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Heavy metal concentration and potential health risk assessment for the European eel (*Anguilla anguilla*, Linnaeus 1758) from the Gediz Delta (Eastern Aegean, Türkiye)

by

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Abstract

The present paper is the first document on heavy metal levels in the European eel (*Anguilla anguilla*) collected from the Gediz Delta in the Eastern Aegean (Türkiye). In this study, concentrations of Cd, Cu, Zn and Pb were determined in the liver, gills, and muscle tissues of *A. anguilla* eels. Sixty dead eels were obtained between June 2015 and January 2016, and their total size and weight were measured. Heavy metal accumulation levels in edible muscle tissue of the eels were compared with national and international standards, and Estimated Weekly Intake (EWI), Target Hazard Quotient (THQ), and Total Target Hazard Quotient (Σ THQ) were calculated. It was determined that metal concentration levels in *A. anguilla* follow the sequence of Zn > Cu > Pb > Cd. Zn has the highest concentration in all sampling periods and in all tissue types. It was found that Σ THQ was below 1 and amounted to 0.41. This result shows that there is no carcinogenic risk associated with the consumption of *A. anguilla* in adults.

Key words: *Anguilla anguilla*, heavy metals, health risk assessment, Gediz River, Türkiye

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1. Introduction

Inland and marine waters continuously receive heavy metals from geological and anthropogenic sources. Today, with increasing awareness of environmental issues, various studies have been conducted to investigate the effects of harmful waste disposal on the food chain and human health, while preventing their release into water bodies. Investigating the levels of toxic heavy metals in aquatic organisms is crucial for human and public health. Heavy metals such as Cd, Pb, Cu, Ni, Zn, Hg, Cr, and As are of concern due to their tendency to accumulate in organisms and their toxic effects at certain concentrations when transferred from one organism to another. Fish, being at the top of the aquatic food chain, can accumulate some metals in large quantities. Fish is a high-quality and valuable food due to the presence of essential amino acids, essential fatty acids (such as omega-3), carbohydrates, fat-soluble vitamins, and important macro- and microelements such as Ca, Mg, and Se, which are necessary for humans. Fish consumption is critical for maintaining and improving human health and is the most commonly consumed aquatic product. Therefore, research on fish is crucial to determine the potential risk of heavy metal pollution in marine and freshwater systems and the potential effects of human consumption (Rashed 2001). *Anguilla anguilla* (Linnaeus 1758), which we have selected for our research, is highly susceptible to biological accumulation due to its long lifespan, high fat content, benthic and relatively inactive behavior, high trophic position in the food chain, and resistance to deteriorating water quality (Yorulmaz et al. 2015). The European eel (*A. anguilla*) from the Anguillidae family has an elongated snake-shaped body and is a catadromous fish species. A common predator and euryhaline fish species at the top of the food web, living in both sediments and open waters, the European eel remains in wetlands for 9–15 years before migrating (Ribeiro et al. 2005). *A. anguilla* is distributed along the western coasts of Europe and North Africa, and is found throughout the Mediterranean coast (Dekker 2003). Sexually mature individuals migrate to the Sargasso Sea in Mexico to breed. The breeding season is in spring and summer, and mature individuals die in groups after spawning. Larvae of European eels undergo metamorphosis and transform into snake-like forms after spending about three years in the larval stage (İlhan 2017). European eels are carnivorous and feed on animals such as insect larvae, crustaceans, snails, worms, mussels, frogs, and small fish, especially those living on the bottom, and can grow to over 1 m in length (İlhan 2017). They can be consumed either dried, salted, smoked, fried, boiled, or baked. The European eel is a delicious fish that is popular in many countries, especially in Asian countries (TUIK 2022). In Türkiye, the yield of European eel increased from 28.3 to 320 tons in the period from 2011 to 2020. *Anguilla anguilla* is an important red-listed species with the CR status, which is worth mentioning as it is consumed as food.

A. anguilla is considered a good biomonitor organism for polluted freshwater systems due to its various ecological and physiological characteristics (Esteve et al. 2012). Since eels can be found in different habitats throughout their life cycle, they can be exposed to various anthropogenic substances, and their accumulation levels, particularly in the liver, can provide information on metal concentrations in aquatic environments. Eels can live in freshwater environments with high levels of pollutants, such as heavy metals originating from industrial or agricultural waste (Özden et al. 2020). Due to these characteristics, it has been noted that eels can be used to monitor environmental waste products at both local and international levels and to determine sources of pollution (Belpaire & Goemans 2007).

The objective of this study was to determine the concentrations of metals (Cd, Cu, Zn, Pb) in different tissues of the European eel, *A. anguilla*, living in the Gediz Delta. The study assesses the possibility of using eels as a bioindicator by providing data on the bioaccumulation of metals by eels in this important wetland area. In addition, the objective was to calculate the risk to human health resulting from the consumption of this eel species.

2. Materials and methods

2.1. Sampling location

The study area, the Gediz Delta, is a vast wetland system located on the western coast of the Gulf of Izmir, where the Gediz River meets the Aegean Sea. The delta is bordered by Mount Yamanlar to the east and southeast, Mount Dumanlıdağ to the northeast, and the Foça Hills to the north. In 1982, a part of the Gediz Delta with an area of 8000 ha was designated as a wildlife protection area due to its large number and diversity of birds, earning it the nickname "İzmir Bird Paradise". It was declared as a Ramsar Site in 1998. The Gediz River, known in ancient times as the Hermos, is the second largest river in the Aegean Region, with a catchment basin covering almost 1.7 million ha and accounting for 2.2% of Türkiye's area (Çağırankaya & Meriç 2013). A total of 60 European eels (*A. anguilla* Linnaeus, 1758) were collected from two locations in the Turkish waters of the Gediz Delta, namely the mouth of the Gediz River (0.5–1.5 m depth) and theKırdeniz Lagoon (0.5–2.5 m depth, 400 ha), between June 2015 and January 2016 (Figure 1).

2.2. Sample collection, preparation and digestion procedure

Dead eel specimens were collected from commercial fyke net catches in two areas of the Gediz Delta. The nets were checked daily by fishers and when enough eels were caught, they were hauled and stored in an icebox before being transferred to the laboratory. In this study, a total of 60 fish samples (*A. anguilla*), with total lengths ranging from 41.4 cm to 72.6 cm (mean: 54.49 ± 0.80 cm) and total weights ranging from 44.17 g to 807.01 g (mean: 304.49 ± 15.73 g), were used to determine metal concentrations. Approximately 5 g of muscle on the dorsal surface of the fish, liver, and two gills were dissected from each sample, and tissue homogenates were prepared according to international standard methods (Arnoux et al. 1981). Composite samples of each tissue were measured as wet weight by XB 22OA, Precisa (Zurich, Switzerland) to the nearest 0.0001 g and stored in a freezer at –20°C until analysis. Samples were digested with concentrated HNO_3:$HClO_4$ (5:1; extra pure Merck) under a reflux and filtered (Bernhard 1976). Heavy metal concentrations (Cd, Cu, Pb, Zn) were analyzed using an inductively coupled plasma-optical emission spectrometer (ICP-OES; Perkin Elmer 2000 DV). All samples were analyzed in triplicate, and results were expressed as mg/kg wet weight. Standard solutions were prepared from stock solutions (Merck, multi-element standard). Standard reference materials, DORM-2 for muscle and DOLT-2 for liver (National Research Council Canada, Ottawa Ontario, Canada), were analyzed for each of the four elements. Replicate analysis of these reference materials showed good accuracy, with metal recovery rates of 92–107% for fish.

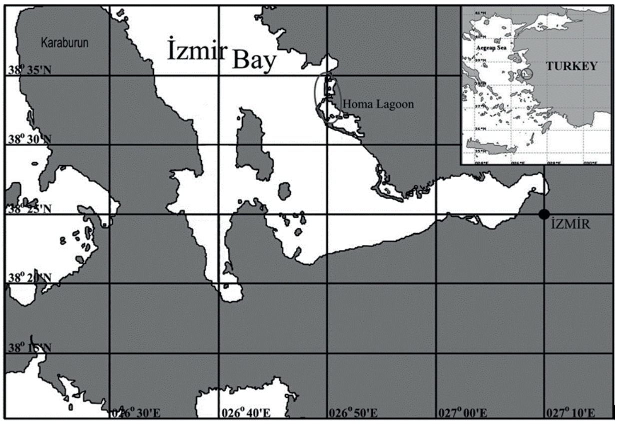

Figure 1

Sampling location.

2.3. Data analysis

Data were tested for normal distribution using the one-sample Kolmogorov–Smirnov test. Homogeneity of the variance was tested using Levene's statistical analysis. Tukey HSD and Tamhane tests were performed to detect differences between organs and sampling periods. Statistically significant differences were expressed as $p < 0.05$. SPSS 25.0 software was used for all analyses.

2.4. Assessment of potential public health risks

According to the Ministry of Agriculture and Forestry (2021), Türkiye's average per capita consumption of fishery products was 5.5 kg in 2017, which increased to 6.3 kg in 2019 and 6.7 kg in 2021. According to the Turkish Statistical Institute (TUIK), the average daily consumption of fishery products in Türkiye is approximately 18.6 g per person (TUIK 2019).

The study estimated the human health risks of heavy metal exposure from fish consumption by calculating Estimated Weekly Intake (EWI) and Estimated Daily Intake (EDI) values, which were then compared to Provisional Tolerable Weekly Intake (PTWI) values. PTWI values represent the maximum permissible weekly intake of heavy metals and are set by the Joint FAO/WHO (Food and Agriculture Organization/World Health Organization) Expert Committee on Food Additives (FAO/WHO 2010; 2011). The PTWI is defined as the estimated amount of a substance in food or drinking water, expressed on a body weight basis (mg/kg or µg/kg body weight), which can be ingested weekly over a lifetime without a significant health risk (FAO/WHO 2010). The EWI was calculated based on the consumption of fish muscle tissue using the formula:

$$EWI = \frac{WFC \times C}{BW}$$

where C is the mean metal level in fish muscle tissue (mg/kg), WFC is the consumption rate (g), and BW is the body weight (kg). The EDI was calculated by dividing the EWI by 7.

In addition, the health risks to Turkish consumers associated with eel consumption were evaluated using the Target Hazard Quotient (THQ). The THQ assesses the risks of non-carcinogenic effects of metal levels on the body according to the following formula (Han et al. 1998; Chien et al. 2002; Storelli 2008; Mol et al. 2017):

$$THQ = \frac{EF \times ED \times IR \times MC}{RfD \times BW \times AT} \times 10^{-3}$$

where EF is the frequency of exposure (365 days/year), ED is the duration of exposure (years) for a 70 kg adult exposed to metals over 30 years of consumption, IR is the daily fish consumption rate, MC is the specific metal concentration (mg kg^{-1}), AT is the mean exposure time (365 days X ED), BW is the body weight, and RfD is the oral reference dose (mg kg^{-1}, day). The RfD values for Cu, Cd, Pb, and Zn were 0.04, 0.001, 0.004, and 0.3 (mg kg^{-1}, day), respectively (US EPA 2009).

The value expressed as Σ THQ refers to the total of the THQ values for all the metals that were analyzed.

$$\Sigma\ THQ = THQ\ Cd + THQ\ Pb + THQ\ Cu + THQ\ Zn$$

(Naseri et al. 2021)

where Σ THQ: sum of target hazard quotients of metals and THQ Cd, THQ Pb, THQ Cu, and THQ Zn are the target hazard quotients for cadmium, lead, copper, and zinc, respectively.

If the Σ THQ is greater than 1, it indicates the existence of non-carcinogenic health risks to consumers (US EPA 2009).

3. Results and discussion

This study focused on the accumulation of heavy metals in *A. anguilla*, and different accumulation levels were determined in different tissues. The accumulation levels of Cd, Cu, Pb, and Zn in the muscle, gills, and liver tissues of *A. anguilla* sampled from the Gediz River are shown in Table 1. In addition, it was determined that the metal concentration levels in *A. anguilla* followed the sequence of Zn > Cu > Pb > Cd. In other words, Zn had the highest concentration in all sampling periods and tissue types, followed by the other metals. The average Zn values in the liver were higher in September 2015 at 563.21 ± 40.23 mg kg^{-1} compared to other sampling periods, although no significant seasonal differences were detected ($p > 0.05$). There were statistically significant differences in Zn accumulation levels between tissues ($p < 0.05$). In addition, the highest average Cd concentration (1.68 ± 0.47 mg kg^{-1}) and the highest average Pb concentration (4.31 ± 0.91 mg kg^{-1}) were found in the liver tissue in September 2015 (Table 1). The liver is a target organ for the accumulation of many heavy metals due to its strong uptake and storage function (Yorulmaz et al. 2015). The amounts detected in this tissue are proportional to the concentrations of metals in the environment. Therefore, this organ is generally considered a good indicator of water pollution (Yılmaz 2009). The Cu levels were higher in the liver tissue (239.04 ± 28.21 mg kg^{-1}) in January 2016 and in the gill tissue in June 2015 (14.02 ± 0.58 mg kg^{-1}) compared to other periods. The liver, gonads, kidneys, and gills are metabolically active tissues and tend to accumulate heavy metals at higher levels, as observed in many experimental and field studies. In this study, the copper accumulation levels in organs showed statistically significant differences between each other ($p < 0.05$), but no significant differences were detected between the sampling periods ($p > 0.05$). The average

Table 1

Mean periodic accumulation of heavy metals in muscle, gills and liver of *A. anguilla* from the Gediz Delta (mg kg^{-1}).

Metals (mg kg^{-1})	Tissue	June 2015 (n = 15) (mean ± SE)	September 2015 (n = 15) (mean ± SE)	November 2015 (n = 15) (mean ± SE)	January 2016 (n = 15) (mean ± SE)
Cd	Gill	0.40 ± 0.16^{a}	0.10 ± 0.02^{a}	0.24 ± 0.08^{a}	0.14 ± 0.03^{a}
	Muscle	0.19 ± 0.06^{a}	0.19 ± 0.06^{a}	0.15 ± 0.05^{a}	0.16 ± 0.04^{a}
	Liver	0.25 ± 0.04^{b}	1.68 ± 0.47^{b}	0.11 ± 0.01^{b}	0.47 ± 0.17^{b}
Pb	Gill	2.79 ± 0.23^{a}	**3.63 ± 1.84^{a}**	**2.01 ± 0.35^{a}**	2.42 ± 0.43^{a}
	Muscle	0.79 ± 0.15^{b}	**0.60 ± 0.19^{b}**	**1.05 ± 0.34^{b}**	2.28 ± 0.99^{b}
	Liver	1.86 ± 0.12^{b}	**4.31 ± 0.91^{b}**	**1.22 ± 0.15^{b}**	2.62 ± 0.64^{b}
Zn	Gill	466.79 ± 12.28^{a}	322.47 ± 23.07^{a}	391.10 ± 25.53^{a}	340.70 ± 19.09^{a}
	Muscle	263.51 ± 9.42^{b}	303.55 ± 17.0^{b}	358.71 ± 17.25^{b}	310.22 ± 25.58^{b}
	Liver	522.48 ± 32.01^{c}	563.21 ± 40.23^{c}	449.29 ± 18.83^{c}	543.74 ± 34.71^{c}
Cu	Gill	14.02 ± 0.58^{a}	7.76 ± 0.28^{a}	11.60 ± 0.61^{a}	10.80 ± 1.03^{a}
	Muscle	4.36 ± 0.24^{a}	3.53 ± 0.18^{a}	5.55 ± 0.33^{a}	4.93 ± 0.38^{a}
	Liver	218.73 ± 24.36^{b}	228.32 ± 21.39^{b}	142.24 ± 13.56^{b}	239.04 ± 28.21^{b}

*a,b,c – Different letters shown for each metal in the columns indicate statistically significant difference ($p < 0.05$). **Bold font** indicates statistically significant difference between the seasons ($p < 0.05$).

concentrations of Cd in gills were highest in July 2015 (0.40 mg kg^{-1}) and November 2015 (0.24 mg kg^{-1}), while those in the liver were 0.25 mg kg^{-1} and 0.11 mg kg^{-1}, respectively. Similarly, the mean Pb levels in gills were higher than those in the liver and muscle tissues for samples collected in July 2015 and November 2015 (Table 1).

Statistical analysis indicated that lead levels in the gill tissue were significantly different from all other organs ($p < 0.05$). The gills are the primary organ that absorbs metal ions from water before they enter other parts of the body. High metal concentrations in the gills may be due to the formation of metal complexes with the mucus, which is impossible to completely remove from the lamellae before analysis (Heath 1987). It is generally accepted that the muscle tissue is not an organ that accumulates heavy metals (Kargın 1996; Yılmaz 2005; Isani et al. 2009). Similar results from studies conducted on many fish species indicate that muscle is not an active tissue in heavy metal accumulation (Kargın 1996; Dural et al. 2007; Taş et al. 2011). As a result of the heavy metal analyses we conducted on different tissues of *A. anguilla*, the lowest values for Pb, Cu, and Zn were determined in the edible part, which is the muscle tissue (Table 2). However, the total average values measured for Cd in the muscle tissue (0.17 ± 0.02 mg kg^{-1}) and gills (0.16 ± 0.02 mg kg^{-1}) were found to be very similar to each other (Table 2). Statistical analysis did not reveal any significant differences between the gills and muscle ($p > 0.05$). The liver was found to be statistically different from all other organs in terms of Cd levels ($p < 0.05$). Our results confirm the differences in heavy metal accumulation in different tissues. However, with the exception of Cd, no statistically significant differences were found between the sampling periods ($p > 0.05$).

Table 2

Mean periodic accumulation of heavy metals in muscle, gills and liver of *A. anguilla* from the Gediz Delta (mg kg^{-1}).

Tissue	Study area	Cd	Cu	Pb	Zn	References
Liver	Camargue Region (France)$^{+}$	0.01–0.25	2.1–99.2	0.01–2.13	15–73	Batty & Pain 1996
	Cadiz Bay (Spain)	0.12–0.48	16.4–32.5	0.40–0.60	31.9–44.6	Usero et al. 2003
	Ferrerias River &Raices River (Spain)	0.462–1.416	5.276–10.503	0.14–1.925	-	Linde et al. 2004
	Camargue Nature Reserve (France)$^{+}$	0.13–0.44	59.9–76.5	0.38–0.64	201–215	Ribeiro et al. 2005
	Neretva River (Croatia)	0.114–0.152	-	0.114–0.149	-	Has-Schön et al. 2006
	Köyçeğiz Lagoon (Türkiye)	0.32–0.54	49.23–92.36	0.98–2.10	1.28–2.34	Yılmaz 2009
	Gediz River (Türkiye)	2.071	0.3030	0.9610	0.0561	Yıldız et al. 2010
	Tagus Estuary (Portugal)$^{+}$	-	23.3–73.2	0.11–1.07	105–211	Neto et al. 2011
	Köyçeğiz Lagoon (Türkiye)	0.125–0.435	11.65–64.6	0.720–2.173	31.97–104.7	Yorulmaz et al. 2015
	Köyçeğiz Lagoon (Türkiye)	0.24	22.11	1.30	53	Genç & Yılmaz 2017
	Mar Menor Lagoon (Spain)	0.114	-	4.402	-	Romero et al. 2020
	Gediz River (Türkiye)	**0.59 ± 0.13**	**206.35 ± 12.14**	**1.89 ± 0.17**	**518.07 ± 16.61**	**This study**
Gill	Neretva River (Croatia)	0.11–0.146	-	0.101–0.131	-	Has-Schön et al. 2006
	Köyçeğiz Lagoon (Türkiye)	0.10–0.19	1.89–3.12	0.23–0.46	83.49–169.87	Yılmaz 2009
	Gediz River, (Türkiye)	0.0650	0.3545	1.0315	5.355	Yıldız et al. 2010
	Köyçeğiz Lagoon (Türkiye)	0.062–0.431	2.954–27.18	0.768–1.958	29.47–75.89	Yorulmaz et al. 2015
	Köyçeğiz Lagoon (Türkiye)	0.21	6.32	1.22	41.44	Genç & Yılmaz 2017
	Gediz River (Türkiye)	**0.16 ± 0.02**	**11.20 ± 0.48**	**2.83 ± 0.49**	**379.38 ± 12.83**	**This study**
Muscle	Cadiz Bay-Spain	0.015–0.050	0.5–1.5	0.03–0.09	10.1–13.0	Usero et al. 2003
	Ferrerias River &Raices River (Spain)	0.006–0.067	0.152–0.296	0.001–0.108	-	Linde et al. 2004
	Camargue Nature Reserve (France)$^{+}$	-	0.19–0.43	0.21–0.79	55.4–57.9	Ribeiro et al. 2005
	Neretva River (Croatia)	0.016–0.041	-	0.031–0.142	-	Has-Schön et al. 2006
	Lesina Lagoon, Italy	0.02–0.04	0.39–1.13	-	17.9–24.6	Storelli et al. 2007
	Loukkos River (Morocco)$^{+}$	0.35–0.52	0.16–6.80	0.02–0.30	33.40–52.90	El Morhit et al. 2009
	Köyçeğiz Lagoon (Türkiye)	0.08–0.23	1.45–2.89	0.98–1.45	65.43–134.76	Yılmaz 2009
	Gediz River (Türkiye)	1.2067	0.3761	0.0032	0.0028	Yıldız et al. 2010
	Tagus Estuary (Portugal)$^{+}$	-	0.70–1.33	0.05–0.56	38.3–90.6	Neto et al. 2011
	Köyçeğiz Lagoon (Türkiye)	0.081–0.425	2.435–43.04	0.518–1.728	16.58–70.04	Yorulmaz et al. 2015
	Köyçeğiz Lagoon (Türkiye)	0.22	8.56	1.07	32.92	Genç & Yılmaz 2017
	Mar Menor Lagoon (Spain)	0.006	-	0.299	-	Romero et al. 2020
	Asi River (Türkiye)	b.d	-	b.d.	-	Özden et al. 2020
	Gediz River (Türkiye)	**0.17 ± 0.02**	**4.59 ± 0.17**	**1.18 ± 0.27**	**308.15 ± 9.92**	**This study**

* + – mg kg^{-1} dry weight; b.d. – below the detection limits

The differences in the metal content in the tissues of fish species may be due to endogenous factors, such as sex and age, as well as exposure to metals (Linde et al. 1999). In particular, eel species are considered indicator species for certain pollutants accumulated in their adipose tissues (Özden et al. 2020). Metal levels detected in various tissues (liver, muscle, gill) of *A. anguilla* obtained from different regions of the world were compared with the results of this study (Table 2). In other studies, Cd levels reported for liver tissue are generally lower than those found in our study, but the Cd concentration in the liver reported by Yıldız et al. (2010) for the Gediz River (2.071 mg kg^{-1} w.w.) was higher than that detected in this study (0.59 ± 0.13 mg kg^{-1} w.w). In addition, the Cd level detected in muscle tissue (0.17 ± 0.02 mg kg^{-1} w.w.) in this study was lower than the Cd concentrations reported in studies conducted in the Köyceğiz Lagoon, Türkiye (Genç & Yılmaz 2017) and in the Gediz River, Türkiye (Yıldız et al. 2010). However, Cd and Pb levels in the muscle tissue of eels obtained from the Asi River were found to be below detectable limits in the study conducted by Özden et al. (2020) – Table 2. Compared to other study areas, we found higher concentrations of Pb and Zn in all tissue types of eels, with the exception of the liver Pb level (4402 mg kg^{-1} w.w.) reported by Romero et al. in 2020. In addition, the Cu concentration we detected in liver tissue (206.35 ± 12.14 mg kg^{-1} w.w.) was much higher than that reported in other studies. However, this is not the case for gill and muscle tissues. The copper concentration we detected in the gill tissue (11.20 ± 0.48 mg kg^{-1} w.w.) was lower than that reported by Ribeiro et al. (2005) in their study conducted in France. Similarly, the Cu level in the muscle tissue was found to be lower than that reported in the Köyceğiz Lagoon, Türkiye (Genç & Yılmaz 2017; Table 2).

Fish exposed to various heavy metals (such as cadmium), with environmental effects, synthesize metal-binding proteins (metallothioneins) that bind not only cadmium, but also zinc and copper in their livers (Noël-Lambot et al. 1978). Therefore, the concentration of copper and zinc accumulated in the liver can be associated not only with high environmental concentrations, but also with high metallothionein synthesis. Furthermore, these differences may be due to the effect of physicochemical parameters such as ecological requirements, metabolism, feeding habits, life cycles, salinity, temperature, and pH on the accumulation of metals in tissues, in addition to the process of exposure to environmental pollutants (Gülcü Gür & Tekin Özan 2017).

For many years, research has been conducted to determine the accumulation of heavy metals in many fish species, which is used to assess human health risks. Therefore, in this study, EWI, EDI, THQ, and Σ THQ were calculated to determine the risks associated with *A. anguilla* consumption. Although toxicological limits are not exceeded for an average consumer, there may be a risk of heavy metal exposure for people who consume fish of a particular species in large quantities (Leblanc et al. 2005). Therefore, weekly and daily intakes were estimated for *A. anguilla*, and non-carcinogenic health risks to consumers were also calculated (Table 3). As shown in Table 3, the EWI and EDI values calculated based on the average Pb and Zn values for *A. anguilla* muscle tissue examined in this study exceeded the recommended PTWI and PTDI values for these metals. The European Commission Regulation (2006) and the Turkish Food Codex (2008) adopted maximum Pb (0.5; 1 mg kg^{-1}) and Zn (30; 50 mg kg^{-1}) limits, respectively, in the edible tissues of fish. Both metals exceed the threshold values recommended by TFC and FAO (Table 3). However, the calculated EWI and EDI values for the average levels of Cd and Cu were below the recommended PTWI and PTDI values for these metals. On the other hand, it was observed that the estimated weekly intake (EWI) for Cd exceeded the threshold values suggested by TFC and FAO (0.1 mg kg^{-1} and 0.05 mg kg^{-1}, respectively). Nevertheless, the situation is different

Table 3

Exposure and human health risk estimates for heavy metals in *A. anguilla* muscle tissue based on the following guidelines.

Metals	PTWI[a]	PTWI[b]	PTDI[c]	Mean conc. (mg/kg)	EWI[d]	EDI[e]	THQ[f]	TFC[h]	FAO[i]
Cd	0.007	0.49	0.07	0.17	0.32	0.04	0.04	0.1	0.05
Pb	0.025	1.75	0.25	1.18	2.20	0.31	0.07	1	0.5
Cu	3.5	245	35	4.59	8.54	1.22	0.03	20	30
Zn	7	490	70	308.15	573.17	81.88	0.27	50	30
							Σ THQ[g] 0.41		

a – PTWI (Provisional Tolerable Weekly Intake) mg/week/kg body wt (FAO/WHO, 2004); b – PTWI for a 70 kg adult person in mg/week/kg body wt; c – PTDI (Permissible Tolerable Daily Intake) in mg/day/70 kg body wt; d – EWI (Estimated Weekly Intake) in mg/week/kg body wt; e – EDI (Estimated Daily Intake) in mg/day/kg body wt; f – THQ (Targeted hazard Quotient); g – Σ THQ (Total Targeted Hazard Quotient); h – TFC (Turkish Food Codex) – tolerable values in fish; i – FAO (Food and Agriculture Organization) – legal limits for hazardous substances in fish for Cu concentration. The permissible limit for Cu is 30 mg kg^{-1} according to FAO (1983), but this limit is recommended as 20 mg kg^{-1} in the Turkish Food Codex (2002). The estimated weekly intake (EWI) calculated for Cu is well below the threshold value recommended by TFC and FAO. Therefore, it was concluded that the average Cu levels in the edible muscle tissue of *A. anguilla* do not pose a risk for human consumption. Furthermore, the total THQ values of all metals investigated in this study were calculated. If Σ THQ is greater than 1, it indicates that there are non-carcinogenic health risks to consumers (EPA 2019). In this study, the Total Hazard Quotient (Σ THQ) was found to be 0.41, which is less than 1 (Σ THQ < 1). This result shows that there is no non-carcinogenic risk associated with the consumption of *A. anguilla* muscle tissue by adults.

4. Conclusion

In conclusion, this is the first study on heavy metal levels in European eels (*A. anguilla*) collected from the Gediz Delta in the Eastern Aegean (Türkiye). In terms of food safety, controlling the contamination of food sources is of utmost importance. Therefore, fish species obtained from freshwater sources are at risk of being exposed to environmental pollution, which poses a health threat to consumers. This pollution can be caused by industrial waste, agricultural chemicals, heavy metals, and other pollutants present in the water source from which the fish are obtained. Such pollutants can pose a serious threat to human health. The results of our study show that there is non-carcinogenic risk associated with the consumption of *A. anguilla* muscle tissue by adults. This study is an important source of information for fish consumers in Türkiye and can serve as a basis for future research. Although it provides evidence for the potential use of *A. anguilla* as a biomonitor, additional research is necessary to fully establish its effectiveness in monitoring metal pollution levels.

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