper,

Table 5
Comparison of the overall metal concentrations in the muscles of mussel species from Lake Gölbaşı with other studies and guidelines

	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
This study (μg g^{-1} wet wt)									
U. terminalis	<0.001	0.002	0.027	0.098	6.799	10.21	0.012	0.008	0.587
P. littoralis	0.006	0.002	0.010	0.093	5.091	10.67	0.016	0.010	0.911
Gundacker (2000)[a]									
Anodonta sp.	0.13–0.76	–	–	0.9–12.7	–	–	–	0.12–0.98	71–269
Unio pictorium	0.15–0.64	–	–	2.5–6.5	–	–	–	0.38–0.88	145–213
Wagner and Boman (2004)[b]	0.05–0.08	–	0.14–0.36	2.4–3.2	390–1900	520–1600	0.42–0.88	0.49–0.53	120–150
Rutkze et al. (2000)[c]									
Dreissena polymorpha	3.4–10	–	4.0–7.5	23–40	–	97–109	16–17	1.0–5.0	164–262
Dreissena bugensis	2.5–8.5	–	5.0–7.5	21–61	–	50–119	8.5–15	1.5–4.8	63–134
Camusso et al. (2001)[d]	0.60–3.44	0.88–1.51	2.03–4.97	14.6–26.3	–	–	11.9–24.2	1.96–5.87	158–346
TKB (2002)[e]	0.1	–	–	20	–	–	–	1.0	50
Nauen (1983)[f]	2.0	–	1.0	10–30	–	–	–	1.0–6.0	40–100

[a] Urban river habitats in Vienna, Austria, (μg g^{-1} dry wt).
[b] The northern part of Vietnam (*Pletholophus swinhoei*), (μg g^{-1} dry wt).
[c] Lakes Erie and Ontario, USA (μg g^{-1} dry wt).
[d] Italian subalpine lakes, Italy (*Dreissena polymorpha*), (μg g^{-1} dry wt).
[e] Turkish Permissible Concentrations.
[f] The ranges of maximum permissible concentrations for different countries (FAO), (μg g^{-1} wet wt).

iron, manganese, nickel, lead and zinc measured in the edible parts of fish and mussels are not heavily burdened with metals, and the concentrations did not exceed the established quality standards for fish and mussels (Nauen, 1983; TKB, 2002). Therefore, it can be concluded that these metals in edible parts of the examined species should pose no health problems for consumers. However, in the future, bioaccumulation of analyzed metals in this study can be a possible risk for the consumption of these species, if agricultural and recreational practices in the surroundings of the lake increase unconsciously.

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References

Alam, M. G. M., Tanaka, A., Allinson, G., Laurenson, L. J. B., Stagnitti, F., & Snow, E. (2002). A comparison of trace element concentrations in cultured and wild carp (*Cyprinus carpio*) of lake Kasumigaura, Japan. *Ecotoxicology and Environmental Safety, 53*, 348–354.

Altındağ, A., & Yiğit, S. (2005). Assessment of heavy metal concentrations in the food web of lake Beyşehir, Turkey. *Chemosphere, 60*, 552–566.

Camusso, M., Balestrini, R., & Binelli, A. (2001). Use of zebra mussel (*Dreissena polymorpha*) to assess trace metal contamination in the largest Italian subalpine lakes. *Chemosphere, 44*, 263–270.

Carpene, E., & Vasak, M. (1989). Hepatic metallothionein from goldfish (*Carassius auratus*). *Comparative Biochemistry and Physiology, 92B*, 463–468.

Farkas, A., Salánki, J., & Specziár, A. (2003). Age and size-specific patterns of heavy metals in the organs of freshwater fish *Abramis Brama* L. populating a low-contaminated site. *Water Research, 37*, 959–964.

Gümgüm, B., Ünlü, E., Tez, Z., & Gülsün, Z. (1994). Heavy metal pollution in water, sediment and fish from the Tigris River in Turkey. *Chemosphere, 29*, 111–116.

Gundacker, C. (2000). Comparison of heavy metal bioaccumulation in freshwater mollusks of urban river habitats in Vienna. *Environmental Pollution, 110*, 61–71.

Karadede, H., Oymak, S. A., & Ünlü, E. (2004). Heavy metals in mullet, *Liza abu*, and cat fish, *Silurus triostegus*, from the Atatürk Dam Lake (Euphrates), Turkey. *Environmental International, 30*, 183–188.

Lee, Y. H., & Stuebing, R. B. (1990). Heavy metal contamination in the River Toad, *Bufo juxtasper* (Inger), near a copper mine in East Malaysia. *Bulletin of Environmental Contamination and Toxicology, 45*, 272–279.

Mendil, D., Uluözlü, Ö. D., Hasdemir, E., Tüzen, M., Sari, H., & Suiçmez, M. (2005). Determination of trace metal levels in seven fish species in lakes in Tokat, Turkey. *Food Chemistry, 90*, 175–179.

Nauen, CE. (1983). Compilation of legal limits for hazardous substances in fish and fishery products. *FAO Fish Circular, 764*, 102.

Papagiannis, I., Kagalou, I., Leonardos, J., Petridis, D., & Kalfakaou, V. (2004). Copper and zinc in four freshwater fish species from Lake Pamvotis (Greece). *Environmental International, 30*, 357–362.

Rutkze, M. A., Gutenmann, W. H., Lisk, D. J., & Mills, E. L. (2000). Toxic and nutrient element concentrations in soft tissues of zebra and quagga mussels from Lakes Erie and Ontario. *Chemosphere, 40*, 1353–1356.

TKB (2002). Fisheries laws and regulations. Ministry of Agriculture and Rural Affairs, Conservation and Control General Management, Ankara.

Türkmen, A., & Türkmen, M. (2005). Seasonal and spatial variations of heavy metals in the spiny rock oyster, *Spondylus spinosus*, from coastal waters of İskenderun Bay, Northern East Mediterranean Sea, Turkey. *Bulletin of Environmental Contamination and Toxicology, 75*, 716–722.

Türkmen, M., Türkmen, A., Akyurt, İ., & Tepe, Y. (2005). Limpet, *Patella caerulea* Linnaeus, 1758 and Barnacle, *Balanus* sp., as biomonitors of trace metals availabilities in İskenderun Bay, Northern East Mediterranean Sea. *Bulletin of Environmental Contamination and Toxicology, 74*, 301–307.

Türkmen, A., Türkmen, M., Tepe, Y., & Akyurt, İ. (2005). Heavy metals in three commercially valuable fish species from İskenderun Bay, Northern East Mediterranean Sea, Turkey. *Food Chemistry, 91*, 167–172.

Wagner, A., & Boman, J. (2004). Biomonitoring of trace elements in Vietnamese freshwater mussels. *Spectrochimica Acta Part B, 59*, 1125–1132.