REPORT

Invisible Face of Boron Pollution in Fluvial Ecosystem: The Level in the Tissues of Sentinel and Nectonic Organisms

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Abstract Turkey is the largest producer of borate products in the world. Among four largest boron mines in Turkey two of them are located in basins of Orhaneli and Emet Streams. In this study, boron levels in abiotic (water–sediment) and some biotic elements (sentinel organisms; *Asellus aquaticus*, *Gammarus pulex*, *Chironomus tentans*, *Limnodrilus hoffmeisteri* and nektonic organism; *Squalius cii*) of Orhaneli and Emet Streams were investigated and their ranks among the food chain were demonstrated. Since Orhaneli and Emet Streams confluence to form Mustafakemalpaşa Brook which feeds Uluabat Lake which is one of the most important Ramsar fields of the world, Boron levels in those two streams have importance in terms of both continuances of aquatic systems. Present study results have shown that boron levels in water of both streams are much higher (vary between 8.64 and 16.73 mg L⁻¹) than not only Turkish Standard but also limits determined by WHO, US EPA, and NAS. Boron levels determined in sediments of two streams vary between 18.05 and 36.7 mg kg⁻¹. The highest boron level in the biotic elements was determined in liver of *Squalius cii* (34.64 mg kg⁻¹), it is followed by *Limnodrilus hoffmeisteri* (2.84 mg kg⁻¹), *Chironomus tentans* (2.11 mg kg⁻¹), and *Gammarus pulex* (1.98 mg kg⁻¹).

Keywords Boron pollution · Orhaneli and Emet streams

INTRODUCTION

Boron, which is a semi-conductive element between metal and nonmetal, is one the elements commonly found in the crust of the earth (ECETOC 1997). Because of its high affinity for oxygen, boron always occurs in nature bound to oxygen in the form of inorganic borates (Budavari et al.

1996). Apart from their occurrence in a few commercially exploitable deposits (mainly as sodium or calcium borate minerals), the Boron is present at low concentrations in rocks (15–300 mgB kg⁻¹), soils (<10–20 mgB kg⁻¹), surface waters (<0.1–0.5 mgB L⁻¹), and sea water (5 mgB L⁻¹), but its higher concentrations are measured in a few areas (ECETOC 1997). Its major release into the environment is through weathering processes and wastewater discharge (Howe 1998; Coughlin 1998) and it also may be found in surface waters as a product of agricultural runoff and decaying plant materials (Provin and Pitt 2002). Large deposits of borate minerals are rare. The only known massive deposits are located in the Mojave Desert of California, USA, and in western Turkey. The four most important minerals are colemanite, kernite, tincal, and ulexite. The world boron reserve is 885 billion tons and Turkey has 64 % of these boron reserves. Boron and boron derivatives are produced and marketed as both raw materials and refined products such as acid borique, anhydrous borax, borax pentahydrate, borax decahydrate, and sodium perborate by Directorate General of Eti Mining Enterprises in Turkey (Kılıç 2004).

Boron mining started in Turkey in 1861 by foreign companies. Later, mining exploitation rights were transferred to state sector, namely, Etibank. Turkey is one of the major boron exporters of the world (Önal and Burat 2008). The known borate reserves in Turkey are located in four main districts: Balıkesir-Bigadiç, Kütahya-Emet, Eskişehir-Kırka, and Bursa-Kestelek. The most important tributary feeding of Uluabat Lake, which is one of the most important Ramsar fields not only in Turkey but also in the world, is Mustafakemalpaşa Stream. This stream is formed by the confluence of Orhaneli and Emet Streams as seen in Fig. 1. Two out of four Boron mining enterprises (Kütahya-Emet and Bursa-Kestelek) in Turkey are located

in this basin (Fig. 1). Therefore, boron levels in Orhaneli and Emet Streams are significant not only for the ecosystem of these two streams but also for the ecosystem of Uluabat Lake. Majority of the scientific studies conducted in Turkey regarding boron is directed towards determination of boron amount in soil, plants, and drinking water. However, there are few studies regarding concentration levels in biotic and abiotic elements of aquatic systems in rivers, lakes, and dams that contain boron mineral in their basin (Emiroğlu et al. 2010; Arslan et al. 2010; Tokatlı

et al. 2011). As it is known, fish is at the top of the food chain in rivers and fish is consumed by humans.

Regarding human health, the effect of boron on water is considered in terms of its effect on drinking and irrigation water. The effect of boron enterprises located on Orhaneli and Emet Streams on waters used for drinking and irrigation has been studied by various researchers (Çöl et al. 2000; Çöl and Çöl 2003). However, boron accumulation is not often studied for aquatic organisms and their habitat. The aquatic invertebrates (such as, Crustaceans *Asellus aquaticus* and

Fig. 1 Geographical situation of study area and sampling stations

Gammarus pulex, Insect *Chironomus tentans*, and Annelid *Limnodrilus hoffmeisteri*) selected in this study are both frequently used as bioindicators and biomonitors in various aquatic systems and constitute the food of fish (Rinderhagen et al. 2000). Furthermore, these so-called species “sentinel” organisms accumulate and concentrate pollutants from their surroundings and/or food so that an analysis of their tissue provides a time-integrated estimate of the environmentally available concentrations of these pollutants. In addition, they are a very successful group with an immense variety of ecological types living in a great number of different habitats. Chubs of the genus *Squalius* represent a large group of cyprinids with about 45 species widespread in the Western Palearctic (Özuluğ and Freyhof 2011). As a nektonic organism *Squalius cii* used in this study, which lives benthopelagically and is an omnivore species, is one of the most common fish species in the study area.

The aim of this study is to determine the boron amount in biotic and abiotic components of Orhaneli and Emet streams, on which two of the biggest boron enterprises in Turkey are located, by studying boron levels in (i) their water and sediment, (ii) in different tissues of *S. cii*, which is a common fish species in both basins and is consumed as food by the locals and in tissues of aquatic invertebrates which may be consumed by this fish.

It is well known that elements accumulate in tissues of aquatic animals and therefore, the levels measured in tissues of organisms can reflect past exposure and element in aquatic environments are transferred to humans through food chain. Therefore, it is important to determine boron amounts both in the habitat (water–sediment) and in the tissues of aquatic organisms in terms of revealing the accumulation levels of boron in the food chain; because, boron is an essential nutrient for many organisms, but can be toxic to organisms when accumulated in high concentrations. The concentrations of many elements, including boron, are increasing in aquatic ecosystems due to anthropogenic activities. In humans, boron exposure occurs primarily through oral intake of food and drinking water.

MATERIALS AND METHODS

Study Area

Orhaneli and Emet Streams located in Lake Uluabat basin (one of the most important Ramsar fields of the world) and they run off Mustafakemalpaşa Creek which feeds the Lake (Fig. 1). Two boron mining enterprises are situated in their basins (Emet and Kestelek Boron Plants). Therefore, boron levels in those two streams have importance in terms of both continuance of aquatic systems and the health of local people.

Sample Collection

In order to determine the boron concentration in abiotic (water–sediment) and some biotic elements (sentinel organisms; *Asellus aquaticus*, *Gammarus pulex*, *Chironomus tentans* (4th instar larvae), *Limnodrilus hoffmeisteri* and nektonic organism; *Squalius cii*) of two important streams (Emet and Orhaneli) samples have been collected from stations shown in Fig. 1. Two replicate sediment, some invertebrates and water samples were collected from four sampling sites from Emet and Orhaneli Streams in different times of 2009 and 2010 (December 2009, March, July, and October 2010). The biotic samples were collected and placed into iceboxes. They were deep frozen at about -20°C and stored until start of analyses. Then, fish samples were dissected by stainless steel (muscle, liver, and gill). All bio-samples were dried for 24 h at 105°C . Bottom sediment samples were dried for 3 h at 105°C for boron analysis. After all samples were passed through a nylon sieve (0.5 mm), 0.5 g of each sample was placed in Pyrex reactors of a CEM Mars 5 microwave digestion unit. $\text{HClO}_4\text{:HNO}_3$ acids of 1:3 proportions for organisms and sediment were inserted in the reactors, respectively. Samples were mineralized at 140°C for 1 h. Afterwards, the samples were filtered in such a way as to make their volumes to 100 mL with 0.1 N HCl. Water samples of 1 L in volume were taken at each sampling point and were adjusted to pH 2 by adding 2 mL of HNO_3 into each. Before sampling, sample bottles were cleaned by washing them with detergent and then soaking them in 50 % HCl for 24 h. Finally, the bottles were washed with water and then rinsed with distilled water. Bottles were kept in 1 % nitric acid before use.

Analyses

The boron amounts in water, sediment, some aquatic invertebrates, which is the food of fish, and fish tissues obtained from four stations located on Orhaneli and Emet Streams were analyzed. Heavy metals were determined by ICP-OES (Varian 720 E) (ASTM 1985; APHA 1992; EPA METHOD 2001). Detection limit value of boron as ($\mu\text{g L}^{-1}$) in ICP-OES was to be 0.07 and the absorption wavelength was 249.678 nm.

Bioaccumulation factor (BAF) was calculated. BAF is defined as the ratio of tissue chemical residue to chemical concentration in an external environmental phase (e.g., sediment, water, soil, air, or food). Thus $\text{BAF}_{\text{organism}} = C_{\text{organism}}/C_{\text{water-sediment}}$, where C_{organism} is the element concentration in organism and $C_{\text{water-sediment}}$ is the element concentration in water or sediment (Nordberg et al. 2009).

Statistical analysis of data was carried out using SPSS statistical package software. The correlation and statistical

significance of the relationship between the boron concentration of the river water–sediment and biological samples and different tissues of the *S. cii* were evaluated using Pearson's correlation coefficient; in addition data were analyzed using one-way ANOVA and LSD test (Tabachnick and Fidell 1996; Sharma 1996).

RESULTS

The minimum, maximum, and average boron concentrations and pH levels in the samples taken from the four stations of the study region are given in Table 1. The ranges of pH are in between 7.68 and 8.13 (Table 1). Because of non-occurrence of extreme limits, pH has not been considered among restrictive factors for the taxonomic diversity. Boron levels in water were found minimum 8.64 mg L^{-1} and maximum 16.73 mg L^{-1} , in sediment were found minimum 18.05 mg kg^{-1} and maximum 36.7 mg kg^{-1} (Table 1). Sediment and water samples from the first and third stations, which are located at the nearest stations to boron production complex (Fig. 1), were determined to have the highest amount of boron content when compared to other two stations (Table 1). In addition, boron levels in water at all stations are higher than that of the Turkish Environmental Guidelines Standard. Water quality regulations in Turkey divide inland waters into four classes. Class I refers to clean water that can be used for domestic purposes after simple disinfection, for recreation and irrigation. Class II refers to fairly clean water that can be used as domestic water after treatment, for recreational purposes or for fishing, farming, etc. Class III includes polluted water, which can only be used as industrial water after treatment. Class IV refers to heavily polluted water

that should not be used at all (Turkish Environmental Guidelines 2004). According to the boron concentrations given in Table 1, the water of both Emet and Orhaneli Streams were included within the fourth class ($>1 \text{ mg L}^{-1}$) category which refers to heavily polluted water that should not be used at all.

Benthically and/or epibenthically living aquatic invertebrates are exposed directly to the effects of elements in both water and sediment. When boron levels in their tissues are examined, it is seen that the highest boron level of 2.84 mg kg^{-1} is detected at the second station in *Limnodrilus hoffmeisteri* (Table 1).

Boron levels determined in different tissues of *Squalius cii* are given in Table 2. The highest boron amount was determined in the liver (34.64 mg kg^{-1}), which is followed by muscle (26.32 mg kg^{-1}) and gills (11.34 mg kg^{-1}), respectively (Table 2). As it is also seen in Table 2, the highest boron levels in each of the three tissues were determined in samples collected from the third station which is one of the closest stations to the boron enterprises. There is no information about maximum permissible boron limits in fish tissues in the Turkish standards. Therefore, our results could not have been compared with the levels of Turkish Food Codex Standard.

The BAFs for boron for *A. aquaticus*, *G. pulex*, *C. tentans*, *L. hoffmeisteri* and tissues of *S. cii* were calculated for the four sites and are given in Table 3. The levels obtained for the boron in the whole body of invertebrates and in the tissues of *S. cii* did not exceeded the values of the boron in the Emet and Orhaneli Streams water system (Tables 1, 2). In general, higher BAFs were observed for *S. cii* tissues samples for all sites as compared to other invertebrates samples (Table 3).

The relationships between boron levels of samples were supported by the Pearson Correlation Index (Table 4). It

Table 1 pH value and boron concentrations in waters, sediments and model invertebrate species in the study region

St	pH	Boron in abiotic samples		Boron in biotic samples (mg kg ^{−1} dw)			
		Water (mg L ^{−1})	Sediment (mg kg ^{−1} dw)	<i>Asellus aquaticus</i>	<i>Gammarus pulex</i>	<i>Chironomus tentans</i>	<i>Limnodrilus hoffmeisteri</i>
		Min–max (AM ± SD)	Min–max (AM ± SD)	Min–max (AM ± SD)	Min–max (AM ± SD)	Min–max (AM ± SD)	Min–max (AM ± SD)
Emet Stream							
1	8.01	11.67–16.73 (13.32 ± 1.84)	21.42–36.7 (31.75 ± 3.12)	ns	ns	ns	0.63–1.45 (1.04 ± 0.18)
2	8.13	9.21–13.94 (11.56 ± 0.92)	19.64–25.55 (21.07 ± 3.14)	0.42–1.09 (0.86 ± 0.79)	1.03–1.53 (1.16 ± 0.29)	1.08–2.11 (1.25 ± 0.62)	1.15–2.84 (1.56 ± 0.39)
Orhaneli Stream							
3	7.97	10.25–14.52 (13.02 ± 1.02)	26.14–32.34 (30.12 ± 2.63)	ns	ns	ns	0.74–1.86 (1.18 ± 0.27)
4	7.68	8.64–11.36 (10.02 ± 1.33)	18.05–26.48 (23.39 ± 2.02)	0.75–1.47 (0.97 ± 0.28)	0.86–1.98 (1.02 ± 0.48)	1.73–2.37 (1.94 ± 0.39)	0.46–0.92 (0.69 ± 0.12)

St station, ns no sample, dw dry weight

Table 2 Boron levels in different tissues of *Squalius cii**

St	Tissue	B (mg kg ⁻¹ dry weight)		
		Min	Max	AM ± SD
2	Muscle	6.25	5.25	5.34 ± 0.44
	Liver	2.45	2.82	2.86 ± 0.11
	Gill	4.34	5.13	4.86 ± 0.93
3	Muscle	19.25	26.32	23.47 ± 2.25
	Liver	11.47	34.64	27.64 ± 4.43
	Gill	5.08	11.34	8.36 ± 2.34
4	Muscle	4.05	5.85	4.79 ± 0.44
	Liver	3.27	3.76	3.86 ± 0.23
	Gill	5.63	7.28	6.44 ± 0.24

St station

* In station 1., no *S. cii* samples

was found that the relation between boron level in water and in *A. aquaticus*, also *G. pulex* ($P < 0.05$, $r = 0.479$; $P < 0.05$, $r = 0.706$, respectively), boron level in sediment and in *C. tentans*, *L. hoffmeisteri* ($P < 0.05$, $r = 0.611$; $P < 0.05$, $r = 0.524$, respectively), boron in water and in sediment ($P < 0.01$, $r = 0.241$), boron in sediment and in *G. pulex*, also muscle ($P < 0.01$, $r = 0.420$ and $P < 0.01$, $r = 0.312$), boron in water and in gill ($P < 0.01$, $r = 0.413$), were directly proportional.

Between sampling sites differences were tested through one-way ANOVA performing LSD test when significant differences were found. Averages of boron levels determined in water, sediment, and biotic samples of Emet-Orhaneli Streams and the results of one-way ANOVA and LSD tests that compares the boron accumulations of biotic and abiotic samples in different stations are given in Table 5. According to the results of one-way ANOVA Test determined by using boron accumulations, statistically significance differences were found in water between 1st–3rd and 4th stations according to boron level ($P < 0.05$). However, statistically significance differences were not found in sediment between 1st–3rd and 2nd–4th according to boron level ($P < 0.05$). According to sampling dates variations of boron levels, significant increases boron level in water were found in only second sampling date (March 2010); in addition, the LSD test showed that significant increases boron level in *L. hoffmeisteri* was found in only

Table 4 Statistically significant Pearson correlation coefficients between boron concentration of water–sediment and organisms

Relation between	Significance level
B in water and in sediment	0.241*
B in water and in <i>A. aquaticus</i>	0.479**
B in water and in <i>G. pulex</i>	0.706**
B in sediment and in <i>C. tentans</i>	0.611**
B in sediment and in <i>L. hoffmeisteri</i>	0.524**
B in sediment and in <i>G. pulex</i>	0.420*
B in water and in gill of <i>S. cii</i>	0.312*
B in sediment and in muscle of <i>S. cii</i>	0.299*

* Significant at $P < 0.05$, ** significant at $P < 0.01$

second sampling date. But, no significant sampling dates changes were found for boron level in sediment.

DISCUSSION

Boron levels determined in waters of Emet and Orhaneli streams vary between 8.64 and 16.73 mg L⁻¹. The median value determined in water at the studied four stations is 11.56 ± 0.92 mg L⁻¹. A study conducted by Çöl and Çöl (2003) around Emet Borax Enterprise demonstrated levels of 0.56–17.50 mg L⁻¹ in surface waters, 0.08–0.47 mg L⁻¹ in ground waters, and 0.03–3.39 mg L⁻¹ in tap water. The minimum value determined by Çöl and Çöl (2003) for surface waters is much lower than the minimum value determined for the first and second stations which represent the same area (Table 2). This fact shows us that how much the boron amount in surface waters can increase during the 7 years between now and then.

As mentioned before, boron is widely distributed in nature in low concentrations, and is usually <0.1–0.5 mgB L⁻¹ in surface freshwaters; but its higher concentrations are measured in a few areas (Coughlin 1998). Boron levels in waters of both Emet and Orhaneli streams at all stations are much higher than the limits determined as 0.3 mgB L⁻¹ by WHO, US EPA, and NAS (NAS 1980; WHO 1998a; US EPA 2004). According to NAS (1980), the recommended maximum level for humans is less than 1.0 mg L⁻¹ for drinking water. Even though waters of

Table 3 Bioaccumulation factors (BAF) in whole body of invertebrate samples, muscle, liver, and gill of *Squalius cii*

	Invertebrate samples				Fish (<i>Squalius cii</i>)		
	<i>Asellus aquaticus</i>	<i>Gammarus pulex</i>	<i>Chironomus tentans</i>	<i>Limnodrilus hoffmeisteri</i>	Muscle	Liver	Gill
BAF _{water}	0.085 ± 0.01	0.101 ± 0.001	0.150 ± 0.060	0.093 ± 0.029	0.914 ± 0.769	0.918 ± 1.045	0.568 ± 0.128
BAF _{sediment}	0.041 ± 0.0004	0.049 ± 0.008	0.071 ± 0.016	0.043 ± 0.0205	0.412 ± 0.318	0.406 ± 0.443	0.261 ± 0.026

Table 5 Minimum, maximum, and average boron levels determined in abiotic and biotic samples and summary of ANOVA results and LSD test performed on boron levels data between sampling sites

St	pH	Boron in abiotic samples		Boron in biotic samples (mg kg ⁻¹ dw)			
		Water (mg L ⁻¹) Min-max (AM ± SD)	Sediment (mg kg ⁻¹ dw) Min-max (AM ± SD)	<i>A. aquaticus</i> Min-max (AM ± SD)	<i>G. pulex</i> Min-max (AM ± SD)	<i>C. tentans</i> Min-max (AM ± SD)	<i>L. hoffmeisteri</i> Min-max (AM ± SD)
Emet Stream							
1	8.01	11.67–16.73 (13.32 ^a ± 1.84)	21.42–36.7 (31.75 ^a ± 3.12)	ns	ns	ns	0.63–1.45
2	8.13	9.21–13.94 (11.56 ^{ab} ± 0.92)	19.64–25.55 (21.07 ^b ± 3.14)	0.42–1.09 (0.86 ^a ± 0.79)	1.03–1.53 (1.16 ^a ± 0.29)	1.08–2.11 (1.25 ^a ± 0.62)	1.15–2.84 (1.56 ^a ± 0.39)
Orhaneli Stream							
3	7.97	10.25–14.52 (13.02 ^a ± 1.02)	26.14–32.34 (30.12 ^a ± 2.63)	ns	ns	ns	0.74–1.86 (1.18 ^{ab} ± 0.27)
4	7.68	8.64–11.36 (10.02 ^b ± 1.33)	18.05–26.48 (23.39 ^b ± 2.02)	0.75–1.47 (0.97 ^a ± 0.28)	0.86–1.98 (1.02 ^a ± 0.48)	1.73–2.37 (1.94 ^a ± 0.39)	0.46–0.92 (0.69 ^b ± 0.12)
The values marked with different letters in the same column are statistically different (<i>P</i> < 0.05)							
<i>Min</i> minimum, <i>max</i> maximum, <i>AM</i> average, <i>SD</i> standard deviation, <i>St</i> sampling stations							

The values marked with different letters in the same column are statistically different ($P < 0.05$)

Min minimum, max maximum, AM average, SD standard deviation, St sampling stations

Emet and Orhaneli streams are not directly used as drinking water, they are used for irrigation purposes in agriculture of the region. In agricultural irrigation; not only irrigation method, irrigation period and the amount of water, but also quality of the water used is important. As it was stated before, the boron level determined in waters of Emet and Orhaneli streams is classified as the fourth quality water according to Turkish Environmental Guidelines (2004). Although, boron is an essential element for plants, it is known that using waters containing boron over the amount of 1 mg L⁻¹ for irrigation purposes causes problems in plants and soil (FAO 1976). It is obvious that high boron amounts in waters of these two streams would negatively affect not only fluvial ecosystem, but also agriculture in the region.

Water of aquatic systems and their sediments represent an important sink for elements in aquatic systems, and sediment-associated metals pose a direct risk to detrital and deposit-feeding benthic organisms, and may also represent long-term sources of contamination to higher trophic levels (Eimers et al. 2001). Fishes may accumulate trace metals via their food chains. As it is seen in Tables 1 and 2, while only *Limnodrilus hoffmeisteri* samples from the annelids were detected at the first and third stations where water and sediments have the highest boron levels, *Asellus aquaticus* and *Gammarus pulex* from the crustacea, which are considered as euryok organisms that have adaptation ability to live in numerous habitat types with different ecological structures (even saline waters, ground waters, and land) and *Chironomus tentans* from the insects (Rinderhagen et al. 2000) could not be detected at these stations. This may be explained with the negative effects of high boron amounts in the water and sediment even upon distribution of the euryok invertebrates with high adaptation ability. BAF results are given in Table 3. In general, higher BAF were observed for *S. cii* tissues samples for all sites as compared to other biotic samples (Table 3). This may be explained with aquatic invertebrates which have short life and small body, can contribute to rapid accumulation under situations in which the boron exposure is limited duration. The aquatic invertebrates that constitute the nutrition of *S. cii*, which is one of the fishes at the top of the food chain in aquatic ecosystems, are a heterogeneous community with various nutritional characteristics (detritivorous, herbivorous, and carnivorous) and various living characteristics (benthic, epibenthic, pelagic, etc.), and they are an important food source for fishes in aquatic environment. The highest boron level in the aquatic invertebrates was determined in *Limnodrilus hoffmeisteri* (2.84 mg kg⁻¹). It is followed by *Chironomus tentans* (2.11 mg kg⁻¹) and *Gammarus pulex* (1.98 mg kg⁻¹), respectively (Table 2). It is known that the acute lethal dose in animals is estimated to be in the range of 400–900 mg boron equivalents kg⁻¹ body weight

(EGVM 2003). Although the boron amount in tissues of the aquatic invertebrates used in the study seems lower than the lethal dose in EGVM (2003), it is a biological truth that it would increase to the next rank in the food chain incrementally and this value would increase too much until reaching the fish which is at the top. All of the four aquatic invertebrate species examined in the present study are food of *S. cii*. As it can be seen in Table 3, in all fish samples studied the BAF of boron in the muscles and liver was 6–9 times higher than invertebrate samples. In addition, according to results of Pearson correlation analysis (Table 4), there is a significant positive correlation between the boron amounts in the water and sediment, and the boron amounts in the tissues of aquatic organisms. Although, BAF results are not high for invertebrates (Table 3), a high level positive relation ($P < 0.01$) was determined between the boron concentration in the water and the boron levels in the tissues of *A. aquaticus* and *G. pulex* ($r = 0.479$ and $r = 0.706$, respectively), and between the boron levels in the sediment and the tissues of *C. tentans* and *L. hoffmeisteri* ($r = 0.611$ and $r = 0.524$, respectively). This situation shows us that aquatic organisms accumulate the elements (much or less) in their habitats within their bodies.

When the average boron levels in the tissues of *S. cii*, which is consumed as food by the people who live in Orhaneli and Emet streams water basin, are examined (Table 2), it is seen that the highest value is determined in liver ($27.64 \pm 4.43 \text{ mg kg}^{-1}$). It is followed by muscle, which is an edible part ($23.47 \pm 2.25 \text{ mg kg}^{-1}$) and gill ($8.36 \pm 2.34 \text{ mg kg}^{-1}$). It is not surprising to determine a relatively high boron value in the muscle tissue (edible part) of *S. cii* which lives in a habitat containing high boron concentrations. In addition, *S. cii* could not be detected at the first station which has the highest boron concentration in the sediment and water. According to Stoumboudi et al. (2006), all populations of this species are under threat due to habitat loss. Not being able to detect *S. cii* at the first station in the study area raises the idea that the distribution area of the species could be limited due to high boron levels in the habitat, and it supports the opinions of Stoumboudi et al. (2006). Furthermore, high boron levels in the aquatic environment may negatively affect also aquatic biodiversity and may cause the organisms to leave the environment by damaging ecology of the habitat. In addition, in the study carried out by Özen et al. (2009), destructive effects of boron compounds on the tissues of *L. hoffmeisteri*, an aquatic indicator organism, following application for 24, 48, and 72 h were examined. It was determined that cell distortions begin in the alimentary canal as from the 48th hour, necrosis appearance in the epithelial cells of the alimentary canal and in the gland cells is severe and almost all of the cells are destroyed at the end of the 72nd hour.

Boron was found to be neither genotoxic nor carcinogenic (WHO 1998b), and no negative effects of boron on reproductive health were found (Şaylı et al. 1998). In addition, many researchers (Çöl et al. 2000; Korkmaz et al. 2011; Türkez et al. 2012) indicated that chronic boron exposure does not have important toxic effects because there is no established clear increase of disease among the people in the region. It is known that boron compounds belong to the second class of toxicological danger (WHO 1998a). Even though boron is an essential element for plants, the biological function of boron in humans is not clear. Natural Health Products Directorate of Canada (2007) indicated that the Tolerable Dietary Upper Intake Level (DRI UL) for boron is 20 mg day for adults (≥ 19 years); 17 mg day for adolescents (14–18 years); 11, 6, and 3 mg day for children (9–13, 4–8, and 1–3 years, respectively). Results of the current study showed that average level of boron in edible part of fish is high and BAF of boron in the muscles of fish samples were 6–9 times higher than invertebrate samples. However, as mentioned above there is no information about maximum permissible boron limits in fish tissues (for edible part) in the Turkish standards. Therefore, results of the present study could not have been compared with the levels of Turkish Food Codex Standard.

CONCLUSION

Certain species of aquatic invertebrates (especially sentinel organisms) are widely used in ecological quality of a fluvial ecosystem by means of different measures, including the bioaccumulation of metals, but in Turkey, few data are available on metal concentrations in natural communities of them. Zoobenthic forms, such as Crustaceae, insect larvae, and annelida, are often the main diet for many fish species (especially Cyprinids) and may contribute to the transfer of metals to higher trophic levels. Although, boron was found to be neither genotoxic nor carcinogenic for human health (WHO 1998b), and no negative effects of boron on reproductive health were found (Şaylı et al. 1998), it is well known that high metal concentrations in aquatic ecosystems lead to a reduction of macroinvertebrate richness and abundance (Watanabe et al. 2000; Hirst et al. 2002; Smolders et al. 2003). This makes it possible to analyse metal concentration in this invertebrate even when the community is very poor as at some sites along the Emet and Orhaneli rivers. Since the solid waste of borate is easily soluble in water, it dissolves after rain and reaches the stream water near the mining area; thus, boron concentration may increase in streams, especially during the wet seasons (Yüce and Ugurluoğlu Yasin 2012). Present study results have shown that boron levels not only in

water of Emet and Orhaneli streams but also in invertebrate species are high. As indicated before waters of both streams are used for irrigation and recreation. It has been previously shown in researches carried out by State Hydraulic Works (DSI) that boron concentrations in some streams and some ground waters of the region have reached hazardous levels (Anonymous 2005). In order to eliminate negativities due to high boron amounts in the aquatic systems: (i) the boron-containing effluents or solutions should be treated before they could be discharged into natural water bodies by using various technologies (Xu and Jiang 2008); (ii) boron levels of surface and irrigation waters should be constantly monitored, and diluted when necessary. In conclusion, periodically, biotic (especially sentinel organism) and abiotic (water–sediment) samples should be collected for monitoring boron levels in aquatic system as well as required precautions taken to prevent further ecosystem quality deterioration in the study area.

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