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# Total metal levels in crayfish *Astacus leptodactylus* (Eschscholtz, 1823), and surface sediments in Lake Terkos, Turkey

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**Abstract** The aim of this study was to determine the total metal accumulation (aluminium, copper, manganese, lead, cadmium and iron) in different organs and eggs of *Astacus leptodactylus* (Eschscholtz, 1823) and sediments total metal contents (aluminium, copper, manganese, lead, cadmium, iron, zinc, chromium, nickel) in Lake Terkos. Water and sediment samples were collected from two stations at two different depths (1 and 2 m) of Lake Terkos in May 2008. Crayfish samples were collected by trammel net at the same region. Primary hydrographic conditions, such as temperature (13.6–19.4°C), salinity (0.27–0.34‰), dissolved oxygen (7.04–12.30 mg $l^{-1}$) and pH (7.42–8.51), were recorded for each sampling point. Moreover, the total organic carbon (1.65–5.44%) and the total calcium carbonate contents (19.44–41.16%) of sediment samples were determined. According to the Turkish Food Codex (J Zool 26:283–288, 2002), the maximum allowable Pb and Cd levels in crayfish are 0.5 mg/kg wet weight. Accordingly, the Pb and Cd levels determined in *A. leptodactylus* samples are below this limit. However, when compared with the acceptable metal limits defined by WHO, Australian National Health and Medical Research Council and Ministry of Agriculture in United Kingdom (UK), it is clear that the Cu level is at the limit and the Cd results exceed the limit. When the metal contents in sediment samples from Lake Terkos are examined, it is seen that the Al, Fe, Mn, Ni and Cu contents are lower while Zn, Cr, Cd and Pb contents are higher than the crustal average values. The high values draw attention to the land-based domestic and industrial inputs. Lake Terkos sediments have high enrichment factors (EF) of Zn, Cr, Cd and Pb metals which corroborate this result. The low EFs of Fe, Ni and Cu are due to the natural (terrigeneous) inputs. Additionally, there is no Al, Fe, Ni and Cu metal enrichment in these lake sediments because of the low contamination factor (CF) values. However, it is moderately contaminated by Zn, Cr and Pb, and heavily contaminated by Cd.

**Keywords** Total metal accumulation · *Astacus leptodactylus* · Lake Terkos · Sediment · Ecological properties

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## Introduction

With its population over 10 million and significant centres of industry and commerce, Istanbul is one of the important mega-cities of Turkey and the world. The population of this socio-economically significant city is increasing gradually with the effect of migration. While the number of business and residential areas increase in an uncontrolled way, the need for new food and water supplies cause people to make use of natural resources more. Lake Terkos is very important since it is the cleanest water supply of Istanbul and provides 25% of the water demand of this Metropolitan Area (Baykal et al. 2000). Extending parallel to the shoreline of the Black Sea in the north part of the Thrace Peninsula in the Marmara Region, the lake has a surface area of 32 km$^2$and a maximum depth of 11 m. Lake Terkos was a lagoon connected to the Black Sea until its disconnection and now it is connected to the Black Sea through a natural canal. Although it is close to the Black Sea, it is a freshwater lake since it is fed by a number of brooks (Güher 2002; Baylan and Karadeniz 2006).

The control of pollution in lakes, which are important sources of food and water, is significant for the sustainability of lake ecosystem as well as human health. Therefore, the physical, chemical and biological parameters in lakes need to be determined and the changes in those parameters need to be followed. Metals are potentially toxic to aquatic environment and the exceedance of their natural limits is harmful to aquatic organisms, environment and human health (Förstner and Wittmann 1981). For this reason, in ecological studies metal accumulation is considered as important parameter and metal accumulations, especially in species consumed as food, are monitored. Metals are known to subside and accumulate in sediments. Also, benthic freshwater invertebrates show an apparent relation with metals and metals accumulate in these species (Timmermans 1993).

The role of sediments in metal bioaccumulation is very important especially in crayfish (Anderson et al. 1997). In freshwaters, after fish, crustaceans and mollusks are the foods consumed most by humans. Various species of crayfish are among luxury food sources and take up a lot of room in markets (Harlioğlu and Holdich 2001). In addition, these species, which have an important place in the trophic chain of benthic communities of lakes and rivers, are considered as the biological indicators of clean water and useful biomarkers in monitoring metal pollution (Anderson et al. 1997; Mackevičienė 2002; Patir et al. 2002). *Astacus*

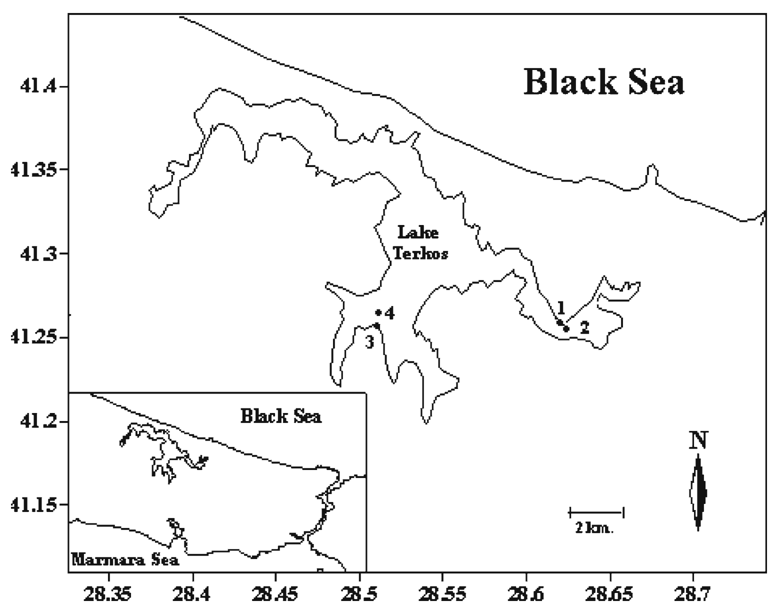


**Fig. 1** Sampling stations in Lake Terkos

**Table 1** Accuracy of AAS analyses used in this study, as determined by analysis of reference materials (the RSD of measured values were ≤7%)

| Reference material | Element | Measured value (this study) ppm (μg/g) | Certified value or range ppm (μg/g) |
|---|---|---|---|
| IAEA433 | Fe | 42,800 | 40,300–41,300 |
| IAEA433 | Al | 78,200 | 76,800–79,600 |
| IAEA405 | Cr | 81.8 | 80–88 |
| IAEA433 | Mn | 316 | 312–320 |
| IAEA405 | Cu | 47.3 | 46.5–48.9 |
| QTM080MS | Zn | 126 | 148 |
| QTM081MS | Ni | 24.1 | 27.5 |
| IAEA405 | Pb | 76.9 | 72.6–77 |
| IAEA407 | Hg | 0.209 | 0.222 |
| IAEA433 | Cd | 0.153 | 0.145–0.161 |

*IAEA433, IAEA405* Marine Sediment-International Atomic Energy Agency; *QTM080MS, QTM081MS* Marine Sediment-Netherlands

*leptodactylus* (Eschscholtz, 1823), an object of this study, is a common species in freshwaters of Turkey (Holthuis 1961).

The aim of this study is to determine the total metal (aluminium, copper, manganese, lead, cadmium and iron) contents in different organs and eggs of *A. leptodactylus* (Eschscholtz, 1823) and sediments (aluminium, copper, manganese, lead, cadmium, iron, zinc, chromium, nickel) in Lake Terkos. We will, thereby, give information about the contamination status of this lake which is an important food and water supply.

## Materials and methods

### Study area

Water and sediment samples were collected from four sampling points at two different depths (1 m, 2 m) of Lake Terkos in May 2008. Crayfish samples were collected by trammel net at same region (Fig. 1).

**Table 2** Ecological properties of the sampling stations

| Station | Temperature (°C) | Salinity (‰) | Dissolved oxygen (mg $l^{-1}$) | pH |
|---|---|---|---|---|
| 1 | 19.4 | 0.27 | 8.03 | 7.42 |
| 2 | 17.2 | 0.27 | 7.04 | 7.48 |
| 3 | 15.0 | 0.34 | 12.12 | 8.30 |
| 4 | 13.6 | 0.27 | 12.30 | 8.51 |

### Sampling, storage and dissection

The crayfish samples were kept in a deep freeze (approximately −18°C) before analysis. The total length and the total weight of every specimen were measured prior to sample preparation for metal analysis. The total lengths were measured from rostrum to telson. Male and female individuals that are equally similar in length and weight were chosen. Different body parts of crayfish samples were separated using the methods recommended by UNEP (1976). These parts were dried at 45°C and kept away from metallic materials to avoid contamination. The results were given as dry and fresh weight.

Surface sediment samples were collected by using a handling Van Veen grab. The top 1 cm of sediment which is of brown colour from the

**Table 3** Dry and fresh weight values of different parts of *A. leptodactylus*

| Body part | Fresh weight (g) | Dry weight (g) |
|---|---|---|
| Muscle (females) | 119.002 | 23.31 |
| Muscle (males) | 73.11 | 13.94 |
| Gill (females) | 30.76 | 13.12 |
| Gill (males) | 55.10 | 20.60 |
| Hepatopancreas (females) | 78.90 | 37.43 |
| Hepatopancreas (males) | 66.05 | 30.03 |
| Ovary | 9.90 | 5.00 |
| Testis | 20.79 | 6.28 |
| Egg | 58.38 | 26.16 |

**Table 4** Total metal concentrations in different organs and eggs of *A. leptodactylus*

| | Al μg g$^{-1}$ | Fe μg g$^{-1}$ | Cu μg g$^{-1}$ | Mn μg g$^{-1}$ | Pb μg g$^{-1}$ | Cd μg g$^{-1}$ |
|---|---|---|---|---|---|---|
| Muscle (females) | < 0.01 | 73.41 | 10.50 | 1.03 | < 0.01 | < 0.01 |
| Muscle (males) | 44.59 | 67.77 | 7.81 | 2.46 | < 0.01 | 0.43 |
| Hepatopancreas (females) | 57.70 | 68.07 | 263.47 | 52.06 | < 0.01 | 0.88 |
| Hepatopancreas (males) | 7.53 | 75.34 | 176.73 | 35.42 | < 0.01 | 0.23 |
| Gill (females) | 1,128.77 | 889.02 | 134.17 | 103.63 | < 0.01 | < 0.01 |
| Gill (males) | 391.56 | 491.18 | 68.09 | 92.22 | < 0.01 | 0.22 |
| Ovary | 57.67 | 15.03 | 32.25 | 5.29 | < 0.01 | < 0.01 |
| Testis | < 0.01 | 33.85 | 8.75 | 4.91 | < 0.01 | 0.12 |
| Egg | 76.56 | 58.10 | 29.06 | 10.01 | < 0.01 | < 0.01 |
| Turkish Seafood Standards | –[a] | –[a] | 20 | –[a] | 0.5 | 0.5 |
| WHO (Pourang et al. 2004) | –[a] | –[a] | 10 | –[a] | –[a] | 0.2 |
| Australian National Health and Medical Research Council (Pourang et al. 2004) | –[a] | –[a] | 10 | –[a] | 1.5 | 0.05 |
| Ministry of Agriculture, Fisheries and Food in UK (Pourang et al. 2004) | –[a] | –[a] | 20 | –[a] | 2.0 | 0.2 |

[a]Not detected

grab was taken by using a plastic spoon. The sediment samples were kept in a deep freeze (approximately −18°C) immediately after collection. The samples were dried at 45°C and homogenised prior to analysis.

## Analytical procedures

Physicochemical parameters such as temperature (°C), salinity (‰), dissolved oxygen (mg l$^{-1}$) and pH values were determined in the sampling area. Temperature and pH were measured in situ using portable instruments. The Mohr–Knudsen (Ivanoff 1972) and the Winkler methods (Winkler 1888) were used to measure salinity and dissolved oxygen (DO), respectively.

Metal contents in samples were determined through a Shimadzu 6701F atomic absorption spectrophotometer (AAS) after a "total" digestion involving $HNO_3 + H_2SO_4 + HNO_3$ in crayfish samples and a "total" digestion involving $HNO_3 + HClO_4 + HF$ acid mixture in the sedi-

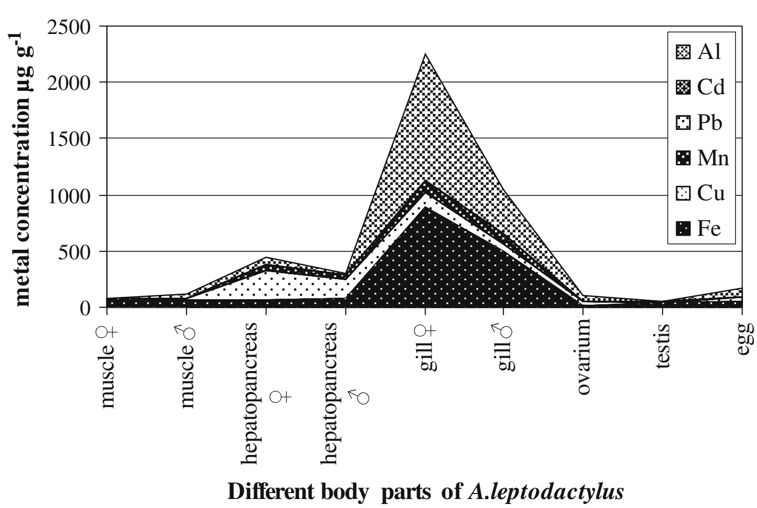


**Fig. 2** Total metal concentrations in different organs and eggs of *A. leptodactylus*

**Table 5** Total metal, total organic carbon (TOC) and calcium carbonate ($CaCO_3$) values in surface sediments from Lake Terkos

| Station | Al % | Fe % | Mn μg g$^{-1}$ | Ni μg g$^{-1}$ | Cu μg g$^{-1}$ | Zn μg g$^{-1}$ | Cr μg g$^{-1}$ | Cd μg g$^{-1}$ | Pb μg g$^{-1}$ | TOC % | $CaCO_3$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.82 | 2.63 | 335.75 | 34.20 | 33.09 | 137.55 | 91.88 | 1.16 | 62.51 | 3.64 | 19.44 |
| 2 | 4.24 | 2.59 | 372.03 | 25.07 | 14.78 | 92.04 | 123.76 | 1.11 | 24.15 | 5.44 | 36.59 |
| 3 | 3.09 | 1.93 | 284.54 | 39.41 | 5.94 | 76.22 | 102.34 | 0.83 | 23.51 | 1.65 | 41.16 |
| 4 | 3.19 | 1.83 | 404.57 | 37.82 | 9.43 | 84.19 | 123.92 | 0.56 | 22.61 | 1.90 | 39.64 |
| Average[a] crust | 8.1 | 5.4 | 1,000 | 75 | 50 | 70 | 100 | 0.15 | 12.5 | 0.8[b] | 6.0[b] |

[a]From Krauskopf (1979)
[b]From Mason and Moore (1982)

ment samples. Pb and Cd contents were measured by using flame technique in AAS after a total digestion, involving $HNO_3 + HClO_4 + HF$ acid mixture (Loring and Rantala 1992). The accuracy of AAS analyses used in this study was determined through the analysis of reference materials (Table 1).

The metal values were normalised to eliminate the grain-size effects using metal/Al ratios (Loring and Rantala 1992). In addition, the crustal abundance of Taylor (1972) was used as background reference in this study.

The total carbonate ($CaCO_3$) contents were determined using a gasometric–volumetric method (Loring and Rantala 1992). The total organic carbon (TOC) was analysed using the Walkey–Blake method, which involves titration after a wet combustion of the samples (Gaudette et al. 1974; Loring and Rantala 1992).

## Results

### Physicochemical parameters of water in Lake Terkos

Since oxic and anoxic conditions are effective on transitions from sediment surfaces to water phase, the oxygen in bottom water is important for metal distributions (Förstner et al. 1986). In addition, physicochemical parameters such as temperature, salinity and dissolved oxygen have some effects on the toxicity of metals (Elmaci et al. 2007). On the other hand, the knowledge about these parameters might give information about the habitat of the crayfish studied on (Table 2).

According to the physicochemical parameters of Lake Terkos, the pH content of water samples taken from this lake ranged between 7.42 and 8.51. These values coincide with those (6.5–8.5)

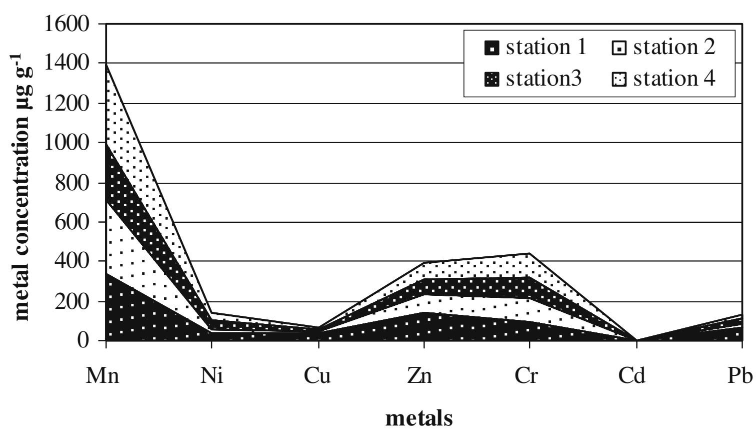


**Fig. 3** Total metal concentrations in surface sediments from Lake Terkos

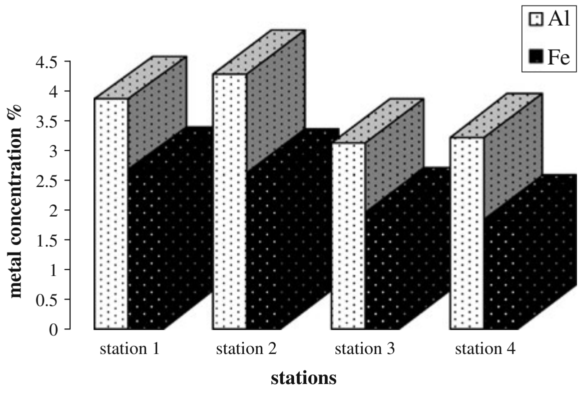


**Fig. 4** Al and Fe concentrations in surface sediments from Lake Terkos

in the World Health Organization Guidelines for Aesthetic Quality (American Water Works Association 1990). Dissolved oxygen values were between 7.04 and 12.30. According to the US Environmental Protection Agency, oxygen values must range between 8 (summer) and 14 mg $l^{-1}$ (winter) (US Environmental Protection Agency, http: //www.epa.gov/glindicators/water/oxygenb.html). The values determined in this study were between these limits. On the other hand, the mean salinity was found as 0.28‰, so Lake Terkos is a fresh water lake.

### The length–weight values of *A. leptodactylus*

Length of 50 female individuals ranged between 10 and 13 cm (mean 11.24 ± SD 1.09 cm) and 50 male individuals between 10 and 14 cm (mean 11.1 ± SD 1.29 cm) were used in this study. The dry and fresh weights of different parts of crayfish are presented in Table 3.

### Metals in different organs and eggs of *A. leptodactylus*

The results of the total metal concentrations in the *A. leptodactylus* are shown in Table 4 and Fig. 2.

### Sediment geochemistry

The results obtained from the analyses performed in order to determine the total metal concentrations and total organic carbon and total carbonate values in sediment samples collected from Lake Terkos are given in Table 5.

The analyses of the metal contents in the sediment samples taken from Lake Terkos showed that metals could be ordered according to the amount of metal accumulation as follows: Al, Fe, Mn, Cr, Zn, Ni, Pb, Cu, Cd (Figs. 3 and 4).

The total organic carbon (TOC) and carbonate ($CaCO_3$) contents ranged between 1.65–5.44% and 19.44–41.16%, respectively.

## Discussion

The accumulation levels of such metals as Fe, Cu, Mn, Al, Pb, Cd in muscles, hepatopancreas, gills, ovaries, testis and eggs of *A. leptodactylus* were analysed and the results were compared with the other studies on *A. leptodactylus* and various crayfish. Also, *A. leptodactylus* was compared with freshwater invertebrates in general terms. However, while making a comparison among metal accumulation amounts, it must be taken into account that these values change according to species, physiology, body weight, diet (Timmermans 1993).

As a regulating metal for freshwater decapods, copper has a significant biochemical role since it constitutes a part of hemocyanin that is a respiratory protein and binds oxygen in arthropods and mollusks (Tahon et al. 1988; Mackevičienė 2002). According to the Cu values determined in this study, the highest values were seen in hepatopancreas followed by gills. In the previous studies on *A. leptodactylus* and *Astacus astacus*, similar results were obtained and it was found that exoskeleton and hepatopancreas might serve as zones for excretion of Cu (Mackevičienė 2002; Güner 2007). Hepatopancreas is also thought to be a main center for metal storage and detoxification in many crustacean species (Dallinger and Rainbow 1993). In the study of Naghshbandi et al. (2007), the metal contents of *A. leptodactylus* samples taken from Aras Dam of Iran were analysed and the similar results were found. The highest Cu concentration was found in the hepatopancreas (female 145.8 μg $g^{-1}$, male 325.0 μg $g^{-1}$) and gills (female 305.1 μg $g^{-1}$, male 284.5 μg $g^{-1}$)

and the lowest in muscles (female 36.0 μg $g^{-1}$, male 36.4 μg $g^{-1}$). The Cu level determined in gills is nearly half of that in samples from Aras Dam (Naghshbandi et al. 2007). According to the results, ovaries include more Cu than testis. Moreover, it is known that copper plays a significant role in the growth of ovary in crustaceans (Sreenivasa Rao and Anjaneyulu 2008).

Fe, Mn and Al were accumulated in gills more than in the other tissues. That besides having a direct contact with the outer environment gills play an active role in the regulation of ionic current might be another reason for their accumulating these metals in high levels (Alcorlo et al. 2006). According to Naghshbandi et al. (2007), in the *A. leptodactylus* samples from Aras Dam, the highest Fe accumulation was observed in gills (female 104.0 μg $g^{-1}$, male 145.0 μg $g^{-1}$) and exoskeleton (female 107.4 μg $g^{-1}$, male 281.0 μg $g^{-1}$) followed by hepatopancreas in the third row (female 77.0 μg $g^{-1}$, male 156.0 μg $g^{-1}$) and the lowest value was observed in abdominal muscles (female 25.7 μg $g^{-1}$, male 21.9 μg $g^{-1}$). As stated before, in this study, the highest values were observed in gills and the amount of Fe in muscles was close to that in hepatopancreas. The lowest Fe determined in the present study was in the ovary (15.03 μg $g^{-1}$). The high Fe content in egg might be related to the role of Fe in oocyte growth and embryogenesis (Méndez et al. 2001).

When Mn amount detected in this study was compared with the *A. leptodactylus* samples taken from Aras Dam, it was seen that in the samples from Aras Dam, the highest concentration (female 40.7 μg $g^{-1}$, male 39.3 μg $g^{-1}$) was in exoskeleton and the lowest (female 7.1 μg $g^{-1}$, male 5.9 μg $g^{-1}$) in abdominal muscles (Naghshbandi et al. 2007). In this study, the highest value was identified in gills. This result is higher than the one determined in the exoskeleton by Naghshbandi et al. (2007). This might be due to the fact that gills play an important role in the uptake of Mn, which is an essential metal (Baden and Eriksson 2006). In this study, it was observed that the Mn content of the ovary was higher than that of the testis and the amount of Mn in the egg was nearly two times more than that in the ovary. The reason might be that Mn plays an important role in the gametogenesis of crustaceans (Méndez et al. 2001).

Al is a metal abundant in nature and there was common belief that it does not have a negative effect on human health (Ranau et al. 2001). Although Al compounds are present in the structure of all stones, surface waters and living organisms it is not an essential metal (Howells et al. 1994). Due to industrialisation, the amount of Al is increasing and especially $Al^{3+}$ ions in water might accumulate in the structure of organisms through food chain. It was found that the edible parts of crustaceans include high amounts of Al 5 mg/kg; (Ranau et al. 2001). In this study, the amount of Al accumulation in the muscles of female individuals were found below the measurement limits and that in the muscles of male individuals (44 μg $g^{-1}$) were found high. In the present study, the Al content in gills was determined to be far higher than this amount and Al accumulation was considerably higher than the other metals analysed. It is known that gills play an important role in the Al uptake and after gills Al accumulates most in hepatopancreas and muscles (Elangovan et al. 1999; Alexopoulos et al. 2003).

Cd is a toxic metal that is not found naturally in the environment (Giesy et al. 1980). When the Cd levels were compared, it was seen that there is no Cd accumulation in the muscles of the samples from Aras Dam and the highest accumulation value (1.90 μg $g^{-1}$) is in the gills of the females (Naghshbandi et al. 2007). In this study, the Cd amount in the gills of the female individuals was below 0.01 μg $g^{-1}$.

While Pb level was high in the gills (female 49.9 μg $g^{-1}$, male 19.00 μg $g^{-1}$) and exoskeleton (female 45.26 μg $g^{-1}$, male 39.26 μg $g^{-1}$) of the samples from Aras Dam, in our study it was below 0.01 μg $g^{-1}$ in all tissues of *A. leptodactylus* samples (Naghshbandi et al. 2007). Timmermans (1993) analysed metal accumulations in various freshwater invertebrate samples collected from freshwater ecosystems that are accepted to be clean by this researcher. It was seen that in most of the samples, Cd levels ranged between 0.01 μg $g^{-1}$ and 1 μg $g^{-1}$. In the samples taken from the Dommel River, which is stated to be polluted, this value ranges between 0.3 μg $g^{-1}$ and 147 μg $g^{-1}$. On the other hand, in this study, the highest Cd value was determined as 0.88 μg $g^{-1}$ while this value was below 0.01 μg $g^{-1}$ in the muscles, gills, ovary and egg of the female samples. These values are very close to those of the invertebrate samples collected from unpolluted ecosystems by the researchers. The concentration of lead ranges between 0.29 μg $g^{-1}$ and 5.0 μg $g^{-1}$ in uncontaminated habitats. In contaminated habitats, for example in the Dommel River, it ranges between 0.7 μg $g^{-1}$ and 74 μg $g^{-1}$ and in the Irwell River between 30 μg $g^{-1}$ and 10.87 μg $g^{-1}$ (Timmermans 1993). In this study, the lead content was below 0.01 μg $g^{-1}$.

Comparing heavy metal contents of *A. leptodactylus* with one another, the regression coefficients were calculated and the correlation between the metals was determined. It is clear that there is positive correlation ($p < 0.05$) between Fe and Mn (+0.88), Fe and Al (+0.97), and Mn and Al (0.79). These strong correlations indicate that these metals have the same accumulation mechanism.

The total metal contents (aluminium, copper, manganese, lead, cadmium, iron, zinc, chromium and nickel) of sediments collected from four different points in Lake Terkos were analysed. It was seen that Al, Fe, Mn, Ni and Cu concentrations are lower than the crustal average while, Zn, Cr, Cd and Pb contents are higher. These high values indicate that there is anthropogenic pollution—namely domestic and industrial pollution. The metal accumulations and origins of sediment species were evaluated calculating their enrichment factor (EF) and contamination factor (CF) values (Table 6).

$0.5 < EF < 1.5$ suggests that the trace metals may be entirely from crustal materials or natural weathering processes. $EF > 1.5$ suggests that a significant portion of the trace metals is provided by other sources (Zhang et al. 2007). EFs of Zn, Cr, Cd and Pb were found higher than 1.5 at four stations sediments (Table 6). These high values are due to anthropogenic sources (domestic and industrial inputs). In contrast, EFs of Fe, Ni, Cu, Mn were determined lower than 1.5 at all stations. These results suggest the presence of natural (terrigeneous) inputs.

CF is classified into four groups in Pekey et al. (2004). If $CF < 1$, there is no metal enrichment by natural or anthropogenic inputs; $1 \leq CF < 3$ for a particular metal means that the sediment is moderately contaminated by the element; $3 \leq CF < 6$ means that there is considerable contamination and if $CF > 6$, then there is very high contamination for that metal. CFs of Al, Fe, Ni and Cu were found lower than 1 at all stations. These results indicate that there is no Al, Fe, Ni and Cu metal enrichment. CFs of Zn, Cr and Pb were determined between 1 and 3 at all stations except for station 1. These results indicate that these sediments are moderately contaminated by Zn, Cr and Pb elements (Table 6). CFs of Cd were found to be higher than 6 at stations 1 and 2. These results indicate very high metal contamination. CFs of Cd were between 3 and 6 at stations 3 and 4. These high values indicate that there is considerable metal contamination at these stations.

While the total organic carbon content ranged between 1.65% and 5.44%, the total carbonate contents were found to range between 19.44% and 41.16%. It was seen that the total carbonate amount is more than the total amount of organic carbon. The abundant existence of total carbonate indicates that sediment samples are composed

**Table 6** Metal enrichment (EF) and contamination factors (CF) of Lake Terkos

| Station | Al % | Fe % | Mn μg $g^{-1}$ | Ni μg $g^{-1}$ | Cu μg $g^{-1}$ | Zn μg $g^{-1}$ | Cr μg $g^{-1}$ | Cd μg $g^{-1}$ | Pb μg $g^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| Enrichment factors | | | | | | | | | |
| 1 | | 1.03 | 0.71 | 0.97 | 1.40 | 4.17 | 1.95 | 15 | 10.62 |
| 2 | | 0.91 | 0.71 | 0.64 | 0.57 | 2.51 | 2.26 | 13 | 3.70 |
| 3 | | 0.93 | 0.75 | 1.38 | 0.31 | 2.86 | 2.68 | 13.5 | 4.94 |
| 4 | | 0.85 | 1.03 | 1.28 | 0.48 | 9.74 | 3.15 | 9 | 4.60 |
| Contamination factors | | | | | | | | | |
| 1 | 0.47 | 0.49 | 335.75 | 0.46 | 0.66 | 1.97 | 0.92 | 7.73 | 5.0 |
| 2 | 0.52 | 0.48 | 372.03 | 0.33 | 0.30 | 1.31 | 1.24 | 7.40 | 1.93 |
| 3 | 0.38 | 0.36 | 284.54 | 0.53 | 0.12 | 1.09 | 1.02 | 5.53 | 1.89 |
| 4 | 0.39 | 0.34 | 404.57 | 0.50 | 0.19 | 1.68 | 1.24 | 3.73 | 1.80 |

**Table 7** Comparison of average metal levels in bulk surface sediments from different lakes of Turkey

| | Al % | Fe % | Mn µg g$^{-1}$ | Ni µg g$^{-1}$ | Cu µg g$^{-1}$ | Zn µg g$^{-1}$ | Cr µg g$^{-1}$ | Cd µg g$^{-1}$ | Pb µg g$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| Lake Terkos µg g$^{-1}$ (this study) | 3.58 (SD 0.54) | 2.25 (SD0.429) | 349.22 (SD51.47) | 34.13 (SD 6.42) | 15.81 (SD 12.08) | 97.50 (SD 27.47) | 110.47 (SD16.01) | 0.91 (SD 0.28) | 33.19 (SD19.55) |
| Lake Sapanca µg g$^{-1}$ (Duman et al. 2007) | NA | NA | 33.781 | 26.72 | 26.68 | 62.00 | 19.087 | 0.29 | 15.20 |
| Lake Uluabat µg g$^{-1}$ (Elmaci et al. 2007) | NA | NA | NA | 0.008 | 0.012 | 0.001 | 0.009 | 0.002 | 0.013 |
| Lake Kovada µg g$^{-1}$ (Kir et al. 2007) | 3,780 | 30,006 | 61.19 | 9.13 | 5.08 | 12.82 | 6.63 | 0.27 | 1.74 |
| Lake Beyşehir µg g$^{-1}$ (Altindağ and Yiğit 2005) | NA | NA | NA | NA | NA | NA | 10.63 | 13.05 | 32.65 |
| Atatürk Dam Lake µg g$^{-1}$ (Karadede and Ünlü 2000) | NA | 12.587 | 0.0736 | NA | 0.01557 | NA | NA | NA | NA |

*N.A.* not analysed

of coarse-grained materials. That the amount of Al, which is the main component in the clay-structured sediment, was low in our samples supported this idea. Carbonates are known to play a thinning role in metal accumulation. Therefore, these values were not included in the assessment since they would not represent the metal enrichment (Filipek and Owen 1978).

Correlation coefficients (*r*) belonging to the metal contents of the surface sediment samples from Lake Terkos were calculated and the results were assessed. When the correlation coefficients of metals found in sediment samples were analysed, it was seen that there is a positive correlation between Fe and Cd (+0.95), Cu and Zn (+1.0) Cu and Pb (0.96), Zn and Pb (0.97) and a strong negative correlation between Al and Ni (−0.95; $p < 0.05$). These results showed that there is no Ni enrichment in fine-grain sediment. The strong positive correlation indicates that the same factors are effective on the accumulation of these metals.

The metal contents determined in sediment samples were also compared with those in some lakes of Turkey (Table 7).

It is clear that Al, Fe, Mn, Ni, Zn, Cr and Pb amounts are generally higher than those in other lakes the values of which are obtained from the literature. Zn and Cr amounts are especially found to be considerably high. The amount of Cu is high in Lake Sapanca and the amount of Cd in Lake Beysehir.

## Conclusion

Consequently, as a result of the metal analyses in various organs of *A. leptodactylus*, it was determined that metals such as Fe, Cu, Mn and Al accumulate in high amounts and toxic metals such as Pb and Cd accumulate in low amounts. When the metal contents in tissues were examined, the metal concentrations in the abdominal muscles of crayfish, which are the parts generally consumed as food, were found to be lower than those in the other organs, and a number of studies support this finding (Anderson et al. 1997; Bollinger et al. 1997; Alcorlo et al. 2006; Naghshbandi et al. 2007). According to the Turkish Food Codex (2002), the maximum allowable Pb and Cd amounts in crayfish are 0.5 mg/kg wet weight. Accordingly, the Pb and Cd amounts determined in *A. leptodactylus* samples are below this limit. However, when compared with the acceptable metal limits defined by WHO, Australian National Health and Medical Research Council and Ministry of Agriculture, Fisheries and Food in United Kingdom (UK; Pourang et al. 2004), it is clear that the Cu level is at limit and the Cd exceeds the limit. If the metal contamination in sediment is taken into account, it is obvious that Lake Terkos has to be taken under protection. It is known that the concentrations of essential elements increase and those of nonessential metals that are toxic decrease with cooking (Abd-Allah and Abdallah 2008). Therefore, it is thought that the consumption of *A. leptodactylus* species caught from Lake Terkos is not harmful for human health for now in terms of metal accumulation; although we believe that if necessary precautions are not taken, the accumulation will increase in the future.

When the metal contents in sediment samples from Lake Terkos are examined, it is seen that the Al, Fe, Mn, Ni and Cu contents are lower than the crustal average while Zn, Cr, Cd and Pb contents are higher than the average values. The high values show terrestrial inputs originating from anthropogenic (domestic and industrial) sources via rivers and rainfalls.

Lake Terkos sediments have high EFs of Zn, Cr, Cd and Pb metals resulting from the anthropogenic sources (domestic and industrial inputs) while they have low EFs of Fe, Ni, Cu due to the natural (terrigeneous) inputs. Additionally, there is no Al, Fe, Ni and Cu metal enrichment in these lake sediments because of the low CF values. However, it is moderately contaminated by Zn, Cr and Pb, and heavily contaminated by Cd.

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