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Comparative study of heavy metals and selenium accumulation in the digestive gland and gills of *Mytilus galloprovincialis* (Lamarck, 1819) caught in Izmir Bay (Turkey)

[İzmir Körfezi'nden (Türkiye) yakalanan *Mytilus galloprovincialis* (Lamarck, 1819)'un sindirim bezi ve solungaçlarındaki ağır metal ve selenyum içeriklerinin karşılaştırması]

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ABSTRACT

Objective: The aim of this study was to evaluate heavy metals (Cr, Fe, Ni, Cu, Zn, As, Cd, Hg, Pb) and selenium levels in digestive gland and gill tissues of wild Mediterranean mussel *Mytilus galloprovincialis* (Lamarck, 1819) collected from four locations in Izmir Bay.

Methods: A total of 180 samples of the wild Mediterranean mussel *M. galloprovincialis* with shell length of 50-60 mm were collected from four locations. Inductively coupled plasma-mass spectroscopy was used to determine heavy metals and selenium concentrations in mussel samples after microwave digestion process.

Results: The highest values (mg kg^{-1} dry weight) obtained for digestive gland and gills were 0.17 and 0.15 for Cr, 28.62 and 29.49 for Fe, 0.25 and 0.29 for Ni, 2.53 and 1.78 for Cu, 18.52 and 22.03 for Zn, 1.26 and 1.08 for As, 0.04 and 0.04 for Cd, 0.02 and 0.02 for Hg, 0.19 and 0.16 for Pb, 0.40 and 0.48 for Se, respectively. Statistically significant differences among digestive gland and gills ($p<0.05$) were found for Cr, Ni, Zn, As, Se and Cd. In general, the levels of the studied elements were higher for the Karşıyaka than for other three stations.

Conclusion: The low levels of toxic metals (Cd, Hg, Pb, Cr, Ni) found in tissues of *M. galloprovincialis*, comparing with the other studies including taken place in the Inner of Izmir Bay. *M. galloprovincialis* can be used as a sensitive biomonitor for the availabilities of studied elements in the Inner Bay of Izmir, Turkey.

Key Words: *Mytilus galloprovincialis*, gill, digestive gland, heavy metal, selenium, Izmir Bay
Conflict of Interest: The authors have no conflict of interest.

ÖZET

Amaç: Bu çalışmanın amacı İzmir Körfezi'nden dört lokasyondan toplanan doğal Akdeniz midyesi *Mytilus galloprovincialis* (Lamarck, 1819)'in sindirim bezleri ve solungaç dokularındaki ağır metal (Cr, Fe, Ni, Cu, Zn, As, Cd, Hg, Pb) ve selenyum seviyelerini değerlendirmektir.

Metod: Dört lokasyondan kabuk uzunlukları 50-60 mm arasında olan toplam 180 doğal Akdeniz midye *M. galloprovincialis* örnekleri toplandı. Mikrodalga yakma işleminden sonra midye örneklerindeki ağır metal ve selenium konsantrasyonları belirlemek için indüktif olarak eşleştirilmiş kütle spektroskopisi kullanıldı.

Bulgular: Sindirim bezi ve solungaçlar için elde edilen en yüksek değerler (mg kg^{-1} kuru ağırlık) sırasıyla 0.17 ve 0.15 Cr, 28.62 ve 29.49 Fe, 0.25 ve 0.29 Ni, 2.53-1.78 Cu, 18.52 ve 22.03 Zn, 1.26 ve 1.08 As, 0.04 ve 0.04 Cd, 0.02 ve 0.02 Hg, 0.19 ve 0.16 Pb, 0.40 ve 0.48 Se'dur. Cr, Ni, Zn, As, Se ve Cd için sindirim bezi ve solungaçlar arasında istatistiksel olarak anlamlı farklılık bulundu ($p<0.05$). Genelde, çalışılan elementlerin seviyeleri Karşıyaka'da diğer üç istasyondan daha yüksek bulundu.

Sonuç: İzmir Körfezi'nde yapılan digger çalışmalarla karşılaştırıldığında *M. galloprovincialis* dokularında düşük seviyelerde toksik metal (Cd, Hg, Pb, Cr, Ni) bulundu. *M. galloprovincialis* İzmir İç Körfezinde çalışılan elementler yönünden duyarlı bir biyomonitör olarak kullanılabilir.

Anahtar Kelimeler: *Mytilus galloprovincialis*, solungaç, sindirim bezi, ağır metal, selenium, İzmir Körfezi
Çıkar Çatışması: Yazarların çıkar çatışması yoktur.

Introduction

Metals, such as Cd, Ni, Cr, Pb and Hg are toxic in aquatic organisms mainly because of the oxidative potential whereas other metals, such as Fe, Zn, Cu, Se and Mn are essential for their metabolism but become toxic when their concentrations are excessive [1]. The interactions of Se, which is also an essential micronutrient for organisms, with the heavy metals such as Hg and As have reported in aquatic vertebrates and invertebrates [2-5]. Since the metal pollution in aquatic ecosystems can be harmful to human health, it is necessary to understand and control the hazard levels of pollution in seafood [6].

It has been recognized in recent years that risk assessment of environmental pollution cannot be based solely on chemical analysis because it does not provide a clear indication of toxic effects of pollutant on the aquatic biota [7].

The word “mussel” is most frequently used to mean the edible bivalves of the marine family Mytilidae, most of which live on exposed shores in the intertidal zone and are of great interest since they are intensively fished and cultured worldwide for human consumption. Mussels are sedentary organisms filtrating large amounts of water allowing them to accumulate the substances from the environment. This characteristic makes it possible to use them as “bioindicators” in an aquatic environment. *M. galloprovincialis* is a very sensitive ‘early warning’ tool for heavy metal contamination of a marine environment [8-10].

There have been many studies carried out concerning metal pollution and eutrophication in the Izmir Bay, especially the Inner Bay reported as polluted area in terms of heavy metal, trace elements, inorganic and organic matters [11-17]. The Metropolitan Wastewater Treatment Plants initiated for domestic and industrial wastes in 2000 has increased its capacity with new plants and facilities by The Izmir Metropolitan Municipality in the last decade, and the effects of these plants on ecosystem of the Izmir bay have been monitored [15,18].

ICP-MS as a technique for the inorganic trace analysis shows an excellent sensitivity for a large numbers of elements of interest and the speed of measurement makes it suitable for routine, multielement determinations at trace and ultratrace levels. Important characteristic is the ability to detect and measure concentrations of analyzed elements at very low levels [19,20].

The aim of this study was to quantify and compare heavy metals and selenium in digestive glands and gill tissues of *M. galloprovincialis* collected from four locations in Izmir Bay.

Material and Methods

Izmir Bay is located in the eastern Aegean Sea between latitudes of 38°20’ and 38°42’ N and longitudes of 29°25’ - 27°10’ E. It is one of the largest natural bays of the Mediterranean. Izmir which is the third largest city in Turkey is located at the west part of the Anatolian peninsula and it is an important industrial and commercial center and a cultural focal point. The Izmir Bay has been considered dividing into three areas as Outer, Middle and Inner Bay according to their physical characteristics. The main industries in the region include food processing, oil, soap and paint production, chemical industries, paper and pulp factories, textile industries and metal processing [21-23].

A total of 180 samples of the wild mussel *M. galloprovincialis* with shell length of 50-60 mm were collected from four locations [1: Pasaport (vicinity of the Pasaport Ferry Bridge), 2: Alsancak (near the Izmir Harbour), 3: Karşıyaka (vicinity of the Karşıyaka Ferry Bridge) and 4: Bostanlı (near the Bostanlı Ferry Bridge)] in the Izmir Bay in early spring 2010. The collection points were shown in Figure 1. Immediately after collection, mussels

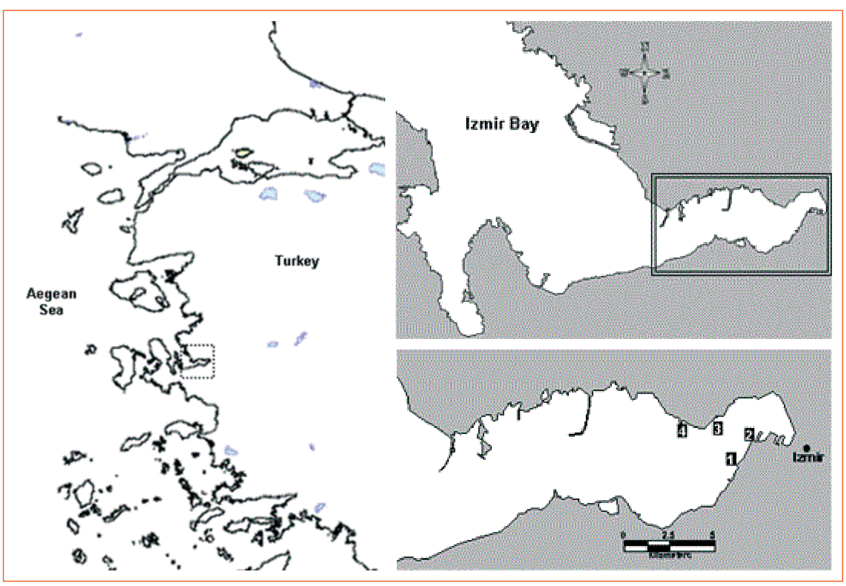

Figure 1. The study area (1: Pasaport, 2: Alsancak, 3: Karşıyaka, 4: Bostanlı).

were transferred freshly to the laboratory where gills and digestive glands were dissected. The samples of *M. galloprovincialis* from each location were separated into 3 groups. Each groups included 15 individuals.

All reagents used were of analytical quality (nitric acid, 65% suprapure Merck; Hydrogen peroxide, 30% suprapure Merck). Multi-element calibration solutions of all investigated elements were prepared daily by dilution of 10 mg/L mix element standard stock solution (Agilent Multi-Element Calibration Standard-2A, 8500-6940) and 10 mg/L mercury standard stock solution (Agilent Mercury Calibration Standard, 8500-6941).

An ELGA Model deionizer system was used to prepare deionized water (resistivity: 18.0 MΩ cm). Berghof speedwave MWS-3 microwave digestion system with DAP 60+ vessels was used to digest fish samples prior to metal analysis. Inductively coupled plasma-mass spectroscopy (Agilent 7700x) with auto sampler (Agilent ASX-500) was used to analyze digested samples for total metals.

The mussel samples were treated by deionized water before dissection. Digestion glands and gill tissues of mussels were dissected. Tissues were homogenized thoroughly in a laboratory blender (Waring trade marker) with stainless steel cutters (each homogenized sample groups were composed of 15 individuals), and then freeze-dried. Digestion of the dried samples were carried out using the following procedure [9]; for each homogenized samples, 0.3 g homogenate (wet weight) was weighed and placed in Polytetrafluoroethylene (PTFE) vessel with 65% nitric acid/30% hydrogen peroxide (4:2). Material was then subjected to a microwave program (Table 1). After digestion procedure, the samples and blank solution were brought to a volume of 25 mL with ultrapure water.

Table 1. Microwave digestion process

Step	1	2	3	4
Temperature (°C)	160	190	190	100
Ramp (min)	5	1	1	1
Hold (min)	5	5	10	10

The estimated average daily intake rate (DIR) of analyzed elements were calculated using the following equation [24], DIR (µg analyzed element/kg-bodyweight/day) = $(C_{metal} x D_{food\ intake})/B_{average\ weight}$ where, C_{metal}: The mean total tissue (gill and digestive gland) heavy metal and selenium concentrations in mussel (µg kg^{-1}), $D_{food\ intake}$: Daily intake of mussel (kg $person^{-1}$), fish consumption rate for the year 2010 was 6.918 kg per person in Turkey [25]; As annual rate of mussel consumption is not known, the calculation is made through annual rate of fish consumption.) and Baverage weight: Average body weight (kg $person^{-1}$), in a risk assessment, a body weight of 70 kg

Table 2. The concentrations of studied elements in digestive gland and gills of *M. galloprovincialis*

Element	Tissue	n	Concentrations (mg kg^{-1} dry weight)			p values
			Minimum	Maximum	Mean±SD	
Cr	G	180	0.09	0.15	0.12±0.02	0.040*
	D	180	0.07	0.17	0.09±0.03	
Fe	G	180	12.22	29.49	18.34±6.15	0.186
	D	180	8.89	28.62	15.88±7.12	
Ni	G	180	0.17	0.33	0.22±0.06	0.000*
	D	180	0.05	0.25	0.12±0.07	
Cu	G	180	0.69	1.78	1.04±0.41	0.831
	D	180	0.42	2.53	1.06±0.71	
Zn	G	180	10.46	22.03	16.00±4.02	0.021*
	D	180	8.14	18.52	12.47±3.55	
As	G	180	0.95	1.08	0.99±0.04	0.000*
	D	180	1.15	1.26	1.19±0.04	
Cd	G	180	0.03	0.04	0.03±0.00	0.001*
	D	180	0.01	0.04	0.02±0.00	
Hg	G	180	0.01	0.02	0.01±0.00	0.039*
	D	180	0.01	0.02	0.02±0.00	
Pb	G	180	nd	0.16	0.05±0.06	0.154
	D	180	nd	0.19	0.04±0.07	
Se	G	180	0.43	0.48	0.45±0.02	0.000*
	D	180	0.32	0.40	0.36±0.03	

G: Gills; D: Digestive gland; nd: not detected; SD: Standard deviation.*: indicates paired-samples t-test at α=0.05.

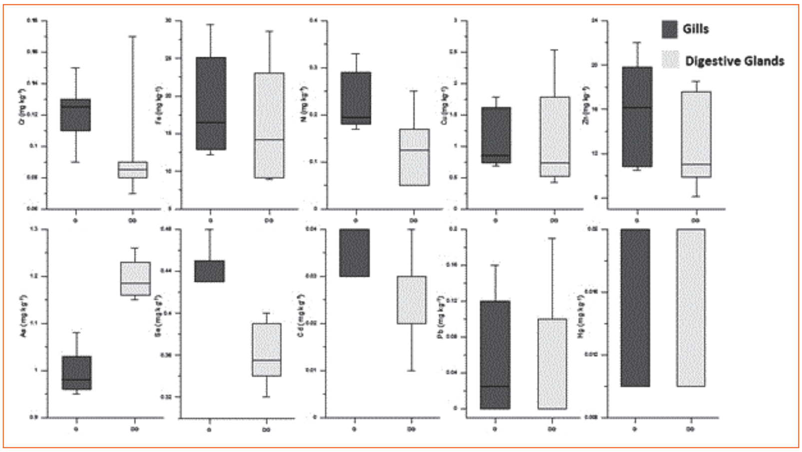

Figure 2. Box Whisker plot of measured metal concentrations in gills (G) and digestive glands (DG), (—; median, □; 25%-75%, I; min-max).

is generally used to represent a typical adult weight [26].

The Shapiro-Wilk statistic was performed for each variable obtained by the values of studied elements to ensure that a normality in distribution existed. Then the data were subjected to one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test to assess significant differences between element concentrations in the stations, while paired samples t-tests were applied to reveal significant differences between the gill and digestive gland. The Pearson Correlation coefficients were calculated between element concentrations. P-values of 0.05 were considered statistically significant. The obtained data were summarized by descriptive statistics and box-whisker plots. Statistics were performed using SPSS software version 15.0.

Results and Discussion

The corresponding mean, standard deviation, and maximum-minimum values of metals and Se concentrations in the gill and digestive gland of *M. galloprovincialis* are reported in Table 2. Fe has the highest concentrations both in the gill and digestive gland while Cd and Hg have the lowest values. The measured concentrations can be grouped in four sets depending on their similarity of mean values (higher to lesser content): Fe-Zn, As-Cu, Cr-Ni-Si, and Cd-Pb-Hg. Generally, content of concentrations in the digestive gland were lower than concentrations in the gill.

The magnitude of element concentrations in digestive gland was determined as Fe>Zn>Cu>As >Se>Ni>Cr>Pb>Cd>Hg. The data obtained showed that accumulated metal concentrations in gills generally in the following sequences: Fe>Zn>As>Cu>Se>Ni>Cr>Pb>Cd≈Hg. In a similar way, the highest metal concentration for the gills reported as 151 mg kg-1 for Fe in Saronikos Gulf of Greece [27]. Mean metal concentrations in soft tissues of *M. galloprovincialis* was detected as Fe>Zn>As>Cu>Pb>Ni>Cr by Orescanin et al. [10].

Figure 2 shows Box-Whisker plots for the measured concentrations, which describe the median marked by a vertical line, the quartiles as the 25th and 75th percentiles drawn by a box, and the minimum and maximum values as whiskers.

According to ANOVA results as shown Table 3, there were no statistically significant differences between the studied tissues in terms of Fe, Cu and Hg but Cr, Ni, Zn, As, Se, Cd, Pb. The results of ANOVA also indicated that the significant differences weren't found among sampling stations in terms of Cr, As, Se, Cd. However, the other elements have shown significant differences in the stations. Remarkably, *Tukey post-hoc* analysis separated station 1 and 3 in terms of these elements. Also, no significant differences were found between station 1 and 2, except for Zn.

Concentrations of the studied elements and their comparison to data from the literature are given in Table 4. The mean chromium concentrations of the analyzed soft tissues of mussels were 0.12 mg kg^{-1} dw for gills, 0.09 mg kg^{-1} for digestive glands. Mean cadmium concentrations of soft tissues of *M. galloprovincialis* were found as 4.92-8.01 92 mg kg^{-1} dw in Spanish North Atlantic Coast [28]. The mean iron concentrations measured in our study is lower than that reported as 395 mg kg^{-1} dw in soft tissues of mussels in Greece [29]. In a similar way, mean nickel levels (16.4 mg kg^{-1} dw) were found higher than this study in soft tissues of mussels in Italy [30]. In the mussels collected from the Eastern Black Sea higher mean copper concentrations in soft tissues (90-260 mg kg^{-1} dw) than the current study were detected [31]. Relatively high mean concentrations (186-398 mg kg^{-1} dw) of zinc were also found in the soft tissues of mussels in Portugal [32]. In general, the arsenic concentrations in soft tissues of *M. galloprovincialis* determined in this study were lower than reported in Eastern Black Sea [31] and the East coast of the Middle Adriatic Sea [10]. Fe, Ni, Cu, Zn Iron, nickel, cobalt and zinc in the soft tissues of *M. galloprovin-*

Table 3. The concentrations of studied elements of *M. galloprovincialis* between stations

Element	Stations	Concentrations (mg kg^{-1} dry weight)			p values
		Minimum	Maximum	Mean±SD	
Cr	S1	0.08	0.13	0.10±0.02	0.960
	S2	0.07	0.15	0.11±0.03	
	S3	0.09	0.17	0.11±0.03	
	S4	0.08	0.13	0.11±0.02	
Fe	S1	9.11	14.49	11.56±2.66^{a}	0.000*
	S2	8.89	12.90	11.57±1.54^{a}	
	S3	18.39	28.62	22.67±3.95^{c}	
	S4	16.17	29.49	22.65±5.42^{c}	
Ni	S1	0.05	0.18	0.12±0.07^{a}	0.002*
	S2	0.05	0.18	0.13±0.06^{a}	
	S3	0.17	0.33	0.26±0.06^{b}	
	S4	0.12	0.22	0.17±0.04^{a}	
Cu	S1	0.42	0.81	0.64±0.16^{a}	0.000*
	S2	0.52	0.75	0.65±0.09^{a}	
	S3	1.62	2.53	1.93±0.34^{c}	
	S4	0.82	1.18	0.98±0.12^{d}	
Zn	S1	8.14	10.85	9.92±1.00^{a}	0.004*
	S2	11.07	22.03	16.35±5.09^{b}	
	S3	13.85	18.52	17.05±1.79^{b}	
	S4	10.75	18.15	13.61±3.21a^{b}	
As	S1	0.95	1.21	1.07±0.12	0.779
	S2	0.96	1.23	1.10±0.14	
	S3	0.95	1.18	1.07±0.11	
	S4	1.03	1.26	1.13±0.09	
Cd	S1	0.01	0.04	0.03±0.01	0.217
	S2	0.02	0.03	0.03±0.01	
	S3	0.03	0.04	0.03±0.01	
	S4	0.02	0.04	0.03±0.01	
Hg	S1	0.02	0.02	0.02±0.00^{a}	0.001*
	S2	0.01	0.02	0.02±0.01^{ac}	
	S3	0.01	0.01	0.01±0.00^{d}	
	S4	0.01	0.02	0.01±0.01^{c}	
Pb	S1	nd	nd	nd	0.000*
	S2	nd	0.07	0.03±0.04^{a}	
	S3	0.10	0.19	0.14±0.03^{b}	
	S4	nd	nd	nd	
Se	S1	0.32	0.45	0.40±0.06	0.758
	S2	0.34	0.46	0.40±0.06	
	S3	0.39	0.48	0.42±0.03	
	S4	0.35	0.45	0.40±0.04	

S1: S2: S3: S4; nd: not detected; SD: Standard deviation. Different superscript letters (a, b, c, d) within same element indicate significant ($p<0.05$) differences among groups by one-way ANOVA followed by Tukey's post-hoc test.

cialis collected along the Montenegrin coastline were determined at lower levels comparing the results of current study [33]. According to the research in Spanish North Atlantic coast [28], the mean mercury concentrations in mussel presented as 0.11-0.25 mg kg^{-1} dw. Obtained mean mercury levels in the present study were found as lower than these values. The mean cadmium contents in analyzed samples showed extremely low concentrations (0.02-0.03 mg kg^{-1} dw) compared to the study (1.3-3.1 mg kg^{-1} dw) in Algarve Coast, Portugal [32]. The mean lead levels (5.0-21.0 mg kg^{-1} dw) in *M. galloprovincialis* from the Eastern Black Sea, Turkey [31] were also higher

Table 4. Other studies' mean heavy metals and selenium concentrations (mg kg^{-1} dry weight) in soft tissues of *Mytilus galloprovincialis*

Area	n	Cr	Fe	Ni	Cu	Zn	As	Hg	Cd	Pb	Se	References
The Thermaikos Gulf, Greece	94	1.85	395	4.34	3.91	56.3						[26]
The Trieste Gulf, Italy	150	<2.5		16.4	8.9	77			0.30	1.8		[27]
The Algarve Coast, Portugal	30		72-294	0.37-0.77	4.8- 7.0	186-398			1.3-3.1			[29]
The Montenegrin Coastline, Montenegro		2.0-4.2	128-603	3.4-18.9	4.6-17.2	132-345						[30]
The Eastern Black Sea, Turkey		1.0-3.0	1150-4030	1.0-6.0	90-260	180-630	2.0-4.0			5.0-21.0		[28]
The East coast of the Middle Adriatic Sea		1.8-1.9	85.8-261.3	1.9-2.4	5.3-6.9	104.7-127.9	13.3-15.6			3.9-4.1		[10]
The Spanish North Atlantic coast	>1000	4.92-8.01				226-286		0.11-0.25	0.61-0.84	1.63-6.11		[25]
Adak, Alaska*		20.7					1.98	0.01-6	0.99	0.49	0.90	[31]
The Izmir Bay, Turkey			53.53-66.1		1.4-6.9	225.7-294				2.6-3.1		[32]
The North Tyrrhenian Sea, Italy**	25		99-514		5- 11.2	61.4-189	7.6-26			0.6-65.2		[33]
The North Tyrrhenian Sea, Italy***	25		114-4041		5.6-26.4	73.2-222	10.4-57.7			1.3- 84.2		
Izmir Bay	180	0.07-0.17	8.89- 29.49	0.05-0.33	0.42-2.53	8.14-22.03	0.95-1.26	0.01-0.02	0.01-0.04	Nd.-0.19	0.32-0.48	[In this study]

* in soft tissues of *Mytilus [edulis] trossulus*, ** in the gills of *Mytilus galloprovincialis*, *** in the digestive gland of *Mytilus galloprovincialis*.

than the present study. We did not find any data for selenium in soft tissues of *M. galloprovincialis*. Therefore we compared the mean selenium levels obtained from data in soft tissues of *Mytilus* [*edulis*] *trossulus* and the mean selenium concentrations in current study is lower than that reported as 0.90 mg kg^{-1} dw [34].

In the Inner of Izmir Bay, Fe, Zn and Pb measurements in the soft tissues of *M. galloprovincialis* sampled in 2003

Table 5. The comparison between DIR rates and reference oral dose levels (µg day^{-1})

	Cr	Fe	Ni	Cu	Zn	As	Cd	Hg	Pb	Se
DIR	0.02	4.63	0.05	0.28	3.85	0.30	0.01	0.004	0.01	0.11
Amounts of Reference oral dose*	60000 PTWI	45000[a] UL	300 TDI	30000 PMTDI	60000 PMTDI	120 PMTDI	60 PTWI	43 PTWI	210 PTWI	---

*The numerical values shown are derived, for a 60 kg person, from provisional tolerable weekly intakes (PTWIs), provisional maximum tolerable daily intake (PMTDIs) or tolerable daily intake (TDI) recommended by the Joint Expert Committee on Food Additives of the Food and Agriculture Organization or the World Health Organization according to Ysart et al. [47]. [a]Tolerable upper intake level (UL) by the Institute of Medicine, Food and Nutrition Board [48].

and 2004 reported as lower levels than measurements remarkably in this study, while Cu levels were relatively lower than the levels in this study [35]. Fe, Cu, Zn, As, and Pb concentrations in the digestive gland and the gills of *M. galloprovincialis* from the North Tyrrhenian Sea have also conducted higher levels than their concentrations in this study crucially [36]. Finally, in comparison to data reported in other studies (Table 4), our findings for *M. galloprovincialis* indicated that most of the data were lower in the literature.

When the studied heavy metals were considered with regard to public health, the highest mean Cr concentration (0.12 mg kg^{-1}) was below the critical value of 8 mg kg^{-1} [37] which was not dangerous for public health.

While Fe is a crucial element for human nutrition, it could be fatal when taken overdose (mean lethal dose 200-250 mg kg^{-1} body weight). Daily iron requirement for humans is almost 10-50 mg [38], and the highest mean Fe amount (18.54 mg kg^{-1}) obtained in this study was in-between the stated amounts and sufficient for meeting the daily iron requirement.

Ni level in the food is between the range of <0.1-0.5 mg kg^{-1} [39]. Ni concentration in which clinical symptoms begin to appear in humans is 7-35 mg kg^{-1} body weight [40]. The maximum mean concentration of Ni (0.22 mg kg^{-1}) in the samples was under this range.

The maximum mean concentration of Cu in the samples (1.06 mg kg^{-1}) were below the permitted limit (10 mg kg^{-1}) recommended [41].

The maximum mean Zn concentration (16.00 mg kg^{-1}) did not exceed the maximum Zn limit as 40 mg kg^{-1} [42] specified in Australian food law.

The selenium ion concentrations in the range 2-8 mg kg^{-1} in food are harmful [43]. In the species of M.galloprovincialis which was our study material the maximum mean selenium concentration was in the range of 0.45 mg kg^{-1}.

The maximum mean concentrations of Cd, Hg and Pb (Cd: 0.03 mg kg^{-1}, Hg: 0.02 mg kg^{-1}, Pb: 0.05 mg kg^{-1}) which are called as toxic trio did not exceed the maximum limits (Cd: 0.05 mg kg^{-1}, Hg: 0.50 mg kg^{-1}, Pb: 0.30 mg kg^{-1}) which could be found in fisheries according to European Union food law [44].

Arsenic is found in nature as organic and inorganic arsenic. Organic arsenic is considered as non-toxic [45]. The most toxic arsenic formsa re the inorganic ones (As III and As V). According to New Zealand legislation, inorganic limit value is 2 mg kg^{-1} [46]. The maximum mean arsenic amount found in this study (1.19 mg kg^{-1}) did not exceed this limit.

Also, the estimated daily intake rate (DIR) determined for each one of the elements considering an adult person was compared with tolerable reference oral dose levels (Table 5) and it was seen that there was noy any danger for human health.

Conclusion

The continuous study of the marine environmental conditions is generally one of the tasks that all the countries must accomplish in order to prevent and eliminate pollution [49]. From a detailed statistical analysis of these results, we can make the following considerations:

- Bioaccumulation levels of the Cr, Ni, Zn, As, Cd and Se varied obviously depending on the factor of tissues.

- *M. galloprovincialis* samples collected from different locations had significantly different heavy metal concentrations.

- Gills had higher concentrations for Cr, Fe, Ni, Zn, Cd, Pb, and Se compared to digestive gland.

- Fe and Zn contents were high both digestive gland and gills at all sites.

- Se showed negative correlations with Hg (r=-0.444, p<0.05) and As (r=-0. 869, p<0.05) but the other measured heavy metals did not. Regarding Se kinetics, further research based on long-term field data is needed on relationship between this element and heavy metals.

-There is not any risk in consuming the species of *M. galloprovincialis* obtained from İzmir Bay in terms of studied heavy metals.

- The low levels of toxic metals (Cd, Hg, Pb, Cr, Ni) were found in tissues of *M. galloprovincialis*, despite considerable urbanization and vessel traffic in the Izmir Bay, comparing with the other studies including the ones, which took place in the Inner of Izmir Bay. This situation might turn out to be a consequence of waste water treatment activities during the last decade in the bay.

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Conflict of Interest

There are no conflicts of interest among the authors.

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