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Accumulation of Some Heavy Metals Seasonally in *Hysterotylacium aduncum* (Nematoda) and Its Host Red Sea Bream, *Pagellus erythrinus* (Sparidae) from Gulf of Iskenderun (North-Eastern Mediterranean)

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Abstract The Red Sea Bream's nematode and *Sparus aurata,* sampled from the Iskenderun Bay, North-eastern Mediterranean in March 2008 were analysed by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) for their some heavy metal (Cd, Cr, Cu, Fe, Hg, Mn, Mg, Pb and Zn) levels. The metal concentrations of the parasites were compared to different organs (liver, muscle, swimbladder, intestine and skin) of the fish hosts. The highest Cd (0.303 mg/kgg ww) concentrations were found in the muscle, highest Cr (4.932 mg/kg ww), Hg (2.350 mg/kg ww) Pb (22.82 mg/kg ww) concentrations were found in the parasite, highest Cu (7.608 mg/kg ww) and Fe (176.7 mg/kg ww) concentrations were found in the liver, highest Mn (31.24 mg/kg ww) Zn (78.51 mg/kg ww) concentrations were found in the swimbladder for parasitized fish. The highest Cd (0.612 mg/kg ww), Cu (8.261 mg/kg ww) Fe (261.1 mg/kg ww) concentrations were found in the liver, highest Cr (6.123 mg/kg ww) and Pb (9.125 mg/kg ww) concentrations were found in the intestine, highest Hg (2.013 mg/kg ww) Zn (83.30 mg/kg ww) and Mn (41.24 mg/kg ww) concentrations were found in the swimbladder for un-parasitized fish.

Keywords *Pagellus erythrinus* · *Hysterotylacium aduncum* · Nematode · Bioindicator · Heavy metals

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Parasites occur in all food webs and some lifecycle stages occupy a higher trophic level than their host because they derive nutrients from host tissues (Valero et al. 1997). Parasite accumulation of heavy metals appears to be dependent upon a suite of factors, such as life cycle stage, developmental time in the host, as well as the host species and tissue that is infected (Sures and Taraschewski 1995).

Infection by parasites may alter host contaminant bioaccumulation, although the evidence is equivocal. For example, infected fish have been shown to accumulate both greater (Pascoe and Cram 1977) and lesser (Sures and Siddall 1999; Sures et al. 2003) amounts of contaminants than non-parasitized fish. Parasite infection is also known to negatively affect fish growth (Johnson and Dick 2001), which, in turn, can strongly influence contaminant concentrations.

A variety of wild freshwater and marine fish are subject to infection by different species of parasites. This aspect in addition to their capacity to accumulate heavy metals suggest that parasites may serve as useful indicators for biologically available metals in aquatic ecosystems that current methods of water and sediment analysis cannot accurately measure (Galli et al. 1998).

Anisakidae characteristically occur in deep waters in meso or benthopelagic species and are typically found in predators. Natural transmission also occurs in specific habitats and in relation to characteristic host diets (Abollo et al. 2001). Anisakid nematodes of the genus *Hysterothylacium* use fish as both intermediate and definitive hosts, in which they attain maturity.

Helminth parasites, *Hysterothylacium* sp. was found in sparid fish with 1.74% prevalence level (Genc 2002) and also elasmobranch fish 7.69%–78.57% prevalence levels in North-eastern Mediterranean Sea, Iskenderun Bay (Genc et al. 2005). Previous researches pointed out *Hysterothylacium* infection all around the world including the Mediterranean Sea (Petter and Cabaret 1995; Petter and Maillard 1988; Costa et al. 2004; Anderson 2000; Henderson et al. 2002; Marques et al. 2005; Valero et al. 1997).

Iskenderun Bay is situated on the Eastern Mediterranean coast of Turkey (36°20′N–35°30′E; 36°50′N–35°00′E). There are numerous plants, such as Iron and Steel Works (Isdemir), Oil Pipeline Installation (Botas) and some other small factories. The city also contains a big harbour. Moreover, due to heavy agricultural and industrial activities in the region, the bay receives large quantities of untreated industrial and domestic sewage. Therefore, it is one of the most polluted coastal waters of Turkey. Meanwhile, the Bay has an economical importance for fishery. Thus, contamination in the region is an important issue regarding the health of the aquatic animals and in turn, health of the seafood consumers.

Red sea bream (*Pagellus erythrinus*) is a sea bream rare in northern European waters, but common in the Mediterranean and southern Biscay. Lives over sand and mud, usually close to rock outcrops. Feeds on small crustaceans, molluscs and fish. Red sea bream (*Pagellus erythrinus* Linnaeus, 1758) is an important commercial species and is also one of the most consumed fish. Heavy metal concentrations in *Pagellus erythrinus* from the Turkish costs were determined by Uluturhan and Kucuksezgin (2007). The concentrations of mercury in the muscle tissue ranged between 16 and 716, in liver 125–5,451, in gonad 2.0–1,858; cadmium in muscle nd–9.6, in liver 1.4–2,245, in gonad nd–192; lead in muscle nd–1,397, in liver 112–8,311, in gonad nd–2,927; zinc in muscle 1,352–6,693, in liver 2,710–78,705, in gonad 7,273–168,655; copper in muscle nd–383, in liver nd–21,986, in gonad nd–20,499 (mg/kg wet weight). Also heavy metal concentration in *Pagellus erythrinus* from Aegean sea were determined by Uluturhan and Kucuksezgin (2005). The concentrations were as follows Hg: 16–716; Cd: nd–9.6; Pb: nd–1,397 ve Cr: nd–1,180 Pg/kg (Uluturhan and Kucuksezgin 2005).

The above mentioned examples demonstrate the great importance and overall presence of parasites in aquatic ecosystems. Due to their wide abundance and distribution several researchers started to focus on the use of parasites as indicators of environmental quality. Our specific objective was to determine whether the valid *Hysterotylacium aduncum* is a useful bioindicator species as part of a parasite-host system with Red Sea Bream, *Pagellus erythrinus* which is highly likely to be exposed to waterborne contaminants.

Materials and Methods

All samples were sampled seasonally from February 2008 until October 2008. 50 *Pagellus erythrinus* caught by fishermen's nets in Iskenderun Bay on February 2008–2009. The fish body weight, lengths, sex and age are given in Table 1. The samples were brought to the laboratory on the same day. The nematodes were collected separately from each intestine of different fish. Approximately 4 g of the muscle on the surface of the fish (epaxial muscle of dorsal side), entire liver, intestine, swimbladder and skin (ventro-lateral side) from each fish were dissected, washed with distilled water, packed in polyethylene bags and kept at −21°C until analysis.

Sample preparation and analysis were carried out according to the procedure described by UNEP/FAO/IOC/IAEA (1984). All samples were diluted with bidistilled water and assayed using ICP-AES (Varian model- Liberty Series II). All digested samples were analysed three times for each metals. The accuracy of analytical procedure was checked by analyzing the standard reference materials (National Research Council of Canada; dogfish muscle and liver) DORM 2 and DOLT 2 in 2 replicates for each batch of 46 samples digested. The metal concentration (Cd, Cr, Cu, Fe, Hg, Mn, Mg, Pb and Zn) in tissue was recorded as μg metal/g wet weight. Differences between parasitized and un-parasitized fish tissues for any metal concentration were checked by "Data analyses" built in MS Excel. ANOVA was used to evaluate the effect of parasite hosting over the metal accumulation in tissues. Then, Duncan multiple range test was performed if significant difference found in ANOVA.

Table 1 Total length–weight of Red Sea bream (*Pagellus erythrinus*)

Sample	N	TL ± SD (range, cm)	*W* ± SD (range, g)
Parasitized	21	16.67 ± 2.01 (12.50–21.40)	131.14 ± 22.52 (85.15–167.37)
Un-parasitized	29	20.07 ± 3.14 (20.78–39.02)	146.09 ± 33.18 (98.12–198.05)

N sample size, *W* mean weight of fish, *TL* mean total length of fish

Result and Discussion

In this study 21 out of 29 specimens were found infected by the anisakid nematode *Hysterothylacium aduncum* (Rudolphi 1802) collected seasonally from the Iskenderun Bay in 2008.

Seasonal concentrations of heavy metals in un-parasitized fish tissues (swimbladder, liver, muscle, intestine and skin) are given in Table 2. There were no significant differences between seasons for Cd, Mn, Pb and Zn concentrations in the muscle; for Cd and Cr concentrations in the skin; for Cd concentrations in the liver; for Cd, Cr, Cu, Fe, Hg, Pb and Zn concentrations in the intestine; for Cd, Cu, Pb and Zn concentrations in the swimbladder tissues of un-parasitized red sea bream however, there were some variations in other metals ($p < 0.05$).

The concentrations of heavy metals in fish tissues and its parasite *H. aduncum* are given in Table 3. Mean concentrations of Hg in parasite were higher than in the other tissues of host fish. There were no significant differences between seasons for Cd and Zn concentrations in the muscle; for Pb and Zn concentrations in the skin; for Hg and Pb concentrations in the liver; for Cd concentrations in the intestine and swimbladder; for Cd, Cr, Fe, Mn, Pb and Zn concentrations in the parasites of parasitized red sea bream.

Our results show that generally metal accumulation are highest in liver, swimbladder, intestine and parasite while it is low in muscle and skin in all seasons.

The highest Cd (0.303 mg/kgg ww) concentrations were found in the muscle, highest Cr (4.932 mg/kg ww), Hg (2.350 mg/kg ww) Pb (22.82 mg/kg ww) concentrations were found in the parasite, highest Cu (7.608 mg/kg ww) and Fe (176.7 mg/kg ww) concentrations were found in the liver, highest Mn (31.24 mg/kg ww) Zn (78.51 mg/kg ww) concentrations were found in the swimbladder for parasitized fish.

The highest Cd (0.612 mg/kg ww), Cu (8.261 mg/kg ww) Fe (261.1 mg/kg ww) concentrations were found in the liver, highest Cr (6.123 mg/kg ww) and Pb (9.125 mg/kg ww) concentrations were found in the intestine, highest Hg (2.013 mg/kg ww) Zn (83.30 mg/kg ww) and Mn (41.24 mg/kg ww) concentrations were found in the swimbladder for un-parasitized fish.

Alterations of metal uptake and accumulation in organisms due to parasites is a comparatively new but very important field in terms of ecotoxicological research. Following the first evidence of reduced metal uptake in infected fish compared to uninfected ones (Sures and Siddall 1999) there is now an increasing number of papers describing alterations of chemical uptake in intermediate hosts (Heinonen et al. 1999; Evans et al. 2001) as well as in final hosts due to parasitism (Sures 2003). A reduced chemical uptake in organisms used for ecotoxicological studies, for example as accumulation indicators, may erroneously indicate low levels of pollution. Therefore, bio-monitoring programmes should take into account the influence of parasite infections on the levels of pollutants in sentinels.

Anisakid nematodes of the genus *Hysterothylacium* use fish as both intermediate and definitive hosts, in which they attain maturity. Some *Hysterothylacium* species were reported from sparid fishes, namely *Pagellus acarne* (Petter and Cabaret 1995) and a related species *Diplodus sargus* from the Mediterranean (Petter and Maillard 1988). In the North Atlantic, the North Sea, the Baltic Sea, the Mediterranean Sea and adjacent temperate and cold waters, the species *Hysterothylacium aduncum* is a very common fish parasite (Margolis and Arthur 1979; Palm et al. 1999; Klimpel et al. 2001). Also Genc (2002) reported that *Hysterothylacium* sp. was found in sparid fish (Sparidae) with 1.74% prevalence level from Eastern Mediterranean of Turkey.

Our results are important in terms of understanding metal uptake and accumulation in fish tissues. The amount of lead accumulated in the different tissues investigated suggests that lead is mainly taken up by the gills. It is known from the literature that lead ions are able to pass across the epithelial membrane by paracellular diffusion and enter the blood-stream (Hofer and Lackner 1995). In the blood Pb binds to the membrane of erythrocytes and is transported by the circulatory system through various organs in the body. The liver as one of the main excretion systems in freshwater fish is believed to expel metal ions by binding them to steroids in the bile (Westerlund et al. 1998; Sures and Siddall 1999). The bile–metal complexes may then pass down the bile duct into the small intestine where these complexes can either be reabsorbed by the intestinal wall or be excreted with the faeces of the fish. This might be the reason that in all studies the highest lead levels were always detected in the intestine of fish (Sures and Siddall 1999, 2001, 2003). Accordingly, the high metal concentrations in the intestine found in the present study could be expected. Due to the repeated reabsorption of metals by the intestinal wall these substances remain in the body instead of being excreted immediately. According to a recent study by Sures and Siddall (1999) the cycling of lead in infected fish differs markedly from uninfected fish. After bile–metal complexes are transported into the intestinal lumen, the parasites are able to take up and accumulate the metals; as acanthocephalans are known to take up bile acids from the host's intestine very efficiently, this idea seems rational. By taking up the available metals from the intestine, the amount which could run through the hepatic intestinal cycle is markedly reduced for infected red sea bream as compared with their uninfected

Table 2 Seasonal and total metal concentrations (mg kg^{-1} wet weight) in tissues of un-parasitized *P. erythrinus*

Tissue	Season	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
Muscle	Spring	0.279 ± 0.04	1.348 ± 0.54^{a}	1.450 ± 0.59^{a}	13.85 ± 4.64^{a}	1.017 ± 0.81^{a}	1.160 ± 0.58	2.413 ± 0.26	16.04 ± 2.43
	Summer	0.282 ± 0.12	0.569 ± 0.09^{ab}	0.782 ± 0.10^{b}	5.502 ± 1.28^{b}	0.755 ± 0.41^{b}	0.474 ± 0.07	1.840 ± 0.37	17.94 ± 1.38
	Autum	0.309 ± 0.02	0.330 ± 0.10^{b}	1.059 ± 0.12^{a}	6.542 ± 0.71^{b}	1.805 ± 1.00^{a}	1.213 ± 0.28	3.702 ± 1.57	18.98 ± 3.70
	Winter	0.223 ± 0.07	0.422 ± 0.11^{b}	1.075 ± 0.14^{a}	9.909 ± 4.03^{ab}	1.804 ± 0.75^{a}	0.846 ± 0.07	3.153 ± 1.08	21.53 ± 2.11
	Total	0.272 ± 0.03	0.626 ± 0.15	1.088 ± 0.13	8.848 ± 1.61	1.411 ± 0.38	0.938 ± 0.15	2.870 ± 0.53	18.85 ± 1.32
Skin	Spring	0.221 ± 0.06	2.736 ± 1.06	1.818 ± 0.14^{a}	30.35 ± 6.16^{a}	0.432 ± 0.28^{a}	2.136 ± 0.41^{a}	1.942 ± 0.51^{a}	57.49 ± 4.70^{a}
	Summer	0.200 ± 0.08	0.976 ± 0.31	4.951 ± 3.31^{b}	25.50 ± 0.23^{ab}	1.524 ± 0.47^{b}	3.027 ± 0.51^{a}	2.053 ± 0.15^{a}	82.78 ± 13.7^{b}
	Autum	0.222 ± 0.01	1.951 ± 0.78	1.784 ± 0.29^{a}	24.53 ± 5.11^{ab}	0.495 ± 0.25^{ab}	6.061 ± 1.42^{b}	2.155 ± 0.62^{a}	52.87 ± 2.80^{a}
	Winter	0.198 ± 0.02	1.031 ± 0.57	0.913 ± 0.23^{a}	19.95 ± 2.42^{b}	0.757 ± 0.23^{ab}	2.840 ± 0.87^{a}	6.204 ± 1.70^{b}	56.42 ± 4.36^{a}
	Total	0.210 ± 0.09	1.703 ± 0.40	2.223 ± 0.73	23.38 ± 2.62	0.772 ± 0.17	3.369 ± 0.54	3.229 ± 0.70	61.61 ± 4.33
Liver	Spring	0.365 ± 0.10	1.980 ± 0.72^{a}	7.590 ± 1.81^{ab}	154.3 ± 43.2^{a}	1.530 ± 0.97^{a}	6.029 ± 1.49^{a}	2.162 ± 0.27^{a}	53.91 ± 7.02^{a}
	Summer	0.612 ± 0.15	0.594 ± 0.33^{b}	8.261 ± 0.66^{a}	261.1 ± 95.7^{b}	0.342 ± 0.30^{b}	5.343 ± 0.18^{a}	3.367 ± 0.92^{ab}	67.07 ± 5.18^{b}
	Autum	0.260 ± 0.05	0.244 ± 0.08^{b}	4.801 ± 1.30^{ab}	120.7 ± 39.5^{a}	0.276 ± 0.16^{b}	15.08 ± 10.6^{b}	1.877 ± 0.39^{a}	56.79 ± 11.8^{a}
	Winter	0.422 ± 0.13	0.244 ± 0.10^{b}	3.584 ± 1.03^{b}	240.5 ± 29.3^{b}	1.143 ± 0.90^{a}	5.107 ± 0.34^{a}	4.147 ± 0.55^{b}	61.45 ± 3.19^{b}
	Total	0.404 ± 0.06	0.691 ± 0.24	5.792 ± 0.76	192.2 ± 28.1	0.806 ± 0.33	8.206 ± 2.99	2.906 ± 0.36	59.71 ± 3.76
Intestine	Spring	0.268 ± 0.09	2.173 ± 0.24	6.328 ± 0.74	156.5 ± 84.2	1.036 ± 0.36	14.78 ± 4.35^{a}	4.823 ± 2.38	51.40 ± 3.86
	Summer	0.275 ± 0.06	6.123 ± 4.89	7.138 ± 2.21	93.13 ± 14.7	1.684 ± 1.42	12.32 ± 4.10^{ab}	2.379 ± 0.24	50.20 ± 2.57
	Autum	0.221 ± 0.04	0.670 ± 0.14	4.321 ± 0.72	51.89 ± 9.75	0.503 ± 0.28	4.373 ± 0.62^{b}	9.125 ± 6.90	44.52 ± 6.80
	Winter	0.309 ± 0.06	0.625 ± 0.09	4.931 ± 0.65	68.21 ± 14.6	1.172 ± 0.60	7.788 ± 2.53^{ab}	6.655 ± 1.96	47.02 ± 3.23
	Total	0.268 ± 0.02	2.148 ± 1.07	5.529 ± 0.57	87.81 ± 19.4	1.061 ± 0.33	9.283 ± 1.69	6.052 ± 2.01	47.93 ± 2.23
Swimbladder	Spring	0.083 ± 0.02	5.726 ± 0.36^{c}	1.373 ± 0.14	16.82 ± 1.08^{a}	2.013 ± 0.61^{a}	41.24 ± 7.65^{a}	1.703 ± 0.29	83.30 ± 1.87
	Summer	0.076 ± 0.04	5.010 ± 0.69^{bc}	0.940 ± 0.03	16.72 ± 6.88^{a}	1.620 ± 0.77^{ab}	32.11 ± 2.78^{b}	1.403 ± 0.41	77.09 ± 4.18
	Autum	0.050 ± 0.01	3.090 ± 0.52^{a}	0.850 ± 0.23	8.935 ± 1.57^{b}	0.562 ± 0.35^{ab}	30.48 ± 3.62^{b}	2.172 ± 0.46	64.45 ± 5.65
	Winter	0.050 ± 0.01	3.712 ± 0.49^{ab}	1.157 ± 0.18	8.385 ± 2.43^{b}	0.285 ± 0.19^{b}	33.86 ± 5.77^{b}	2.497 ± 0.43	79.27 ± 7.86
	Total	0.062 ± 0.01	4.244 ± 0.36	1.069 ± 0.09	12.13 ± 1.84	1.020 ± 0.28	34.10 ± 2.53	2.000 ± 0.22	75.43 ± 3.30

a,b,c letters show differences among seasons ($p < 0.05$)

Table 3 Seasonal and total metal concentrations (mg kg^{-1} wet weight) in tissues of *P. erythrinus* and in the parasite *H. Aduncum*

Tissue	Season	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Zn
Muscle	Spring	0.229 ± 0.01	1.020 ± 0.04^{a}	2.142 ± 0.16^{a}	10.71 ± 0.38^{a}	0.306 ± 0.03^{ab}	0.678 ± 0.02^{a}	2.610 ± 0.20^{ab}	16.20 ± 0.82
	Summer	0.303 ± 0.05	0.780 ± 0.05^{a}	1.216 ± 0.23^{b}	7.080 ± 1.94^{b}	0.270 ± 0.01^{a}	0.840 ± 0.06^{b}	2.210 ± 0.16^{a}	16.20 ± 0.82
	Autum	0.302 ± 0.01	0.493 ± 0.01^{b}	0.940 ± 0.02^{b}	6.984 ± 0.99^{b}	0.568 ± 0.16^{bc}	1.033 ± 0.01^{c}	4.929 ± 1.82^{bc}	16.90 ± 0.33
	Winter	0.300 ± 0.01	0.567 ± 0.04^{b}	1.087 ± 0.07^{b}	7.010 ± 0.35^{b}	0.652 ± 0.07^{c}	0.970 ± 0.03^{c}	7.117 ± 0.43^{c}	13.35 ± 0.66
	Total	0.281 ± 0.01	0.726 ± 0.06	1.385 ± 0.14	8.078 ± 0.62	0.453 ± 0.05	0.872 ± 0.04	4.309 ± 0.66	15.69 ± 0.64
Skin	Spring	0.237 ± 0.02^{a}	2.197 ± 0.08^{ab}	1.642 ± 0.04^{ab}	23.87 ± 1.42^{a}	0.996 ± 0.08^{a}	2.137 ± 0.05^{a}	2.420 ± 0.13	44.31 ± 1.61
	Summer	0.180 ± 0.01^{ab}	1.833 ± 0.14^{a}	1.420 ± 0.11^{a}	23.66 ± 1.58^{ab}	0.563 ± 0.14^{b}	2.853 ± 0.20^{a}	2.213 ± 0.21	44.94 ± 1.81
	Autum	0.205 ± 0.01^{ab}	2.162 ± 0.66^{ab}	1.767 ± 0.30^{ab}	25.48 ± 4.61^{ab}	0.281 ± 0.04^{b}	5.809 ± 1.53^{b}	2.290 ± 0.57	51.82 ± 3.16
	Winter	0.172 ± 0.02^{b}	2.927 ± 0.12^{b}	2.102 ± 0.07^{b}	28.01 ± 1.96^{b}	0.280 ± 0.06^{b}	3.862 ± 0.28^{ab}	2.845 ± 0.28	47.66 ± 3.28
	Total	0.199 ± 0.01	2.320 ± 0.17	1.753 ± 0.09	25.35 ± 1.19	0.545 ± 0.09	3.570 ± 0.47	2.469 ± 0.15	47.01 ± 1.39
Liver	Spring	0.237 ± 0.02^{a}	0.960 ± 0.10^{a}	3.689 ± 0.62^{ab}	108.8 ± 2.75^{a}	0.013 ± 0.01	4.838 ± 0.43^{ab}	1.999 ± 0.05	47.92 ± 1.84^{a}
	Summer	0.132 ± 0.01^{ab}	0.621 ± 0.29^{ab}	2.678 ± 0.14^{a}	111.8 ± 7.80^{ab}	0.019 ± 0.01	2.460 ± 0.38^{a}	1.940 ± 0.12	43.43 ± 5.85^{a}
	Autum	0.205 ± 0.01^{ab}	0.240 ± 0.04^{b}	7.608 ± 0.60^{b}	176.7 ± 36.9^{c}	0.012 ± 0.01	5.226 ± 1.66^{b}	2.221 ± 0.36	64.07 ± 7.97^{b}
	Winter	0.197 ± 0.03^{b}	0.287 ± 0.06^{b}	4.480 ± 0.33^{c}	164.3 ± 9.02^{bc}	0.017 ± 0.01	5.092 ± 0.33^{b}	1.992 ± 0.04	57.22 ± 1.33^{ab}
	Total	0.196 ± 0.01	0.541 ± 0.10	4.538 ± 0.52	139.9 ± 11.1	0.015 ± 0.01	4.484 ± 0.45	2.032 ± 0.07	53.08 ± 2.83
Intestine	Spring	0.229 ± 0.01	2.115 ± 0.12^{a}	6.444 ± 0.37^{a}	251.9 ± 37.3^{a}	1.386 ± 0.12^{a}	17.84 ± 2.05^{a}	8.632 ± 0.36^{a}	51.49 ± 1.62^{a}
	Summer	0.198 ± 0.03	1.420 ± 0.19^{b}	4.341 ± 0.58^{b}	53.92 ± 4.45^{b}	1.262 ± 0.21^{a}	6.038 ± 1.96^{b}	3.700 ± 0.98^{a}	50.92 ± 1.58^{a}
	Autum	0.167 ± 0.03	0.695 ± 0.18^{c}	3.459 ± 0.23^{b}	38.50 ± 2.46^{b}	0.886 ± 0.06^{b}	4.612 ± 0.19^{b}	21.72 ± 4.24^{b}	33.72 ± 1.75^{b}
	Winter	0.160 ± 0.02	0.765 ± 0.05^{c}	3.620 ± 0.13^{b}	47.67 ± 3.45^{b}	0.757 ± 0.03^{b}	7.637 ± 0.80^{b}	9.307 ± 0.38^{a}	33.65 ± 1.56^{b}
	Total	0.189 ± 0.05	1.276 ± 0.17	4.547 ± 0.37	105.4 ± 27.5	1.072 ± 0.09	9.562 ± 1.62	10.57 ± 1.89	42.46 ± 2.54
Swimbladder	Spring	0.025 ± 0.01	4.906 ± 0.64^{a}	1.653 ± 0.12^{a}	14.45 ± 1.15^{a}	0.769 ± 0.03^{a}	31.24 ± 0.98^{a}	2.199 ± 0.09^{ab}	78.51 ± 1.69^{a}
	Summer	0.036 ± 0.01	4.700 ± 0.32^{a}	1.066 ± 0.14^{b}	12.51 ± 1.70^{a}	0.620 ± 0.13^{ab}	27.76 ± 1.45^{ab}	1.960 ± 0.03^{a}	71.86 ± 2.26^{a}
	Autum	0.036 ± 0.01	2.832 ± 0.56^{b}	1.072 ± 0.13^{b}	8.547 ± 1.01^{b}	0.295 ± 0.21^{b}	24.33 ± 2.34^{b}	2.505 ± 0.51^{ab}	62.13 ± 5.52^{b}
	Winter	0.037 ± 0.01	2.667 ± 0.46^{b}	1.042 ± 0.17^{b}	7.470 ± 0.27^{b}	0.530 ± 0.03^{ab}	26.19 ± 1.46^{ab}	2.920 ± 0.05^{b}	57.43 ± 0.82^{b}
	Total	0.035 ± 0.01	3.778 ± 0.37	1.228 ± 0.09	10.77 ± 0.94	0.567 ± 0.06	27.57 ± 0.98	2.419 ± 0.14	67.55 ± 2.66
Parasite	Spring	0.053 ± 0.02	0.388 ± 0.12	0.895 ± 0.04^{a}	4.906 ± 0.14	0.827 ± 0.08^{ab}	0.804 ± 0.03	3.106 ± 0.39	25.58 ± 5.81
	Summer	0.056 ± 0.01	2.812 ± 0.14	1.275 ± 0.07^{b}	37.69 ± 1.75	1.496 ± 0.10^{a}	1.640 ± 0.17	9.823 ± 0.70	27.71 ± 2.72
	Autum	0.030 ± 0.01	2.603 ± 0.07	2.170 ± 0.14^{a}	29.55 ± 2.46	2.350 ± 0.31^{b}	2.358 ± 0.33	9.596 ± 0.39	28.59 ± 2.06
	Winter	0.060 ± 0.01	4.932 ± 1.61	2.307 ± 0.26^{ab}	53.66 ± 4.21	2.160 ± 0.26^{c}	2.522 ± 0.73	22.82 ± 4.60	32.12 ± 2.78
	Total	0.050 ± 0.01	2.684 ± 0.59	1.661 ± 0.19	31.45 ± 5.42	1.708 ± 0.20	1.831 ± 0.27	11.33 ± 2.37	28.50 ± 1.71

a,b,c letters show differences among seasons ($p < 0.05$)

conspecifics. As a consequence, Sures and Siddall (1999) described significantly lower metal levels in the intestine of infected fish than of uninfected fish.

A number of studies have shown that various factors such as season (Kargın 1996), length and weight, physical and chemical status of water (Jezierska and Witeska 2001) can play a role in the tissue accumulation of metals. Seasonal changes of metal concentrations in fish and parasites may result from intrinsic factors such as growth cycle and reproductive cycle and from changes in water temperature. Additionally, the differences noted in the metal concentrations in different tissues between seasons could have been the result of local pollution. Generally metal concentrations in the tissues and parasite were significantly different among seasons ($p < 0.05$) (Tables 2, 3). Muscle, generally, accumulated the lowest levels of metals in every season except Cd for parasited fish.

Recent field studies have demonstrated that particular fish parasites can accumulate toxic metals from the aquatic environment. Thus, the application of certain parasites as sentinel organisms could provide a promising new domain for future research in environmental parasitology research.

Turkish legislation establishes maximum levels for four of the metals studied, above which human consumption is not permitted as; 0.1 mg/kg for Cd, 1.0 mg/kg for Pb, 20.0 mg/kg for Cu, 50 mg/kg for Zn (Anonymous 1996). Food and Agricultural Organization limits for Cd and Pb 0.5 mg/kg, for Cu and Zn 30 mg/kg (FAO 1983). All seasons the concentrations of Cd, Pb concentrations in the muscle tissues were higher than the maximum levels set by law.

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