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Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt

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ABSTRACT

The concentrations of heavy metals (Cu, Zn, Pb, Cd, Fe and Mn) were measured in the liver, gills and muscles of fourteen benthic and pelagic fish species collected from three main landing areas (Shalateen, Hurghada and Suez) in the Egyptian Red Sea. The levels of heavy metals varied significantly among fish species and organs. As expected, muscles always possessed the lowest concentrations of all metals. In most studied fish, the liver was the target organ for Cu, Zn and Fe accumulation. Pb and Mn, however, exhibited their highest concentrations in the gills. Different species of fish showed inter-specific variation of metals, as well as variations between fish from the same species. These differences were discussed for the contribution of potential factors that affected metals' uptake, like age, geographical distribution and species' specific factors. Generally, recorded metal concentrations were within the range or below the levels in similar species from global studies. The concentration of metals in the present fish muscles were accepted by the international legislation limits and are safe for human consumption.

1. Introduction

In the recent years, world consumption of fish has increased simultaneously with the growing concern of their nutritional and therapeutic benefits. In addition to its important source of protein, fish typically have rich contents of essential minerals, vitamins and unsaturated fatty acids [1]. The American Heart Association recommended eating fish at least twice per weak in order to reach the daily intake of omega-3 fatty acids [2].

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However, fish are relatively situated at the top of the aquatic food chain; therefore, they normally can accumulate heavy metals from food, water and sediments [3,4]. The content of toxic heavy metals in fish can counteract their beneficial effects; several adverse effects of heavy metals to human health have been known for long time [5]. This may include serious threats like renal failure, liver damage, cardiovascular diseases and even death [6,7]. Therefore, many international monitoring programs have been established in order to assess the quality of fish for human consumption and to monitor the health of the aquatic ecosystem [8].

In the last few decades, the concentrations of heavy metals in fish have been extensively studied in different parts of the world [9]. Most of these studies concentrated mainly on the heavy metals in the edible part (fish muscles). However, other studies reported the distribution of metals in different organs like the liver, kidneys, heart, gonads, bone, digestive tract and brain.

According to the literatures, metal bioaccumulation by fish and subsequent distribution in organs is greatly inter-specific. In addition, many factors can influence metal uptake like sex, age, size, reproductive cycle, swimming patterns, feeding behavior and living environment (i.e., geographical location) [4,10].

Red Sea is a semi-enclosed tropical body of water. It has been considered to be a relatively unpolluted marine environment. In the last few decades, however, evidence of heavy metal pollution has been found in various locations [12]. In the northern part of the Egyptian Red Sea, increasing population growth and industrial activities in Suez City are the main sources of heavy metal pollution. While in the southern part, the tourism industry and shipping of ores are the major sources of the anthropogenic input of heavy metals.

In Egypt, the Red Sea is of great ecological interest; it is an important source of fisheries and tourism industry. In spite of that, heavy metals' studies in the Red Sea are restricted. Relatively few studies investigated the levels of metals in some fish species from the Red Sea [13–20]. However due to increasing anthropogenic and industrial stress on the Red Sea, continuous monitoring of the environmental conditions of the Red Sea is required.

In the present study, levels of heavy metals in the organs of some commercial fish from landing areas on the Egyptian Red Sea were determined, aiming to evaluate the current environmental status of this broad section of the Red Sea. Also metals' content in muscles were compared against the recommended maximum permissible limit (MPL) to assess the quality of fish for human consumption.

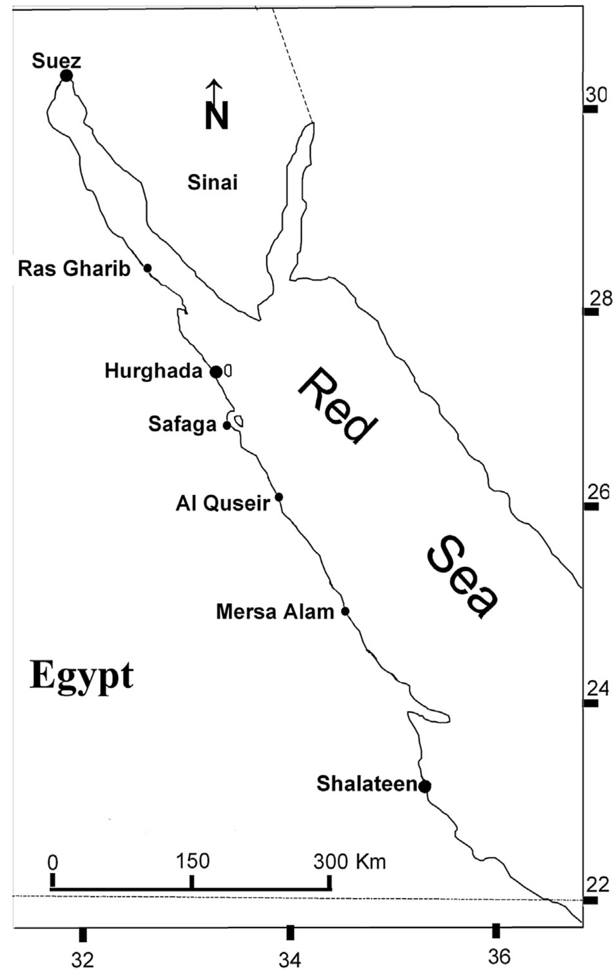

Fig. 1 – Red Sea map showing the sites of sampling.

2. Materials and methods

2.1. *Fish sampling*

Fourteen commercial fish species were purchased from local fishermen at three main fish landing areas on the Red Sea: Shalateen, Hurghada and Suez (Fig. 1) during December 2010 and January 2011. The collected species were: *Epinephelus* sp., *Caranx* sp., *Scarus gibbus*, *Nemipterus japonicus*, *Sardinella* sp., *Synodus* sp., *Carangoides bajad*, *Lutjanus bohar*, *Thunnus albacares*, *Gerres oyena*, *Sargocentron spiniferum*, *Siganus rivulatus*, *Lethrinus* sp. and *Trachurus mediterraneus*. These fish species represent different biotops and are economically important (Table 1).

Collected fish were immediately preserved in an ice box and transferred to the laboratory where they were classified, weighed, measured by total length and kept frozen at −20 °C until further analysis.

2.2. *Determination of metal concentrations*

Preparation of subsamples and analysis were made according to FAO Technical Paper No. 212 [21]. For metal analysis, frozen fish were partially thawed, and each fish was dissected using stainless steel instruments. Muscles, liver and gills were taken out; composite samples of 2–5 g were used for subsequent analysis.

The samples were digested with ultra pure nitric acid (and perchloric acid for gills 4:1) at 100 °C until the solution become clear. The solution was made up to known volume with deionized distilled water and analyzed for Cu, Zn, Pb, Cd, Fe and Mn using the Atomic Absorption Spectrophotometer (AAS model GPC A932 ver. 1.1). The obtained results were expressed as μg/g wet weight.

Table 1 – The ecological characteristics and recorded morphometric measures of examined fish species.

	Scientific name	English name	Feeding habits	Biotype complex	No. of samples	Length (cm)	Weight (g)
Shalateen	*Epinephelus* sp.	Grouper	Predatory, Carnivore (small fish and benthic invertebrates)	Reef-associated	5	27–35	259–680
	Caranx sp.	Trevally	Carnivore (fish and invertebrates)	Plagic	1	87.5	24,500
	Scarus gibbus	Parrotfish	Herbivore (on algae)	Pelagic (Reef-associated)	4	34.1–37.6	450–555
	Synodus sp.	Lizard fish	Carnivore (small fish)	Demersal (benthic)	10	16.5–20.1	32–51
	Nemipterus japonicus	Threadfine bream	Carnivore (small fish, invertebrates polychates)	Demersal	10	14.5–19.1	33–69
	Carangoides bajad	Gold-spotted trevally	Carnivore (fish and crusteceans)	Plagic	1	33.50	496.00
	Lutjanus bohar	Snappers	Canivore (fish and invertebrates)	Plagic (Reef-associated)	4	32–36	456–635
	Thunnus albacares	yellowfin tuna	Carnivore (fish and invertebrates)	Plagic	4	39–50	448–7500
	Gerres oyena	Silver biddy	Carnivore (small invertebrates living on sandy bottoms)	Demersal	5	17.5–24.7	58–168
	Sargocentron spiniferum	Squirrelfish	Carnivore (on small crusteceans)	Plagic (Reef-associated)	5	17.9–29	83.5–413
Hurghada	*Epinephelus* sp.	Grouper	Predatory, Carnivore (small fish and benthic invertebrates)	Reef-associated	4	32–34.8	543–650
	Caranx sp.	Trevally	Carnivore (fish and invertebrates)	Plagic	1	39.6	6250
	Scarus gibbus	parrotfish	herbivore (on algae)	Pelagic (Reef-associated)	4	26.20–33.6	315–486
	Sardinella sp.	Sardinella	Filter feeders on phytoplankton and zooplankton	Plagic	8	20.1–25	69–142
	Siganus rivulatus	Marbled Spinefoot	Herbivore	Demersal (Reef-associated)	10	18.2–20.1	68–105
Suez	*Epinephelus* sp.	Grouper	Predatory, Carnivore (small fish and benthic invertebrates)	Reef-associated	4	23–24.5	156.3–189
	Synodus synodus	Lizard fish	Carnivore (small fish)	Demersal (benthic)	10	16–17	22.2–34
	Nemipterus japonicus	Threadfine bream	Carnivore (small fish, invertebrates polychates)	Demersal	10	16–19	59.5–89.5
	Sardinella sp.	Sardinella	Filter feeders on phytoplankton and zooplankton	Plagic	10	13–15.5	17.3–31.5
	Trachurus mediterraneus	horse mackerel	Carnivore (invertebrates and fish)	Plagic	10	14.5–18	26.9–43.7
	Lethrinus sp.	Emperor	Carvivore (echinoderms, mollusks and crustaceans)	Plagic (Reef-associated)	4	21–28	138–257

All reagents were of analytical grade; glassware were soaked in 10% nitric acid and later rinsed with distilled water prior to use in order to avoid metal contamination.

Accuracy and precision were verified by using reference materials (MA-A-2/TM) provided by the International Atomic Agency (IAEA). Analytical results of the quality control samples indicated a satisfactory performance of heavy metal determination within the range of certified values 95–111% recovery for the metals studied.

2.3. Statistical analysis

Three-way analysis of variance (ANOVA) was used to indicate significant differences in metal levels among sites, species and organs. And one-way (ANOVA) was used to compare metals between species in single organ (significant values, $p \leq 0.05$). All data were checked, beforehand, for the homogeneity of variances and normality; the data which were not normally distributed or not homogeneous were transformed. ANOVA was followed by Duncan's multiple range test to determine the position of the variance. All statistical calculations were carried out with SPSS 18.0 for Windows.

3. Results

Concentrations of heavy metals (Cu, Zn, Pb, Cd, Fe and Mn) in the muscles, liver and gills of fish collected from landing sites (Shalateen, Hurghada and Suez) on the Red Sea are given in Tables 2–4, respectively. Accumulation patterns of all metals were significantly different ($p < 0.001$) between the different species, organs and sites (except for Fe) (Table 5).

As shown in Tables 2–4, all fish contained the lowest concentrations of metals in muscles, while almost all fish species showed the highest concentrations of Cu, Zn and Fe in the liver, and the highest concentrations of Pb and Mn in the gills. For Cd, the highest concentrations fluctuated between the liver in some species and gills in others. Duncan's multiple range test indicated variations of metals as the highest levels of Cu, Zn, Cd and Fe in the liver and the highest Pb and Mn in the gills; while muscles significantly possessed lowest concentration of all metals.

Regarding the geographical variation of metals, there was no consistent increase of metals in all fish species from one site. However, statistically, Suez showed significantly high

Table 2 – Mean (±SD) concentrations of heavy metals (μg/g wet weight) in some organs of fish species collected from Shalateen.

		Cu^{C}	Zn^{B}	Pb^{B}	Cd^{B}	Fe	Mn^{B}
Epinephelus sp.	Muscle	0.29 ± 0.05	2.42 ± 0.22	**0.88 ± 0.12**^{a}	0.12 ± 0.02	3.35 ± 0.79	0.15 ± 0.04
	Liver	9.60 ± 2.33	**59.89 ± 10.02**^{ab}	**3.08 ± 0.78**^{a}	0.86 ± 0.15	291.76 ± 47.60	1.02 ± 0.40
	Gills	1.88 ± 0.32	29.00 ± 1.24	4.86 ± 1.82	0.75 ± 0.24	44.52 ± 8.05	1.73 ± 0.14
Caranx sp.	Muscle	0.36 ± 0.02	2.88 ± 0.11	0.28 ± 0.05	0.07 ± 0.01	7.12 ± 0.74	0.16 ± 0.02
	Liver	2.93 ± 0.18	27.30 ± 1.51	0.48 ± 0.11	**8.37 ± 0.32**^{a}	71.93 ± 8.35	0.97 ± 0.04
	Gills	1.36 ± 0.05	15.10 ± 1.49	1.92 ± 0.20	0.32 ± 0.04	46.05 ± 5.17	1.94 ± 0.49
Scarus gibbus	Muscle	0.30 ± 0.06	*1.17 ± 0.63*^{x}	*0.21 ± 0.09*^{x}	0.03 ± 0.01	2.07 ± 0.42	0.12 ± 0.02
	Liver	*0.76 ± 0.13*^{x}	*1.76 ± 0.33*^{x}	*0.14 ± 0.15*^{x}	*0.03 ± 0.02*^{x}	45.05 ± 6.61	*0.17 ± 0.02*^{x}
	Gills	2.26 ± 0.55	*7.77 ± 1.18*^{x}	1.54 ± 0.59	0.27 ± 0.08	58.59 ± 10.89	8.80 ± 2.35
Synodus sp.	Muscle	0.22 ± 0.06	1.92 ± 0.45	0.51 ± 0.14	0.07 ± 0.02	2.81 ± 0.34	0.24 ± 0.08
	Liver	4.65 ± 1.22	29.31 ± 2.99	1.00 ± 0.11	0.34 ± 0.24	142.46 ± 7.23	0.86 ± 0.19
	Gills	**2.97 ± 0.28**^{a}	**42.87 ± 6.98**^{b}	**6.93 ± 1.40**^{a}	1.15 ± 0.14	**324.40 ± 46.25**^{a}	**15.54 ± 4.27**^{b}
Nemipterus japonicus	Muscle	0.29 ± 0.04	2.22 ± 0.21	0.46 ± 0.15	0.06 ± 0.02	2.21 ± 0.87	0.12 ± 0.03
	Liver	2.15 ± 0.29	42.50 ± 10.08	0.17 ± 0.02	0.40 ± 0.15	74.99 ± 18.64	1.12 ± 0.14
	Gills	1.68 ± 0.18	19.78 ± 1.57	2.27 ± 0.65	0.70 ± 0.13	73.61 ± 8.09	7.98 ± 1.40
Carangoides bajad	Muscle	0.33 ± 0.04	3.08 ± 0.77	0.52 ± 0.27	0.08 ± 0.04	3.10 ± 0.12	0.13 ± 0.03
	Liver	3.09 ± 0.61	27.49 ± 0.56	1.64 ± 0.15	0.78 ± 0.04	335.47 ± 45.51	0.94 ± 0.03
	Gills	2.27 ± 0.24	24.77 ± 2.92	4.46 ± 1.17	0.70 ± 0.09	61.74 ± 3.08	3.72 ± 0.42
Lutjanus bohar	Muscle	0.24 ± 0.11	2.08 ± 0.28	0.51 ± 0.05	0.03 ± 0.02	2.05 ± 0.26	0.10 ± 0.03
	Liver	4.41 ± 0.36	36.02 ± 0.26	0.83 ± 0.03	0.86 ± 0.01	322.55 ± 58.10	1.29 ± 0.12
	Gills	2.50 ± 0.16	25.45 ± 2.31	2.30 ± 0.45	0.59 ± 0.05	44.18 ± 9.17	1.43 ± 0.08
Thunnus albacares	Muscle	0.35 ± 0.06	1.99 ± 0.33	0.32 ± 0.03	0.06 ± 0.01	2.93 ± 0.98	0.11 ± 0.02
	Liver	5.61 ± 0.85	24.54 ± 3.16	0.63 ± 0.10	0.40 ± 0.02	224.43 ± 32.68	0.77 ± 0.29
	Gills	1.71 ± 0.04	33.41 ± 3.48	2.61 ± 0.33	0.51 ± 0.06	69.65 ± 10.06	5.88 ± 0.78
Gerres oyena	Muscle	0.31 ± 0.03	**12.03 ± 1.72**^{a}	0.41 ± 0.11	0.05 ± 0.01	5.73 ± 2.13	0.17 ± 0.06
	Liver	2.53 ± 0.83	27.16 ± 2.73	0.82 ± 0.12	0.31 ± 0.10	282.68 ± 65.45	1.58 ± 0.32
	Gills	2.04 ± 0.11	29.36 ± 5.61	2.98 ± 0.84	0.50 ± 0.13	91.52 ± 22.93	4.70 ± 0.14
Sargocentron spiniferum	Muscle	0.24 ± 0.04	2.43 ± 0.22	0.28 ± 0.07	0.06 ± 0.02	5.48 ± 1.94	0.20 ± 0.08
	Liver	3.19 ± 0.96	34.01 ± 3.57	0.19 ± 0.01	0.59 ± 0.06	181.00 ± 12.64	1.40 ± 0.24
	Gills	1.45 ± 0.22	21.06 ± 1.82	2.01 ± 0.42	0.51 ± 0.08	50.36 ± 4.88	6.57 ± 1.81

Capital letters indicate significant variations between sites.
Small letters mark significant highest concentrations in different species from the three sites.
x is the lowest metal concentration in different species.

concentrations of metals (Cu, Zn, Pb, Cd and Mn) when compared to other sites (Table 5).

The accumulation of metals in a single species showed significant inter-specific variations in all metals. However it can be noticed that, different organs exhibited different patterns in metals accumulation. In other words, no single type of fish showed the highest metals in all organs (except Mn in *Sardinella* sp.). Therefore, concentrations of metals between

Table 3 – Mean (±SD) concentrations of heavy metals (μg/g wet weight) in some organs of fish species collected from Hurghada.

		Cu^{B}	Zn^{B}	Pb^{C}	Cd^{C}	Fe	Mn^{B}
Epinephelus sp.	Muscle	0.21 ± 0.07	3.00 ± 0.43	0.45 ± 0.09	0.05 ± 0.01	2.96 ± 0.38	0.17 ± 0.04
	Liver	8.79 ± 2.70	34.63 ± 4.86	1.16 ± 0.49	0.24 ± 0.03	156.78 ± 105.61	0.58 ± 0.20
	Gills	*1.07 ± 0.19*^{x}	20.23 ± 4.78	1.60 ± 0.52	0.33 ± 0.07	*19.95 ± 3.10*^{x}	*1.01 ± 0.40*^{x}
Caranx sp.	Muscle	0.46 ± 0.01	4.94 ± 2.52	0.25 ± 0.10	0.05 ± 0.02	9.53 ± 2.77	0.13 ± 0.03
	Liver	6.23 ± 0.82	37.12 ± 2.23	0.62 ± 0.17	0.40 ± 0.09	184.07 ± 71.46	1.27 ± 0.11
	Gills	1.26 ± 0.31	21.96 ± 0.59	2.18 ± 0.43	0.38 ± 0.05	67.68 ± 12.41	1.97 ± 0.27
Scarus gibbus	Muscle	0.37 ± 0.01	2.07 ± 0.09	0.24 ± 0.03	*0.03 ± 0.004*^{x}	3.04 ± 0.48	0.16 ± 0.02
	Liver	2.29 ± 0.11	17.66 ± 0.04	2.02 ± 0.19	0.35 ± 0.04	118.56 ± 3.46	1.06 ± 0.04
	Gills	2.38 ± 0.86	11.68 ± 4.51	*1.03 ± 0.50*^{x}	*0.19 ± 0.06*^{x}	30.92 ± 10.70	4.63 ± 1.79
Sardinella sp.	Muscle	**0.63 ± 0.10**^{a}	**6.49 ± 1.83**^{b}	0.25 ± 0.08	0.07 ± 0.01	**11.53 ± 1.68**^{a}	0.29 ± 0.05
	Liver	2.81 ± 0.14	22.07 ± 1.39	1.05 ± 0.45	0.42 ± 0.08	189.35 ± 5.24	**1.84 ± 0.45**^{b}
	Gills	1.63 ± 0.15	39.45 ± 12.15	1.46 ± 0.23	0.49 ± 0.09	121.37 ± 20.35	8.37 ± 2.43
Siganus rivulatus	Muscle	0.35 ± 0.03	3.20 ± 0.67	0.44 ± 0.11	0.05 ± 0.01	9.12 ± 4.45	0.27 ± 0.12
	Liver	**18.62 ± 2.52**^{a}	51.70 ± 15.26	0.64 ± 0.28	1.14 ± 0.48	139.27 ± 19.21	0.80 ± 0.18
	Gills	2.55 ± 0.04	23.08 ± 0.92	2.32 ± 0.46	0.52 ± 0.04	117.38 ± 19.05	7.96 ± 2.77

Capital letters indicate significant variations between sites.
Small letters mark significant highest concentrations in different species from the three sites.
x is the lowest metal concentration in different species.

Table 4 – Mean (±SD) concentrations of heavy metals (μg/g wet weight) in some organs of fish species collected from Suez.

		Cu[A]	Zn[A]	Pb[A]	Cd[A]	Fe	Mn[A]
Epinephelus sp.	Muscle	0.23 ± 0.01	3.98 ± 0.61	0.43 ± 0.05	**0.20 ± 0.06**[b]	2.54 ± 1.29	0.16 ± 0.01
	Liver	8.51 ± 1.13	**64.61 ± 6.46**[a]	1.45 ± 0.20	1.68 ± 0.45	418.64 ± 37.42	1.16 ± 0.04
	Gills	2.32 ± 0.35	29.29 ± 4.20	4.86 ± 1.45	**1.33 ± 0.26**[b]	27.04 ± 3.93	6.29 ± 1.42
Synodus sp.	Muscle	0.17 ± 0.02 [x]	3.71 ± 0.10	0.28 ± 0.09	0.04 ± 0.01	1.61 ± 0.54	0.23 ± 0.03
	Liver	8.00 ± 2.78	37.91 ± 1.95	1.60 ± 0.52	0.19 ± 0.01	34.75 ± 3.34 [x]	0.81 ± 0.16
	Gills	1.67 ± 0.23	34.04 ± 6.72	3.24 ± 0.12	0.40 ± 0.03	**241.47 ± 96.20**[b]	8.94 ± 2.27
Nemipterus japonicus	Muscle	0.20 ± 0.09	2.70 ± 0.09	0.28 ± 0.01	0.04 ± 0.01	**1.15 ± 0.23**	0.11 ± 0.01
	Liver	**17.54 ± 5.42**[a]	**60.90 ± 15.76**[ab]	0.39 ± 0.08	0.15 ± 0.03	83.64 ± 48.54	0.75 ± 0.27
	Gills	1.32 ± 0.11	23.32 ± 2.30	2.36 ± 0.43	0.34 ± 0.02	68.32 ± 7.99	9.90 ± 2.33
Sardinella sp.	Muscle	**0.74 ± 0.28**[a]	**8.23 ± 1.88**[b]	0.50 ± 0.43	**0.38 ± 0.29**[a]	**10.92 ± 4.11**[a]	**0.93 ± 0.19**[a]
	Liver	3.94 ± 0.88	25.12 ± 6.57	1.34 ± 0.12	1.98 ± 0.17	225.14 ± 10.71	**2.87 ± 0.28**[a]
	Gills	2.06 ± 0.15	**59.90 ± 2.72**[a]	3.76 ± 1.13	**1.68 ± 0.38**[a]	112.52 ± 23.43	**33.98 ± 6.25**[a]
Trachurus mediterraneus	Muscle	**0.77 ± 0.14**[a]	4.21 ± 0.19	0.40 ± 0.17	**0.20 ± 0.02**[b]	6.25 ± 0.46	0.18 ± 0.02
	Liver	4.52 ± 0.28	43.64 ± 3.49	1.59 ± 0.06	1.59 ± 0.37	304.52 ± 146.56	0.94 ± 0.17
	Gills	2.26 ± 0.04	39.80 ± 8.16	4.03 ± 1.06	0.56 ± 0.15	168.93 ± 38.69	6.31 ± 0.50
Lethrinus sp.	Muscle	0.25 ± 0.07	3.41 ± 0.69	0.25 ± 0.07	**0.23 ± 0.06**[b]	3.03 ± 0.38	0.10 ± 0.03 [x]
	Liver	7.63 ± 0.91	52.94 ± 7.70	1.09 ± 0.84	1.44 ± 0.10	**656.98 ± 60.13**[a]	1.29 ± 0.27
	Gills	1.99 ± 0.94	21.43 ± 3.61	3.09 ± 0.79	1.00 ± 0.31	41.80 ± 12.69	3.17 ± 0.07

Capital letters indicate significant variations between sites.
Small letters mark significant highest concentrations in different species from the three sites.
x is the lowest metal concentration in different species.

species were analyzed in single organ; all results showed significant variations between species. Furthermore, some fish from the same species collected from different sites also significantly accumulated different concentrations of metals (ANOVA: $p < 0.001$ in all cases). Variations of metals distribution in the studied fish can be summarized as the following:

3.1. *Copper (Cu)*

In the liver, the herbivore *S. rivulatus* accumulated the highest concentration of Cu (18.62 ± 2.52 μg/g wet wt); while another herbivore species (*S. gibbus*) showed the lowest values (0.76 ± 0.13 μg/g wet wt). Gills showed a narrow range of Cu levels and recorded concentrations from 1.07 ± 0.19 (*Epinephelus* sp., Hurghada) to 2.97 ± 0.28 μg/g wet wt (*Synodus* sp., Shalateen). Concentrations of Cu in muscles ranged from 0.17 ± 0.02 (*Synodus* sp., Suez) to 0.77 ± 0.14 μg/g wet wt (*T. mediterraneus*, Suez).

3.2. *Zinc (Zn)*

Epinephelus sp. exhibited a tendency to accumulated high concentration of Zn in the liver when compared to other species (64.61 ± 6.46 μg/g wet wt in Shalateen). *Sardinella* sp. recorded the highest concentrations of Zn in gills (59.90 ± 2.72 μg/g wet wt in Suez), while the highest concentrations of Zn in muscles were recorded in *G. oyena* (12.03 ± 1.72 μg/g wet wt). On the other hand, the herbivore *S. gibbus* (from Shalateen) recorded the lowest Zn concentrations in all studied organs (1.76 ± 0.33, 7.77 ± 1.18 and 1.17 ± 0.63 μg/g wet wt in the liver, gills and muscles respectively).

3.3. *Lead (Pb)*

Concentrations of Pb in gills ranged from 1.03 ± 0.5 (*S. gibbus*, Hurghada) to 6.93 ± 1.40 μg/g wet wt (*Synodus* sp., Shalateen). Liver showed a wide range of Pb levels ranging from 0.14 ± 0.15 (*S. gibbus*, Shalateen) to 3.08 ± 0.78 μg/g wet wt (*Epinephelus* sp., Shalateen), while the concentrations of Pb in muscles ranged from 0.21 ± 0.09 (*S. gibbus*, Shalateen) to 0.88 ± 0.12 μg/g wet wt (*Epinephelus* sp., Shalateen).

3.4. *Cadmium (Cd)*

Liver showed a wide range of Cd concentrations among the studied fish, a very low Cd concentration (0.03 ± 0.02 μg/g wet wt) was recorded in *S. gibbus* (from Shalateen), and an

Table 5 – Three-way ANOVA showing variations in metals between locations, organs and different species.

	Source	df	F	*p*	Cd	Source	df	F	*p*
Cu	Site	2	27.689	<0.001		Site	2	542.142	<0.001
	Species	13	22.027	<0.001		Species	13	183.981	<0.001
	Organ	2	596.528	<0.001		Organ	2	459.103	<0.001
Zn	Site	2	18.894	<0.001	Fe	Site	2	1.087	0.34
	Species	13	17.039	<0.001		Species	13	20.536	<0.001
	Organ	2	803.842	<0.001		Organ	2	680.953	<0.001
Pb	Site	2	13.067	<0.001	Mn	Site	2	73.435	<0.001
	Species	13	14.084	<0.001		Species	13	45.616	<0.001
	Organ	2	314.038	<0.001		Organ	2	570.757	<0.001

extremely high concentration (8.37 ± 0.32 μg Cd/g wet wt) was observed in the liver of *Caranx* sp. (Shalateen). In gills, Cd levels varied between 0.19 ± 0.06 (*S. gibbus*, Hurghada) and 1.68 ± 0.38 μg/g wet wt (*Sardinella* sp., Suez). Cd concentrations in the muscles ranged from 0.03 ± 0.01 (*S. gibbus*, Shalateen) to 0.38 ± 0.29 μg/g wet wt (*Sardinella* sp., Suez).

3.5. *Iron (Fe)*

In liver, Fe concentrations were found to be between 34.75 ± 3.34 and 656.98 ± 60.13 μg/g wet wt (*Synodus* sp. and *Lethrinus* sp. from Suez, respectively). The concentrations of Fe in gills ranged from 19.95 ± 3.10 (*Epinephelus* sp., Hurghada) to 324.40 ± 46.25 μg/g wet wt (*Synodus* sp., Shalateen). Muscles recorded Fe concentrations from 1.15 ± 0.23 (*N. japonicus*, Suez) to 11.53 ± 1.68 μg/g wet wt (*Sardinella* sp., Hurghada).

3.6. *Manganese (Mn)*

Manganese concentrations in gills showed a wide variation and ranged between 1.01 ± 0.40 (*Epinephelus* sp., Hurghada) and 33.98 ± 6.25 μg/g wet wt (*Sardinella* sp., Suez). In liver, concentrations of Mn ranged from 0.17 ± 0.02 (*S. gibbus*, Shalateen) to 2.87 ± 0.28 μg/g wet wt (*Sardinella* sp., Suez). Fish muscles recorded the lowest concentrations of Mn and ranged between 0.10 ± 0.03 (*Lethrinus* sp., Suez) and 0.93 ± 0.19 μg/g wet wt (*Sardinella* sp., Suez).

4. Discussions

4.1. *Variations in organs ability to accumulate metals*

Fish of the present study always showed the lowest concentration of metals in muscle. The essential metals Cu, Zn and Fe were accumulated mainly in the liver, while Pb and Mn exhibited their highest concentrations in gills. The accumulation pattern of Cd differed between species where the highest concentrations were fluctuated between the liver and gills.

The accumulation of essential metals in the liver is likely linked to its role in metabolism [4]; high levels of Zn and Cu in hepatic tissues are usually related to a natural binding proteins such as metallothioneins (MT) [27] which act as an essential metal store (i.e., Zn and Cu) to fulfill enzymatic and other metabolic demands [28,29]. In the same way, Fe tends to accumulate in hepatic tissues due to the physiological role of the liver in blood cells and hemoglobin synthesis [27]. On the other hand, the liver also showed high levels of non-essential metals such as Cd; this finding could be explained by the ability of Cd to displace the normally MT-associated essential metals in hepatic tissues [29]. Similar results of high Zn, Cu and Cd in the liver were observed in many field studies [4,30–33].

The studied fish tend to accumulate Pb, Mn and to some extent Cd in gills. Gills are the main route of metal ion exchange from water [26] as they have very large surface areas that facilitate rapid diffusion of toxic metals [25]. Therefore, it is suggested that metals accumulated in gills are mainly concentrated from water. This is in agreement with the findings of Moore and Ramamoorthy [24]. They reported the lack of correlation between Pb residues and feeding habits in aquatic organisms. Similar results for high Pb concentrations in gills were recorded by Kargin [34], Avenant-Oldewage and Marx [35], Abu Hilal and Ismail [37] and Qadir and Malik [26]. Also, Eisler [30] reported that fish's hard tissues had consistently higher accumulations of Mn than soft tissues.

4.2. *Inter-specific variations in metal accumulation*

Fish in the present study were collected from different habitat and have various morphometric parameters (Table 1). The present results showed that fish exhibited wide inter-specific variations in metals accumulation in all organs.

Many studies attributed high metal accumulation to the feeding habit of the fish. For instance, Khaled [23] argued that because *S. rivulatus* is an herbivore, it accumulated higher concentrations of metals in their muscles than the carnivore *Sargus sargus*; This suggestion was not a reasonable cause for high metal accumulation in the current study since *S. gibbus* (a herbivore) recorded the lowest concentration of metals in most cases during the study, while the other herbivore (*S. rivulatus*) showed minor variations (as high concentrations of Cu in liver). Alternatively, Al-Busaidi et al. [6] suggested that, high Cd concentrations in muscles of yellowfine tuna *T. albacares* was due to their feeding at the higher trophic levels (carnivorous); however metal accumulations in carnivorous fish were not consistently the highest recorded in the present study except *Epinephelus* sp. which showed a tendency to accumulate metals (Zn, Pb and Cu) in the liver with relatively high concentrations. Apart from previous suggestions, feeding habit may be one reason of metal variation in the filter feeder *Sardinella* sp. which accumulated relatively high concentrations of all metals except Pb in muscles and exhibited ability to accumulate Mn with high concentrations in all organs. These findings in *Sardinella* sp. could be linked to feeding on phytoplankton since it is the most likely biota compartment for Zn and Cu concentration [22,38]. Petkevich [39] also generalized that bony tissues of plankton-feeding fish concentrated manganese to a greater extent than benthos-feeders [30]. Wide agreement with these results in *Sardinella* sp. was observed in the previous studies; Abdallah [22] recorded high Zn and Pb concentration in the muscles of *sardinella aurita* collected from El-Mex Bay; Alturiqi and Albedair [40] found relatively high concentrations of Zn, Cd, Fe and Mn in sardine collected from the Saudi market in comparison to Grouper and blackspot emperor. Chen and Chen [41] found that the muscles of *Sardinella lemuru* recorded the highest concentrations of Zn, Fe, Cu, and Mn among nine fish species collected from the Ann-Ping coastal waters, Taiwan.

It was interesting to note that a large fish of *Caranx* sp. (from Shalateen) showed very high concentrations of Cd in liver (8.37 ± 0.32 μg/g wet wt), which was several times of magnitude greater than other studied fish, even from the same species (Tables 2–4). This finding can be linked to the age of the fish; since Cd is difficult to be excreted from liver once it is accumulated [23]. This large fish (length 87.8 cm, weight 24500 g) likely accumulated high Cd concentrations throughout its long life. This agrees with the suggestions of Eisler [30] that Cd in liver is positively linked to the age of the

Table 6 – Maximum Permissible Limit (MPL) of heavy metals in fish muscles (μg/g wet wt.) according to international standards.

	Metals						Reference
	Cu	Zn	Pb	Cd	Fe	Mn	
FAO (1983)	30	30	0.5	0.05			FAO [46]
FAO/WHO limit	30	40	0.5	0.5			FAO/WHO [50]
WHO 1989	30	100	2	1	100	1	Mokhtar [52]
European community			0.2	0.05			EC [49]
England	20	50	2	0.2			MAFF [48]

fish. In this context, Ploetz et al. [42] stated that Cd concentrations in the liver of king mackerel, *Scomberomorus cavalla* increased with increasing fork length. Furthermore, Kojadinovic et al. [43] recorded Cd concentrations in the liver of Swordfish, *Xiphias gladius* up to 46.9 μg/g wet wt.

It is suggested that benthic fish are likely to have higher heavy metal concentrations than fish inhabiting the upper water column because they are in direct contact with the sediments and their greater uptake of heavy metal concentrations from zoobenthic predators [44]. However, results from several studies did not support this suggestion or even contradict it; Zhao et al. [4] found that *Cynoglossus gracilis* had the lowest level of metal accumulation among investigated species despite that it is a typical benthic fish. Also, Bustamante et al. [45] did not find segregation between pelagic and benthic fish in their accumulation of metals in the liver and kidneys. Results of the present study provide weak or no support for this suggestion, where variations between pelagic and benthic organisms were detected only as high concentration of Fe in the gills of the benthic fish *Synodus* sp. when compared to other species. This finding may be attributed to higher levels of Fe in subsurface water of the Red Sea as recorded in the study of Sheridah et al. [36].

Although fish are mostly migratory and seldom settle in one place, metal accumulation in fish organs provides evidences of exposure to contaminated aquatic environment [26] and could be used to assess the health condition of the area from which they were collected. In the present study, spatial distribution of metals showed significant high concentrations of Cu, Zn, Pb, Cd and Mn in Suez. Also, the results from single species showed that, pelagic fish collected from Suez (*Epinephelus* sp., *Sardinella* sp., *Lethrinus* sp. and *T. mediterraneus*) recorded significantly the highest concentration of Cd in muscles, and relatively high Cd concentrations in other organs (liver and gills). These results agree with the previous studies that reported high metal levels in the seawater of Suez Bay when compared to those from the Red Sea proper [11,14], which is mainly due to the industrial and anthropogenic input of metals from Suez City and the maritime activities through the Suez Canal.

4.3. *Health-risk assessment for fish consumption*

It is well known that muscles are not an active site for metal biotransformation and accumulation [9]. But in polluted aquatic habitats the concentration of metals in fish muscles may exceed the permissible limits for human consumption and imply severe health threats.

To asses public health risk of the Red Sea fish consumption, we compared metal levels in muscles of the current study (Tables 2–4) with the maximum permissible limits for human consumption (MPL) established by many different organizations (Table 6); as well as comparing metal concentrations in muscles to those reported in similar fish species from the previous studies (Table 7). For the comparison to the data published as dry weight, they were converted to wet weight using converting factor 0.3; since the moisture is usually about 70% in the muscles [22].

With few exceptions, the metal concentrations in the examined fish species from the Red Sea fall below the (MPL)

Table 7 – Heavy metals in muscles (μg/g) of fish from the Red Sea and other regions.

Species	Site	Cu	Zn	Pb	Cd	Fe	Mn	Reference
Epinephelus sp.[a]	Red Sea	0.66	3.37	0.53	0.17			Emara et al., [17]
Epinephelus fasciatus[b]	Gulf of Aqaba	0.97	9.13	4.80	0.97	5.93	1.63	Abu Hilal and Ismail, [37]
Lethrinus sp.[a]	Red Sea	0.40		0.89	0.45			Abdelmoneim and El-Deek, [18]
Siganus rivulatus[a]	Alexandria	1.59	7.95	0.73	0.25	37.53	0.54	Khaled [23]
Siganus rivulatus[b]	Alexandria	2.70	43.90	1.20	2.80			Abdallah, [22]
Sardinella aurita[b]	Alexandria	4.00	42.00	4.70	1.20			Abdallah, [22]
Trachurus mediterraneus[b]	Black Sea (Turky)	0.40	7.76	<0.001		8.52	0.58	Gorur et al., [27]
Synodus saurus[b]	Alexandria	4.00	16.70	1.40	1.90			Abdallah, [22]
Thunnus albacares[a]	Oman market			0.03	0.01			Al-Busaidi et al., [6]
Epinephelus chlorostigma[a]	Oman market			0.05	0.02			Al-Busaidi et al., [6]
Scarus gibbus[a]	Hurghada	0.81		0.88		35.1	0.29	Ahmed et al., [20]
Nemipterus japonicus[a]	Hurghada	1.03		1.07		33.1	0.12	Ahmed et al., [20]
Nemipterus japonicus[a]	Hurghada	0.28	2.13	0.33	0.02	6.31		El-Moselhy, [15]
Lethrinus nebulous[b]	Jeddah coast	0.13	3.98	1.03	0.13			Ali et al., [51]
Lethrinus mahsena[b]	Jeddah coast	0.47	9.3	6.1	1.06			Ali et al., [51]
Caranx sexfaciatus[b]	Jeddah coast	0.91	5.33	3.4	0.9			Ali et al., [51]
Sardinella lemuru[a]	Taiwan coastal water	0.41	7.28		<0.0005	7.72	0.73	Chen and Chen [41]
21 species[b]	Red Sea	1.7–39.6	8.4–195	0.05–1.3	0.16–3.5			Hanna, [13]

[a] Wet wt.
[b] Dry wt.

for human consumption recommended by FAO [46], WHO [47], MAFF [48] and EC [49], and were generally in the same range or below the concentrations in the muscles of the same fish species from pervious studies conducted in relatively unpolluted waters.

The essential metals Cu, Zn, Fe and Mn were clearly below all the permissible limits for human consumption. While, the non-essential metal Pb was below the PML recommended by WHO [47] and MAFF [48], and was around or a little bit higher than the levels recommended by FAO [46] and FAO/WHO [50]. Similarly Cd was generally below the PML in most cases except for the pelagic species from Suez that were higher than the levels recommended by FAO [46] and EC [49], but still below FAO/WHO [50], WHO [47] and MAFF [48] recommended limit.

The results in previous literatures were somewhat closer to or higher than our obtained data for similar fish species. For example, Abdallah [22] recorded the concentrations of Cd, Pb, Cu and Zn in muscles of *Sardinella aurita*, *S. rivulatus* and *Synodus saurus* from two main harbors in Alexandria, Egypt, who reported metal levels much higher than those recorded in the same species of the current work. In addition, metal levels in the present study were generally lower or within the ranges of those found in the fish of the Red Sea recorded by Hanna [13], Abdelmoneim and El-Deek [18], Emara et al. [17], Ahmed et al. [20], El-Moselhy [15] and Ali et al. [51].

After all, fish in the Red Sea were found to be safe for consumption and do not pose a significant threat to the health of human consumers.

5. Conclusions

Metal concentrations in the three studied locations were within the same range or below the concentrations in similar species from previous studies in the Egyptian waters or elsewhere. The results also showed that metal accumulation varied between organs and species depending on species-specific factors like feeding behavior, swimming patterns and genetic tendency, and/or other factors like age and geographical distribution that caused variation in metals accumulations between fish even from the same species.

Health risk analysis of heavy metals in the edible parts of the fish indicated safe levels for human consumption and concentrations in the muscles are generally accepted by the international legislation limits. However, the levels of metals in pelagic fish and *Sardinella* sp. should be continuously monitored in potential polluted areas since pelagic fish showed a tendency to accumulate cadmium in muscles from polluted water, and *Sardinella* sp. accumulated high concentrations of Cu, Zn, Cd, Fe and Mn in the muscles when compared to other species.

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