

Health risk assessment: heavy metals in fish from the southern Black Sea

Levent Bat*^{ORCID}, Aşah Öztekin^{ORCID}, Elif Arici^{ORCID}, Fatih Şahin^{ORCID}

Sinop University, Sinop, Turkey

* e-mail: leventbat@gmail.com

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Abstract:

Introduction. The coastal contamination of the Black Sea has been an important issue for several decades. Heavy metals are the most harmful contaminants which affect people health. The research objective of the present study was to determine the amounts of Cd, Hg, Pb, Cu, and Zn found in the whiting (*M. merlangus* L.) and the red mullet (*M. barbatus* L.). These Black Sea bottom fish species have the highest commercial value. The obtained data were used to assess the risk which the fish represents for human consumers.

Study objects and methods. The elements were detected using an inductively coupled plasma mass spectrometer (ICP-MS). The amounts of the metals arranged in the following order: Zn > Cu > Pb > Hg > Cd.

Results and discussion. The mean values of Cd, Hg, Pb, Cu, and Zn in the edible tissues were 0.013, 0.024, 0.07, 0.195, and 9.05 mg/kg wet wt. for whiting and 0.017, 0.036, 0.05, 0.29, and 6.4 mg/kg wet wt. for red mullet, respectively. These levels proved lower than the permitted values set by the Ministry of Agriculture, Forestry, and Fisheries of the UK (MAFF), Turkish Food Codex (TFC), and EU Commission Regulation. The target hazard quotient (THQ) for all the elements via consumption of whiting and red mullet were also low.

Conclusion. Hazard index (HI) was < 1, which means that the fish caused no health problems in people who consumed whiting and red mullet caught in the southern Black Sea during the fishing seasons of 2017–2018. The carcinogenic risk index (CRI) for whiting and red mullet was also considered insignificant.

Keywords: Heavy metals, Black Sea, fish, risk assessment, target hazard quotient, carcinogenic risk index

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INTRODUCTION

Fish is usually located at the top of the food chain in the marine ecosystem. It accumulates contaminants from water, food, bottom sediment, and suspended particles in the water column. Even though available and accessible literature shows that heavy metals accumulated in the Black Sea commercial fish have no detrimental effect on human health [1], this issue remains a matter of public concern. However, the present research confirmed the fact that Black Sea fish is unaffected by environmental situation and is safe to eat.

A review conducted by Bat *et al.* showed some concern about the increase of unregulated settlements and anthropogenic activities along the marine coastal area of the Black Sea [2]. The growing urbanization and industrialization, as well as the fast development of agriculture, tourism, and fishery, increase the concentration of heavy metals discharged by major

rivers into the coastal waters of the Black Sea. The resulting increase in heavy metals adversely affects the coastal ecosystem.

The contaminants eventually accumulate in marine biota, particularly in fish [3, 4]. Subsequently, metals pass on to people that consume contaminated fish, thus threatening their health [5]. As a result, the environmental issues related to heavy metal contamination of the Black Sea are relevant to all countries along the Black Sea coast. After Romania and Bulgaria entered the European Union, the problem affected the whole of Europe.

The Marine Environment Policy of the Marine Strategy Framework Directive (MSFD) concerns the matters of monitoring chemical elements in edible tissues of seafood and avoiding heavy metal transfer from sea biota to human body via food chain [6]. The MSFD targets the

subject of sea contamination in Descriptor 8 “Concentrations of contaminants are at levels not giving rise to pollution effect” and Descriptor 9 “Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards” [6]. The objective of the MSFD with concern to Descriptors 8 and 9 is to ensure that contaminants are represented in foods in safe amounts.

According to the main guideline of the European Union, European seas are to obtain the Good Environmental Status (GES) by 2020. The abovementioned facts make studies of chemical elements in commercial fish extremely relevant.

The current study featured two commercial demersal fish species and assessed the heavy metal contamination, as well as the risk that the detected heavy metals represent for human health. The current study concentrated on the effect of Cd, Hg, Pb, Cu, and Zn on consumers’ health. The concentrations of the metals were measured in the muscle tissues of whiting and red mullet caught along the Sinop coast of the southern Black Sea and sold on fish markets. The research also included a thorough analysis of scientific literature on the amounts of Cd, Hg, Pb, Cu, and Zn in Black Sea whiting and red mullet. The obtained results could help in achieving the goals set by MSFD 2008/56/EC [6].

STUDY OBJECTS AND METHODS

Sample Collection. Twenty specimens of whiting and red mullet were purchased on fish markets. The sampling was conducted during the fishing seasons of

2017 and 2018 on the Sinop coast of the Black Sea (Fig. 1). The fish samples were processed according to the method depicted by Bernhard and UNEP [6–8]. The edible tissues of *M. merlangus* L. and *M. barbatus* L. were dissolved with Suprapur® HNO₃ (nitric acid) using a microwave digestion system. The elemental concentrations (Cd, Hg, Pb, Cu, and Zn) of the digested edible samples of whiting and red mullet were studied using the methods recognized by the Environmental Food Analysis Lab Industry and Trade Inc.

Fish tissues were prepared using an inductively coupled plasma mass spectrometer (ICP-MS), based on m-AOAC 999.10 (Association of Official Analytical Chemists with TS EN ISO IEC 17025 AB-0364-T references number) and CSN EN 15763 European Standards. The presence and quantity of the metals were detected according to the instrumental reaction of the equipment. The results were given as mg·kg⁻¹ wet weight (wt.).

Health risk assessment. The risk assessment for infants, children, and adults was performed to estimate the possible hazard associated with the consumption of heavy metals contained in the Black Sea fish. The risk exposure demands taking the mean daily intake of the heavy metals (mg/kg/day). The estimated daily intake (EDI) is subjected to the element levels and the amount of ingestion of fish. The EDI of heavy metals was calculated according to the equation below:

$$EDI = \frac{C_{\text{metal}} \times W_{\text{fish}}}{BW} \quad (1)$$

where C_{metal} is the amounts of elements in edible tissues;

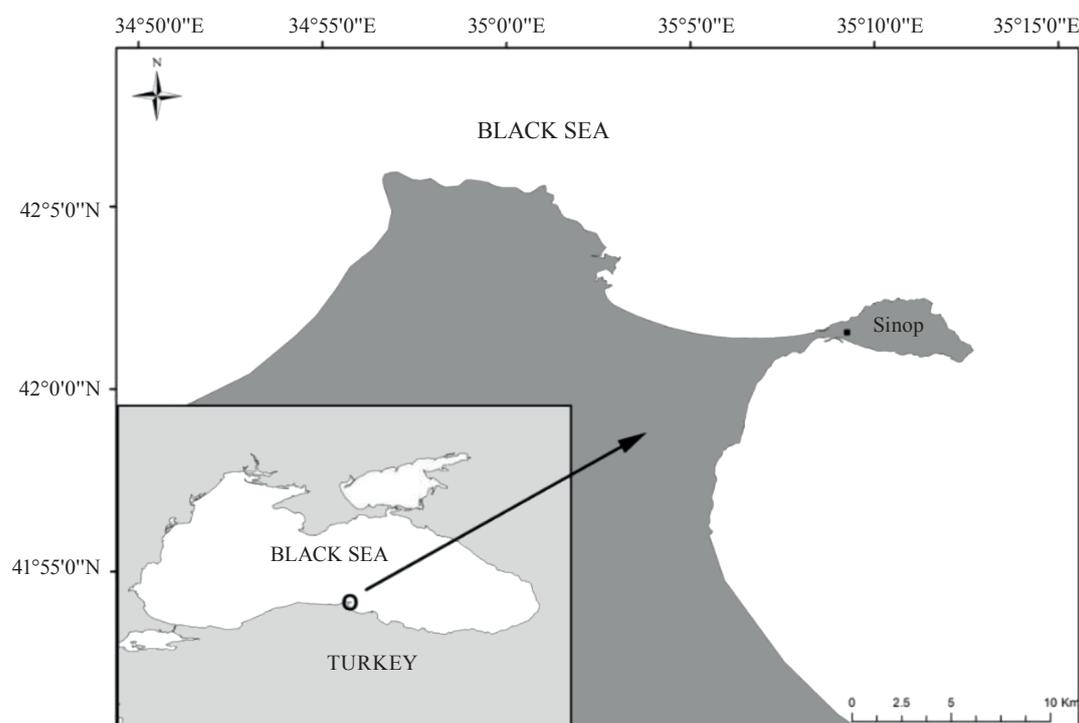


Figure 1 Fishing area

W_{fish} represents the daily mean ingestion of fish given as 0.013, 0.027, and 0.041 kg/day for infants, children, and adults, respectively [10]; BW is the body weight of 10 kg for infants, 30 kg for children, and 70 kg for adults.

The target hazard quotient (THQ) has been used in many studies to analyze the potential non-carcinogenic effect of the metals in the edible tissues of fish. The EDI (mg/kg of body wt. per day) of each heavy metal was related with the reference dose (Rf. D, mg/kg/day) as described in the equation below [11–13]:

$$\text{THQ} = \frac{\text{EDI}}{\text{Rf.D.}} \quad (2)$$

Rf. D. is the oral reference dose for Zn, Cu, Pb, Hg, and Cd as suggested by the US Environmental Protection Agency, i.e. 0.3, 0.04, 0.004, 0.0005, and 0.001 mg/kg/day, respectively [14, 15]. However, in the Risk Assessment Information System (RAIS), the mercury inorganic salts Rf. D. value is 0.0003, and there is no Rf. D. value for lead and compounds [15]. In contrast, oral slope factor is given only for lead and compounds as 0.0085 mg/kg/day [16]. The hazard index (HI) was defined as the sum of the THQs as described in the equation below:

$$\text{HI} = \text{THQ (Zn)} + \text{THQ (Cu)} + \text{THQ (Pb)} + \text{THQ (Hg)} + \text{THQ (Cd)} \quad (3)$$

The HI was used in this study to describe the cumulative non-carcinogenic effect. If $\text{HI} > 1.0$, then the EDI of a specific element exceeds the Rf. D, showing that there is a potential risk associated with that element.

The risk index (RI) represents the probability of developing any type of cancer over a lifetime. It is calculated by integrating the EDI with the respective oral slope factors (SF) for heavy metals. Slope factors (SF) are used to reckon the risk of cancer along with exposure to a carcinogenic or probably carcinogenic matter [17]. The description is presented in the equation below:

$$\text{RI} = \text{EDI} \times \text{SF} \quad (4)$$

The RI was considered insignificant if the RI was $< 10^{-6}$; the RI was considered allowable or tolerable if $10^{-6} < \text{RI} < 10^{-4}$; the RI was considered significant if the RI was $> 10^{-4}$.

RESULTS AND DISCUSSION

The average amounts of the heavy metals in Black Sea whiting and red mullet are given in Fig. 2. The amounts of heavy metals in both *M. merlangus* L. and *M. barbatus* L. decreased in the following order: $\text{Zn} > \text{Cu} > \text{Pb} > \text{Hg} > \text{Cd}$. The essential metals Zn and Cu were represented in higher amounts due to their biological functions, whereas the toxic metals Pb, Hg, and Cd have no biological functions, and their amounts in fish tissues were considerably lower.

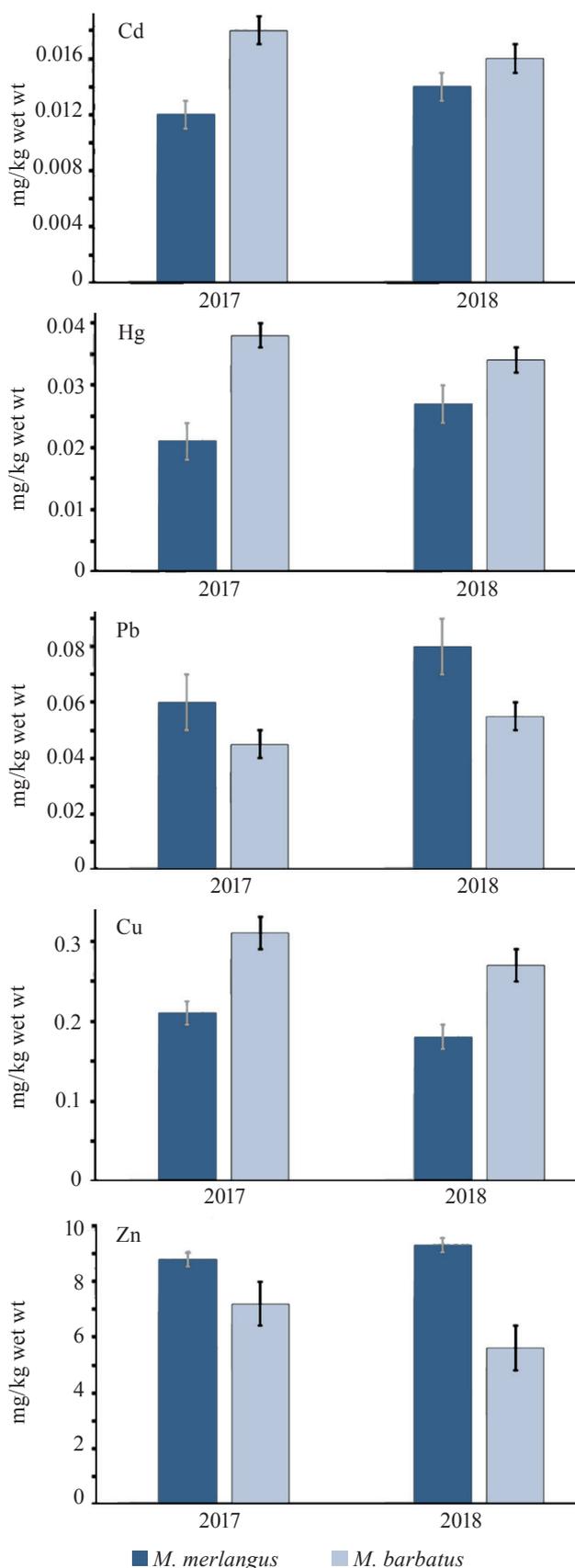


Figure 2 Heavy metal amounts with standard deviation for Cd, Hg, Pb, Cu, and Zn in the edible tissues of *M. merlangus* L. and *M. barbatus* L. from the Black Sea coasts caught in 2017 and 2018

Table 1 Estimated daily intakes (EDI) of elements in the edible tissues of *Merlangius merlangus* L. from the southern Black Sea

Heavy metals	EDI (2017), mg/day/kg body wt.			EDI (2018), mg/day/kg body wt.		
	Infants	Children	Adults	Infants	Children	Adults
Cd	0.0000156	0.0000108	0.0000070	0.0000182	0.0000126	0.0000082
Hg	0.0000273	0.0000189	0.0000123	0.0000351	0.0000243	0.0000158
Pb	0.0000780	0.0000540	0.0000351	0.0001040	0.0000720	0.0000468
Cu	0.0002730	0.0001890	0.0001230	0.0002340	0.0001620	0.0001054
Zn	0.0114400	0.0079200	0.00515428	0.0120900	0.0083700	0.0054471

Table 2 Estimated daily intakes (EDI) of elements in edible tissues of *Mullus barbatus* L. from the southern Black Sea

Heavy metals	EDI (2017), mg/day/kg body wt.			EDI (2018), mg/day/kg body wt.		
	Infants	Children	Adults	Infants	Children	Adults
Cd	0.0000234	0.0000162	0.0000105	0.0000208	0.0000144	0.00000937
Hg	0.0000494	0.0000342	0.0000222	0.0000442	0.0000306	0.0000199
Pb	0.0000585	0.0000405	0.0000263	0.0000715	0.0000495	0.0000322
Cu	0.0004030	0.0002790	0.0001815	0.0003510	0.0002430	0.00015814
Zn	0.0093600	0.0064800	0.0042171	0.0072800	0.0050400	0.0032800

Table 3 Target hazard quotients (THQ) and hazard index (HI) of elements consumed with *Merlangius merlangus* L. caught near the southern coast of the Black Sea in 2017 and 2018

Heavy metals	THQ (2017)			THQ (2018)		
	Infants	Children	Adults	Infants	Children	Adults
Cd	0.0156000	0.0108000	0.00702857	0.0182000	0.0126000	0.0082000
Hg	0.0546000	0.0378000	0.0246000	0.0702000	0.0486000	0.03162857
Pb	0.0195000	0.0135000	0.008785714	0.0260000	0.0180000	0.011714286
Cu	0.0068250	0.0047250	0.0030750	0.0058500	0.0040500	0.00263571
Zn	0.0381330	0.0264000	0.01718095	0.0403000	0.0279000	0.01815714
HI	0.1346580	0.0932250	0.060670238	0.1605500	0.1111500	0.072335714

Table 4 Target hazard quotients (THQ) and hazard index (HI) of elements consumed with *Mullus barbatus* L. caught near the southern coast of the Black Sea in 2017 and 2018

Heavy metals	THQ (2017)			THQ (2018)		
	Infants	Children	Adults	Infants	Children	Adults
Cd	0.0234000	0.0162000	0.010542857	0.0208000	0.0144000	0.009371429
Hg	0.0988000	0.0684000	0.044514286	0.0884000	0.0612000	0.039828571
Pb	0.0146250	0.0101250	0.006589286	0.0178750	0.0123750	0.008053571
Cu	0.0100750	0.0069750	0.004539286	0.0087750	0.0060750	0.003953571
Zn	0.0312000	0.0216000	0.014057143	0.0242666	0.0168000	0.010933333
HI	0.1781000	0.1233000	0.080242857	0.160116667	0.1108500	0.072140476

In this study, the heavy metal amounts in edible tissues varied according to the species. Cd, Hg, and Cu were high in *M. barbatus*, whereas *M. merlangus* proved rich in Pb and Zn. These differences may be related to habitat and feeding habits. The red mullet is demersal fish found near sand, gravel, and mud bottoms of the continental shelf. It feeds on small benthic mollusks, crustaceans, and worms. The whiting is benthopelagic fish found mostly near gravel and mud bottoms. Less frequently, it can be found on rock and sand. The whiting feeds on crabs, shrimps, mollusks, polychaetes, and small fish [17].

Cu and Zn are relatively safe for living biota. Therefore, the permissible values of such essential heavy metals as Cu and Zn are not available in the

current European Union and TFC regulations. However, they can be harmful if consumed in large amounts. According to the Ministry of Agriculture, Forestry, and Fisheries of the UK (MAFF), the maximal tolerable limits of Cu and Zn are 20 and 50 mg/kg wet wt., respectively [18]. In this study, the amount of heavy metal detected in whiting and red mullet was found to be significantly lower than these values.

Similarly, the present study revealed that toxic metal values (Cd, Hg and Pb) in edible tissues of whiting and red mullet were below the permissible values (0.05, 0.5, and 0.3 mg/kg wet wt.) set by European Union Commission Regulation and Turkish Food Codex [19, 20]. The Global Agriculture Information Network (GAIN) Report of the Russian Federation defined the

Table 5 Carcinogenic concentration of consumed fish (CDI), hazard quotient (HQ), risk index (RI), and hazard risk (HI) of elements in *Merlangius merlangus* L. caught near the southern coast of the Black Sea in 2017 and 2018

Heavy metals	2017			2018		
	CDI, mg/kg/day	HQ	RI	CDI, mg/kg/day	HQ	RI
Cd	0.0000026	0.0070290		0.0000030	0.0082000	
Hg	0.0000045	0.0246000		0.0000058	0.0316290	
Pb	0.0000130	–	0.00000011	0.0000170	–	0.00000014
Cu	0.0000450	0.0030750		0.0000390	0.0026360	
Zn	0.0019144	0.0171810		0.0020232	0.0181570	
HI		0.0518850	0.00000011		0.0606220	0.00000014

Table 6 Carcinogenic concentration of consumed fish (CDI), hazard quotient (HQ), risk index (RI), and hazard risk (HI) of elements in *Mullus barbatus* L. caught near the southern coast of the Black Sea in 2017 and 2018

Heavy metals	2017			2018		
	CDI, mg/kg/day	HQ	RI	CDI, mg/kg/day	HQ	RI
Cd	0.0000039	0.0105430		0.0000034	0.0093710	
Hg	0.0000082	0.0445140		0.0000082	0.0398290	
Pb	0.0000097	–	0.000000083	0.0000119	–	0.0000001
Cu	0.0000670	0.0045390		0.0000580	0.0039540	
Zn	0.0015663	0.0140570		0.0012182	0.0109330	
HI		0.0736530	0.000000083		0.0640870	0.0000001

permissible amounts of Cd, Hg, and Pb as 0.2, 0.5, and 1 mg/kg wet wt., respectively [21].

Tables 1 and 2 present the EDI values for whiting and red mullet caught near the Sinop coast of the Black Sea in 2017 and 2018 for infants, children, and adults. Tables 3 and 4 feature the THQ and HI values.

The EDI levels of Cd, Hg, Pb, Cu, and Zn were very low for both whiting and red mullet. These values were observed to be lower than their Rf. D. values. Likewise, THQ levels of these elements were very low. The HI values for infants were observed to be higher than those for children and adults. This result suggests that, at a relatively high level of exposure, infants will be more likely at risk than children and adults. Obviously, infants weigh much less than children and adults. However, the total non-carcinogenic indices (HI), which is the sum of THQ values for all the heavy metals studied for each sampling year, were lower than the threshold value of 1.0. Therefore, there were no health risks for infants, children, and adults who consumed whiting and red mullet caught near the southern coast of the Black Sea during the fishing seasons of 2017 and 2018.

In the Risk Assessment Information System, the SP value is given for Pb and its compounds only. The lifetime of a person is stated to be 70 years on average, while the exposure duration is assumed to be 26 years [16]. Tables 5 and 6 show carcinogenic concentration of consumed fish (CDI), hazard quotient (HQ), risk index (RI), and hazard risk (HI) of heavy metals in *M. merlangus* and *M. barbatus* caught near the southern coast of the Black Sea. The carcinogenic risk for whiting and red mullet was lower than 10^{-6} and is considered insignificant. The lowest RI was found in red mullet in 2017.

The results of this study were compared with the studies that featured *Merlangius merlangus* and *Mullus barbatus* from the Black Sea. They are presented in Tables 7 and 8, respectively.

In general, the amount of heavy metal found in both *Merlangius merlangus* and *Mullus barbatus* proved to be lower than that in other studies. Likewise, Zn is the heaviest metal found in both species. It is followed by Cu, Pb, Cd, and Hg. When compared, Zn, Cu, and Pb were found in high amounts in the whiting collected near the Amasra coasts of the southern Black Sea [31]. Hg was the highest in the whiting caught near the shores of Istanbul in the Black Sea [30]. Cd was detected in both fish species caught near the Trabzon shores. The highest Hg level species was obtained from *M. barbatus* caught near the shores of Istanbul and Kocaeli in the Black Sea [37]. The highest Pb value was found in the red mullet fished near the Kastamonu shores of the Black Sea [45].

The differences in the amounts of heavy metals found in these fish species may be due to the fact that they were caught during different fishing seasons and in different areas of the Black Sea. Metabolism, physiology, and feeding habits of the fish are different in different seasons. The pollution load also varies in different areas of the Black Sea coast [2]. Similarly, one should not dismiss different applications in heavy metal measurements, equipment accuracy, and human error. Although there are some exceptions, the amounts of heavy metals in these fish species proved to be low. Therefore, they posed no threat to human health.

CONCLUSION

The research featured the effect of Cd, Hg, Pb, Cu, and Zn on the health of infants, children, and adults who

Table 7 Comparison of the amounts (ppm) of heavy metals in the edible tissues of *Merlangius merlangus* L. caught near various areas of the Black Sea coast

Location	dw/ww	Metals					Ref.
		Zn	Cu	Pb	Cd	Hg	
Black Sea	d.w.	48.6 ± 3.9	1.25 ± 0.10	0.93 ± 0.07	0.55 ± 0.04	–	[22]
Black Sea	d.w.	8.86–163.28	0.91–8.95	–	–	–	[23]
Trabzon	w.w.	8.62 ± 0.54	0.88 ± 0.12	0.25 ± 0.07	0.01 ± 0.00	–	[24]
Sinop		12.9 ± 4.14	2.90 ± 0.78	0.46 ± 0.08	0.04 ± 0.01	–	
Bartın		5.73 ± 0.37	0.77 ± 0.07	0.18 ± 0.04	0.02 ± 0.00	–	
İstanbul	d.w.	6.03 ± 0.55		0.50 ± 0.10	0.19 ± 0.02	–	[25]
Black Sea	w.w.	65.4 ± 4.2	1.32 ± 0.11	0.53 ± 0.04	0.21 ± 0.02	84 ± 5 µg·kg ⁻¹	[26]
Sinop	d.w.	–	–	< 0.05	< 0.02	< 0.05	[27]
Samsun		–	–	< 0.05	< 0.02	< 0.05	
Samsun, Ordu, Trabzon, Rize	d.w.	20.6 ± 2.1	1.8 ± 0.2	0.46 ± 0.05	0.18 ± 0.02	–	[28]
Samsun, Sinop, Terme, Fatsa Ordu	d.w.	31.34 ± 1.61	3.72 ± 0.59	0.58 ± 0.03	0.002 ± 0.000	not detect	[29]
İstanbul	w.w.	4.248–30.842	0.001–4.915	0.004–1.581	0.001–0.151	0.003–0.491	[30]
Amasra-West Black Sea	w.w.	77.99 ± 46.91	8.53 ± 2.14	6.80 ± 5.88	0.40 ± 0.29	–	[31]
Samsun- Turkey	d.w.	58 ± 3.5	2.3 ± 0.7	0.9 ± 0.2	0.2 ± 0.03	–	[32]
		28.3 ± 1	2.7 ± 0.7	not detect	not detect		
Terkos	d.w.	–	–	15	0.35	0.07	[33]
Sakarya		–	–	12	0.24	< 0.01	
Bafra		–	–	15	0.07	0.09	
Ordu		–	–	13	0.22	0.5	
Trabzon-Turkey	d.w.	22.76 ± 2.01	1.02 ± 0.05	0.08 ± 0.03	0.04 ± 0.01	0.05 ± 0.01	[34]
Black Sea	d.w.	8.49	0.51	0.01	–	–	[35]
Sinop	d.w.	22.82–34.33	2.85–5.26	0.02	0.08–0.18	–	[36]
Black Sea	d.w.	18 ± 1.4	2.5 ± 0.06	0.05 ± 0.01	0.03 ± 0.01	0.33 ± 0.02	[37]
Eastern Black Sea, Turkey Ordu-Samsun	d.w.	21.5	1.56	0.024	0.031	–	[38]
West Black Sea	w.w.	18.1 ± 0.3	1.28 ± 0.07	–	–	–	[39]
Sinop	d.w.	16.34 ± 3.83	1.20 ± 0.31	0.69 ± 0.34	0.027 ± 0.012	–	[40]
Trabzon-Turkey	w.w.	–	–	0.02 ± 0.00	4.05 ± 0.14	–	[41]
Sinop	w.w.	3.4	< 0.5	< 0.05	< 0.02	< 0.05	[42]
Sinop	w.w.	43 ± 6	0.41 ± 0.02	0.88 ± 0.006	0.075 ± 0.006	not detect	[43]
Samsun	w.w.	5.04 ± 0.58	1.28 ± 0.09	1.41 ± 0.23	0.06 ± 0.02	–	[44]
Sinop		3.47 ± 0.27	0.92 ± 0.08	0.63 ± 0.06	0.05 ± 0.003	–	
Kocaeli		3.99 ± 0.5	1.46 ± 0.18	0.69 ± 0.12	0.06 ± 0.01	–	
Kastamonu	w.w.	5.45 ± 1.12	4.52 ± 0.70	6.12 ± 1.45	0.24 ± 0.02	–	[45]
Giresun	w.w.	3.77 ± 0.22	2.40 ± 0.25	0.05 ± 0.00	0.66 ± 0.08	–	[46]
Trabzon		5.65 ± 0.58	1.62 ± 0.25	1.30 ± 0.31	0.12 ± 0.03	–	
Rize		4.08 ± 0.36	1.65 ± 0.26	1.29 ± 0.21	0.08 ± 0.02	–	
Southwestern Black Sea	w.w.	23.54 ± 6.77	2.44 ± 0.54	0.36 ± 0.42	0.02 ± 0.01	0.01 ± 0.01	[47]
Black Sea	w.w.	–	–	0.099	0.013	0.081	[48]
Sinop	w.w.	7.11–17.88	0.18–0.33	0.03–0.09	0.007–0.0085	0.01–0.017	[49]
Sinop	w.w.	9.70 ± 1.9	2.90 ± 0.99	1.17 ± 1.01	0.02 ± 0.01	–	[50]
Kastamonu		6.74 ± 1.63	2.35 ± 0.36	1.18 ± 0.45	0.03 ± 0.01	–	
Zonguldak		6.24 ± 0.8	2.25 ± 0.25	0.86 ± 0.34	0.03 ± 0.01	–	
Sinop	w.w.	12.63 ± 0.22	0.59 ± 0.06	0.19 ± 0.02	0.03 ± 0.00	0.13 ± 0.01	[51]
		18.52 ± 0.60	2.10 ± 0.67	0.90 ± 0.28	0.22 ± 0.03	0.23 ± 0.00	
Western Black Sea	w.w.	–	–	–	–	0.01 ± 0.01	[52]

d.w.= dry wt.; w.w. = wet wt.

Table 8 Comparison of the amounts (ppm) of heavy metals in the edible tissues of *Mullus barbatus* L. caught near various areas of the Black Sea coast

Location	dw/ ww	Metals					Ref.
		Zn	Cu	Pb	Cd	Hg	
Black Sea	d.w.	106 ± 9.1	0.98 ± 0.07	0.84 ± 0.07	0.45 ± 0.04	–	[22]
Black Sea	d.w.	1.424–63.290	0.380–2.714	–	–	–	[23]
Trabzon	w.w.	8.26 ± 0.77	1.30 ± 0.13	0.22 ± 0.08	0.02 ± 0.00	–	[24]
Sinop		10.5 ± 2.03	0.87 ± 0.09	0.39 ± 0.03	0.03 ± 0.00	–	
İstanbul	d.w.	7.573 ± 0.389	–	0.727 ± 0.141	0.208 ± 0.017	–	[25]
Black Sea	w.w.	75.5 ± 5.3	0.96 ± 0.08	0.36 ± 0.03	0.17 ± 0.02	36 ± 2 µg·kg ⁻¹	[26]
Sinop	d.w.	–	–	0.0525	< 0.02	< 0.05	[27]
Samsun		–	–	0.0815	< 0.02	< 0.05	
Samsun, Ordu, Trabzon, Rize	d.w.	17.8 ± 1.8	1.4 ± 0.1	0.40 ± 0.04	0.23 ± 0.02	–	[28]
Samsun, Sinop, Terme, Fatsa Ordu	d.w.	23.71 ± 0.71	3.14 ± 0.31	0.92 ± 0.12	0.020 ± 0.002	–	[29]
Amasra	w.w.	16.03 ± 14.05 (3.48–40.72)	4.08 ± 2.79 (1.23–9.21)	1.11 ± 1.60 (0.09–7.00)	0.11 ± 0.13 (0.02–0.55)	–	[31]
Trabzon-Turkey	d.w.	27.36	1.12	0.10	0.02	0.11	[32]
Sinop	d.w.	6.95–18.43	4.93–7.74	0.09–0.31	0.02	–	[53]
Black Sea (İstanbul and Kocaeli)	d.w.	14.6 ± 1.3	1 ± 0.18	0.02 ± 0.01	0.02 ± 0.01	0.47 ± 0.02	[37]
Eastern Black Sea, Turkey Ordu-Samsun	d.w.	19.7	1.36	0.020	0.018	–	[38]
West Black Sea	d.w.	36.4 ± 3.2	2.28 ± 0.03	–	–	–	[39]
Sinop	d.w.	17.15 ± 3.78	0.95 ± 0.41	0.82 ± 0.34	0.035 ± 0.018	–	[40]
Trabzon-Turkey	w.w.	–	–	< LOD	3.38 ± 0.06	–	[41]
Sinop	d.w.	3.2	< 0.5	< 0.05	< 0.02	< 0.05	[42]
Sinop	d.w.	10.64–19.53	2.79–5.45	0.11–0.45	0.03–0.19	–	[54]
Samsun	w.w.	4.95 ± 0.6	1.27 ± 0.19	1.76 ± 0.40	0.20 ± 0.11	–	[44]
Sinop		9.49 ± 0.38	2.38 ± 0.12	2.94 ± 0.81	0.07 ± 0.02	–	
Kocaeli		5.71 ± 0.88	1.4 ± 0.12	0.88 ± 0.12	0.06 ± 0.005	–	
Kastamonu	w.w.	6.14 ± 1.46	2.35 ± 0.38	7.21 ± 1.56	0.28 ± 0.03	–	[45]
Giresun	w.w.	6.02 ± 0.45	1.99 ± 0.18	0.45 ± 0.05	0.04 ± 0.00	–	[46]
Trabzon		7.15 ± 0.64	1.74 ± 0.13	1.03 ± 0.10	0.12 ± 0.03	–	
Rize		5 ± 0.31	1.81 ± 0.15	1.30 ± 0.16	0.09 ± 0.02	–	
Southwestern Black Sea	w.w.	20.80–34.94	1.36–11.85	0.03–1.70	0.02–0.05	0.01–0.03	[47]
Ordu	d.w.	44.85 ± 7.11 83.13 ± 8.4	1.64 ± 0.37 3.95 ± 0.74	0.81 ± 0.04 1.54 ± 0.36	0.8 ± 0.02 0.91 ± 0.02	–	[55]
Black Sea	w.w.	–	–	0.165	0.016	0.032	[48]
Sinop	w.w.	5.61–11.8	0.27–0.49	0.025–0.06	0.007–0.011	0.015–0.021	[49]
Romania	w.w.	–	3.486 ± 2.45	0.32 ± 0.25	0.026 ± 0.001	–	[56]
Romania	w.w.	–	–	–	–	0.035 ± 0.01 (0.021–0.072)	[57]
West Black Sea	w.w.	–	–	–	–	0.03 ± 0.02	[52]

d.w.= dry wt.; w.w. = wet wt.

consumed whiting (*M. merlangus* L.) and red mullet (*M. barbatus* L.) caught near the southern coast of the Black Sea in 2017 and 2018. For all age groups, the EDI values for each heavy metal decreased in the following order: Zn > Cu > Pb > Hg > Cd. The mean values of Cd, Hg, Pb, Cu, and Zn in the edible tissues were 0.013, 0.024, 0.07, 0.195, and 9.05 mg/kg wet wt. for whiting and 0.017, 0.036, 0.05, 0.29, and 6.4 mg/kg wet wt. for red mullet, respectively. The differences might have been caused by the fact that the samples were caught

during different fishing seasons and in different areas of the Black Sea.

In all cases, HI values for each metal were < 1, suggesting no health risk. The concentrations also met the standards set up by regulatory bodies of Turkey and the European Union. The RI values for whiting and red mullet did not exceed the insignificant limit (10⁻⁶). In addition, these two commercial species caught near the Sinop coast showed no carcinogenic potential.

CONTRIBUTION

The authors were equally involved in writing the manuscript and are equally responsible for plagiarism.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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ORCID IDs

Levent Bat  <https://orcid.org/0000-0002-2289-6691>

Ayşah Öztekin  <https://orcid.org/0000-0002-3726-7134>

Elif Arici  <https://orcid.org/0000-0001-6359-9194>

Fatih Şahin  <https://orcid.org/0000-0003-0605-2672>