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Research Article

Assessment of some heavy metal accumulation and potential health risk for three fish species from three consecutive bay in North-Eastern Mediterranean Sea

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ABSTRACT

Due to rapid urbanization and industrialization especially near water resources, heavy metal pollution in both water and inland environments have been studied all around the world. In this study, some selected heavy metals (Al, Sr, Cd, Co, Ni and, Pb) and fish species *(Mullus barbatus, Solea solea,* and *Siganus rivulatus)* from three Bays (İskenderun, Mersin, and Antalya from North-Eastern Mediterranean Sea) were used for heavy metal accumulation level evaluation and health risk assessment on both general and fish populations. A variety of accumulation patterns for considered metals were observed in tissues. Significant ($p<0.05$) inter- and intraspecies/tissues/bays differences were detected. The most stable tissue in terms of Al and Sr accumulation was determined as muscle. For Cd, Co and Ni accumulation the most stable tissue was found as liver. Lastly, for Ni accumulation skin was found to be the most stable tissue. The Target Hazard Quotients (THQ) and Total Target Hazard Quotients (TTHQ) values based on muscle were not exceeded 1.00. Therefore, these results suggest that both general and fish populations are not subjected to the significant potential health risk from those bays.

Keywords
Heavy metal accumulation
Fish
Human health
THQ
Mullus barbatus
Solea solea
Siganus rivulatus

Introduction

In the last century, due to the industrialization and urbanization in the world, aquatic environments have been seriously threatened by pollutants. Heavy metals are one of these anthropogenic pollutants and they are considered as dangerous for the aquatic environment because of their toxicity, high persistence, non- biodegradability, and tendency to accumulate in organisms (Çoğun et al., 2017). The accumulation rate and amount of heavy metals may vary depending on the fish species, quality of some environmental parameters, such as salinity, temperature, pH, hardness, heavy metal concentration, exposure period, sex and size of fish (Yılmaz et al., 2010). Thus, metal accumulation ratios in fish tissues may show fluctuations at different locations, even for the same fish species (Yılmaz, 2003).

Since fisheries products have many polyunsaturated fatty acids, liposoluble vitamins, minerals and essential proteins, they are important for human consumption in terms of nutritional value (Mohanty et al., 2019; Kılıç et al., 2019). For those reasons, there have been growing interest in "food safety" and keeping food quality at acceptable levels on aquatic products for human beings worldwide. The Target Hazard Quotients (THQ) and Total Target Hazard Quotients (TTHQ) values have been used for assessing potential health risks of individual and total effects of heavy metals, respectively. However, TTHQ has been expected to be much more reliably helpful to assess and compare their combined risks and therefore have been widely employed in recent literature (Yi et al., 2011; Korkmaz et al., 2017; Rajan and Ishak, 2017).

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İskenderun Bay, Mersin Bay, and Antalya Bay have rapid and intense urbanization, industrialization along with marine traffic issues, ship accidents (Can et al., 2020). All these have been resulting in the intensity of anthropogenic pollutants on these three bays from the North-Eastern Mediterranean. Red mullet *(Mullus barbatus)*, Common sole *(Solea solea)*, and Marbled spine foot (*Siganus rivulatus)* are fish species that exist in these three bays. While red mullet and common sole are sharing similar habitats in terms of depth, seabed and feeding types, marbled spine foot found on shore and feeds on algae. Therefore, in this study, accumulation rates of some selected heavy metals (Al, Sr, Cd, Co, Ni, and Pb) in the different tissues (muscle, liver, skin, and intestine) of Red mullet *(M. barbatus),* Common sole *(S. solea),* and Marbled spine foot *(S. rivulatus)* were determined and compared according to both inter- and intra-species/ tissues/bays.

Also, the accumulation stability of these metals in different tissues was examined. Target Hazard Quotients (THQ) and Total Target Hazard Quotients (TTHQ) values (both general and fish population) of these heavy metals accumulation in muscle tissue as the edible part of fish were assessed.

Material and Methods

Fish Species

Solea solea, Mullus barbatus, and *Siganus rivulatus* were studied. Fish species were confirmed according to Froese and Pauly (2020).

Common sole *(S. solea)* is demersal marine species living on sandy or muddy bottoms, ranging from nearshore to 200 m of depth. Adults feed mainly on polychaete worms, mollusks, and small crustaceans.

Red mullet *(M. barbatus)* is benthic species on muddy bottoms of the continental shelf between 5 and 300 m. They are also found on gravels and sandy bottoms and it feeds on benthic invertebrates (crustaceans, worms, mollusks).

Marbled spine foot *(S. rivulatus)* occurs in shallow waters over substrates clothed with algae, including rocky and sandy areas at depths of less than 15 m. They are herbivorous, feeding mainly on algae.

Studied Areas

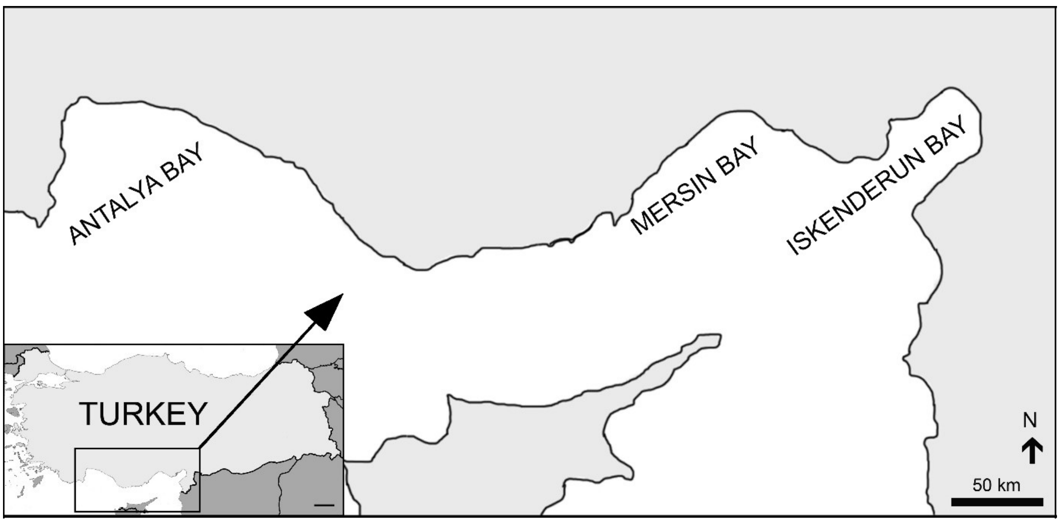
Fish samples were taken from local fishermen in the İskenderun, Mersin, and Antalya Bay, in April 2016. These three consecutive bays are located in the Northern East coast of the Mediterranean Sea (Figure 1). All bays have intensive marine traffic, tourism activities and shelf regions are surrounded by domestic areas. Moreover, many heavy industrial facilities have been established around İskenderun and Mersin bays which may cause an increase in heavy metal pollution risk for aquatic life. They interact with each other through current systems (Hamad et al., 2005).

Sampling, Preparation and Metal Analysis

Sampling

Fish samples (n=15 specimens for each species) were taken from local fishermen in İskenderun, Mersin, and Antalya Bays in April 2016 (Figure 1). The samples were brought to the laboratory on ice immediately and then frozen at -25°C until dissection. Total fish length and weight were measured to the nearest millimeter and gram before dissection. The mean length and weight of the *S. solea, M. barbatus,* and *S. rivulatus* were 25.22±2.20 cm and 135.90±43.11 g, 19.64±4.07 cm and 158.31±123.61 g and 17.29±2.08 cm and 108.34±72.52 g, respectively. The mean body length of each species from three bays were not significantly different (p>0.05).

Figure 1. Map of Studied Areas (İskenderun, Mersin, and Antalya Bay) from North Eastern Mediterranean Sea



Preparation

Fish samples were dissected to get tissue samples (epaxial muscle, intestine, skin, and liver). Studied tissue from each fish was transferred to a petri dish after being wet weighed and 2 mL nitric acid (HNO_3, 65%, S.W.: 1.40, Merck) and 1 mL perchloric acid ($HClO_4$, 60%, S.W.: 1.53, Merck) mixture were added in the sample which is located in the experimental tube. Then, tissue samples were wet digested on a hotplate at 120°C for 8 h. They were transferred to polyethylene tubes and volume were set up to 10 mL using deionized water. Samples were passed through a 0.45-µm membrane filter before analysis.

Analysis

All analyses were carried out in triplicate by using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Perkin Elmer Nexion 350 X). Blanks were carried out in the same manner as samples and concentrations were determined using standard solutions prepared in the same acid matrix. Calibration standarts were prepared from a multi-element ICP Standard (Merck). The quality of data was checked against the analysis of standard reference material DORM-2 (National Research Council of Canada; dogfish muscle and liver MA-A-2/TM Fish Flesh). The recovery values for Al, Sr, Cd, Co, Ni, and Pb were measured as 99.98, 93.25, 94.16, 96.57, 91.22 and 97.12%, respectively. Metal concentrations were calculated in micrograms per gram wet weight (µg metal g^{-1} w.wt.).

Target Hazard Quotients (THQ) and Total Target Hazard Quotients (TTHQ)

Estimated weekly intake (EWI) amount were calculated by multiplying the mean concentrations of each metal and the weight (g) of weekly consumed fish. In Turkey, the weekly fish consumption amount is 105.42 g (TUIK, 2018). The average weight of a person was considered as 72.8 kg (TUIK, 2016) and multiplied by provisional tolerable weekly intakes (PTWI) values, proposed for each element. Then the percent PTWI was calculated.

In order to evaluate the potential health risk of *S. solea, M. barbatus,* and *S. rivulatus* consumption, Target Hazard Quotients (THQ) which is indication of heavy metal exposure risk was calculated. THQ calculation formula is given below (Han et al., 1998; Chien et al., 2002; Storelli, 2008).

$$THQ = [(E_F x E_D x F_{IR} x C)/(R_{FD} x W_{AB} x T_A)]x10^{-3}$$

where, E_F is the exposure frequency: 365 days/year, E_D is the exposure duration: the average lifetime is assumed as 70 years according to (Bennett et al.,1999). F_{IR} is the food ingestion rate: 15.06 g/day for Turkish consumers, according to TUIK (2018). C is the determined metal concentration in muscle tissue (mg/kg).

R_{FD} is the oral reference dose (mg/kg/day): Al, Sr, Cd, Co, Ni, and Pb have been suggested as 1 (EFSA, 2008), 0.6 (US EPA, 2009), 0.0001 (ATSDR. (2012), 0.0003 (CDEP, 2008), 0.02 (US EPA, 2009) and 0.00357 (FAO/WHO, 2004) respectively.

W_{AB} is the average body weight: 72.8 kg, according to TUIK (2016). T_A is the average exposure time for non-carcinogens (365 days/year x E_D, assuming 70 years in this study). In this study, the total THQ (TTHQ) is treated as the arithmetic sum of the individual metal THQ values (Yi et al., 2011):

TTHQ= THQ (toxicant 1) + THQ (toxicant 2)+ ……. + THQ (toxicant n)

THQ and TTHQ values were estimated for the general population (THQ_{gp}) and fishermen (THQ_f) separately to compare the risk of heavy metals from different consumers. In this study, FIR was assumed for Turkish fishermen to be two times higher than the general population as 30.12 g/day. The THQ and TTHQ ≥ 1.0 refers to people may experience significant health risk from the intake of individual metals through fish consumption (Yi et al., 2011).

Statistical analyses

All data were checked for outliers and then descriptive statistics and Box-Whisker plots were calculated and drawn, respectively. Both inter- and intra-species/ tissues/bays differences were assessed using by one-way PERMANOVA (Permutational multivariate analysis of variance) test.

The stability (variability) of heavy metal accumulation in different tissues was evaluated by coefficient of variation (Cv, %), i.e. high variability indicates low stability and low variability indicates high stability. All computations and statistical analyses were carried out using Microsoft Excel and Past software (V. 3.23) (Hammer et al., 2001).

Results and Discussion

Heavy metals were widely studied polluters in marine ecosystems. Some of them (iron, chromium, manganese, cobalt, selenium) are essential in trace amounts for aquatic life; while others were harmful to aquatic life (Kalay and Canlı, 2000). Results of essential metal accumulation of *S. solea, M. barbatus, and S. rivulatus* can be found at Can et al. (2020).

It is well known that cadmium and lead are harmful metals for any biological process. Although aluminum, cobalt, nickel are considered as non-essential, these are playing important role in bioactivities at trace amounts. Sr mainly accumulates in bony tissues of fish and results in the development of scoliosis and osteoporosis. At high concentrations, Sr also is accumulated in soft tissues (Neff, 2002).

The mean values (µg g^{-1} w.wt.) with standard deviation (x̄±sd) and coefficient of variation (Cv, %) of measured heavy metals (Al, Sr, Cd, Co, Ni, and Pb) in the tissues muscle (M), intestine (I), skin (S), and liver (L) of *S. solea, M. barbatus, and S. rivulatus* by studied locations are given in Table 1-6 and Table 7, respectively. Also, mean and standard deviations of heavy metal concentration in muscle tissues of studied species and the estimated Target Hazard Quotients (THQ) in Table 8, respectively.

Aluminum (Al)

Aluminum, one of the most abundant metal in the Earth (7.5-8.1%), has very active ion (Al^{3+}) and bonds covalently with some compounds. Although it is not classified as heavy metal, it has toxic effects. Al toxicity and bioavailability to aquatic biota largely depends on its solubility and represents inverse relationship. Aluminum toxicity is reported to be among the factors lead to Alzheimer's disease, dementia, and Parkinson's disease (Chin-Chan et al., 2015).

There were no significant differences detected among the tissues for three species in each bays, except S. rivulatus (skin and muscle, $p<0.05$) from Antalya Bay (Table 1, denoted as A, B, C). Mean Al concentrations in the tissues of *S. solea* had same pattern for three bays as I> S> L> M. Al concentration for *M. barbatus* was ranked as I> L> S> M for İskenderun, Mersin Bays and I> S> L> M for Antalya Bay. Mean Al level ranking of *S. rivulatus* for İskenderun Bay was ordered as I> S> L> M; on the other hand, the ranking for Mersin and Antalya Bays were as I> M> S> L and S> I> L> M, respectively.

The mean Al concentrations in the muscle tissue of *S. solea* among the three locations were not significantly different ($p>0.05$), but a significant difference was found in the muscle of *M. barbatus*

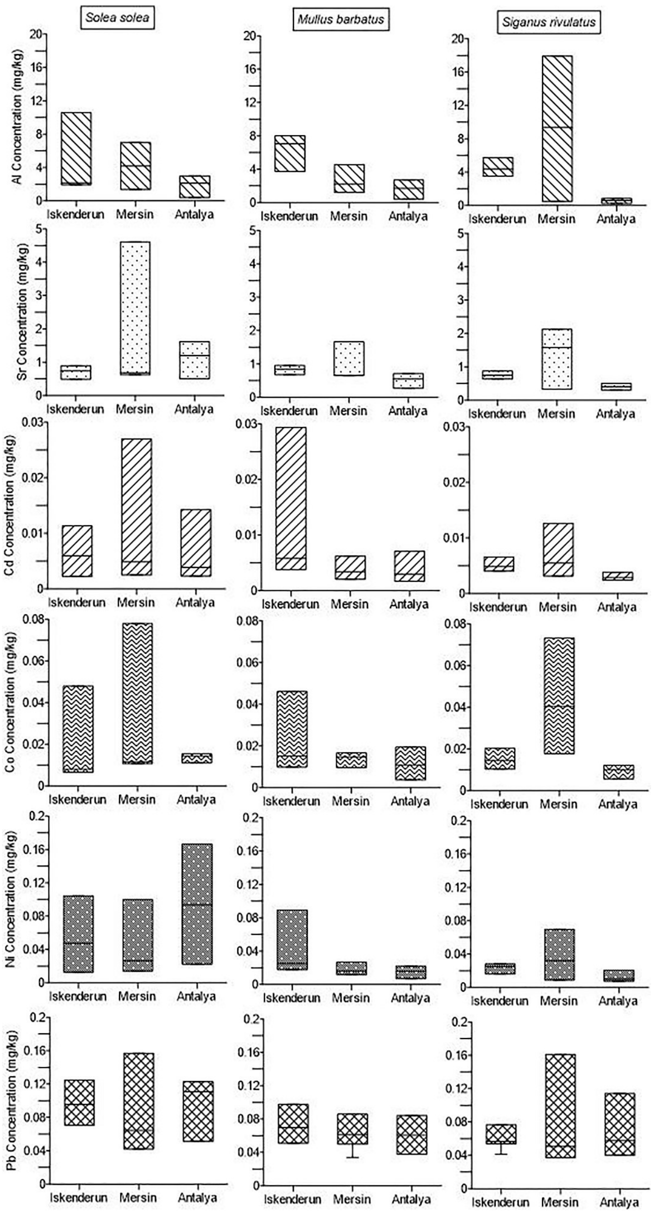


Figure 2. Box and whisker plots indicating heavy metal concentration in muscle tissues of *Solea solea, Mullus barbatus, Siganus rivulatus*

and *S. rivulatus* among locations ($p<0.05$, Table 1 denoted as x, y). There were no significant differences among the same tissues of different species at the same locations of all samples ($p>0.05$, Table 1, denoted as a).

The highest mean Al accumulation in muscle tissues was observed in *S. rivulatus* at Mersin Bay (7.62 ±9.40 µg g^{-1} w.wt. Figure 2a). Also, in general, Al accumulation stability was somehow higher in muscle than that of the other tissues for all species and bays (Table 7).

Table 1. Mean Al concentration (μg metal g^{-1} wet weight [w.wt.]) with standard deviation in the tissues of *Solea solea, Mullus barbatus, Siganus rivulatus* with respect to studied locations

	Location		Intestine	Skin	Liver	Muscle
S. solea	İskenderun	x̄	$49.57^{A;a;x}$	$15.28^{A;a;x}$	$5.55^{A;a;x}$	$7.49^{A;a;x}$
		±s	40.20	9.82	3.55	8.15
	Mersin	x̄	$34.14^{A;a;x}$	$5.34^{A;a;x}$	$4.49^{A;a;x}$	$3.61^{A;a;x}$
		±s	28.20	3.62	6.68	2.58
	Antalya	x̄	$5.32^{A;a;x}$	$3.79^{A;a;x}$	$3.83^{A;a;x}$	$1.83^{A;a;x}$
		±s	2.16	3.03	3.22	1.34
M. barbatus	İskenderun	x̄	$91.65^{A;a;x}$	$13.32^{A;a;x}$	$25.89^{A;a;x}$	$6.46^{A;a;y}$
		±s	88.47	7.26	11.68	1.99
	Mersin	x̄	$19.75^{A,a,x}$	$4.11^{A;a;x}$	$9.56^{A;a;x}$	$2.38^{A;a;x}$
		±s	9.16	3.12	9.39	1.29
	Antalya	x̄	$125.90^{A;a;x}$	$15.81^{A;a;x}$	$3.99^{A,a,x}$	$1.63^{A,a,x}$
		±s	70.21	15.56	4.01	1.14
S. rivulatus	İskenderun	x̄	$28.31^{A;a;x}$	$27.80^{A;a;y}$	$4.73^{A;a;y}$	$4.50^{A;a;y}$
		±s	13.91	14.99	1.01	1.08
	Mersin	x̄	$29.06^{A;a;x}$	$6.33^{A;a;xy}$	$2.54^{A;a;xy}$	$7.62^{A;a;xy}$
		±s	39.40	6.91	1.53	9.40
	Antalya	x̄	$2.04^{A;a;x}$	$2.46^{AB;a;x}$	$1.91^{AB;a;x}$	$0.56^{B;a;x}$
		±s	0.39	2.25	1.31	0.27

A,B,C denotes differences among tissues in the same species at the same location
a,b,c denotes differences among same tissues of different species at same locations
x,y,z denotes differences among locations in the same tissues of same species

The range of mean Al accumulation in muscle tissues of *M. barbatus* (1.63-6.46) in our study was higher than that of previous studies (0.45-1.68). No data was available for the Al accumulation in *S. rivulatus* (0.56-7.62) and *S. solea* (1.83- 7.49) on the same species in same bays (Table 1, Table 9). But, Yılmaz et al., (2010) reported the Al accumulation in the muscle tissue of *T. lucerna, L. budegassa* and *S. lascaris* from İskenderun Bay with the range of 2.23 to 4.93 μg g^{-1} w.wt.

Strontium (Sr)

Strontium is involved in bone and cartilage metabolic processes in combination with calcium. Strontium is rarely distributed in the environment, thus, limited number of studies conducted about its accumulation on the aquatic organisms (Carvalho et al., 2005; Yılmaz et al., 2018).

The following differences were detected among tissues (Table 2, denoted as A, B, C); *S. solea* (skin and liver from Mersin) and *S. rivulatus* (skin, liver, and muscle from İskenderun and Mersin). With regard to the results given in Table 2, the patterns of Sr occurrence in the selected tissues can be listed as follows in descending order: *S. solea* (İskenderun), *M. barbatus* (İskenderun and Antalya Bays); I> S> L> M and for *S. rivulatus* (İskenderun and Antalya Bays); S> I> L> M.

The mean Sr concentrations in the muscle tissue of *S. solea* and *M. barbatus* among the three locations were not significantly different (p>0.05), except for *S. rivulatus* from İskenderun and Mersin Bays (p< 0.05, Table 2; denoted as x, y, z). There were no significant differences among the same tissues of different species at the same locations of all samples (p>0.05, Table 2; denoted as a).

Strontium levels (μg g^{-1} w.wt.) of muscle ranged from 0.74 to 2.25 for *S. solea*, 0.51 to 0.90 for *M. barbatus* and 0.40 to 1.23 for *S. rivulatus* from bays (Figure 2b).

There has been no research conducted on the Sr accumulation in the studied fishes from three bays, except the current one. The maximum variability in Sr accumulation was detected in the intestine, the minimum variability was detected in the muscle. These results show that in terms of Sr accumulation stability in tissues, the muscle was much more stable than other tissues (Table 7).

Table 2. Mean Sr concentration (µg metal g^{-1} wet weight [w.wt.]) with standard deviation in the tissues of *Solea solea, Mullus barbatus,* and *Siganus rivulatus* with respect to studied locations.

	Location		Intestine	Skin	Liver	Muscle
S. solea	İskenderun	x̄	$9.92^{A;a;x}$	$8.59^{A;a;x}$	$1.54^{A;a;x}$	$0.74^{A;a;x}$
		±s	6.84	4.41	0.66	0.18
	Mersin	x̄	$10.32^{A;a;x}$	$91.6^{AB;b;x}$	$0.96^{AC;a;x}$	$2.25^{A;a;x}$
		±s	5.54	3.44	0.33	1.95
	Antalya	x̄	$1.32^{A;a;x}$	$13.76^{A;a;x}$	$2.72^{A;a;x}$	$1.11^{A;a;x}$
		±s	0.82	10.45	2.20	0.57
M. barbatus	İskenderun	x̄	$13.19^{A;a;x}$	$9.38^{A;a;x}$	$3.14^{A;a;x}$	$0.88^{A;a;x}$
		±s	10.87	15.49	0.95	0.17
	Mersin	x̄	$3.69^{A;a;x}$	$0.76^{A;a;x}$	$0.84^{A;a;x}$	$0.90^{A;a;x}$
		±s	2.64	0.60	0.51	0.47
	Antalya	x̄	$14.44^{A;a;x}$	$3.34^{A;a;x}$	$1.25^{A;a;x}$	$0.51^{A;a;x}$
		±s	7.12	1.91	0.26	0.22
S. rivulatus	İskenderun	x̄	$11.97^{A;a;x}$	$14.51^{AB;a;y}$	$0.88^{AC;a;x}$	$0.72^{AC;a;y}$
		±s	10.84	3.82	0.23	0.11
	Mersin	x̄	$11.22^{A;a;x}$	$7.75^{AB;b;x}$	$0.84^{AC;a;x}$	$1.23^{AC;a;y}$
		±s	16.16	3.26	0.40	0.81
	Antalya	x̄	$1.46^{A;a;x}$	$5.68^{A;a;x}$	$1.01^{A;a;x}$	$0.40^{A;a;x}$
		±s	0.84	1.64	0.68	0.09

A,B,C denotes differences among tissues in the same species at the same location
a,b,c denotes differences among same tissues of different species at same locations
x,y,z denotes differences among locations in the same tissues of same species

For *L. budegassa* and *S. lascaris* from İskenderun Bay, significant differences in Sr concentrations in the liver were observed; however, there was no such difference in skin and muscle of the same species. Also in the same study, Sr levels ranged from 0.78 µg g^{-1} w.wt. in *L. budegassa* to 1.58 (µg g^{-1} w.wt. in *S. lascaris* for muscles, and from 2.03 in *L. budegassa* to 2.46 µg g^{-1} w.wt. in *S. lascaris* for livers (Yılmaz et al., 2010).

Carvalho et al. (2005) found that Sr concentrations were significantly different between demersal and pelagic species, tend to higher concentration for demersal species. Our results on muscle were consistent with that pattern (Figure 2b).

Cadmium (Cd)

Cadmium and its chloride and sulfate salts are freely soluble and all of them are poisonous for living organisms and it may cause enzyme inhibition in high concentrations. It could be taken up through Ca channels in the gills of fish and mollusks (Galvez et al., 2006) and also could get from food (McRae et al., 2018).

Mean cadmium concentrations of fish tissues from three bay are shown in Table 3 (µg g^{-1} w.wt.). No significantly differences were detected among the tissues of each location for *S. solea* (Table 3, denoted as A, B, C) and the accumulation rate in the tissues of *S. solea* was the same for all stations and ranked as L > I > S > M. Except İskenderun Bay ($p<0.05$, denoted as A, B, C), there was no differences among the tissues of *M. barbatus* and Cd concentration was ranked as L> I > S > M for three Bays. Some differences were observed among tissues of *S. rivulatus* from Mersin and Antalya Bays (Table 3, denoted as A, B, C) and it was ranked as L > I> S > M except Antalya Bay where it follows I > L > S > M.

The mean Cd concentrations in the muscle tissue of *S. solea* and *M. barbatus* among the three locations were not significantly different ($p>0.05$), except for *S. rivulatus* from İskenderun Bay ($p< 0.05$, Table 3; denoted as x, y).

There were no significant differences among same tissues of different species at same locations of all samples ($p>0.05$, Table 3; denoted as a), except in the liver tissue of *S. solea* and *S. rivulatus* from İskenderun Bay ($p<0.05$, Table 3; denoted as b).

Maximum Cd concentrations in the muscle tissue (µg g^{-1} w.wt.) of *S. solea, M. barbatus,* and *S. rivulatus* were found as 0.01, 0.03 and, 0.01 (İskenderun Bay), 0.03, 0.01 and, 0.01 (Mersin Bay) and 0.01, 0.01 and, 0.003 (Antalya Bay), respectively (Figure 2c).

Table 3. Mean Cd concentration (µg metal g^{-1} wet weight [w.wt.]) with standard deviation in the tissues of *Solea solea, Mullus barbatus, Siganus rivulatus* with respect to studied locations

	Location		Intestine	Skin	Liver	Muscle
S. solea	İskenderun	x̄	$0.01^{A;a;x}$	$0.008^{A;a;x}$	$0.04^{A;b;x}$	$0.004^{A;a;x}$
		±s	0.00	0.01	0.03	0.01
	Mersin	x̄	$0.01^{A;a;x}$	$0.04^{A;a;x}$	$0.02^{A;a;x}$	$0.01^{A;a;x}$
		±s	0.00	0.01	0.03	0.01
	Antalya	x̄	$0.02^{A;a;x}$	$0.02^{A;a;x}$	$0.06^{A;ab;x}$	$0.002^{A;a;x}$
		±s	0.02	0.02	0.05	0.01
M. barbatus	İskenderun	x̄	$0.20^{A;a;x}$	$0.007^{AB;a;x}$	$0.11^{AC;a;x}$	$0.01^{AB;a;x}$
		±s	0.12	0.01	0.01	0.01
	Mersin	x̄	$0.03^{A;a;x}$	$0.004^{A;a;x}$	$0.004^{A;a;y}$	$0.002^{A;a;x}$
		±s	0.03	0.01	0.03	0.00
	Antalya	x̄	$0.08^{A;a;x}$	$0.01^{A;a;x}$	$0.16^{A;a;z}$	$0.003^{A;a;x}$
		±s	0.10	0.01	0.01	0.01
S. rivulatus	İskenderun	x̄	$0.02^{A;a;x}$	$0.02^{A;a;x}$	$0.04^{A;b;y}$	$0.004^{A;a;x}$
		±s	0.01	0.01	0.03	0.01
	Mersin	x̄	$0.06^{A;a;x}$	$0.004^{AB;a;x}$	$0.10^{AC;a;xy}$	$0.004^{AB;a;x}$
		±s	0.06	0.01	0.04	0.01
	Antalya	x̄	$0.12^{A;a;x}$	$0.004^{AB;a;x}$	$0.01^{AC;a;x}$	$0.003^{A;a;x}$
		±s	0.03	0.01	0.03	0.001

A,B,C denotes differences among tissues in the same species at the same location
a,b,c denotes differences among same tissues of different species at same locations
x,y,z denotes differences among locations in the same tissues of same species

Table 4. Mean Co concentration (µg metal g^{-1} wet weight [w.wt.]) with standard deviation in the tissues of *Solea solea, Mullus barbatus, Siganus rivulatus* with respect to studied locations.

	Location		Intestine	Skin	Liver	Muscle
S. solea	İskenderun	x̄	$0.17^{A;a;x}$	$0.03^{A;a;x}$	$0.033^{A;a;x}$	$0.02^{A;a;x}$
		±s	0.19	0.01	0.02	0.02
	Mersin	x̄	$0.08^{A;a;x}$	$0.02^{A;a;x}$	$0.09^{A;a;x}$	$0.03^{A;a;x}$
		±s	0.06	0.01	0.12	0.04
	Antalya	x̄	$0.08^{A;a;x}$	$0.13^{A;a;x}$	$0.08^{A;b;x}$	$0.01^{A;a;x}$
		±s	0.08	0.15	0.08	0.01
M. barbatus	İskenderun	x̄	$0.31^{A;a;x}$	$0.03^{A;a;x}$	$0.11^{A;a;x}$	$0.02^{A;a;x}$
		±s	0.30	0.02	0.07	0.02
	Mersin	x̄	$0.07^{A;a;x}$	$0.02^{B;a;x}$	$0.10^{AB;a;y}$	$0.01^{B;a;x}$
		±s	0.03	0.01	0.04	0.01
	Antalya	x̄	$0.15^{A;a;x}$	$0.05^{AB;a;x}$	$0.33^{AC;a;x}$	$0.01^{AB;a;x}$
		±s	0.05	0.03	0.01	0.01
S. rivulatus	İskenderun	x̄	$0.18^{A;a;x}$	$0.09^{A;b;y}$	$0.13^{A;ac;xy}$	$0.01^{B;a;x}$
		±s	0.12	0.03	0.06	0.01
	Mersin	x̄	$0.32^{A;a;x}$	$0.07^{AB;a;xy}$	$0.23^{AC;ac;x}$	$0.04^{AB;a;x}$
		±s	0.37	0.04	0.08	0.02
	Antalya	x̄	$0.08^{A;a;x}$	$0.02^{A;a;x}$	$0.04^{A;a;x}$	$0.01^{A;a;x}$
		±s	0.06	0.01	0.03	0.00

A,B,C denotes differences among tissues in the same species at the same location
a,b,c denotes differences among same tissues of different species at same locations
x,y,z denotes differences among locations in the same tissues of same species

The maximum variability in Cd accumulation was detected in the muscle, the minimum variability was detected in the liver (Table 7). These results show that in terms of Cd accumulation stability in tissues, the liver was much more stable than other tissues.

The mean Cd concentrations in the muscle tissues of (µg metal g^{-1} w.wt.) *S. solea* (0.004-0.01), M. barbatus (0.003-0.01) and *S. rivulatus* (0.003-0.004) were very lower than previous studies from same bays as 0.11-0.38, 0.01-2.04 and, 0.06-0.24, respectively (Table 3, Table 9).

Cobalt (Co)

Although cobalt is interpreted as a non-essential metal, it is essential in very small amounts for all living organisms. Co is the active center of coenzymes called cobalamins which is found in vitamin B12 and it has a role in blood pressure regulation and thyroid function. Its inorganic form is also a micronutrient for bacteria, algae, and fungi (Lison, 2015).

There were no significant difference (p>0.05) detected among the tissues of *S. solea* in all locations. But the differences were detected for *M. barbatus* (Mersin and Antalya Bays) and *S. rivulatus* (İskenderun and Mersin Bays), (Table 4, denoted as A, B, C). Mean Co concentrations in the tissues of *M. barbatus* and *S. rivulatus* had the same pattern for three bays as I> L> S> M. But there was no regular pattern observed for *S. solea* from three bays (Table 4). The mean Co concentrations in the muscle tissue of *S. solea* and *M. barbatus* among the three locations were not significantly different (p>0.05, Table 4 denoted as x). But a significant difference was found in the muscle of *S. rivulatus* among locations (p<0.05, Table 4 denoted as x, y). There were no significant difference detected among muscle tissues of different species at the same locations of all samples, except *S. rivulatus* (İskenderun and Mersin Bays: skin and liver, p>0.05, Table 4; denoted as a, b, c).

Maximum Co concentrations in the muscle tissue (µg g^{-1} w.wt.) of *S. solea, M. barbatus,* and *S. rivulatus* were found as 0.05, 0.05 and, 0.02 in İskenderun Bay, 0.08, 0.02 and, 0.07 in Mersin Bay and 0.02, 0.02 and, 0.01 in Antalya Bay, respectively (Figure 2d).

The maximum variability in Co accumulation was detected in the intestine and the minimum variability was detected in the liver. These results show that in terms of Co accumulation stability in tissues, the liver was much more stable than other tissues (Table 7).

The mean Co concentrations in the muscle tissues of (µg metal g^{-1} w.wt.) *S. solea* (0.01- 0.03), *M. barbatus* (0.01-0.02) and *S. rivulatus* (0.01-0.04) (Table 4) were found remarkable smaller than previous studies from same bays as 0.17-0.43, 0.02-0.44 and, 0.08-0.39 respectively (Table 9).

Nickel (Ni)

Nickel and certain nickel compounds, which are essential for human beings, are listed as carcinogens (ATSDR, 2011). Nickel is rarely found in fish, plants, and animals and its accumulation in aquatic life is very rare (Yılmaz et al., 2018).

There were no significant differences among the tissues for *S. solea* in each location. The accumulation rate in the tissues of *S. solea* had different patterns and muscle showed the lowest rate in all locations. (Table 5, denoted as A, B, C). Except for Antalya Bay (p<0.05, denoted as A, B, C), there were no difference detected among the tissues of *M. barbatus*. Ni concentration was ranked as I > S > L> M for Mersin and Antalya Bays, I > L > S > M for İskenderun Bay. Significant differences were not detected among the tissues of *S. rivulatus* for each bays (p >0.05, Table 5; denoted as A, B, C) and it was ranked as I > S > L > M except from Antalya Bay where it followed S > I > L > M pattern (Table 5). The mean Ni concentrations in the muscle tissue of S. solea and *M. barbatus* among the three locations were not significantly different (p>0.05, Table 5 denoted as x). But a significant difference was found in the muscle of *S. rivulatus* among locations (p<0.05, Table 5 denoted as x, y). There were no significant differences among the same tissues of different species at the same locations of all samples (p>0.05, Table 5 denoted as a).

The maximum variability in Ni accumulation was detected in the intestine, the minimum variability was detected in the skin. These results show that in terms of Ni accumulation stability in tissues, the skin was much more stable than other tissues (Table 7).

Ni concentrations in the muscle tissue (µg g^{-1} w.wt.) of *S. solea, M. barbatus* and *S. rivulatus* were varied from 0.01-0.10, 0.02-0.09, 0.02-0.03 in İskenderun Bay; 0.01-0.10, 0.01-0.06, 0.01-0.07 in Mersin Bay; and 0.02-0.17, 0.01-0.02, 0.01-0.02 in Antalya Bay, respectively (Figure 2e).

The range of mean Ni accumulation in muscle tissues of *S. solea*, (0.04-0.05), *M. barbatus*

Table 5. Mean Ni concentration (µg metal g^{-1} wet weight [w.wt.]) with standard deviation in the tissues of *Solea solea, Mullus barbatus, Siganus rivulatus* with respect to studied locations.

	Location		Intestine	Skin	Liver	Muscle
S. solea	İskenderun	x̄	$0.19^{A;a;x}$	$0.07^{A;a;x}$	$0.05^{A;a;x}$	$0.05^{A;a;x}$
		±s	0.15	0.03	0.02	0.04
	Mersin	x̄	$0.10^{A;a;x}$	$0.04^{A;a;x}$	$0.09^{A;a;x}$	$0.04^{A;a;x}$
		±s	0.08	0.01	0.12	0.04
	Antalya	x̄	$0.08^{A;a;x}$	$0.21^{A;a;x}$	$0.09^{A;b;x}$	$0.04^{A;a;x}$
		±s	0.09	0.13	0.10	0.08
M. barbatus	İskenderun	x̄	$0.35^{A;;xy}$	$0.06^{A;a;x}$	$0.09^{A;a;x}$	$0.04^{A;a;x}$
		±s	0.30	0.04	0.01	0.03
	Mersin	x̄	$0.06^{A;a;y}$	$0.05^{A;a;x}$	$0.03^{A;a;y}$	$0.03^{A;a;x}$
		±s	0.03	0.05	0.02	0.02
	Antalya	x̄	$0.38^{A;a;x}$	$0.10^{B;a;x}$	$0.03^{BC;a;x}$	$0.02^{C;a;x}$
		±s	0.40	0.04	0.01	0.006
S. rivulatus	İskenderun	x̄	$0.25^{A;a;x}$	$0.15^{A;a;x}$	$0.03^{A;a;x}$	$0.02^{A;a;y}$
		±s	0.23	0.08	0.01	0.005
	Mersin	x̄	$0.18^{A;a;x}$	$0.04^{A;a;x}$	$0.03^{A;a;x}$	$0.03^{A;a;xy}$
		±s	0.25	0.02	0.008	0.02
	Antalya	x̄	$0.04^{A;b;x}$	$0.08^{A;a;x}$	$0.02^{A;a;x}$	$0.01^{A;a;x}$
		±s	0.03	0.09	0.008	0.005

A,B,C denotes differences among tissues in the same species at the same location
a,b,c denotes differences among same tissues of different species at same locations
x,y,z denotes differences among locations in the same tissues of same species

Table 6. Mean Pb concentration (µg metal g-1 wet weight [w.wt.]) with standard deviation in the tissues of Solea solea, Mullus barbatus, Siganus rivulatus with respect to studied locations

	Location		Intestine	Skin	Liver	Muscle
S. solea	İskenderun	x̄	$0.21^{A;a;x}$	$0.18^{A;ab;x}$	$0.22^{A;a;x}$	$0.10^{A;a;x}$
		±s	0.10	0.06	0.09	0.02
	Mersin	x̄	$0.01^{A;a;x}$	$0.24^{A;a;x}$	$0.05^{A;a;x}$	$0.08^{A;a;x}$
		±s	0.10	0.34	0.04	0.05
	Antalya	x̄	$0.10^{A;a;x}$	$0.63^{A;a;x}$	$0.37^{A;a;x}$	$0.09^{A;a;x}$
		±s	0.06	0.88	0.48	0.03
M. barbatus	İskenderun	x̄	$0.47^{A;a;x}$	$0.21^{A;a;x}$	$0.49^{A;a;x}$	$0.24^{A;a;x}$
		±s	0.23	0.22	0.40	0.38
	Mersin	x̄	$0.43^{A;a;x}$	$0.20^{A;a;x}$	$0.47^{A;a;x}$	$0.06^{A;a;x}$
		±s	0.59	0.29	0.50	0.02
	Antalya	x̄	$0.35^{A;a;x}$	$0.29^{A;a;x}$	$0.20^{A;a;x}$	$0.06^{A;a;x}$
		±s	0.13	0.17	0.04	0.02
S. rivulatus	İskenderun	x̄	$0.33^{A;a;x}$	$0.37^{AB;ac;x}$	$0.15^{A;a;x}$	$0.06^{AC;a;x}$
		±s	0.15	0.11	0.07	0.01
	Mersin	x̄	$2.03^{A;a;x}$	$0.34^{A;a;y}$	$0.52^{A;a;x}$	$0.23^{AB;a;x}$
		±s	2.62	0.09	0.36	0.35
	Antalya	x̄	$0.56^{A;a;x}$	$0.17^{A;a;x}$	$0.27^{A;a;x}$	$0.06^{A;a;x}$
		±s	0.55	0.07	0.12	0.03

A,B,C denotes differences among tissues in the same species at the same location
a,b,c denotes differences among same tissues of different species at same locations
x,y,z denotes differences among locations in the same tissues of same species

(0.006-0.03), and *S. rivulatus* (0.005-0.02) in our study (Table 5) were lower than that of previous studies (0.14-3.27), (0.13-4.22), and (0.69-3.43), respectively (Table 9).

Lead (Pb)

The inorganic lead salts are considered to be moderately toxic to marine organisms because of their low solubility. Lead binds to enzymes and hormones in live cells, it can cause in fish to deficit or decrease in survival, growth, development, and metabolism, to increase mucus formation (Burger et al., 2002).

There were no significant differences (p>0.05) among the tissues for studied fish in each location, except *S. rivulatus* from İskenderun and Mersin Bays and no regular pattern on accumulation rates was observed in among studied tissues. (Table 6, denoted as A, B, C). The mean Pb concentrations among the muscle tissue of all species from three bays were not significantly different (p>0.05, Table 6; denoted as x). Also, there were no significant differences among muscle tissues of different species at the same locations of all samples (p>0.05, Table 6; denoted as a).

Maximum Pb concentrations in the muscle tissue (µg g-1 w.wt.) of *S. solea, M. barbatus,* and *S. rivulatus* were found as 0.12, 0.91 and, 0.08 in İskenderun Bay, 0.16, 0.09 and, 0.84 in Mersin Bay and 0.12, 0.08 and, 0.11 in Antalya Bay, respectively (Figure 2f).

The maximum variability in Pb accumulation was detected in the intestine, the minimum variability was detected in the liver. These results show that in terms of Pb accumulation stability in tissues, the liver was much more stable than other tissues (Table 7).

The range of mean Pb accumulation in muscle tissues of *S. solea* (0.08-0.10) and *M. barbatus* (0.006-0.24) (Table 6) were smaller than of previous studies (0.037-1.31) and (0.03-5.94), respectively (Table 9). There was no conducted study on Pb accumulation for *S. rivulatus* in the same bays.

THQ and TTHQ

The highest levels of THQ_{gp} and THQ_f for *S. solea, M. barbatus* and *S. rivulatus* in İskenderun, Mersin and Antalya Bays were determined for Al (Table 8). The $TTHQ_{gp}$ and $TTHQ_f$ for *S. solea, M. barbatus* and *S. rivulatus* in İskenderun, Mersin, and Antalya Bays were calculated as (0.257 and 0.514), (0.479 and 0.958), and (0.149 and 0.298); (0.178 and 0.356), (0.103 and 0.206), (0.153 and 0.306); (0.028 and 0.056), (0.655 and 1.310), and (0.013 and 0.026), respectively. Among these values, only TTHQ for fishermen (1.310) is exceeded the value of 1 (reference value). But it does not mean that fishermen are under the risk.

Table 7. Coefficient of variation (%CV) of heavy metals in the tissues of *Solea solea, Mullus barbatus, Siganus rivulatus* with respect to studied locations.

Station	Species	Metal	Muscle	Intes-tine	Skin	Liver	Metal	Muscle	Intes-tine	Skin	Liver	Metal	Muscle	Intes-tine	Skin	Liver
iskenderun	*S. solea*	Al	108.86	81.08	64.23	63.91	Ni	82.54	78.33	34.48	36.51	Pb	21.91	48.72	34.23	42.20
Mersin			71.56	82.61	67.87	148.74		94.85	80.92	31.67	146.78		65.92	72.60	137.29	75.77
Antalya			73.08	40.53	79.94	84.13		85.29	116.81	63.78	110.16		40.56	56.97	140.55	129.99
iskenderun	*M. barbatus*		30.85	96.52	54.52	45.11		84.71	85.58	62.36	15.71		156.26	49.19	105.04	83.10
Mersin			54.20	46.36	75.78	98.21		79.75	47.84	117.67	85.92		104.55	136.07	144.17	104.55
Antalya			69.75	55.76	98.40	100.35		28.57	105.06	39.46	47.14		38.49	35.94	59.43	21.21
iskenderun	*S. rivulatus*		24.05	49.14	53.91	21.36		22.82	90.74	56.17	33.33		25.57	45.43	30.07	46.42
Mersin			123.24	135.61	109.10	60.32		84.98	135.22	57.60	29.88		151.59	129.07	27.19	69.04
Antalya			48.68	19.01	90.97	68.20		40.00	75.90	113.73	46.48		47.83	96.45	42.82	44.83
iskenderun	*S. solea*	Co	81.22	111.15	34.81	52.54	Cd	136.93	-	104.58	61.88	Sr	23.88	68.95	51.39	42.74
Mersin			127.27	67.39	60.85	139.77		141.42	-	136.93	111.11		86.62	53.72	37.51	34.67
Antalya			43.30	100.51	117.83	100.51		200.00	66.66	158.69	6.73		51.12	61.82	75.94	81.06
iskenderun	*M. barbatus*		86.60	95.94	52.54	64.28		122.47	61.51	66.66	6.73		18.90	82.41	165.16	30.17
Mersin			39.12	38.06	46.48	36.51		223.60	94.28	136.93	61.88		52.53	71.62	79.52	60.88
Antalya			81.64	32.17	63.19	4.28		200.00	125.41	91.28	4.56		43.66	49.28	57.15	21.01
iskenderun	*S. rivulatus*		39.12	69.05	32.96	42.31		136.93	46.48	55.90	69.72		15.15	90.56	26.34	25.96
Mersin			57.05	115.78	47.39	35.83		136.93	106.71	223.60	45.50		66.13	144.04	41.98	47.81
Antalya				86.06	50.00	57.04			23.00	136.93	30.01			57.25	28.87	66.77

Table 8. The estimated weekly intakes (EWI), established provisional tolerable weekly intake (PTWI) and percent PTWI (%) of the muscle tissue of *S. solea, M. barbatus* and *S. rivulatus* from three bays of Northern East Mediterranean Sea consumed by adult people in Turkey.

Station	Heavy Metal	PTWI	PTWI*	*S. solea*			*M. barbatus*			*S. rivulatus*		
				EWI*	PTWI (%)	THQ (unitless)	EWI*	PTWI (%)	THQ (unitless)	EWI*	PTWI (%)	THQ (unitless)
İskenderun	Al	7000	509600	5239.55	1.0	0.256	9687.41	1.901	0.4740	2992.37	0.6	0.15
	Sr	4200	305760	1048.54	0.34	0.014	1394.18	0.5	0.0018	1265.23	0.4	0.002
	Cd	0.7	510	1.06	2.0	0.0001	20.88	41.0	0.0029	1.90	3.7	0.0003
	Co	2.1	153	17.97	11.8	0.0001	32.77	21.4	0.0001	19.03	12.4	0.0001
	Ni	140	10192	20.08	0.2	0.0001	37.00	0.4	0.0002	26.43	0.3	0.0002
	Pb	25	1820	22.20	1.2	0.0001	49.68	2.7	0.0003	34.88	1.9	0.0002
Mersin	Al	7000	509600	3607.54	0.708	0.18	2087.58	0.41	0.10	3070.59	0.60	0.0015
	Sr	4200	305760	1048.54	0.3	0.0014	387.92	0.1	0.0005	1185.95	0.4	0.004
	Cd	0.7	510	1.06	2.0	0.0001	3.17	6.2	0.0004	6.34	12.4	0.0009
	Co	2.1	153	8.46	5.5	0.0000	7.19	4.7	0.0000	33.82	22.1	0.0001
	Ni	140	10192	10.25	0.1	0.0001	6.34	0.06	0.0000	19.03	0.2	0.0001
	Pb	25	1820	14.80	0.8	0.0001	45.45	2.5	0.0003	214.57	11.8	0.0014
Antalya	Al	7000	509600	562.32	0.11	0.028	13307.63	2.61	0.6511	215.63	0.04	0.0106
	Sr	4200	305760	139.52	0.0	0.0002	1527.37	0.5	0.002	154.32	0.1	0.0002
	Cd	0.7	510	2.33	4.5	0.0003	8.46	16.6	0.0012	12.16	23.8	0.0017
	Co	2.1	153	8.46	5.5	0.0000	15.86	10.4	0.0000	39.11	25.5	0.0001
	Ni	140	10192	8.46	0.08	0.0001	41.22	0.4	0.0003	4.76	0.0	0.0000
		25	1820	102.21	5.6	0.0007	37.00	2.0	0.0002	60.25	3.3	0.0004

EWI : estimated weekly intake in µg/week
PTWI: Established Provisional Tolerable Weekly Intake in (µg/week/kg body weight)
*PTWI for average Turkish adult (body weight is taken as 72.8 kg based on TUIK (2016) data (µg/week/72.8 kg body weight)

Conclusion

This study was conducted to evaluate heavy metal accumulation (Al, Sr, Cd, Co, Ni and, Pb) in the tissues of (intestine, skin, liver, and muscle) selected fish species (*M. barbatus, S. rivulatus,* and *S. solea*) and to access health risk potential for both general and fish populations. Results showed different accumulation patterns among tissues for all species. Significant ($p< 0.05$) inter- and intraspecies/tissues/bays differences were detected. The most stable tissue in terms of Al, Sr, Cd, Co, Ni and, Pb accumulation was determined as muscle, muscle, liver, liver, skin and, liver, respectively.

Considering edible part of fish which is mainly muscle tissue, THQ and TTHQ values were calculated and results did not exceeded by 1.00. Therefore, these results suggest that both general and fish populations have not subjected to the significant potential health risk from these bays, yet. Our findings on heavy metal accumulation in fish were mostly consistent with previous studies conducted in the same areas while monitoring programs should be continued to keep protecting the environment and human health in the future.

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COMPLIANCE WITH ETHICAL STANDARDS

Authors' Contributions

Authors contributed equally to this paper.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Table 9. Heavy metal accumulation (µg g⁻¹ w.wt.) and THQ values of muscle tissue of fish from previous studies evaluated in Iskenderun, Mersin and Antalya Bays.

Species	Metal	Bay	w.wt*	THQ	Reference
M. barbatus	Al	İskenderun	1.33	0.007	(Dural et al., 2010)
M. barbatus	Al	İskenderun	1.68	0.009	(Turan et al., 2009)
M. barbatus	Al	İskenderun	0.45	0.002	(Türkmen et al., 2005)
S. solea	Cd	İskenderun	0.20	0.001	(Türkmen, 2011)
S. solea	Cd	İskenderun	0.11	0.001	(Ersoy and Çelik, 2010)
S. solea	Cd	Mersin	nd	nd	(Korkmaz et al., 2017)
S. solea	Cd	Mersin	0.38	0.002	(Türkmen, 2011)
M. barbatus	Cd	İskenderun	0.10	0.001	(Turan et al., 2009)
M. barbatus	Cd	İskenderun	0.17	0.001	(Türkmen et al., 2005)
M. barbatus	Cd	İskenderun	0.62	0.003	(Çoğun et al., 2005)
M. barbatus	Cd	İskenderun	0.29	0.001	(Kalay et al, 1999)
M. barbatus	Cd	İskenderun	2.04	0.011	(Kargin, 1996)
M. barbatus	Cd	Mersin	nd	nd	(Korkmaz et al., 2017)
M. barbatus	Cd	Mersin	0.21	0.001	(Kalay et al., 1999)
M. barbatus	Cd	Antalya	0.01	<0.001	(Yipel and Yarsan, 2014)
M. barbatus	Cd	Antalya	0.02	<0.001	(Türkmen & Pınar, 2018)
S. rivulatus	Cd	İskenderun	0.24	0.001	(Ateș et al., 2015)
S. rivulatus	Cd	Antalya	0.06	<0.001	(Ateș et al., 2015)
S. solea	Co	İskenderun	0.17	0.001	(Türkmen, 2011)
S. solea	Co	Mersin	0.43	0.002	(Türkmen, 2011)
M. barbatus	Co	İskenderun	0.19	0.001	(Türkmen et al., 2005)
M. barbatus	Co	İskenderun	0.06	<0.001	(Tepe et al., 2008)
M. barbatus	Co	Mersin	0.44	0.002	(Tepe et al., 2008)
M. barbatus	Co	Antalya	0.02	<0.001	(Türkmen and Pınar, 2018)
M. barbatus	Co	Antalya	0.05	<0.001	(Tepe et al., 2008)
S. rivulatus	Co	İskenderun	0.39	0.002	(Ateș et al., 2015)
S. rivulatus	Co	Antalya	0.08	<0.001	(Ateș et al., 2015)
S. solea	Ni	İskenderun	0.22	0.001	(Ersoy and Çelik, 2010)
S. solea	Ni	İskenderun	0.14	0.001	(Kaya and Turkoglu, 2017)
S. solea	Ni	İskenderun	0.83	0.004	(Türkmen, 2011)
S. solea	Ni	Mersin	3.27	0.017	(Türkmen, 2011)
S. solea	Ni	Mersin	0.26	0.001	(Korkmaz et al., 2017)
M. barbatus	Ni	İskenderun	0.13	0.001	(Turan et al., 2009)
M. barbatus	Ni	İskenderun	0.27	0.001	(Türkmen et al., 2005)
M. barbatus	Ni	İskenderun	1.21	0.006	(Kalay et al., 1999)
M. barbatus	Ni	İskenderun	0.92	0.005	(Tepe et al., 2008)
M. barbatus	Ni	Mersin	0.61	0.003	(Kalay et al., 1999)
M. barbatus	Ni	Mersin	0.14	0.001	(Korkmaz et al., 2017)
M. barbatus	Ni	Mersin	4.22	0.022	(Tepe et al., 2008)
M. barbatus	Ni	Antalya	0.42	0.002	(Türkmen and Pınar, 2018)
M. barbatus	Ni	Antalya	0.96	0.005	(Tepe et al., 2008)
S. rivulatus	Ni	Antalya	0.69	0.004	(Ateș et al., 2015)
S .rivulatus	Ni	İskenderun	3.43	0.018	(Ateș et al., 2015)
S .solea	Pb	Mersin	0.48	0.002	(Korkmaz et al., 2017)
S .solea	Pb	İskenderun	0.38	0.002	(Ersoy & Çelik, 2010)

S. solea	Pb	İskenderun	1.13	0.006	(Türkmen, 2011)
S. solea	Pb	Mersin	1.31	0.007	(Külcü et al., 2014)
S. solea	Pb	Mersin	0.37	0.002	(Türkmen, 2011)
M. barbatus	Pb	İskenderun	0.45	0.002	(Dural et al., 2010)
M. barbatus	Pb	İskenderun	0.11	0.001	(Turan et al., 2009)
M. barbatus	Pb	İskenderun	0.82	0.004	(Türkmen et al., 2005)
M. barbatus	Pb	İskenderun	0.04	<0.001	(Tepe et al., 2008)
M. barbatus	Pb	İskenderun	1.88	0.010	(Çoğun et al, 2006)
M. barbatus	Pb	İskenderun	1.82	0.009	(Kalay et al., 1999)
M. barbatus	Pb	İskenderun	0.50	0.003	(Tepe et al., 2008)
M. barbatus	Pb	Mersin	5.94	0.031	(Kalay et al., 1999)
M. barbatus	Pb	Mersin	1.27	0.007	(Külcü et al., 2014)
M. barbatus	Pb	Mersin	0.40	0.002	(Tepe et al., 2008)
M. barbatus	Pb	Mersin	0.16	0.001	(Korkmaz et al., 2017)
M. barbatus	Pb	Mersin	0.89	0.005	(Tepe et al., 2008)
M. barbatus	Pb	Antalya	0.03	<0.001	(Türkmen and Pınar, 2018)
M. barbatus	Pb	Antalya	0.32	0.002	(Tepe et al., 2008)
M. barbatus	Pb	Antalya	0.22	0.001	(Tepe et al., 2008)
M. barbatus	Pb	İskenderun	0.39	0.002	(Ateş et al., 2015)
M. barbatus	Pb	Antalya	0.13	0.001	(Ateş et al., 2015)
Dry weight values were converted to wet wt. dividing by 5 [According to Yılmaz (2010)]					

References

Ateş, A., Türkmen, M. & Tepe, Y. (2015). Assessment of heavy metals in fourteen marine fish species of four Turkish Seas. *Indian Journal of Marine Sciences,* 44(1): 49-55.

ATSDR. (2012). Agency for Toxic Substances and Disease Registry. Toxicological profile for cadmium (draft for public comment). Atlanta, G. (2012). (Agency for Toxic Substances and Disease Registry) Toxicological profile for cadmium (draft for public comment). Atlanta, GA. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp5.pdf

ATSDR. (2011). Agency for Toxic Substances and Disease Registry. Nickel. Retrieved August 2, 2019, from https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=44

Bennett, D. H., Kastenberg, W. E. E. & McKone, T. E. E. (1999). A multimedia, multiple pathway risk assessment of atrazine: The impact of age differentiated exposure including joint uncertainty and variability. *Reliability Engineering & System Safety,* 63(2): 185-198.

Burger, J., Gaines, K. F., Boring, C. S., Stephens, W. L., Snodgrass, J., Dixon, C., McMahon, M., Shukla, S., Shukla, T. & Gochfeld, M. (2002). Metal levels in fish from the Savannah River: Potential hazards to fish and other receptors. *Environmental Research,* 89(1): 85-97.

Carvalho, L., Maberly, S., May, L., Reynolds, C., Hughes, M., Brazier, R., Heathwaite, A. L., Shuming, L., Hilton, J., Hornby, D., Bennion, H., Elliott, A., Willby, N., Dils, R., Phillips, G., Pope, L. & Fozzard, I. (2005). Risk assessment methodology for determining nutrient impacts in surface freshwater bodies. Environment Agency, Bristol.

Can, M. F., Yılmaz, A. B., Yanar, A. & Kilic, E. (2020). Assessment of accumulation and potential health risk of Cr, Mn, Fe, Cu, and Zn in fish from North-Eastern Mediterranean Sea. *Pollution,* 6(3): 597-610.

CDEP. (2008). (Connecticut Department of Environmental Protection) Bureau of water protection and land reuse. Connecticut Remediation Criteria: Technical support Document Proposed Revisions to the Connecticut Remediation Standart Regulations. Connecticut.

Chien, L. C., Hung, T. C., Choang, K. Y., Yeh, C. Y., Meng, P. J., Shieh, M. J. & Han, B. C. (2002). Daily intake of TBT, Cu, Zn, Cd and As for fishermen in Taiwan. Science of the Total Environment, 285(1-3): 177-185.

Chin-Chan, M., Navarro-Yepes, J. & Quintanilla-Vega, B. (2015). Environmental pollutants as risk factors for neurodegenerative disorders: Alzheimer and Parkinson diseases. *Frontiers in Cellular Neuroscience,* 9, 124.

Çoğun, H. Y., Firat, Ö., Aytekin, T., Firidin, G., Firat, Ö., Varkal, H., Temiz, Ö. & Kargin, F. (2017). Heavy metals in the Blue crab (*Callinectes sapidus*) in Mersin Bay, Turkey. *Bulletin of Environmental Contamination and Toxicology,* 98(6): 824-829.

Çoğun, H. Y., Yüzereroğlu, T. A., Firat, Ö., Gök, G. & Kargin, F. (2006). Metal concentrations in fish species from the Northeast Mediterranean Sea. *Environmental Monitoring and Assessment,* 121(1-3): 431-438.

Çoğun, H., Yüzereroğlu, T. A., Kargin, F. & Firat, Ö. (2005). Seasonal variation and tissue distribution of heavy metals in shrimp and fish species from the Yumurtalik Coast of Iskenderun Gulf, Mediterranean. *Bulletin of Environmental Contamination and Toxicology,* 75(4): 707-715.

Dural, M., Bıçkıcı, E. & Manaşırlı, M. (2010). Heavy metal concentrations in diffirent tissues of *Mullus barbatus* and *Mullus surmeletus* from Iskenderun Bay, Eastern Cost of Mediterranean, Turkey. *Rapp. Comm. Int. Mer. Médit,* (39): 499.

EFSA. (2008). (European Food Safety Authority) Scientific opinion of the panel on food additives, flavourings, processing aids and food contact materials on a request from European Commission on safety of aluminium from dietary intake. *The EFSA Journal,* (754): 1-34.

Ersoy, B. & Çelik, M. (2010). The essential and toxic elements in tissues of six commercial demersal fish from Eastern Mediterranean Sea. *Food and Chemical Toxicology,* 48(5): 1377–1382.

FAO/WHO. (2004). Summary of evaluations performed by the joint FAO/WHO expert committee on food additives (JECFA 1956–2003). Retrieved March 13, 2019, from ftp://ftp.fao.org/es/esn/jecfa/call_63.pdf

Froese, R. & Pauly, D. (2020). FishBase. 2020. World Wide Web Electronic Publication. Available at: Http://Www. Fishbase. Org (Accessed on 8 September 2020).

Galvez, F., Wong, D. & Wood, C. M. (2006). Cadmium and calcium uptake in isolated mitochondria-rich cell populations from the gills of the freshwater rainbow trout. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology,* 291(1): R170–R176.

Hamad, N., Millot, C. & Taupier-Letage, I. (2005). A new hypothesis about the surface circulation in the eastern basin of the mediterranean sea. *Progress in Oceanography,* 66(2–4): 287–298.

Hammer, Ø., Harper, D. A. T. & Ryan, P. D. (2001). Past: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica,* 4(1): 9. Retrieved from https://palaeo-electronica.org/2001_1/past/issue1_01.htm

Han, B. C., Jeng, W. L., Chen, R. Y., Fang, G. T., Hung, T. C. & Tseng, R. J. (1998). Estimation of target hazard quotients and potential health risks for metals by consumption of seafood in Taiwan. *Archives of Environmental Contamination and Toxicology,* 35: 711–720.

J. M. Neff. (2002). Bioaccumulation in Marine Organisms. Elsevier. https://doi.org/10.1016/B978-0-08-043716-3.X5000-3

Kalay, M., Ay, Ö. & Canli, M. (1999). Heavy metal concentrations in fish tissues from the Northeast Mediterranean Sea. *Bulletin of Environmental Contamination and Toxicology,* 63(5): 673-681.

Kalay, M. & Canlı, M. (2000) Elimination of essential (Cu, Zn) and non-essential (Cd, Pb) metals from tissues of a freshwater fish Tilapia zilli. *Turkish Journal of Zoology*, 24(4): 429-436

Kargin, F. (1996). Seasonal changes in levels of heavy metals in tissues of *Mullus barbatus* and *Sparus aurata* collected from Iskenderun Gulf (Turkey). *Water, Air, and Soil Pollution,* 90(3–4): 557-562.

Kaya, G. & Turkoglu, S. (2017). Bioaccumulation of heavy metals in various tissues of some fish species and Green tiger shrimp (*Penaeus semisulcatus*) from İskenderun Bay, Turkey, and risk assessment for human health. *Biological Trace Element Research,* 180(2): 314-326.

Kılıç, E., Yanar, A., Can, M. F. & Yılmaz, A. B. (2019). Assessment of magnesium content of three fish species from three bays in North Eastern Mediterranean Sea. *Marine and Life Sciences,* 1(1): 10-16.

Korkmaz, C., Ay, Ö., Çolakfakıoğlu, C., Cicik, B. & Erdem, C. (2017). Heavy metal levels in muscle tissues of *Solea solea, Mullus barbatus,* and *Sardina pilchardus* marketed for consumption in Mersin, Turkey. *Water, Air, & Soil Pollution,* 228(8): 315.

Külcü, A. M., Ayas, D., Köşker, A. R. & Yatkın, K. (2014). The investigation of metal and mineral levels of some marine species from the Northeastern Mediterranean Sea. *Journal of Marine Biology & Oceanography,* 3(2): 1000127.

Lison, D. (2015). Cobalt. In F. G. Nordberg, B. A. Fowler, & M. Nordberg (Eds.), Handbook on the Toxicology of Metals (Fourth Edi, pp. 743–763). AMSTERDAM: Academic Press.

McRae, N. K., Gaw, S. & Glover, C. N. (2018). Effects of waterborne cadmium on metabolic rate, oxidative stress, and ion regulation in the freshwater fish, inanga (Galaxias maculatus). Aquatic Toxicology, 194, 1–9. https://doi.org/10.1016/J.AQUATOX.2017.10.027

Mohanty, B. P., Mahanty, A., Ganguly, S., Mitra, T., Karunakaran, D. & Anandan, R. (2019). Nutritional composition of food fishes and their importance in providing food and nutritional security. *Food Chemistry,* 293: 561–570.

Rajan, S. & Ishak, N. S. (2017). Estimation of target hazard quotients and potential health risks for metals by consumption of Shrimp (*Litopenaeus vannamei*) in Selangor, Malaysia. *Sains Malaysiana,* 46(10): 1825-1830.

Storelli, M. M. (2008). Potential human health risks from metals (Hg, Cd, and Pb) and polychlorinated biphenyls (PCBs) via seafood consumption: Estimation of target hazard quotients (THQs) and toxic equivalents (TEQs). *Food and Chemical Toxicology,* 46(8): 2782-2788.

Tepe, Y., Türkmen, M. & Türkmen, A. (2008). Assessment of heavy metals in two commercial fish species of four Turkish seas. *Environmental Monitoring and Assessment,* 146(1-3): 277-284.

TUIK. (2016). Turkish Statistical Institute. Turkey Health Interview Survey. Retrieved March 13, 2019, from http://www.tuik.gov.tr/PrelstatistikTablo.do?istab_id=2388

TUIK. (2018). Turkish Statistical Institute. Fisheries Statistics. Ankara,Turkey.

Turan, C., Dural, M., Oksuz, A. & Öztürk, B. (2009). Levels of heavy metals in some commercial fish species captured from the Black Sea and Mediterranean Coast of Turkey. *Bulletin of Environmental Contamination and Toxicology,* 82(5): 601-604.

Türkmen, A. (2011). Determination of heavy metal levels in liver and muscle tissues of Solea solea L., 1758 caught from Seas of Turkey. *The Black Sea Journal of Sciences,* 2(1): 139-151.

Türkmen, A., Türkmen, M., Tepe, Y. & Akyurt, İ. (2005). Heavy metals in three commercially valuable fish species from İskenderun Bay, Northern East Mediterranean Sea, Turkey. *Food Chemistry,* 91(1): 167-172.

Türkmen, M. & Pınar, E. O. (2018). Bioaccumulation of metals in economically important fish species from antalya bay, northeastern mediterranean sea. *Indian Journal of Geo-Marine Sciences,* 47(01), 180-184.

US EPA. (2009). Environmental Protection Agency. Risk-based Concentration Table. Washington.

Yi, Y., Yang, Z. & Zhang, S. (2011). Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. *Environmental Pollution,* 159(10): 2575-2585.

Yipel, M. & Yarsan, E. (2014). A risk assessment of heavy metal concentrations in fish and an Invertebrate from the Gulf of Antalya. *Bulletin of Environmental Contamination and Toxicology,* 93(5): 542-548.

Yılmaz, A. B. (2003). Levels of heavy metals (Fe, Cu, Ni, Cr, Pb, and Zn) in tissue of *Mugil cephalus* and *Trachurus mediterraneus* from Iskenderun Bay, Turkey. *Environmental Research,* 92(3): 277-281.

Yılmaz, A. B. (2010). Heavy metal pollution in aquatic environments. In A. El Nemr (Ed.), Impact, Monitoring and Management of Environmental Pollution (Pollution, pp. 193-221). New York, United States: Nova Science Publishers Incorporated.

Yılmaz, A. B., Sangün, M. K., Yağlıoğlu, D. & Turan, C. (2010). Metals (major, essential to non-essential) composition of the different tissues of three demersal fish species from İskenderun Bay, Turkey. *Food Chemistry,* 123(2): 410–415.

Yılmaz, A. B., Yanar, A. & Alkan, E. N. (2018). Review of heavy metal accumulation in aquatic environment of Northern East Mediterrenean Sea Part II: Some non-essential metals. *Pollution,* 4(1): 143-181.