

Distribution of heavy metals in (Fe, Hg, Ni and Pb) sediment and blue crab, *Portunus pelagicus* from four estuaries, Persian Gulf

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Present study consist levels of heavy metals (Fe, Hg, Ni and Pb) in sediments and tissues of blue swimming crab, *Portunus pelagicus* from the Persian Gulf coasts, south Iran. The concentration of heavy metals in sediments at all sampling stations occurs in descending order of Fe > Ni > Hg > Pb. This study assessed the relationship between metals trace in hepatopancreas tissue, muscle and exoskeleton with carapace width and weight. Significant increase in the metals levels in hepatopancreas tissue ($p < 0.05$) with an increase in carapace width and weight for this species. Hepatopancreas accumulate higher levels of the metals in comparison to muscle and exoskeleton. Variation in heavy metals levels among the species is likely to have resulted from metal bioavailability, changes in tissue composition, organism size, age and locations.

[Key words: Heavy Metal, Bioaccumulation, *Portunus pelagicus*, Persian Gulf]

Introduction

Heavy metal is one of the main groups of those pollutants which could enter via wastewaters or atmospheric deposition. This sort of contaminants may sink in sediment or enter directly into aquatic organisms¹. They could be circulated by blood in the body and accumulate in the target organs, interfere with organ function, and subsequently appear in toxic forms both for the organisms and humans who consume seafood. The accumulation of metals in fish depends on size, age, feeding habits, and habitats of fish. In addition, physicochemical factors of water and sediment, which control the availability of metals, could play a significant role in their accumulation patterns².

Estuaries are highly productive and sensitive areas in the marine environment because they play an important role as a nursery ground for many commercial fish, shrimp and other marine species^{2, 3}. On the other hand, many different types of pollutants may be discharged into these

areas, because of their proximity to sources of contamination, and decrease their natural ability and capacity⁴. The Persian Gulf, a part of ROPME sea area, is polluted by several human activities such as shipping and tanker traffic, industrial, and agriculture development. National Research Council in 1985 estimated that oil pollution in the Persian Gulf is 4.7% of the whole oil pollution in the world^{4, 5, 6, 7}.

The blue swimming crab *Portunus pelagicus* is a benthic invertebrate that feed on crustacean, fish, bivalves, plant and benthic animals and they have a slow growth rate and long life cycle⁸. This species is a bottom-dwelling crab in which lipophilic contaminants, such as heavy metal compounds, tend to accumulate in high concentrations because of its considerable fat content⁹. Also some studies have suggested that the high levels of heavy metal residues found in this species are due to biomagnification through the food chain. In addition, eels are relatively insensitive to poor water quality and are often

exposed to high levels of persistent pollutants in industrial areas and therefore its suitability for the purpose of this study. This species is abundant in many marine ecosystems and they are also crab species subjected to exploitation by fisheries in the area, being part of the human diet. Although in other countries, this variety has a special place in nutrition and includes a huge part of industrial hunting, but in our country it is treated like an incident hunting and

Material and Methods

The study was carried out in the four estuaries in the Khuzestan Province, northwest of the Persian Gulf. The four stations were including S1= Bahrekan estuary, S2= Musa estuary, S3= Ahmadi estuary, S4= Zangi estuary (Figure 1). Samples of surficial sediments and available species of blue swimming crabs were collected from 4 coastal localities during two seasons (between February and September 2012). The sampling stations were selected to reflect progression of pollution, ecological particularity and human activities in the area.

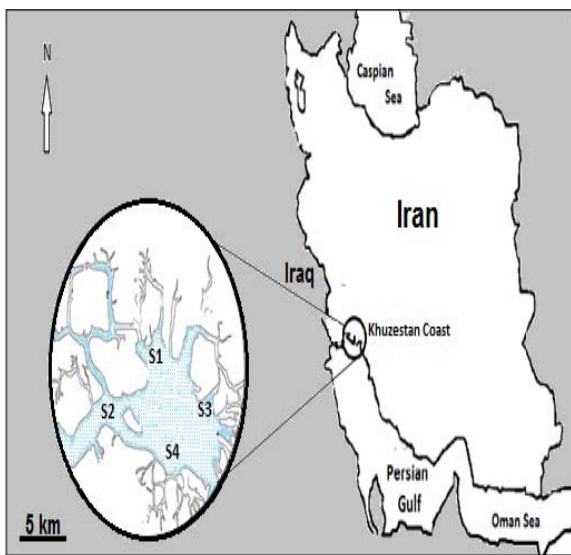


Figure.1—Map of Persian Gulf showing sampling stations

The analysis of total heavy metals were done by the cold vapor method¹³ using a Perkin-Elmer Atomic Absorption System AA-2380

it is eaten as a food only in limited areas of south of the country such as Bushehr, Hormozgan and Boushehr provinces¹⁰. Therefore, their contamination is also a matter of concern for human health. This study was to determine the distribution and concentration of heavy metals (Fe, Hg, Ni and Pb) in sediments and tissues of species *Portunus pelagicus* from Persian Gulf coasts located in South Iran.

Sediment Sampling was performed with van veen grab from the bottom at all stations. After sampling, the samples were packed in plastic bags, preserved and transferred to laboratory for analysis. Samples of biological material and sediment were immediately transferred to new polyethylene bags. All samples were frozen or stored at about 5 °C until further processing. Each aliquot of sediment was digested for 4 h in a water bath at 60 °C, after adding 3 ml each of concentrated HNO₃, H₂SO₄ and HF. H₂SO₄ was used because the sediment from most of the sampling sites contains 8 to 10% of organic matter¹². The digestion of each sample of sediment was made in duplicate. Each sample of crabs was homogenized in an acid-cleaned mortar and 2 g were digested in triplicate in a water bath at 60 °C for 6 h after adding 2.5 ml each of concentrated HNO₃ and H₂SO₄^{13, 14}.

Crabs sampling was performed with shrimp trawl. After sampling, samples were transferred to the laboratory in a cooler and stored in a deep freezer for further analysis. Each crab was properly cleaned by rinsing with distilled water to remove debris, planktons and other external adherent, and then they were dissected for collect tissues hepatopancreas, muscle and exoskeleton. It was then drained under folds of filter, weighed, wrapped in aluminum foil and then frozen at 10°C prior to analysis. The tissues were placed in clean watch glasses and were oven dried at 105°C for 1 hour and later cooled in the desiccators¹⁶.

with automatic background correction and a Perkin-Elmer Mercury Analysis System 303-0830. Replicate (3 to 5) measurements were

made on each sample. All glass-ware used was cleaned by the procedure described by Sankar *et al.* (2006) ¹⁵. All the reagents used were of spectroscopic grade and ultra-high purity (99.9 %). In all experiences several blanks were performed with the reagents used, in order to check for possible contamination. The data obtained were statistically analyzed for confirmation of the results. Metal toxicity from

different tissues and sediments was calculated by using regression equation and results were expressed in $\mu\text{g}/\text{gm}$ dry weight. Statistical analysis was performed using SPSS program. In order to assess significant differences between species and tissues, one-way ANOVA and Duncan multiple comparison test were applied. The significance level was set at $\alpha = 0.05$.

Results and Discussion

The concentrations of the heavy metals in the sediments from different stations are presented in Table 1. Heavy metal concentration in sediments at all sampling stations occurs in descending order of $\text{Fe} > \text{Ni} > \text{Hg} > \text{Pb}$ during both seasons. Highest concentrations of the heavy metal in sediment were recorded in Musa estuary station and the least was in Zangi estuary during both seasons. There was significant difference ($P < 0.05$) between the level of heavy metals in the different stations during two season. High metals levels in the sediments of Musa estuary can be explained by the located Emmam port, tremendous traffic of oil tankers, enormous discharges of petrochemical units, agricultural activities and urban developing in the area. Crabs collected from the Bahrekan estuary also demonstrated relatively high metals levels in their tissues in comparison to those from Ahmadi estuary and Zangi estuary. Bahrekan estuary is used for many Iranian industrial, shipping and irrigation purposes. In addition, it passes a lot of cities, ports and harbors. Therefore, these sources

could result in huge amount of metals in this coast and its organisms.

The concentrations of Fe were higher than the other metals, suggesting that there is an influence of the industrial activities in surroundings of the sampled stations. Research same showed that the highest levels of Fe in water and sediments were found in lakes which had the lowest water pH and the lowest sediment pH ^{14, 15}. Low value of Pb level in the present study may indicates that the tissues of *P. pelagicus* is not the target organs for Pb accumulation. The absence or low level of Pb in the crab may be due to the activities around the location of the Gulf. The area consist mainly farmland and few residential houses. There are few or no industrial activities around the location. This may agree to the study of Samecka-Cymerman and Kempers (2001) ¹⁶. They concluded that Pb level in the tissues of crustacean is low than other metals ¹⁸. Research same showed that the highest concentration of lead was found in the Nuuanu watershed (Hawaii) when there were high boating activities.

Table 1 — Mean concentration of heavy metal ($\mu\text{g/g}$ dry weight) in Sediments from different stations along Persian Gulf coast

Season	Metal	Station			
		S1	S2	S3	S4
Summer	Hg	0.88 ± 0.05^c	6.10 ± 0.01^c	0.58 ± 0.05^b	0.75 ± 0.05^c
	Fe	16.30 ± 0.06^a	51.40 ± 0.40^b	13.20 ± 0.01^a	25.84 ± 0.02^a
	Pb	1.09 ± 0.04^a	3.35 ± 0.04^b	0.70 ± 0.02^b	0.85 ± 0.03^b
	Ni	18.50 ± 0.02^a	25.7 ± 0.02^a	08.53 ± 0.08^b	15.01 ± 0.02^b
Winter	Hg	0.65 ± 0.05^c	4.30 ± 0.03^b	0.46 ± 0.02^b	0.60 ± 0.01^c
	Fe	15.05 ± 0.04^a	48.05 ± 0.01^b	11.05 ± 0.01^a	23.51 ± 0.06^b
	Pb	0.86 ± 0.02^b	2.90 ± 0.05^a	0.54 ± 0.02^b	0.68 ± 0.01^a
	Ni	16.80 ± 0.01^a	23.80 ± 0.03^a	7.04 ± 0.10^b	14.10 ± 0.01^b

S1= Bahrekan estuary, S2= Musa estuary, S3= Ahmadi estuary, S4= Zangi estuary

a, b, c show significant differences among tissues

Table 2 — Mean concentration of heavy metal (μ g/g dry weight) in tissues of crab, *P. pelagicus* during summer season from different stations along Persian Gulf coasts

Tissue	Metal	Station			
		S1	S2	S3	S4
H	Hg	0.65 $\pm$ 0.02 ^c	3.08 $\pm$ 0.05 ^c	0.40 $\pm$ 0.05 ^c	0.48 $\pm$ 0.01 ^c
	Fe	14.20 $\pm$ 0.03 ^a	44.43 $\pm$ 0.40 ^b	10.59 $\pm$ 0.01 ^a	20.80 $\pm$ 1.05 ^a
	Pb	0.79 $\pm$ 0.02 ^a	2.85 $\pm$ 0.04 ^b	0.46 $\pm$ 0.02 ^b	0.55 $\pm$ 0.02 ^b
	Ni	15.65 $\pm$ 0.01 ^a	21.80 $\pm$ 0.02 ^a	6.85 $\pm$ 0.02 ^a	11.05 $\pm$ 0.01 ^a
M	Hg	0.28 $\pm$ 0.05 ^c	1.60 $\pm$ 0.05 ^b	0.16 $\pm$ 0.05 ^b	0.17 $\pm$ 0.02 ^c
	Fe	7.30 $\pm$ 0.04 ^a	18.85 $\pm$ 0.02 ^b	4.55 $\pm$ 0.04 ^a	11.01 $\pm$ 0.10 ^b
	Pb	0.10 $\pm$ 0.02 ^b	1.92 $\pm$ 0.01 ^a	0.14 $\pm$ 0.30 ^b	0.20 $\pm$ 0.30 ^a
	Ni	8.05 $\pm$ 0.02 ^a	10.82 $\pm$ 0.02 ^a	3.04 $\pm$ 0.10 ^b	7.10 $\pm$ 0.01 ^b
E	Hg	0.15 $\pm$ 0.05 ^c	1.04 $\pm$ 0.02 ^b	0.12 $\pm$ 0.02 ^b	0.40 $\pm$ 0.05 ^c
	Fe	5.30 $\pm$ 0.04 ^a	13.15 $\pm$ 0.01 ^b	3.50 $\pm$ 0.01 ^a	8.01 $\pm$ 0.10 ^b
	Pb	0.06 $\pm$ 0.02 ^b	1.02 $\pm$ 0.01 ^a	0.10 $\pm$ 0.02 ^b	0.11 $\pm$ 0.30 ^a
	Ni	6.05 $\pm$ 0.02 ^a	6.02 $\pm$ 0.05 ^a	2.04 $\pm$ 0.10 ^b	5.10 $\pm$ 0.01 ^b

S1= Bahrekan estuary, S2= Musa estuary, S3= Ahmadi estuary, S4= Zangi estuary

H= Hepatopancreas, M= Muscle, E= Exoskeleton

a, b, c show significant differences among tissues

Table 3 — Mean concentration of heavy metal (μ g/g dry weight) in tissues of crab, *P. pelagicus* during winter season from different stations along Persian Gulf coasts

Tissue	Metal	Station			
		S1	S2	S3	S4
H	Hg	0.46 $\pm$ 0.02 ^c	2.78 $\pm$ 0.05 ^c	0.28 $\pm$ 0.02 ^c	0.41 $\pm$ 0.01 ^c
	Fe	12.34 $\pm$ 0.01 ^a	41.43 $\pm$ 0.10 ^b	8.29 $\pm$ 0.01 ^a	18.80 $\pm$ 1.03 ^a
	Pb	0.40 $\pm$ 0.02 ^a	2.15 $\pm$ 0.05 ^b	0.29 $\pm$ 0.01 ^b	0.40 $\pm$ 0.02 ^b
	Ni	13.05 $\pm$ 0.01 ^a	19.10 $\pm$ 0.02 ^a	4.05 $\pm$ 0.01 ^a	10.22 $\pm$ 0.01 ^a
M	Hg	0.23 $\pm$ 0.01 ^c	1.61 $\pm$ 0.02 ^b	0.16 $\pm$ 0.02 ^b	0.20 $\pm$ 0.02 ^c
	Fe	8.30 $\pm$ 0.02 ^a	29.05 $\pm$ 0.01 ^b	6.55 $\pm$ 0.01 ^a	12.01 $\pm$ 0.10 ^b
	Pb	0.10 $\pm$ 0.01 ^b	0.95 $\pm$ 0.01 ^a	0.21 $\pm$ 0.30 ^b	0.16 $\pm$ 0.30 ^a
	Ni	7.05 $\pm$ 0.02 ^a	11.02 $\pm$ 0.01 ^a	2.04 $\pm$ 0.04 ^b	6.10 $\pm$ 0.02 ^b
E	Hg	0.18 $\pm$ 0.02 ^c	0.60 $\pm$ 0.00 ^b	0.06 $\pm$ 0.02 ^b	0.12 $\pm$ 0.05 ^c
	Fe	6.05 $\pm$ 0.03 ^a	24.80 $\pm$ 0.02 ^b	4.15 $\pm$ 0.04 ^a	10.01 $\pm$ 0.10 ^b
	Pb	0.06 $\pm$ 0.02 ^b	0.40 $\pm$ 0.01 ^a	0.14 $\pm$ 0.04 ^b	0.09 $\pm$ 0.02 ^a
	Ni	5.05 $\pm$ 0.01 ^a	8.02 $\pm$ 0.00 ^a	1.14 $\pm$ 0.03 ^b	5.10 $\pm$ 0.02 ^b

S1= Bahrekan estuary, S2= Musa estuary, S3= Ahmadi estuary, S4= Zangi estuary

H= Hepatopancreas, M= Muscle, E= Exoskeleton

a, b, c show significant differences among tissues

The results indicated that concentrations of all heavy metals in the sediments and tissues of crab during summer season were higher than concentrations of all heavy metals during winter season. There was no significant difference

($P > 0.05$) between the level of heavy metals during different seasons. Seasonal variation may effect metal concentration in body organism (Fig. 2). This variation could result in internal biological cycle in organism or

variation in bioavailability of metal in environment. Temperature, food availability and water could increase metal concentration in summer than winter²⁶. Such this condition was happened during present study and metals levels in different tissues showed higher in summer season compared to winter season. In other words, most levels of metals in body organism is in the form methyl metal which is soluble in fatty tissues, thus seasonal reproduction could be cause reduce heavy metals in winter season. Similarly in the present study, less metal uptake was showed during winter season. According to different studies the heavy metal levels in

invertebrates showed higher in winter season²¹⁻²³. It was revealed that algae and invertebrates all show similar seasonal patterns in metal concentrations it would seem likely that environmental factors (discharges to the estuary, pH, salinity, suspended matter, etc.) are having a greater overall influence on seasonality than biological factors (metabolism, reproduction, fluctuations in tissue weight, etc.). Seasonal variation in metal levels may be caused by such factors as land drainage to the marine environment availability of food, temperature and reproductive cycle and condition of the organism²⁴.

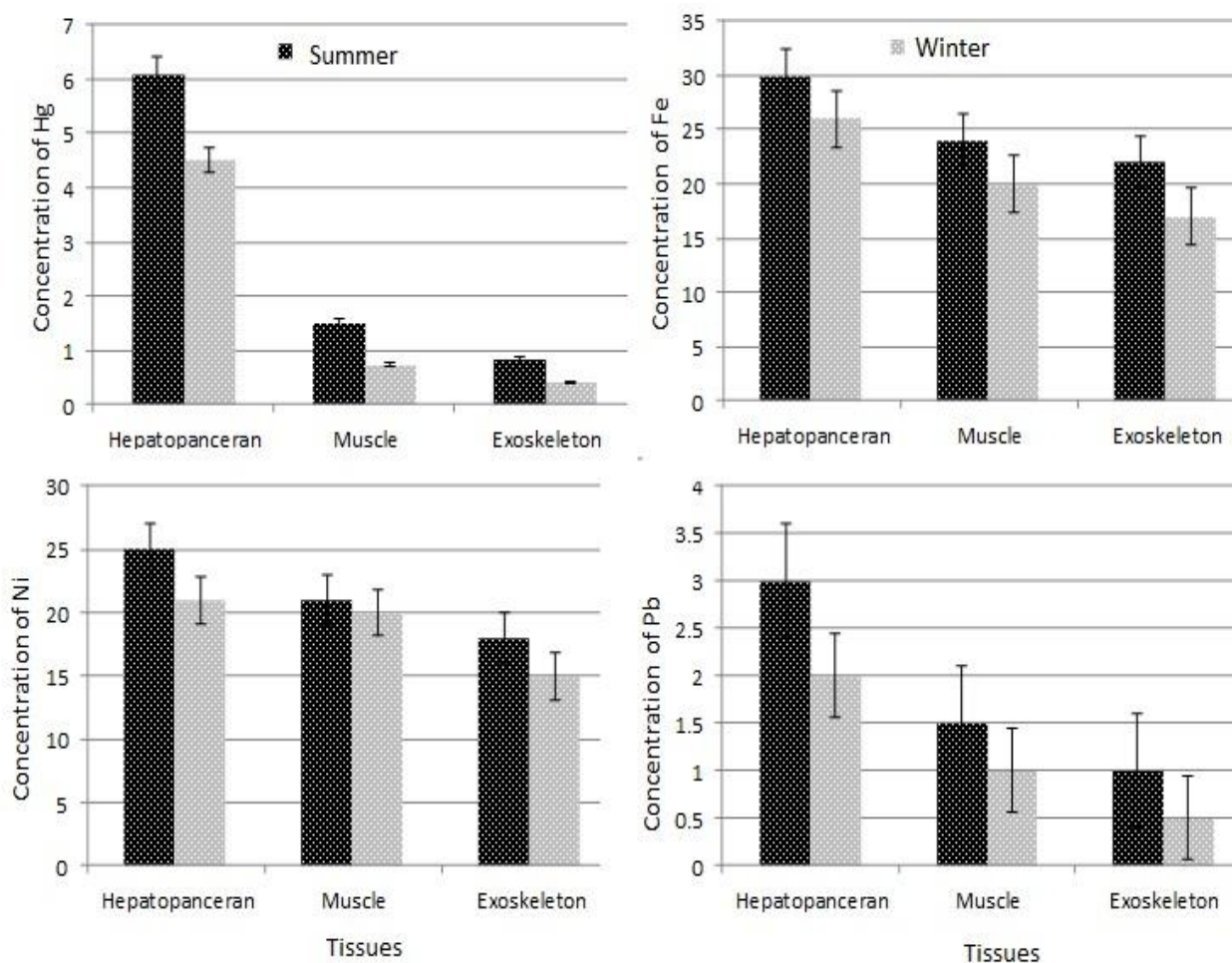


Fig. 2 — Comparison of heavy metal level ($\mu\text{g/g}$ dry weight) in three tissues of *P. pelagicus* between summer and winter

In this species, significant correlations ($r = 0.89$) were found between carapace width and weight in *P. pelagicus* (Fig. 3). There were

positive significant relationships ($p < 0.05$) between Carapace Width and metals concentrations in tissues of *P. pelagicus*.

Therefore, we used carapace width crab, to investigate their relationship with heavy metals levels in hepatopancreas, muscle and exoskeleton tissues. The primary biological factors governing the accumulation of heavy metals include age, weight and diet, and numerous field studies have shown that the level of total heavy metals in crab correlates positively with age, length and weight²⁵. Storelli et al. (2007) found that heavy metals levels increased with size for 7 species of marine fish from the Adriatic Sea²⁵. There was a positive correlation between size and heavy metals concentrations for 11 of 14 species of marine fish collected in the western Aleutians (Bering Sea/North Pacific). Additionally, because larger Crustacean specimens have been exposed a longer time compared of smaller and thus bioaccumulated higher heavy metals concentrations (usually size is used as a surrogate for age). Larger specimens are also more dependent to bed (benthic) and less to surface (pelagic) in comparison to smaller specimens and thus are longer present in polluted sediment²⁶.

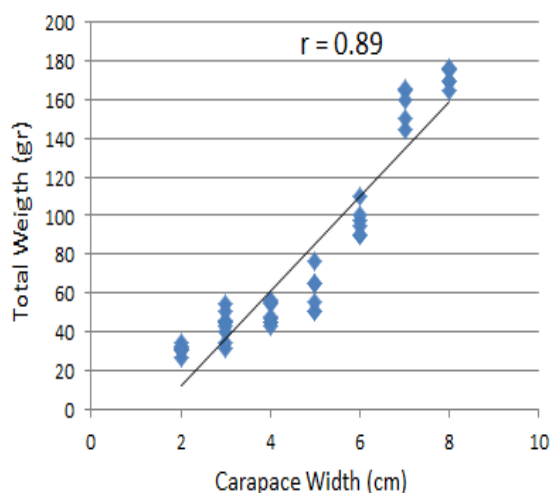


Fig. 3 — Relationship between Carapace Width and weight in *P. pelagicus*

However, total heavy metals levels may not always correlate with size due to differences associated with diet and residence time in a contaminated habitat²⁷. In contrast to muscle and exoskeleton tissues, there were no

significant correlations ($p > 0.05$) between carapace width and heavy metals concentrations in exoskeleton and muscle tissues in any of this species ($r < 0.24$). This is probably due to the moulting process. Since crustaceans have several moulting stages in their life, the bioaccumulation process in the exoskeleton is also cycling and each time, new bioaccumulation starts in a new exoskeleton. Therefore, one does not expect any relationship between carapace width and heavy metals in exoskeleton. According to field and experimental studies, tissue distribution and accumulation of heavy metals in crabs varies widely depending on size, sex, growth stage, molting, migration, season of sampling, metal bioavailability, hydrodynamics of the environment, changes in tissue composition, reproductive cycle, habitat, feeding habits, capacity of metals accumulation and kind of species³⁷. Despite of being benthic and non-migratory species indicated different metals accumulation in their tissues. These differences may be resulted from the variation in their diet and accumulation strategies. Generally, the benthic species accumulated higher concentrations of the metals, due to the greater exposure to metals enriched sediment and interactions with benthic organisms²⁸.

Current study provides new information on the distribution of metals in the sediments and tissues of blue swimming crab, *Portunus pelagicus* from the Persian Gulf. In general, the metals showed a strong tendency to accumulate in the sediments and followed by hepatopancreas, muscle and exoskeleton tissue respectively. Metals levels in edible part of the crab are below the proposed limit values for human consumption except in some cases. In addition, the results of present study showed that different tissue have various capacities to accumulate the metals from the surrounding environment. Thus, people how consume crab from this area should eat a diversity of crab to avoid consuming harmful quantity of essential and non-essential metals.

References

- 1 Abdolapur Monikh, F., Safahieh, A. R., Savari, A., & Doraghi, A., Heavy metal concentration in sediment, benthic, benthopelagic, and pelagic fish species from Musa Estuary (Persian Gulf). *Environmental Monitoring and Assessment*, (2012) DOI 10.1007/s10661-012-2545-
- 2 Brasher, A. M. D., & Wolff, R. H., Relations between land use and organochlorine pesticides, PCBs, and semivolatile organic compounds in streambed sediment and fish on the Island of Oahu, Hawaii. *Archive of Environmental Contamination and Toxicology*, 46 (2004): 385–398.
- 3 Gewurtz, S. B., Bhavsar, S. P., Fletcher, R., 2011. Influence of fish size and sex on mercury/PCB concentration: importance for fish consumption advisories. *Environ Int*, 37 (2011): 425–434.
- 4 Perugini, M., Visciano, P., Giammarino, A., Manera, M., Di Nardo, W., & Amorena, M., Polycyclic aromatic hydrocarbons in marine organisms from the Adriatic Sea, Italy. *Chemosphere*, 66 (2007): 1904–1910.
- 5 Abdolapur, M. F., Peery, S., Karami, O., Hosseini, M., Bastami, A. A., Ghasemi, A. F., Distribution of Metals in the Tissues of Benthic, *Euryglossa orientalis* and *Cynoglossus arel.*, and Benthopelagic, *Johnius belangerii.*, Fish from Three Estuaries, Persian Gulf. *Bull Environ Contam Toxicol*, 18 (2012): 319–324
- 6 Eimers, M. C., Evans, R., D. and Welbourn, P. M., Cadmium accumulation in the freshwater isopod *Asellus racovitzai*: The relative importance of solute and particulate sources at trace concentrations. *Environmental Pollution*, 111 (2001): 247–253.
- 7 Ho, S. T., Tsai L. J., and Yu, K. C., Correlations among aqua- regia extractable heavy metals in vertical river sediments. Diffuse Pollution Conference, Dublin. 1 (2003): 12–18.
- 8 Kumar, M., Ferguson, G., Xiao, Y., Hooper, G., Venema, S., Studies on reproductive biology and distribution of blue swimmer crab (*Portunus pelagicus*) in South Australian Waters. *Research report series*, 47 (2000) 1324–2083.
- 9 Reinecke, A. J., Snyman, R. G., Nel, J. A. J., Uptake and distribution of lead (Pb) and cadmium (Cd) in the freshwater crab, *Potamonautes perlatus* (Crustacea) in the Eerste River, South Africa. *Water Air Soil Pollution*, 145 (2000) 395–408.
- 10 Wang, L., Yang, X. Q., Wang, Q., Wang, D. X., The accumulation of Cd and the effect of EST in five tissues and organs of *Eriocheir sinensis*. *Acta Zoologica Sinica*, 47 (2001): 96–100.
- 11 Kabata-Pendias, A., and Pendias, H., Trace elements in soils and plants (3rd ed). Boca Raton, FL: CRC Press. (2001).
- 12 Pazooki, J., Hosseini, M., Vazirzade, A., 2012. The dietary compositions of the blue swimming crab, *Portunus segnis* (Forsk., 1775) from Persian Gulf, South Iran. *World Applied Sciences Journal*, 20 (2012): 416–422.
- 13 Safahieh, A., Abdolapur Monikh, F., Savari, A., 2011. Heavy metals contamination in sediment and Sole fish (*Euryglossa orientalis*) from Musa estuary (Persian Gulf). *W J Fish Mar Sci*, 3(2000): 290–297.
- 14 Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R. P., & Bustamante, P., Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean. *Environmental Pollution*, 146 (2007): 548–566.
- 15 Sankar, T. V., Zynudheen, A. A., Anandan, R., & Viswanathan-Nair, P. G., Distribution of organochlorine pesticides and heavy metal residues in fish and shellfish from Calicut region, Kerala, India. *Chemosphere*, 65(2006): 583–590.
- 16 Samecka-Cymerman, A., and Kempers, A. J., Concentrations of heavy metals and plant nutrients in water, sediments and aquatic macrophytes of anthropogenic lakes former open cut brown coal/mines differing in stage of acidification. *Science of the Total Environment*, 281(2001): 87–98.
- 17 Craig, S., and Overmell, J., 2003. Metals in squid, *Loligo forbesi*, adults, eggs and hatchlings. No evidence for a role for Cu- or Zn-metallothionein. *Comparative Biochemistry and Physiology*. 134(2003): 311–317.
- 18 Schuwerack, P. M. M., Lewis, J. W., Jones, P., 2001. The potential use of the South African river crab, *Potamonautes warreni*, as a bioindicator species for heavy metal contamination. *Ecotoxicology*, 10(2000): 159–166.
- 19 Andrews, S., and Sutherland, R. A., Cu, Pb and Zn contamination in Nuuanu watershed, Oahu, Hawaii. *Science of the Total Environment*. 324(2004): 173–182.
- 20 Yilmaz, A. B., Yilmaz, L., Influences of sex and seasons on levels of heavy metals in tissues of green tiger shrimp (*Penaeus semisulcatus*). *Food Chem*. 101 (2007): 1664–1669.
- 21 Yilmaz, F., Ozdemir, N., Demirak, A., Levent Tuna, A., Heavy metal levels in two fish species *Leuciscus cephalus* and *Lepomis gibbosus*. *Food Chem*, 100 (2007): 830–835.
- 22 Sen, A., Semiz, A., Effects of metals and detergents on biotransformation and detoxification enzymes of leaping mullet (*Liza saliens*). *Ecotoxicol Environ Saf*, 68(2007): 405–411.
- 23 Al-Yousuf, M. H., El-Shahawi, M. S., Al-Ghais, S. M., Trace metals in liver, skin and muscle of *Lethrinus lentjan* fish species in relation to body length and sex. *Sci Total Environ*, 256 (2000): 87–94.
- 24 Szefer, P. B. S., Kima, C. k., Kima, E. H., and Leeb, C. B., Distribution and co associations of trace elements in soft tissues and byssus of *Mitylus galloprovincialis* relative to the surrounding seawater and suspended matter of the southern part of the Korean Peninsula. *Environmental Pollution*, 129 (2004): 209–228.
- 25 Storelli, M. M., Storelli, A. D., ddabbo, R., Marano, C., Bruno, R., Marcotrigiano, G. O., Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern

- Mediterranean Sea: Overview and evaluation. *Environmental Pollution*, 135 (2005): 163–170.
- 26 Burger, J., Gochfeld, M., Jeitner, C., Burke, S., Stamm, T., Snigaroff, R. , Mercury levels and potential risk from subsistence food from the Aleutians. *Sci Total Environ*, 384 (2007): 93–105.
- 27 Huang, W. B., Heavy metal concentration in the common benthic fishes caught from the coastal waters of Eastern Taiwan. *J Food Drug Anal*, 11(2003): 324–330.
- 28 Yi, Y., Wang, Z., Zhang, K., Yu, G., Duan, X., Sediment pollution and its effect on fish through food chain in the Yangtze River. *Int J Sediment Res*, 23(2008): 338–347.