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Analytical Methods

Determination of metal contaminations in sea foods from Marmara, Aegean and Mediterranean seas: Twelve fish species

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Abstract

The concentrations of cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead and zinc were determined by ICP-AES in muscles and livers of 12 fish species sampled from the Marmara, Aegean and Mediterranean seas of Turkey. Iron showed the highest levels in examined tissues of all fish species. Following Fe, Zn generally showed the second highest levels. Metal concentrations in edible parts of fish species were 0.02–0.37 mg kg^{-1} for cadmium, 0.04–0.41 mg kg^{-1} for cobalt, 0.04–1.75 mg kg^{-1} for chromium, 0.32–6.48 mg kg^{-1} for copper, 7.46–40.1 mg kg^{-1} for iron, 0.10–0.99 mg kg^{-1} for manganese, 0.02–3.97 mg kg^{-1} for nickel, 0.33–0.86 mg kg^{-1} for lead, 4.49–11.2 mg kg^{-1} for zinc, respectively. All metal concentrations in livers were higher than those in muscles. In some stations, cadmium and chromium concentrations in both muscles and livers, and lead levels in livers of the examined species were higher than permissible safety levels for human uses.

Keywords: Metal contaminations; Twelve fish species; Marmara sea; Aegean sea; Mediterranean sea; Turkey

1. Introduction

Over the last few decades the marine environment has been contaminated by persistent pollutants of agriculture and industrial origin. Heavy metal contamination has been identified as a concern in coastal environment, due to discharges from industrial wastes, agricultural and urban sewage. Heavy metals can be accumulated by marine organisms through a variety of pathways, including respiration, adsorption and ingestion (Zhou, Salvador, Liu, & Sequeria, 2001). Metals such as iron, copper, zinc and manganese, are essential metals since they play an important role in biological systems, whereas mercury, lead and cadmium are non-essential metals, as they are toxic, even in traces. The essential metals can also produce toxic effects when the metal intake is excessively elevated. Fish and mussels are the major part of the human diet and it is not surprising that numerous studies have been carried out on metal accumulation in different fish species (Alam et al., 2002; Dural, Göksu, & Özak, 2007; Farkas, Salánki, & Specziár, 2003; Mendil et al., 2005; Türkmen & Ciminli, 2007; Türkmen, Türkmen, Tepe, & Akyurt, 2005; Türkmen, Türkmen, Tepe, Mazlum, & Oymael, 2006).

Turkey is surrounded by four different seas with 8333 km long coastal line and fishing is one of the biggest income sources for the country. The four seas around Turkey each reflect a different ecological character, for instance salinity is 18 per thousand in the Black Sea, 23 per thousand in the Marmara sea, 32 per thousand in the Aegean sea and 38 per thousand in the Mediterranean sea. The aim of this study was to determine the metal levels (Cd, Co, Cr, Cu, Fe, Mn, Pb, Ni and Zn) in muscles and livers of 12 different fish species from Turkish seas having different ecological characteristics, and to assess whether these fish acceptable for human consumption.

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2. Materials and methods

2.1. Sampling

Fish samples were collected in 5–40 m depths by using various fishing methods such as bottom trawl, fishing nets, longline fishing, fly fishing and handline fishing with commercial fishing vessels from six different sites in the coastal waters of Turkey from March to July 2005. These sampling sites are Yalova coasts (YLV) in the Marmara sea; Çanakkale offshore in Northern Aegean Sea (NAS) and outer part of İzmir Bay in Central Aegean sea (CAS) in Aegean sea, the coastal line between Finike and Demre coasts of Antalya Bay (AB), eastern coasts of Mersin Bay (MB) and the coastal area between Arsuz and İskenderun city coasts of İskenderun Bay (IB) in Mediterranean sea (Fig. 1). Twelve fish species (159 samples) examined in this study were summarized with their number, length (cm) and weight (g) in Table 1. These species are grey gurnard (*Trigla gurnardus*), black scorpionfish (*Scorpaena porcus*), salema (*Sarpa salpa*), gilthead seabream (*Sparus aurata*), bogue (*Boops boops*), common two-banded seabream (*Diplodus vulgaris*), European barracuda (*Sphyraena sphyraena*), snake blenny (*Ophidion barbatum*), whalesucker (*Remora australis*), sharpsnout seabream (*Diplodus puntazzo*), brown meagre (*Sciaena umbra*), blackspot seabream (*Pagellus bogaraveo*). Specimens collected during the sampling period were brought to the laboratory on ice. Total length and weight of the samples were measured to the nearest millimeter and gram before dissection. Approximately 1 g sample of muscle and entire liver from each fish were dissected, washed with distilled water, weighed, packed in polyethylene bags and stored at −18 °C until the performance of chemical analysis.

2.2. Chemical analyses

Special care was taken to prevent metal contamination of the samples by the hauling and laboratory equipment, and tissues were dissected by plastic knife and all laboratory-ware was soaked in 2 M HNO_3 for 48 h, and rinsed five times with distilled water, and then five times with deionized water prior to use. All tissue samples were transferred into 100 ml Teflon beakers. There after, 10 ml ultrapure concentrated nitric acid was added slowly to the sample. The Teflon beaker was covered with a watch glass, and heated at 200 °C on a hot plate for 3 h, until the solution evaporate slowly to near dryness. Two milliliters of 1 N HNO_3 was added to the residue and the solution was evaporated again on the hot plate. By repeating the additional digestion twice, all organic materials in each sample were completely digested. After cooling, 2.5 ml of 1 N HNO_3 was added to digested residue and was transferred to 25 ml volumetric flasks, then diluted to level with deionized water. Before analysis, the samples were filtered through a 0.45 μm nitrocellulose membrane filter. Sample blanks were prepared in the laboratory in a similar manner to the field samples (Alam et al., 2002). All metal concentrations were determined on wet weight basis as mg kg^{-1}.

All samples were analyzed three times for Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn by inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Varian Model-Liberty Series II). Standard solutions were prepared from stock solutions (Merck, multi element standard). A

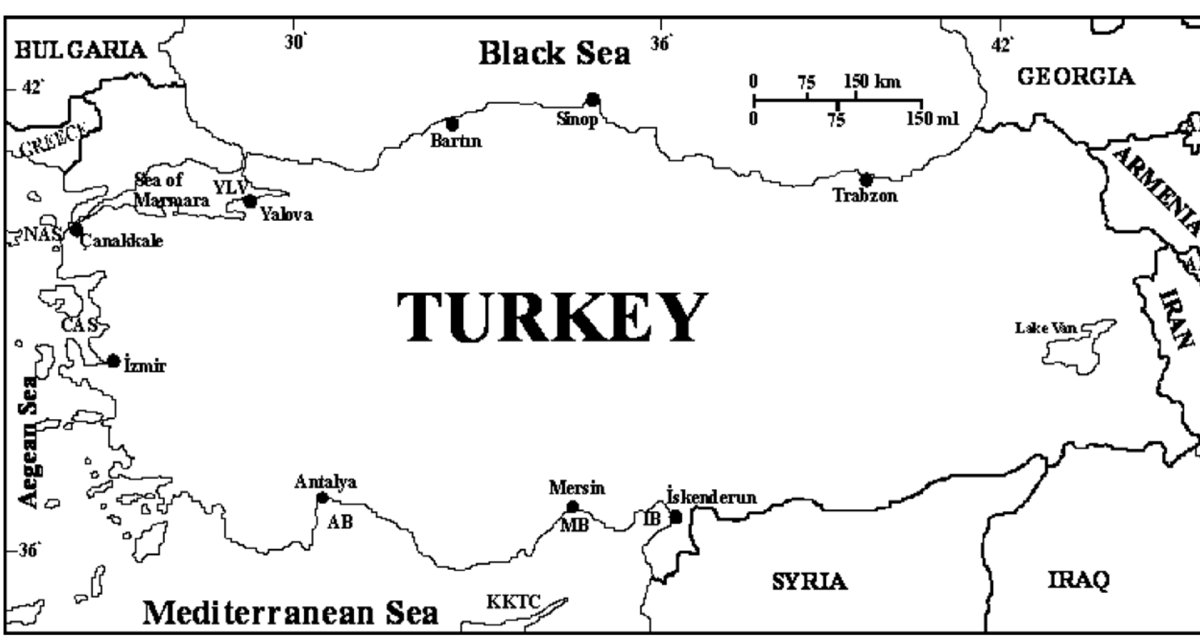

Fig. 1. The sampling locations from the coastal waters of Turkey (sampling locations are YLV: Yalova, NAS: North Aegean sea, CAS: Central Aegean sea, AB: Antalya Bay, MB: Mersin Bay, IB: İskenderun Bay).

Table 1
Biometric data (mean ± SE) of fish from the coastal waters of the Marmara, Aegean and Mediterranean seas

Locations	Species	N	Length (cm)	Weight (g)
Yalova (YLV)	*Trigla gurnardus*	7	22.4 ± 0.4	74.8 ± 5.1
	Scorpaena porcus	5	21.0 ± 1.8	215 ± 48
North Aegean sea (NAS)	*Sarpa salpa*	7	22.8 ± 0.3	155 ± 9.1
	Boops boops	10	19.7 ± 0.5	86.3 ± 6.1
	Diplodus vulgaris	7	17.6 ± 0.8	91.0 ± 4.4
	Sciaena umbra	5	21.3 ± 0.8	109 ± 17
	Pagellus bogaraveo	8	15.4 ± 0.3	52.9 ± 6.7
	Sparus aurata	8	21.7 ± 0.2	125 ± 2.6
Central Aegean sea (CAS)	*Sarpa salpa*	8	15.3 ± 1.1	45.3 ± 7.8
	Boops boops	10	14.4 ± 0.6	35.9 ± 6.2
Antalya Bay (AB)	*Sarpa salpa*	7	24.3 ± 0.3	210 ± 3.6
	Sparus aurata	7	20.8 ± 0.4	115 ± 10
	Diplodus vulgaris	7	20.9 ± 0.7	172 ± 22
Mersin Bay (MB)	*Sparus aurata*	7	13.8 ± 0.3	34.8 ± 1.9
İskenderun Bay (IB)	*Sarpa salpa*	8	17.2 ± 0.3	59.6 ± 2.1
	Boops boops	10	18.0 ± 0.5	69.3 ± 7.7
	Sparus aurata	9	14.9 ± 0.7	57.3 ± 3.8
	Diplodus vulgaris	7	17.5 ± 0.2	71.4 ± 2.8
	Sphyraena sphyraena	5	19.5 ± 1.6	44.7 ± 5.1
	Ophidion barbatum	5	52.0 ± 0.8	96.0 ± 3.0
	Remora australis	5	44.3 ± 1.1	316 ± 19
	Diplodus puntazzo	7	17.8 ± 0.5	36.6 ± 1.9

Table 2
Concentrations of metals found in Certified Reference Material Dorm-2 (dogfish muscle) from the NRC, Canada

Metals	Certified ± SE	Observed ± SE[a]	Recovery (%)
Cadmium	0.043 ± 0.008	0.046 ± 0.007	107
Cobalt	0.182 ± 0.031	0.173 ± 0.029	95
Chromium	34.7 ± 5.5	33.4 ± 5.2	96
Copper	2.34 ± 0.16	2.43 ± 0.17	104
Iron	142 ± 10	136 ± 9.5	96
Manganese	3.66 ± 0.34	3.45 ± 0.44	94
Nickel	19.4 ± 3.1	20.6 ± 2.9	106
Lead	0.065 ± 0.007	0.071 ± 0.009	109
Zinc	26.6 ± 2.3	24.7 ± 2.5	93

Means ± standard errors, in mg kg^{-1} dry wt.
[a] Each value is the average of 12 determinations.

Dorm-2 certified dogfish tissue was used as the calibration verification standard. Recoveries between 90% and 110% were accepted to validate the calibration. All specimens were run in batches that included blanks, a standard calibration curve, two spiked specimens, and one duplicate. The results showed good agreement between the certified and the analytical values, the recovery of elements being partially complete for most of them (Table 2).

2.3. Statistical analyses

A logarithmic transformation was done on the data to improve normality. To test the differences between species, one way ANOVA was performed. Post-hoc test (Duncan) was applied to determine statistically significant differences following ANOVA. Possibilities less than 0.05 were considered statistically significant ($p < 0.05$). All statistical calculations were performed with SPSS 13.0 for Windows.

3. Results and discussion

Concentrations of nine elements in the muscle and liver of 12 fish species from Turkish coastal waters are shown in Tables 3 and 4. Metal concentrations in livers of examined species were generally higher than those in muscles. Iron was the highest in both muscle and liver of analyzed species in this study, followed by Zn. On the other hand, cadmium and cobalt were generally the lowest. Similar situations were reported many researchers (Dural et al., 2007; Farkas et al., 2003; Türkmen & Ciminli, 2007; Türkmen et al., 2005; Uluozlu, Tuzen, Mendil, & Soylak, 2007).

The lowest and highest cadmium concentrations in analyzed fish were 0.02 mg kg^{-1} in YLV and 0.37 mg kg^{-1} in MB for muscles, and 0.13 mg kg^{-1} in NAS and 0.47 mg kg^{-1} in AB for livers. Cadmium levels in the literature were 0.1–1.2 mg kg^{-1} for muscles of fish from lakes in Tokat, Turkey (Mendil et al., 2005), <0.01–0.04 mg kg^{-1} for muscles of fish in southeastern Aegean Sea, Turkey (Dalman, Demirak, & Balcı, 2006), 0.03–0.12 mg kg^{-1} for muscles and 0.02–0.35 mg kg^{-1} for livers of fish in Tuzla Lagoon, Mediterranean region, Turkey (Dural et al., 2007), 0.02–1.32 mg kg^{-1} for muscles of fish from internal markets of India (Sivaperumal, Sankar, & Nair, 2007). Maximum cadmium levels for the muscles and livers in this study were found to be higher than Turkish permissible limit that is 0.1 mg kg^{-1} for cadmium (TKB, 2002). On the other hand, according to Nauen (1983) the maximum permissible cadmium levels for fish are 0.05–5.5 mg kg^{-1}. Our values were in agreement with the literature such as Nauen (1983).

The minimum and maximum cobalt concentrations obtained were 0.04 mg kg^{-1} in YLV and 0.41 mg kg^{-1} in MB for muscles, and 0.14 mg kg^{-1} in YLV and 0.51 mg kg^{-1} in CAS for livers. Cobalt concentrations in the literature have been reported in the range of 0.006–0.244 mg kg^{-1} for muscles of fish from the coastal waters of the Caspian sea (Anan, Kunito, Tanabe, Mitrofanov, & Aubrey, 2005), 0.02–0.67 mg kg^{-1} for muscles of fish from internal markets of India (Sivaperumal et al., 2007), 0.003–0.015 mg kg^{-1} for livers of fish from Mediterranean sea region, Turkey (Türkmen & Ciminli, 2007). Our cobalt levels were approximate with the literature values. There is no information about maximum permissible cobalt limits in fish tissues in Turkish standards (TKB, 2002).

The lowest and highest chromium concentrations in analyzed fish were 0.04 mg kg^{-1} in CAS and 1.75 mg kg^{-1} in MB for muscles, and 0.19 mg kg^{-1} in YLV and 2.63 mg kg^{-1} in CAS for livers. In the literature, chromium contents in fish have been reported in the range of 0.08–1.4 mg kg^{-1} for muscles of fish from the coastal waters of the Caspian sea (Anan et al., 2005), 0.95–1.98 mg kg^{-1} for muscles of fish from the Black and Aegean seas, Turkey (Uluozlu et al., 2007), 0.59–1.69 mg kg^{-1} for muscles of fish

Table 3
Mean metal contents with standard error in the muscle tissues of the examined species from Marmara, Aegean and Mediterranean seas, Turkey (mg kg^{-1} wet wt)[a]

Location	Species	*N*	Cadmium	Cobalt	Chromium	Copper	Iron	Manganese	Nickel	Lead	Zinc
YLV	*T. gurnardus*	7	0.02 ± 0.00^{a}	0.04 ± 0.01^{a}	0.11 ± 0.03^{ab}	0.72 ± 0.14^{a}	7.46 ± 0.77^{a}	0.10 ± 0.03^{a}	0.02 ± 0.00^{a}	0.33 ± 0.08^{a}	4.49 ± 0.51^{a}
	S. porcus	5									
NAS	*S. salpa*	7									
	B. boops	10									
	D. vulgaris	7									
	S. umbra	5	0.03 ± 0.00^{a}	0.16 ± 0.03^{a}	0.25 ± 0.06^{ab}	6.48 ± 1.57^{b}	40.1 ± 8.69^{a}	0.99 ± 0.17^{b}	0.51 ± 0.11^{a}	0.54 ± 0.10^{a}	11.6 ± 1.64^{a}
	P. bogaraveo	8									
	S. aurata	8									
CAS	*Sarpa salpa*	8	0.07 ± 0.02^{ab}	0.05 ± 0.00^{a}	0.04 ± 0.01^{a}	0.92 ± 0.21^{a}	37.7 ± 8.36^{a}	0.22 ± 0.06^{ab}	0.64 ± 0.12^{a}	0.48 ± 0.13^{a}	5.59 ± 0.61^{a}
	B. boops	10									
	S. salpa	7									
AB	*S. aurata*	7	$0.16 \pm 0.a06^{b}$	0.18 ± 0.03^{a}	0.65 ± 0.19^{b}	1.36 ± 0.29^{a}	22.3 ± 6.35^{a}	0.49 ± 0.11^{ab}	2.03 ± 0.58^{b}	0.72 ± 0.24^{a}	6.34 ± 0.60^{a}
	D. vulgaris	7									
MB	*S. aurata*	7	0.37 ± 0.08^{c}	0.41 ± 0.03^{b}	1.75 ± 0.11^{c}	0.32 ± 0.08^{a}	14.5 ± 1.84^{a}	0.90 ± 0.08^{b}	3.97 ± 0.09^{c}	0.51 ± 0.07^{a}	6.22 ± 1.07^{a}
IB	*S. salpa*	8									
	B. boops	10									
	S. aurata	9									
	D. vulgaris	7	0.09 ± 0.02^{ab}	0.11 ± 0.02^{a}	0.62 ± 0.19^{b}	1.40 ± 0.14^{a}	34.9 ± 4.39^{a}	0.50 ± 0.04^{ab}	0.74 ± 0.14^{a}	0.86 ± 0.15^{a}	11.2 ± 1.03^{a}
	S. sphyraena	5									
	O. barbatum	5									
	R. australis	5									
	D. puntazzo	7									

[a] Vertically, letters a, b and c show differences among sites. Means with the different letters are statistically significant, $p < 0.05$.

Table 4
Mean metal contents with standard error in the liver tissues of the examined species from Marmara, Aegean and Mediterranean seas, Turkey (mg kg^{-1} wet wt)[a]

Location	Species	*N*	Cadmium	Cobalt	Chromium	Copper	Iron	Manganese	Nickel	Lead	Zinc
YLV	*T. gurnardus*	7									
	S. porcus	5	0.20 ± 0.07^{a}	0.14 ± 0.03^{a}	0.19 ± 0.05^{a}	5.29 ± 1.88^{a}	105 ± 15.1^{a}	0.55 ± 0.09^{a}	0.13 ± 0.03^{a}	0.83 ± 0.19^{a}	26.2 ± 4.31^{a}
NAS	*S. salpa*	7									
	B. boops	10									
	D. vulgaris	7									
	S. umbra	5	0.13 ± 0.03^{a}	0.45 ± 0.10^{a}	0.52 ± 0.09^{ab}	14.9 ± 3.52^{a}	148 ± 21.6^{a}	2.57 ± 0.51^{a}	1.51 ± 0.21^{ab}	1.29 ± 0.17^{a}	28.3 ± 4.12^{a}
	P. bogaraveo	8									
	S. aurata	8									
CAS	*S. salpa*	8									
	B. boops	10	0.46 ± 0.13^{a}	0.51 ± 0.18^{a}	2.63 ± 0.71^{c}	7.71 ± 1.92^{a}	442 ± 63.0^{b}	5.40 ± 1.88^{b}	8.89 ± 3.15^{c}	3.71 ± 1.05^{b}	43.5 ± 10.3^{a}
AB	*S. salpa*	7									
	S. aurata	7	0.47 ± 0.11^{a}	0.33 ± 0.12^{a}	1.17 ± 0.36^{abc}	7.69 ± 1.53^{a}	358 ± 70.8^{b}	1.86 ± 0.26^{a}	3.87 ± 1.20^{b}	1.11 ± 0.28^{a}	30.7 ± 4.32^{a}
	D. vulgaris	7									
IB	*S. salpa*	8									
	B. boops	10									
	S. aurata	9									
	D. vulgaris	7	0.36 ± 0.07^{a}	0.30 ± 0.07^{a}	1.83 ± 0.33^{bc}	11.3 ± 2.91^{a}	178 ± 19.2^{a}	1.42 ± 0.13^{a}	2.96 ± 0.49^{ab}	2.06 ± 0.27^{ab}	38.7 ± 3.30^{a}
	S. sphyraena	5									
	O. barbatum	5									
	R. australis	5									
	D. puntazzo	7									

[a] Vertically, letters a, b and c show differences among sites. Means with the different letters are statistically significant, $p < 0.05$.

from the İskenderun Bay, Turkey (Türkmen et al., 2006). There is no information about maximum permissible chromium limits in fish tissues in Turkish standards (TKB, 2002). On the other hand, the maximum permissible chromium levels for fish are 1.0 mg kg^{-1} (Nauen, 1983). Maximum chromium levels in muscles and livers in examined fish species were found to be higher than permissible limits reported by Nauen (1983).

The minimum and maximum copper levels were 0.32 mg kg^{-1} in MB and 6.48 mg kg^{-1} in NAS for muscles, and 5.29 mg kg^{-1} in YLV and 14.9 mg kg^{-1} in NAS for livers. Copper levels in the literature have been reported as 1.57 mg kg^{-1} for muscles of fish from İskenderun Bay, Turkey (Türkmen et al., 2005), 0.7–27 mg kg^{-1} for muscles and 3.1–323 mg kg^{-1} for livers of fish from Lake Budi, IX Region, Chile (Tapia et al., 2006), <3.17 mg kg^{-1} for muscles and 305 mg kg^{-1} for livers of fish from Esmoriz-Paramos coastal lagoon, Portugal (Fernandes, Fontainhas-Fernandes, Peixoto, & Salgado, 2007), 0.57 mg kg^{-1} for muscles of *Pagrus pagrus* (Miniadis-Meimaroglou et al., 2007). Copper levels of the present study were generally in similar ranges with the literature. The permissible copper concentration for fish is 20 mg kg^{-1} according to Turkish Food Standards (TKB, 2002). Maximum copper level in both edible parts and livers of fish were found to be lower than the Turkish permissible standards. The maximum permissible copper levels stated by Nauen (1983) were 10.0–100 mg kg^{-1} for fish, and our results were also in these ranges.

The lowest and highest iron levels in fish were 7.46 mg kg^{-1} in YLV and 40.1 mg kg^{-1} in NAS for muscles, and 105 mg kg^{-1} in YLV and 442 mg kg^{-1} in CAS for livers. Iron contents in the literature have been reported in the range of 8.87–18.8 mg kg^{-1} for muscles of fish from İskenderun bay, Turkey (Türkmen et al., 2006), 7.16–16.5 mg kg^{-1} for muscles and 48.1–384 mg kg^{-1} for livers of fish from Tuzla Lagoon, Mediterranean sea region (Dural et al., 2007), 1.49–3.69 mg kg^{-1} for muscles and 19.5–21.6 mg kg^{-1} for livers of fish from Mediterranean sea region (Türkmen & Ciminli, 2007). Our iron concentrations were generally in agreement with the literature. There is no information about maximum permissible iron concentrations in fish tissues in Turkish standards (TKB, 2002).

The minimum and maximum manganese contents were found as 0.10 mg kg^{-1} in YLV and 0.99 mg kg^{-1} in NAS for muscles, and 0.55 mg kg^{-1} in YLV and 5.40 mg kg^{-1} in CAS for livers. Manganese in the literature have been reported in the range of 0.09–9.23 mg kg^{-1} for muscles of fish from coastal waters of Caspian sea (Anan et al., 2005), 0.16 mg kg^{-1} for muscles of *P. pagrus* (Miniadis-Meimaroglou et al., 2007), 0.14–3.36 mg kg^{-1} for muscles of fish from Indian markets (Sivaperumal et al., 2007), 0.07–0.45 mg kg^{-1} for muscles and 0.89–3.32 mg kg^{-1} for livers (Türkmen and Ciminli 2007). There is no record on maximum permissible manganese concentrations in fish tissues in Turkish standards (TKB, 2002).

The lowest and highest nickel levels in fish were found as 0.02 mg kg^{-1} in YLV and 3.97 mg kg^{-1} in MB for muscles, and 0.13 mg kg^{-1} in YLV and 8.89 mg kg^{-1} in CAS for livers. Reported nickel levels in the literature are in the range of 0.03–0.69 mg kg^{-1} for muscles of fish from Indian markets (Sivaperumal et al., 2007), 0.66–1.59 mg kg^{-1} for muscles of fish from İskenderun bay, Mediterranean sea (Türkmen et al., 2006), 0.009–0.011 mg kg^{-1} for muscles and 0.07–0.10 mg kg^{-1} for livers of fish from Mediterranean region (Türkmen & Ciminli, 2007). There is no information about maximum permissible nickel concentrations in fish tissues in Turkish standards (TKB, 2002).

The minimum and maximum lead contents were 0.33 mg kg^{-1} in YLV and 0.86 mg kg^{-1} in IB for muscles, and 0.83 mg kg^{-1} in YLV and 3.71 mg kg^{-1} in CAS for livers. Lead in the literature have been reported in the range of 0.33–0.93 mg kg^{-1} for muscles of fish from Black and Aegean seas (Uluozlu et al., 2007), 0.01–0.15 mg kg^{-1} for muscles of fish from Ria de Averio, Portugal (Perez Cid, Boia, Pombo, & Rebelo, 2001), 0.40–2.44 mg kg^{-1} for muscles and 1.41–3.92 mg kg^{-1} for livers of fish from Tuzla Lagoon (Dural et al., 2007), 0,03–0.40 mg kg^{-1} for muscles and 1.10–3.95 mg kg^{-1} for livers of fish from the Eastern Aegean sea (Uluturhan & Kucuksezgin, 2007). The permissible lead concentration for fish is 1.0 mg kg^{-1} according to Turkish Food Standards (TKB, 2002). Although maximum lead level in edible parts of fish were found to be lower than the Turkish permissible standards, the maximum level in livers were higher than it. In addition to, according to Nauen (1983) the maximum permissible lead levels are 0.5–6.0 mg kg^{-1} for fish, and our results were in agreement with it.

The lowest and highest zinc levels in fish were found as 4.49 mg kg^{-1} in YLV and 11.6 mg kg^{-1} in NAS for muscles, and 26.2 mg kg^{-1} in YLV and 43.5 mg kg^{-1} in CAS for livers. Zinc contents in the literature have been reported in the range of 4.71–23.1 mg kg^{-1} for muscles of fish from Ria de Averio, Portugal (Perez Cid et al., 2001), 6.1 mg kg^{-1} for muscles of *P. pagrus* (Miniadis-Meimaroglou et al., 2007), 10.7 mg kg^{-1} for muscles 36.4 mg kg^{-1} for livers of fish from Esmoriz-Paramos coastal lagoon, Portugal (Fernandes et al., 2007), 4.36 mg kg^{-1} for muscles of fish from İskenderun Bay, Turkey (Türkmen et al., 2005), 2.61–3.13 mg kg^{-1} for muscles and 19.9–38.9 mg kg^{-1} for livers of fish from the Eastern Aegean sea (Uluturhan & Kucuksezgin, 2007). The permissible zinc concentration for fish is 50 mg kg^{-1} according to Turkish Food Standards (TKB, 2002). Maximum zinc level in both edible parts and livers of fish were found to be lower than the both Turkish permissible standards and the levels (30–100 mg kg^{-1} for fish) reported by Nauen (1983).

One way ANOVA was performed to test the differences between stations. In muscles, the differences between stations were statistically significant for cadmium, cobalt, chromium, copper, manganese and nickel (Table 3). On the other hand, in livers, the differences between stations were statistically significant for chromium, iron, manganese, nickel and lead (Table 4).

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