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Metal Bioaccumulation in the Gill, Liver, and Muscle of Bluefish (*Pomatomus saltatrix*) From the Northeastern Mediterranean and Human Health Risk Assessment Associated with Their Seasonal Consumption

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Abstract

Heavy metals are continuously released into the oceans from both natural and anthropogenic sources. They are serious threats to both ecosystem and human health because of their toxicity, persistence, bioaccumulation, and biomagnification. We present metal concentrations in the economically important bluefish from Iskenderun Bay, providing valuable information on Northeastern Mediterranean aquatic ecosystem health, as well as the human health risk. The concentrations of manganese, iron, copper, zinc, selenium, cadmium, lead, and mercury were determined in the gill, liver, and muscle tissues of bluefish (*Pomatomus saltatrix*) caught in Iskenderun Bay (Turkey) during four seasons. Samples were analysed via inductively coupled plasma mass spectrometer. Fe and Zn were detected in the highest concentrations during all four seasons. The ranges of Fe concentrations were 61.15–108.76, 229.78–377.02, and 6.35–8.63 and those of Zn were 25.21–44.25, 42.25–76.08, and 6.27–13.59 in the gills, livers, and muscles, respectively. In contrast, Hg and Cd were not found in the bluefish tissues in any season with the exception of Cd in the gills during the spring (0.757 mg/kg, above the legal limit of 0.5 mg/kg). On a seasonal basis, no meaningful accumulation trend was observed for the muscles or gills, while the highest concentrations of Mn, Fe, Cu, Zn, and Se in the liver were found in the spring. Liver tissues possessed higher metal concentrations than gill and muscle tissues. Estimated daily and weekly intakes of the metals due to human consumption of the bluefish were considerably lower than the provisional tolerable intake. In this study, there was an inflow of metals into Iskenderun Bay; however, no significant metal accumulation was found in bluefish tissues at a rate that would harm human health.

Intensive agricultural and industrial activities have the potential to cause environmental pollution. Pollution with heavy metals poses a serious hazard due to their toxicity. Toxic metal aggregation in dietary foodstuffs can severely decrease some significant nutrients in the body, reduce immunological defences, retard growth, disrupt psychosocial behaviours, cause malnutrition, and much more (Junejo et al. 2019). Metals are ubiquitous in aquatic environments. Understanding their behaviours and interactions with fish is of great socioeconomic significance. Fish are very susceptible to aquatic contaminants and take up metals primarily through the gills, skin, and in food and water (Anvari Far et al. 2018). It is known that the accumulation of heavy metals in fish tissues and organs affects various blood parameters, enzyme activities, growth, and development (Dick and Dixon 1985). In addition to the direct damage that these pollutants cause to aquatic organisms, their biological accumulation can threaten human health when those organisms are consumed, with symptoms such as impaired kidney function, poor reproductive capacity, liver damage, skin and bladder cancer, and even death (Wei et al. 2014). The fish serve a significant purpose for biomagnifications of metals, because they stand at the tip of the food pyramid and act as allowable transfer media to human beings (Sonone et al. 2020). Although some essential heavy metals, such as Fe, Zn, and Cu, are biologically necessary for both aquatic organisms and humans, it also is known that prolonged exposure to

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these metals can be toxic. Moreover, there are some toxic metals, such as Cd and Pb, that have no known potential benefit for humans (Saha et al. 2016). AnvariFar et al. (2018) reported that fish inhabiting polluted water provide valuable information on the etiology of pollutant-mediated diseases, such as cancer, and seem to be a convenient tool for health-risk analyses.

Iskenderun Bay is located on the Northeastern Mediterranean coast of Turkey and has an area of approximately 2275 km^2, length of 65 km, and width of 35 km. Çukurova Plain, which is the main agricultural area in the region, is a significant agriculturally productive area due to its large stretch of flat, fertile land. Pollutants are discharged from the agricultural area to Iskenderun Bay through agricultural drainage channels and the Ceyhan River. Industries are expanding in this region, including a cement factory, iron and steel plants, a thermal power plant, waste treatment facilities, oil pipelines, a marine terminal, and fertilizer factories. It has been known since the 1940s that Iskenderun Bay supports a more productive fishery compared to other parts of the Eastern Mediterranean (Kosswig 1953). In consequence, a large fishing fleet has developed in this region, including all kinds of fishing methods. An important part of this fleet utilises longline fishing. Bluefish (*Pomatomus saltatrix*) is an economically important species caught by fishermen using pelagic longlines. The area also attracts attention from amateur anglers who participate in bluefish fishing. Fishermen in this area have stated that bluefish fishing can be done throughout the year but that autumn and spring are more productive. Because Iskenderun Bay is affected by pollutants, such as heavy metals (Türkmen et al. 2005), the health risks of fish consumption should be evaluated. Özkütük et al. (2017) reviewed published heavy metal concentrations in the muscle tissues of some fish species (red mullet *Mullus barbatus*, gray mullet *Mugil cephalus*, and gilthead seabream *Sparus aurata*) measured since approximately 2000 in the Northeastern Mediterranean Sea. They observed that heavy metal concentrations in their selected fish could generally be ranked Fe > Zn > Pb > Cu > Cr > Ni > Cd > Mn > Co. The Fe, Ni, Mn, and Co concentrations of the selected fish captured from this region were within the limitations enacted by the Turkish Food Codex and FAO. Zn concentrations (0.11–123.6 µg Zn/g) of *M. cephalus* and *S. aurata* exceeded those limitations around 2000 and then decreased after 2001. However, it was reported that the Pb, Cd, and Cr concentrations were over the limitations in almost all years. They also reported that heavy metal concentrations in the liver were one to more than ten times the muscle concentrations. Ali et al. (2021) reported that bioaccumulation was highest in the gills, followed by intestine > muscles > skin > bones.

Bluefish is considered delicious and nutritious, which has made it an economically important species for Iskenderun Bay. However, there has been limited research on its nutritional quality and elemental safety (Özoğul et al. 2007; Türkmen et al. 2009). The studies that have been performed to date did not investigate seasonal changes in the elemental concentrations of bluefish from this region. In this study, the gills, liver, and muscles were selected as the target organs, because gills reflect the concentrations of metals in the water, the concentrations in the liver indicate the storage of heavy metals in the fish, and the muscle concentrations are important for human consumption.

Materials and Methods

Sampling Area and Sample Preparation

Bluefish (*Pomatomus saltatrix*, 440.28 ± 110 g average weight and 35.32 ± 2.93 cm average length) were caught by academic staff of the Fisheries Faculty between November 2017 and December 2018 in Yumurtalık Bight (Iskenderun Bay; Figs. 1 and 2). All samples were caught by longline with 2 sets of 100 hooks. When the fish were removed from the water, they were already dead. Ten fish samples for each season were placed in polystyrene boxes with ice and transported to the laboratory within 6 h. Fish samples were carefully dissected using clean equipment in the laboratory, and gill (10.01 ± 3.13 g), liver (5.0 ± 1.93 g), and muscle (30.0 ± 6.09 g) tissue samples were removed and kept at − 80 °C until analysis.

Analytical Methods

Analyses were performed at the Mersin University Advanced Technology Education, Research and Application Centre (MEITAM). Homogenised samples were weighed and digested in a microwave oven with 2 mL of hydrogen peroxide solution (34.5–36.5%, Sigma-Aldrich) and 8 mL of nitric acid (65%, Sigma-Aldrich). The digested samples were then diluted to a final volume of 50 mL with ultrapure water. The concentration of metals in the fish tissues were determined by inductively coupled plasma mass spectrometer (ICP-MS), using a 7500ce model instrument purchased from Agilent, Hachioji, Japan. The operating conditions were as follows: auxiliary gas flow rate (L min^{-1}), 1; radio frequency (RF) (W), 1500; carrier gas flow rate (L min^{-1}), 1.1; plasma gas flow rate (L min^{-1}), 15; nebulizer pump (rps), 0.1; sample depth (mm), 8.6; sample introduction flow rate (mL min^{-1}), 1; and extract lens (V), 1.5. Triplicate analyses were performed for each metal. Calibration standards were obtained from High-Purity Multi Standard (Perkin Elmer, PE N9300233). The instrument was calibrated using five aqueous standard solutions of concentrations 1, 10, 25, 50, and 100 µg/L prepared using ultrapure water in 2.5%

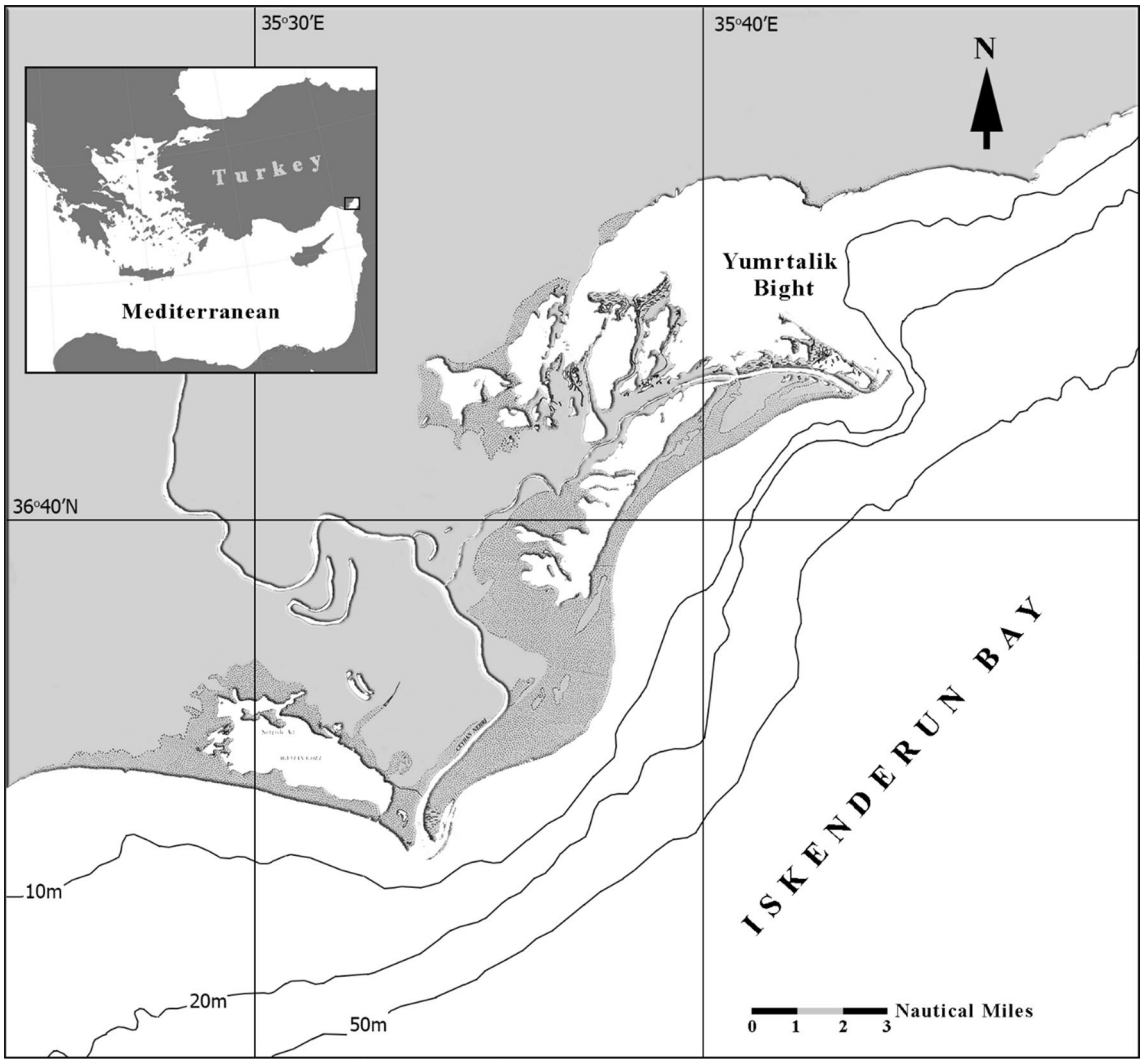

Fig. 1 Sampling area

(v/v) HNO3 (purity 65%); the calibration curves obtained were analysed using linear regression with a minimum R^2 of 0.999. After every ten-sample analysis, a standard solution was analysed for calibration control. In and Ge were added to each standard, blank solution, and sample as an internal standard.

Estimated weekly and daily metal intakes were calculated using the following formulas:

$$\text{EWI (mg/week/70 kg body weight)} = c \times \text{FIR} \times 7$$

$$\text{EDI (mg/day/70 kg body weight)} = c \times \text{FIR} \times 1$$

where c = mean metal level in the tissue (mg kg^{-1}) and FIR = daily amount of fish consumed in Turkey, 0.017 kg/person/day according to TUIK (2019). The yearly amount of fish consumed in Turkey is 6.2 kg/person/year in 2018 according to TUIK (2019).

Statistical Analyses

Data obtained for all tissues in each season were subjected to analysis of variance (one-way ANOVA) at a 5% confidence level using Duncan's (1955) multiple range test. All data analysis and visualization procedures were performed using R Language and Environment for Statistical Computing (R Core Team 2019) and "ggplot2" library (Wickham 2009).

Results and Discussion

Mn, Fe, Cu, Zn, Se, Cd, Pb, and Hg concentrations were determined in the gills, liver, and muscle of the bluefish in this study. The mean concentrations of these metals in the gill, liver, and muscle tissues during the different seasons are shown in Tables 1, 2, and 3, respectively. The highest

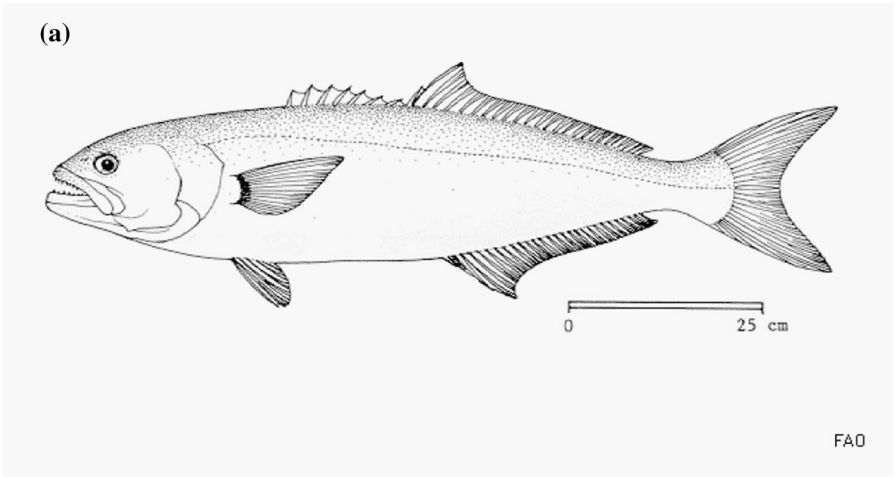

Fig. 2 **a** Bluefish (*Pomatomus saltatrix*). **b** Schematic view of the special longline used to catch bluefish in the water column

Table 1 Mean concentrations of detected metals in gill of bluefish from Iskenderun Bay, Northeastern Mediterranean (mg/kg ww)

	Autumn	Winter	Spring	Summer
Mn	4.07 ± 0.45^{d}	0.53 ± 0.02^{a}	0.84 ± 0.02^{b}	2.12 ± 0.06^{c}
Fe	91.79 ± 0.39^{b}	61.15 ± 3.13^{a}	100.71 ± 1.79^{c}	108.76 ± 3.45^{d}
Cu	5.39 ± 0.03	< DL	0.42 ± 0.01	0.40 ± 0.01
Zn	44.25 ± 0.28^{d}	35.18 ± 0.59^{b}	41.39 ± 0.05^{c}	25.21 ± 0.31^{a}
Se	0.97 ± 0.07^{a}	0.95 ± 0.08^{a}	1.03 ± 0.03^{a}	1.07 ± 0.07^{a}
Cd	< DL	< DL	0.757 ± 0.00	< DL
Pb	< DL	< DL	< DL	0.37 ± 0.00
Hg	< DL	< DL	< DL	< DL

DL detection limit

Detection limit is 0.001 mg/kg

Values are expressed as mean ± standard deviation, n = 3

[a–d]Significant differences ($P < 0.05$) in concentrations between seasons in a line

Table 2 Mean concentrations of detected metals in liver of bluefish from Iskenderun Bay, Northeastern Mediterranean (mg/kg ww)

	Autumn	Winter	Spring	Summer
Mn	1.34 ± 0.01^{a}	1.77 ± 0.02^{c}	2.97 ± 0.05^{d}	1.53 ± 0.01^{b}
Fe	229.78 ± 1.09^{a}	354.18 ± 3.23^{c}	377.02 ± 3.06^{d}	303.16 ± 1.13^{b}
Cu	8.73 ± 0.03^{a}	10.57 ± 0.01^{b}	14.71 ± 0.09^{d}	13.01 ± 0.17^{c}
Zn	53.83 ± 0.43^{c}	45.71 ± 0.09^{b}	76.08 ± 0.30^{d}	42.25 ± 0.19^{a}
Se	2.52 ± 0.06^{a}	3.37 ± 0.03^{c}	3.94 ± 0.04^{d}	2.61 ± 0.05^{b}
Cd	< DL	< DL	< DL	< DL
Pb	0.0078 ± 0.00^{a}	< DL	< DL	0.063 ± 0.00^{b}
Hg	< DL	< DL	< DL	< DL

DL detection limit

Detection limit is 0.001 mg/kg

Values are expressed as mean ± standard deviation, n = 3

[a–d]Significant differences ($P < 0.05$) in concentrations between seasons in a line

Table 3 Mean concentrations of detected metals in muscle of bluefish from Iskenderun Bay, Northeastern Mediterranean (mg/kg ww)

	Autumn	Winter	Spring	Summer
Mn	< DL	0.44 ± 0.01	< DL	< DL
Fe	8.63 ± 0.55[b]	6.42 ± 0.81[a]	< DL	6.35 ± 1.09[a]
Cu	< DL	< DL	< DL	< DL
Zn	10.60 ± 0.12[c]	6.27 ± 0.09[a]	9.00 ± 0.15[b]	13.59 ± 0.17[d]
Se	< DL	< DL	< DL	< DL
Cd	< DL	< DL	< DL	< DL
Pb	0.046 ± 0.00[b]	< DL	< DL	0.0119 ± 0.00[a]
Hg	< DL	< DL	< DL	< DL

DL detection limit

Detection limit is 0.001 mg/kg

Values are expressed as mean ± standard deviation, n = 3

[a–d]Significant differences ($P < 0.05$) in concentrations between seasons in a line

element concentrations detected during four seasons in the investigated bluefish tissues were Fe and Zn. In contrast, Hg and Cd were not found in the bluefish tissues in any season with the exception of Cd in the gills during the spring.

Mn is vital for skeletal structure, in reproduction and for normal brain function. However, exposure to high levels of Mn through inhalation or ingestion may cause health problems. In industrial applications, it is generally used in metal alloys and is a necessary raw material, especially in stainless steel production. Because of the lack of data on Mn intake and health outcomes, no recommended dietary allowance (RDA) for manganese has been established by authorities. Observed mean intakes of Mn for adults in the EU range from 2.5 to 6.6 mg in men and from 2.0 to 5.5 mg in women, with most values around 3 mg/day (ESFA 2013). It has been reported that these value ranges are associated with neither deficiency nor toxicity (D.A.CH 2013). In this study, the detected concentrations of Mn in bluefish ranged from 0.44 to 4.07 mg/kg (wet weight, ww). Concentrations were considerably higher in the gills during the autumn and summer seasons (4.07 and 2.12 mg/kg ww, respectively) than in the liver and muscles (Tables 1, 2, and 3). The highest Mn levels observed in the liver occurred in the spring (2.97 mg/kg ww) and winter (1.77 mg/kg ww) seasons. Mn was only detected in the bluefish muscle tissue in winter (0.44 mg/kg ww). It has been reported that Mn levels in the muscle of common sole (*Solea solea*) captured from Iskenderun Bay ranged from 0.2 to 0.41 mg/kg (Ersoy and Çelik 2010) and that the levels in the muscle and skin of sand sole (*Solea lascaris*) were 1.64 to 6.37 mg/kg (Yılmaz et al. 2010). Concentrations of manganese also were investigated in three commercially valuable fish species from Iskenderun Bay, lizardfish (*Saurida undosquamis*), gilthead seabream (*Sparus aurata*), and red mullet (*Mullus barbatus*) with reported concentrations of 0.05 to 4.64 mg/kg dry weight (dw). Türkmen et al. (2010) examined the Mn levels of gill, liver, and muscle tissues of some fish species caught from the same region. They reported that the Mn levels of the gill, liver, and muscle tissues were 5.41, 2.67, and 0.75 mg/kg ww, respectively, for sea bream (*S. aurata*) and 6.29, 1.29, and 0.96 mg/kg, respectively, for keeled mullet (*L. carinata*). Similarly, the highest Mn accumulation also was observed in the gills by other researchers (Kır and Tumantozlu 2012; El Moselhy et al. 2014; Çetin et al. 2013).

Fe, one of the most abundant elements on Earth, also is the first metal processed by humans. Fe acts as an oxygen carrier in the haemoglobin found in red blood cells, as a transport medium for electrons within cells, and as an integrated part of important enzyme systems in various tissues. Therefore, Fe has vital functions in living organisms, but excessive iron intake can be toxic. While a dose of 3–6 mg/kg/day dose is prescribed for iron deficiency anaemia, toxic effects occur at doses above 20 mg/kg elementary iron, and ingestion of more than 60 mg/kg causes serious toxicity (Yuen and Becker 2019). Concentrations of iron in the gill, liver, and muscle tissues of bluefish in this study ranged from 61.15 to 108.76 mg/kg ww, from 229.78 to 377.02 mg/kg ww and 6.35 to 8.63 mg/kg ww, respectively (Tables 1, 2, and 3) and varied from season to season. In this study, Fe was the measured element present at the highest concentrations in the gill and liver, which seems to be consistent with the results reported in other studies (Mzimela et al. 2003; Arain et al. 2008; Ongeri et al. 2012).

The highest Cu concentrations (8.73–14.71 mg/kg) were measured in the liver, whereas Cu was not detected in the muscle in any season. In the gills, it was measured as 0.40 mg/kg in spring and summer and 5.39 mg/kg in autumn. Because of its presence in several enzymes, copper is essential for living organisms. However, it can cause acute toxicity at high levels. The concentrations measured in this study were significantly lower than the Food and Agricultural Organization of the United Nations (FAO 1983) maximum guidelines of 30 mg/kg. The detected Cu concentrations were also lower than the liver (23–38 mg/kg ww) and muscle (4–6 mg/kg ww) levels of some deep-water fish species (*Triglia lucerna, Lophius budegassa, Solea lascaris*) from the same region reported by Yılmaz et al. (2010).

Zn was detected at the second highest concentrations after iron in bluefish gill tissues and the highest concentrations in muscle tissues. The maximum Zn levels in bluefish (Table 2) were found to range from 42.25 to 76.08 mg/kg in the liver, 25.21–44.25 mg/kg in the gills, and 6.27–13.59 mg/kg in the muscle. As a component of many enzymes, Zn is an essential element in all organisms and metabolic processes, but it also can be toxic above the limit of 50 mg/kg ww in muscle (Hussein and Khaled 2014). The acceptable limit for zinc was exceeded in the bluefish liver in the autumn

and spring seasons. However, because the likelihood of a person consuming a kilogram of bluefish liver in their diet is low, the risk also is low. The concentration of Zn in the bluefish muscle was also lower than those in an earlier report on other fish species from Iskenderun Bay (38.23 mg/kg and 19.55 mg/kg for grey mullet *Mugil cephalus* and Mediterranean horse mackerel *Trachurus mediterraneus* muscle, respectively; Yılmaz 2003).

Adequate Se is essential because it can defend cells and whole organisms against oxidative damage. Foods supplemented with dietary Se have gained importance recently, as Se supplements are promising as a means of treating inflammatory conditions, rejuvenating an aging immune system, and protecting against carcinogenesis (McKenzie et al. 1998). Given all of this, fish is known as a good source of selenium (WHO 1987). However, Se was not detectable in the muscle mass of bluefish in this study. The highest concentration of Se was found in the liver in the range of 2.52–3.94 mg/kg. In the gills, it was detected at lower concentrations (0.95–1.07 mg/kg) than in the liver. Se contents in seafoods from Turkish seas have been reported as varying from 0.30 to 0.38 mg/kg for seabream (*Sparus aurata*) by Öztürk et al. (2019), 0.46–2.93 mg/kg for oyster (*Ostrea edulis*) by Erkan et al. (2011), and 0.2–1.5 mg/kg for shrimp (*Parapenaus longirostris*) by Özden (2010).

Cd is a nonessential heavy metal and is a major environmental concern due to its high toxicity. Like other heavy metals, Cd also tends to accumulate in living organisms. However, it has been emphasized that Cd does not notably bioconcentrate in fish species (Saiki et al. 1995) but accumulates more readily in invertebrates (Satarug et al. 2003). Türkmen et al. (2008) found that the ranges of Cd concentrations were 0.02–0.37 mg/kg for muscles and 0.13–0.47 mg/kg for livers from Turkish seas. Dobaradaran et al. (2010) reported mean Cd values ranging from 0.17 to 0.26 mg/kg for some marine fish species from the Persian Gulf. Anvari-Far et al. (2018) emphasized that the gills are the major route of Cd uptake, as expected the chloride cells are the more sensitive, because in fish species, high number of immature, necrotic and apoptotic chloride cells, and apoptotic bodies also were frequently found. In this study, Cd was not detected in the muscle, liver, or gill tissues throughout the study period except for the gills in spring. In the spring season, Cd was detected in the gill samples at 0.757 mg/kg. According to the European Commission (1997), the maximum permissible concentration for Cd in fish is 0.5 mg/kg. It can be seen that the bluefish gills were contaminated with Cd in the spring, indicating that stricter monitoring is needed.

The Pb concentration in bluefish gills was found to be 0.37 mg/kg in summer and below the detection limit in the other seasons. Pb concentrations were only detectable in the liver in the autumn and summer seasons at 0.0078 and 0.063 mg/kg, respectively. As for muscle, 0.046 and 0.012 mg/kg Pb concentrations were found in autumn and summer, respectively. Özden (2013) reported that in some seasons, the Pb concentrations measured in bluefish and sardines purchased from a local fish market in Istanbul in 2006–2007 were over the European Commission's legislative limit for seafood of 0.30 mg/kg fresh weight (2006). Turkmen (2009) reported a 0.38 mg/kg Pb concentration for bluefish captured from the Black Sea. The Pb level in fish species harvested from the Persian Gulf was found to range from 0.19 to 0.41 mg/kg ww (Abadi et al. 2015). Yılmaz et al. (2010) found that the Pb concentrations were high in the liver of *S. lascaris* (2.98 mg/kg) and low (0.14–0.39 mg/kg) in the muscle tissues of fish. Junejo et al. (2019) emphasized that fish species in Turkey, Japan, the United States, and Europe had lower levels of Pb than their studied fish species (> 0.50 µg/g ww). It is known that Pb is a nonessential element and a toxic metal. Therefore, only fish with low Pb levels can be acceptable for consumption. In this respect, the bluefish captured from Iskenderun Bay are safe concerning Pb except for the gills in the summer season.

Hg, a very toxic metal, is considered a global pollutant with a high environmental risk. Hg is easily absorbed by the human body and can cause damage to the central nervous system. Seafood, especially mussels, oysters, etc. that are fed by seawater, is considered to be the major source of Hg in the human food chain. Therefore, seafood is an important indicator of Hg pollution in marine ecosystems. In this study, Hg was not detected in the gill, liver, or muscle tissues of the bluefish in any season.

It is known that with regard to the bioaccumulation of metals, different fish tissues have different accumulation capacities depending on their structure and function (Ali and Khan 2018). In this study, the liver of the bluefish generally accumulated larger amounts of metal. As shown in Fig. 3, the Mn, Fe, Cu, Zn, and Se levels were significantly higher in the liver than in the gill and muscle, but not the Pb level ($P < 0.05$). Similarly, many researchers have reported higher metal accumulation in the liver and lower accumulation in fish muscles (Mulk et al. 2017; Al-Ghanim et al. 2016; Omwenga et al. 2014, Waheed et al. 2014, Vinodhini and Narayanan 2008, Kalay and Canli 2000).

The daily intake of an element due to fish consumption is naturally dependent on the element concentration in the fish and the amount of fish consumed. The EWI and EDI values shown in Table 4 were calculated by assuming that a 70 kg individual will consume 17 g of bluefish muscle per day (approximately 120 g per week). Each EWI and EDI value for the measured elements was significantly lower than the respective provisional tolerable weekly intake (PTWI). In other words, there was no significant risk in consuming bluefish captured from Iskenderun Bay when considering Mn, Fe, Cu, Zn, Se, Cd, Pb, and Hg intake.

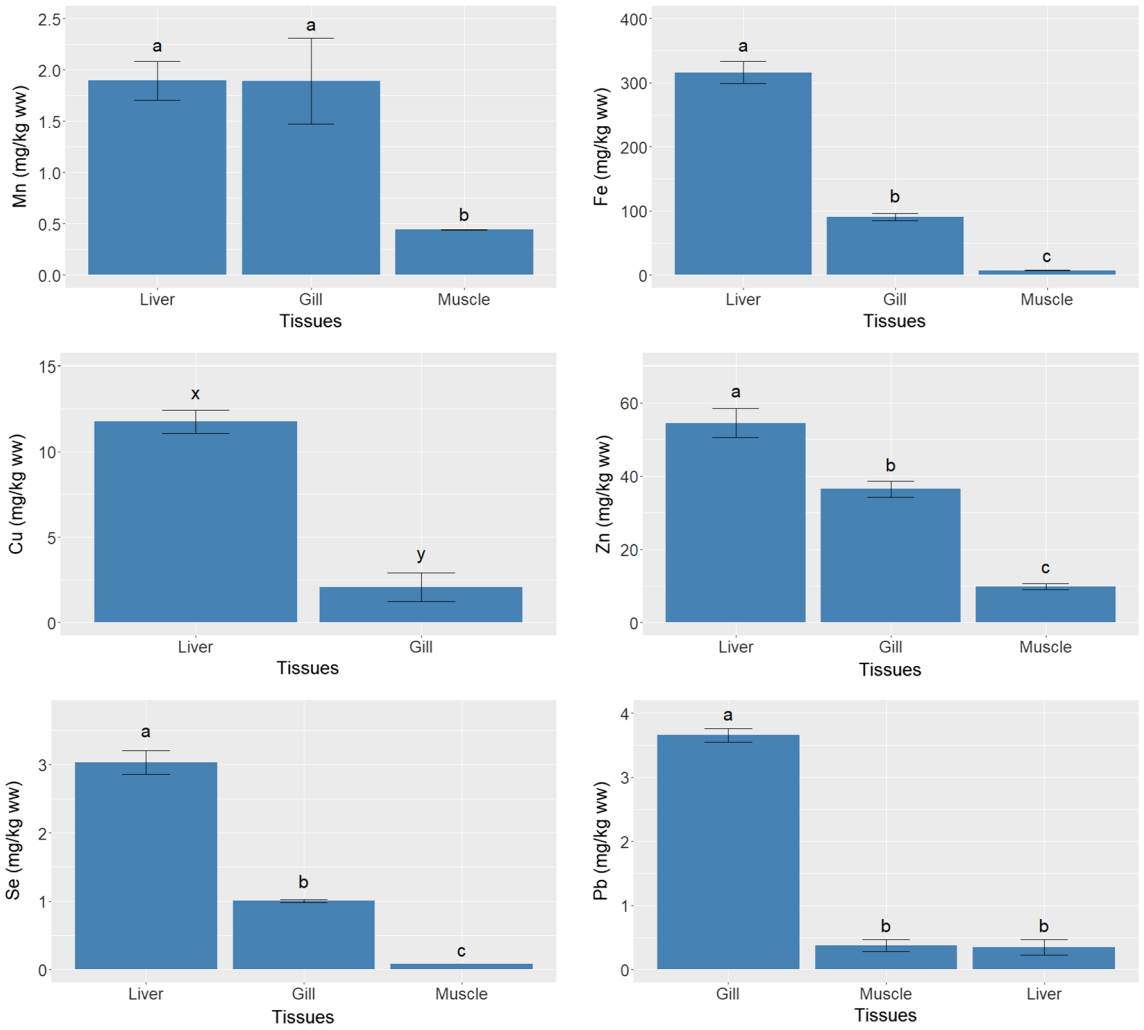

Fig. 3 Comparison of metal levels in different bluefish (*Pomatomus saltatrix*) tissues. Bars with different letters indicate a significant difference in the parameter among the tissues of that species ($P < 0.05$)

Table 4 Estimated weekly intakes (EWI) and estimated daily intakes (EDI) of the measured metals resulting from consumption of the muscle of bluefish from Iskenderun Bay, North-eastern Mediterranean

	PTWI* (mg/week/70 kg body wt)	PTDI* (mg/day/70 kg body wt)	EWI	EDI
Mn	68.6 (EPA, 2008)	9.8	0.052	0.007
Fe	392 (FAO/WHO, 2011)	56	0.848	0.121
Cu	245 (EC, 2006)	35	–	–
Zn	490 (EC, 2006)	70	1.173	0.167
Se	–	–	–	–
Cd	0.49 (WHO, 2000)	0.07	–	–
Pb	1.75 (WHO, 2000)	0.25	0.003	0.001
Hg	0.35 (EFSA, 2009)	0.05	–	–

PTWI provisional tolerable weekly intake; *PTDI* provisional tolerable daily intake; *EWI* estimated weekly intake; *EDI* estimated daily intake

*Internationally accepted safe levels for the studied metals

Conclusions

In addition to essential nutrients, fish can accumulate a significant amount of toxic or potentially hazardous chemicals such as heavy metals in their tissues. Therefore, fish is a food that requires appropriate precautions to avoid the potential risks arising from its consumption. Precautions should be followed particularly carefully in vulnerable populations, such as children and pregnant women. Iskenderun Bay is a significant fishing area, but at the same time, it is under the influence of industrial enterprises, such as iron and steel mills and agricultural activities. The development of technology and industry in this region in recent years requires monitoring of toxic mineral levels in marine organisms. In general, when the seasonal accumulation of the measured elements was evaluated in this study, no meaningful accumulation trend was detected in the muscles or gills, while the highest concentrations of Mn, Fe, Cu, Zn, and Se in the

liver were found in the spring season. It is possible that the transportation of metal-containing fungicides, pesticides, and fertilizers used for agricultural purposes in the region to the marine environment by heavy rains in winter may cause this spring maxima. The highest element concentrations detected throughout the study in the investigated bluefish tissues were Fe and Zn. Meanwhile, Hg and Cd were not detected in any season at the same bluefish tissues except for Cd in the gill in spring. When the investigated tissues were compared in terms of metal accumulation, it was observed in this study that liver tissues had higher metal concentrations than gill and muscle tissues. The data obtained from this study showed that there is an inflow of metals into Iskenderun Bay, but there was no significant accumulation in bluefish tissues that would pose a health risk. These results also underlined that careful monitoring studies should be carried out in order to ensure the safety of human consumption seafood. It should not be ignored that periodic or continuous data collection on the quality of seafood, water, and sediments is essential for stakeholders in various countries.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

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