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Heavy metal bioaccumulation (Ni, V and Hg) in soft tissues of crustaceans, bivalves and gastropods: A case study on the Northern Persian Gulf

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ABSTRACT

The efficacy of *Planaxis sulcatus* (Gastropoda), *Clibanarius signatus* (Crustacea) and *Circenita callipyga* (Bivalvia) with different feeding guilds were compared as bioindicator of heavy metal pollution (Ni, V, Hg) in an area subjected to petrochemical development in the Northern Persian Gulf, Iran. Sampling was conducted in two locations with different degrees of exposure to petrochemical development: (i) on the intertidal zone adjacent to the petrochemical effluent (Impacted location); and (ii) on the intertidal zone unimpacted by the petrochemical effluent (Control location). No significance differences were found in heavy metal concentrations in whole-soft tissues of the selected organisms, seawater and sediment samples between two locations. The accumulation patterns for the heavy metals in the tissues of organisms and sediment samples followed the order of Ni > V > Hg, except in seawater. The concentration of nickel varied among the studied taxa and followed the order of *C. callipyga* > *P. sulcatus* > *C. signatus*. The bivalve, *C. callipyga* showed the high concentration of nickel in its soft tissue and the highest values for bioaccumulation factors (BAFs) as well as the biota-sediment accumulation factors (BSAFs) for nickel among the studied taxa. The results of the present study suggest that *C. callipyga* and *P. sulcatus* are efficient accumulators of nickel, while *P. sulcatus* and *C. signatus* are efficient accumulator of vanadium.

Keywords: The Persian Gulf, Heavy metals, Bioindicator, Trace metal, Oil pollution.
Article type: Research Article.

INTRODUCTION

Heavy metals are permanent pollutants in the environment that cause diverse effects in marine communities (Golovanova 2008). Several studies have been accomplished about the effects and biodynamic of heavy metals on aquatic environment using marine organisms as bioindicator of pollutants (Markert 2007). Measurement of trace metal bioaccumulation in organisms and its related factors is one of the most reliable methods to monitor pollutants bioavailability to the indicator organisms (Zauke *et al*. 1998; Amiard *et al.* 2004; Budovich 2021; Al-Wahab & Gany Fadeel 2022; Talib Jawad *et al.* 2022). The source of heavy metals in an aquatic organism is associated with its feeding habit, including filter feeding, grazing, deposit feeding, and predation (Griscom & Fisher 2004). The food-associated metals predominantly are the main source of heavy metals for some predatory arthropods. However, in the case of filter-feeders, dissolved metals and associated metals with suspended particles in water column are the main source of pollutant, while deposit-feeders also are under effects of sediments (Golovanova 2008). The effect of feeding guild of organisms on concentration of heavy metals in their tissues has been widely studied. Pan & Wang (2011) compared the mercury (Hg) levels in five bivalve species with different feeding guilds and found that level of various mercury compounds was associated with feeding strategy (Pan & Wang 2011). Soto *et al.* (2011) compared the level of heavy metals (i.e., Cd, Pb, Hg, Se, Cr, Cu, As, Zn) in 16 species constructing a food web including primary producer, primary consumer and secondary consumer in Spain

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and found that most species were appropriate for monitoring of mercury (Soto *et al.* 2011). The Persian Gulf is one of the most polluted areas in the world (Mallahi *et al.* 2012). Heavy metals such as mercury, nickel and vanadium have entered the marine environment of the Persian Gulf from the oil and petrochemical-associated industries. In particular, nickel and vanadium are found at significant levels in crude oil naturally, making these elements as efficient indicator for the oil pollution (Amiard *et al.* 2004; Chiffoleau *et al.* 2004). Several studies have been conducted in order to measure the level of heavy metals in different marine species in the Persian Gulf (Pourang *et al.* 2005; Mortazavi *et al.* 2005; Alimohammadi 2009; Kamyab 2010; Khoshnood *et al.* 2010). These studies explored the bioindication capability of different tissues from various species in the Northern Persian Gulf and the feeding mode of selected species was used as an effective parameter in primary selection of these species. In the present study, the efficacy of *Planaxis sulcatus* (Gastropoda; Born 1791), *Clibanarius signatus* (Crustacea; Heller 1861) and *Circenita callipyga* (Bivalvia; Von Born 1778) with different feeding guilds were compared as bioindicators for heavy metal pollutions (Ni, V, Hg) in an area subjected to petrochemical development in the Northern Persian Gulf, so called South Pars Special Economic Energy Zone (SPSEEZ).

MATERIALS AND METHODS

Study area and sampling

This study was conducted in SPSEEZ in 230 km south of Bushehr City, the coastal zone of Nayband Bay, the Northern Persian Gulf. Sampling was performed in two locations with different degrees of exposure to petrochemical development: (i) on the intertidal zone adjacent to the petrochemical effluent (Impacted location); and (ii) on the intertidal zone unimpacted by the petrochemical effluent (Control location). The former was selected in the centre of the area dedicated to SPSEEZ petrochemical development (N 27° 30.604, E 52° 34.437), while the latter in the southern part of the Nayband Bay, 7.7 km distance far from the area dedicated to SPSEEZ petrochemical development (N 27° 23.921, E 52° 38.987; Fig. 1). Sampling was performed in February 2010 during the cold season when the ambient air temperature was 27.35 °C. A total of 364 individuals of *Planaxis sulcatus* (Gastropoda; Born 1791), *Clibanarius signatus* (Crustacea; Heller 1861) and *Circenita callipyga* (Bivalvia; Von Born 1778) with different feeding guilds (i.e. *Planaxis sulcatus* = microphage grazer*; Clibanarius signatus* = detritus feeder and *Circenita callipyga* = suspension feeder) were collected from intertidal areas with sandy-rocky substrate (Table 1). Specimens were collected by walking along the shoreline during low tide (ROPME 1999). All specimens were brushed and washed with clean seawater immediately after sampling and placed in separate clean polythene bags, then transported in a cool box to the laboratory of Ecology and Marine Conservation in Shahid Beheshti University, Tehran, Iran. Three seawater samples were collected from depth of 1 meter in each location. Seawater was first adjusted to pH = 2 with concentrated HNO_3, transferred to plastic bottles that were pre-washed with 30% nitric acid and rinsed with Milli-Q water (Balkis *et al.* 2010). To collect sediment samples, the upper 3-cm of sediment was collected with a stainless-steel spatula (Beauvais *et al.* 1995). Immediately after collection, the sediments were placed in acid cleaned polyethylene bottles and frozen (at -17 °C). Subsequently, samples were dried in an oven at 50°C, then sieved to pass 63 μm and homogenized (Uluturhan 2010).

Table 1. Summary of individual number in pooled samples for each species.

Species	Location	Number of pooled samples	Replicate	Total
P. sulcatus	Impact location	14	3	84
	Control location	17	3	107
C. signatus	Impact location	7	3	42
	Control location	11	3	67
C. callipyga	Impact location	5	3	34
	Control location	5	3	30

Laboratory analyses

Morphometric parameters including shell length (SL) for bivalves and gastropods (Helm *et al.* 2004), and the carapace shield length (CSL) for hermit crabs (Biagi *et al.* 2006; Sant'Anna *et al.* 2006) were measured using a digital calipers (± 0.01 mm accuracy). Total weights (TW) of all individuals were weighed on a top-loading digital

balance (precision 0.001 g). The shells of gastropod and hermit crabs were broken using a hammer and the soft tissues from all individuals were removed carefully by shelling with a plastic knife.

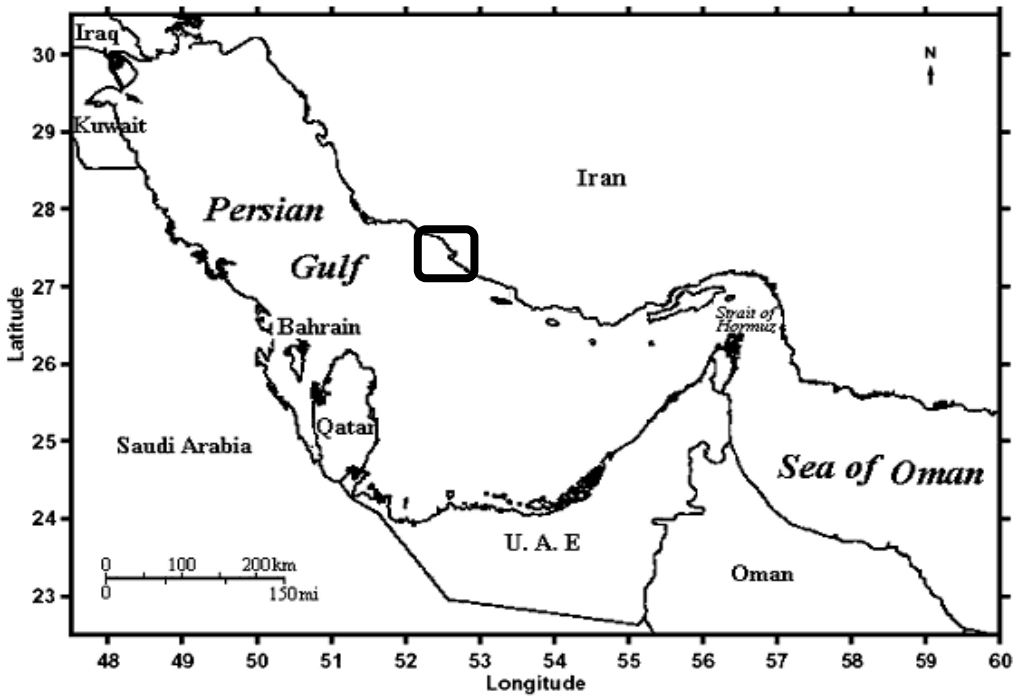

Fig. 1. The study area in the northern Persian Gulf.

The whole-soft tissue samples were then oven-dried for 48 h at 60 °C. Preparation of seawater samples for determination of total recoverable metals (Ni and V) was performed by adding HNO_3 followed by reducing and concentrating the volume of solution (EPA method 200.7). For determination of mercury, seawater samples were prepared according the EPA Method 245.1. Chemical digestion of sediments was done according to EPA 3050B. The samples were digested by adding a HNO_3-HCl acid mixture (1:3) to 1 g of dry sediment (grain size < 63µ) for determination of nickel and vanadium. For detection of mercury, 8 mL HNO_3 and 4 mL concentrated H_2SO_4 were added to the vials and placed on water bath for 3 h at 60 °C. Finally, the solution reached to volume by adding sufficient Milli-Q water and 1 mL $K_2Cr_2O_7$ 2 % (ROPME, 1999). The sediment grain size analysis was performed according to the ROPME (1999). To supply sufficient amount of dry tissues for determination of heavy metal concentrations, each sample type pooled in 3 replicates (Table 1). The specimens that used in each pooled sample were selected from similar size groups (Beldi *et al*. 2006). Chemical digestion of soft tissues was done by adding 6 mL HNO_3 and 2 mL H_2O_2 30% to the vials that contain 1 g of powdered dry tissues to measure the nickel and vanadium concentrations (Foster & Cravo 2003; Cebrian *et al.* 2007). After 24 h, the solutions were placed on water bath for 3 h at 60 °C. Digestion of biological specimens for detection of mercury was carried out by adding 45 mg V_2O_5 and 5 mL concentrated HNO_3 (or either more amounts if it was required) to the 1 g powdered dry tissues (ROPME 1999). The solution was placed on laboratory temperature to finish the strong reactions. Then, the vials were placed on water bath to complete the digestion for 3 h at 60 °C. After cooling, the solutions reached to volume by adding adequate Milli-Q water and 1 mL $K_2Cr_2O_7$ 2%. Finally, all solutions were passed through Whatman filter paper (No. 42) and reached to volume by adding Milli-Q water. In all of the procedures mentioned above, the accuracy of the acid digestion methods and the quality of the material used were controlled by preparing 3 blank samples in accordance with the same preparation methods as the actual samples. Nickel and vanadium were analyzed using Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-OES). Mercury/Hydride System- Atomic Absorption Spectrometry (MHS-AAS) was also used for instrumental analysis of mercury. Instrumental analyses of nickel and vanadium were carried out in Iranian Mineral Processing Research Centre (IMPRC) that is one of the accredited laboratories by Iranian Department of Environment. Mercury was determined in ICP-OES lab of Research Institute of Petroleum Industry (RIPI). The detection limits for mercury, nickel, and vanadium were 5, 50 and 20 pbb, respectively. To evaluate the efficiency of metal bioaccumulation by each species, the bioaccumulation factors, including BAFs and BSAFs (Equations 1 and 2) were calculated as a ratio of trace metal content in an organism versus that in water or sediment (Ravera 2002; Feng *et al.* 2020).

(1) BSAFs= C_{Biota} /$C_{Sediment}$

(2) BAFs= C_{Biota} /C_{Water}

where C_{Biota} and $C_{Sediment}$ were the chemical concentration (µg g^{-1} dry weight) in the organism and the superficial sediment, respectively, while C_{Water} was the chemical concentration (µg g^{-1} dry weight) in the seawater. The categories of BAFs are presented as: High potential if BAFs > 1000; moderate potential if 1000 > BAFs> 250; and low potential if BAFs < 250 (Abdullah *et al.* 2007). Likewise the categories of BSAFs values are presented as macro concentrator (BSAF > 2), micro concentrator (1 < BSAF < 2) and deconcentrator (BSAF < 1) (Berandah *et al.* 2010).

Data analyses

Statistical analyses were performed using SPSS 19.0 software. The data on concentration of nickel in soft tissues of the studied species, seawater and sediments collected from 2 locations exhibited normal distribution according to the Shapiro-Wilk normality test. Therefore, independent sample *t*-test was used to compare the mean concentrations of nickel in soft tissues of the studied species, seawater and sediment samples between 2 locations. The data on concentration of vanadium in soft tissues of the studied species and sediments collected from 2 locations were normally distributed; therefore, the significant difference in vanadium concentrations between locations was tested using independent sample *t*-test. Since data on concentration of vanadium in seawater was not normally distributed and none of the transformation methods provided a guarantee of a normal distribution, therefore, the significant difference in vanadium concentrations between locations was tested using non-parametric Mann-Whitney U test. Data on concentration of mercury in soft tissues for hermit crab were not normally distributed. Thus, data on Mercury in all species were normalized using logarithmic transformation and others data were kept untransformed. The mean values of mercury in soft tissues of the studied species between locations were compared by independent-sample *t*-test. Bio-indication capability of the species for bioaccumulation of each heavy metal (Ni, V and Hg) was compared by two-way analysis of variance. The species were employed as fixed factor and location was random factor.

RESULTS AND DISCUSSION

Sea sediments were largely made of sand typical of coral reef sediments followed by gravel and silt-clay in the study area (Table 2). The presence of shell and coral fragments was observed in sediments. Sediment samples lacked unpleasant odor of hydrogen sulfide suggesting lack of organic contaminants in sediments.

Table 2. Sediment grain size composition in impacted and control locations.

Location	Silt and clay 63 µm > sediment	Sand 63 µm < sediment < 2000µm	Gravel Sediment > 2000 µm
Control location	0.40 %	85.59 %	14.00 %
Impacted location	0.12 %	80.39 %	19.49 %

The concentration of mercury in seawater and sediment samples in both locations were lower than detection limits (Table 3). No significant differences were found in concentrations of nickel (t = 0.42, df = 44, p = 0.69) and vanadium (Mann-Whitney U = 3.00, Z = -0.66, p = 0.51) in seawater between the impacted and control locations. Likewise, no significant differences were found in the concentrations of nickel (t = -0.68, df = 4, p = 0.53) and vanadium (t = -1.39, df = 4, p = 24) in the sediment samples between the locations. Heavy metal concentrations of all blank samples for nickel, vanadium and mercury in the seawater and sediment samples were lower than detection limits. No significant difference was found in the mercury concentrations between locations in selected species (Tables 4 and 5). However, concentrations of mercury in *C. callipyga* followed by *C. signatus* were significantly higher than that of *P. sulcatus* in control location (Tables 4 and 5). Significant differences were found in nickel concentrations between pairwise species comparisons and between impacted and control locations with higher levels in impacted location and in *C. callipyga* followed by *P. sulcatus* and *C. signatus* (Tables 4 and 5). No significant difference was found in the vanadium concentrations between locations in selected species (Tables 4 and 5). Concentration of vanadium in *C. callipyga* was significantly lower than those of *P. sulcatus* and *C. signatus* (Tables 4 and 5). However, no significant difference was found in vanadium concentrations between *P. sulcatus* and *C. signatus.*

Table 3. Mean (± SE), minimum and maximum levels of heavy metals in the seawater (mg L^{-1}) and sediment (μg g^{-1} dry weight) samples.

Location	Sample type	Heavy metal	Mean (± SE)	Max	Min
Control location	Seawater	Hg	Not detected	< 0.005	< 0.005
		Ni	0.04 ± 0.01	0.05	0.03
		V	0.12 ± 0.01	0.13	0.11
	Sediment	Hg	Not detected	< 0.005	< 0.005
		Ni	6.81 ± 0.10	6.98	6.64
		V	5.72 ± 0.31	6.34	5.35
Impacted location	Seawater	Hg	Not detected	< 0.005	< 0.005
		Ni	0.04 ± 0.01	0.06	0.02
		V	0.12 ± 0.01	0.13	0.11
	Sediment	Hg	Not detected	< 0.005	< 0.005
		Ni	7.67 ± 0.17	9.63	5.60
		V	6.77 ± 0.69	8.08	5.73

The values of BSAFs and BAFs for nickel were higher in all three species than those for vanadium (Table 6). Of three species, *C. callipyga* exhibited a higher potential for concentrating nickel than the other species (Table 6). In addition, *P. sulcatus* displayed a higher potential for concentrating vanadium (Table 5). The values of BAFs for nickel and vanadium in each species demonstrated that *C. callipyga* and *P. sulcatus* had high potential for nickel uptake from seawater (Table 6). BAFs and BSAFs were not calculated for mercury, since its concentrations in seawater and sediment samples were lower than apparatus detection limit (Table 2).

Heavy metals in seawater and sea sediments

The concentrations of selected heavy metals in seawater followed the order of V >Ni > Hg, while the accumulation pattern for these metals in the sediments followed the order of Ni > V > Hg. Kamyab (2010) reported the order of Ni > V > Hg in seawater in the same study area. Comparing the results of present study for heavy metals in seawater with previous studies by Kamyab (2010) and Alimohammadi (2009) suggests an overall increase in concentrations of nickel and vanadium in the study area.

Heavy metal concentrations in soft tissues of selected species

Different molecular forms of heavy metals (i.e., physical, chemical) have different bioavailability for species with different feeding guilds (such as microphage-grazing, filter-feeding, detritus-feeding, predatory etc.; Zauke *et al.* 1998; Griscom & Fisher 2004). The selected species in the present study have different feeding guilds. The feeding strategy for *C. callipyga* is suspension feeder and burrows the sediments in shallow waters (Bosch *et al.* 1995). The individuals of *P. sulcatus* are microphage-grazer and feed on microorganism's biofilm being formed on hard surface (Houbrick 1987). Hermit crabs including *C. signatus* are detritus-feeder and predator to other invertebrates (Williams & McDermott 2004). The higher levels of nickel in *C. callipyga* (Bivalvia) might be attributed to the higher bioavailability of various chemical and physical forms of nickel for this species with suspension feeding strategy. Heavy metals can bind to organic matter in sea sediment (Bat *et al.* 2015). The suspension-feeders uptake metallic components form sedimentary medium by ingestion of sediments and or by exposure to the water in interstitial spaces in fine particles (Rainbow 2006). Feeding mode of *C. callipyga* causes the animal to intake non-soluble forms of pollutants associated with the nutritional and non-nutritional particles via digestive systems and also uptake of dissolved pollutant by respiration organs (Cossa 1989; Odzak *et al.* 2000). Previous studies on the bioaccumulation of trace elements in phytoplankton showed that the level of heavy metals concentration in these microorganisms have direct relation to the dissolved forms of elements in water column (Khummongkol *et al.* 1982; Gonzalez-Dkila 1995). Soft tissues of *C. callipyga* showed high concentration of nickel and also highest BAF and BSAF for nickel among studied species, suggesting that this species is an efficient accumulator of nickel. The low accumulation of vanadium in *C. callipyga* tissues, along with the low BAF and BSAF indicates that this species has low potential for accumulation of vanadium.

Table 4. Mean values (± SE), minimum and maximum levels of heavy metals bioaccumulation in whole-soft tissue samples (μg g^{-1} dry weight) of *Planaxis sulcatus* (Gastropoda), *Clibanarius signatus* (Crustacea) and *Circenita callipyga* (Bivalvia).

Location	Heavy metal	Species	Mean (± SE)	Max	Min
Control location	Ni	*P. sulcatus*	12.42 ± 0.35	12.79	11.72
		C. signatus	2.66 ± 0.22	3.10	2.40
		C. callipyga	24.36 ± 2.06	27.45	20.46
	V	*P. sulcatus*	1.48 ± 0.13	1.74	1.29
		C. signatus	1.51 ± 0.22	1.94	1.24
		C. callipyga	0.35 ± 0.14	0.60	0.13
	Hg	*P. sulcatus*	0.09 ± 0.001	0.100	0.078
		C. signatus	0.049 ± 0.001	0.050	0.049
		C. callipyga	0.072 ± 0.011	0.088	0.050
Impacted location	Ni	*P. sulcatus*	11.46 ± 0.47	12.37	10.78
		C. signatus	1.22 ± 0.02	1.25	1.17
		C. callipyga	19.89 ± 1.00	21.83	18.54
	V	*P. sulcatus*	1.40 ± 0.17	1.74	1.16
		C. signatus	1.071 ± 0.09	1.25	0.93
		C. callipyga	0.36 ± 0.15	0.64	0.12
	Hg	*P. sulcatus*	0.078 ± 0.006	0.089	0.066
		C. signatus	0.087 ± 0.017	0.120	0.062
		C. callipyga	0.096 ± 0.007	0.107	0.075

Table 5. Summary of Two-Way ANOVA testing the difference in heavy metal bioaccumulations among species and locations.

Comparisons	source of Variation	*df*	MS	F
Hg	Species	2	0.02	2.91 ns
	Location	1	0.05	5.67 ns
	Species × location	2	0.03	*3.90
	Residual	13	0.01	
	Total	19		
Ni	Species	2	611.28	**217.14
	Location	1	23.60	*8.38
	Species × location	2	5.47	1.94 ns
	Residual	12	2.82	
	Total	18		
V	Species	2	2.08	**1.78
	Location	1	0.13	28.33 ns
	Species × location	2	0.09	1.18 ns
	Residual	12	0.07	
	Total	18		

Note|**. $p < 0.01$; *. $p < 0.05$; $p > 0.05$: ns = non-significant.

Table 6. BAFs and BSAFs for nickel and vanadium calculated in seawater and sea sediment.

Measure	Heavy metal	*C. callipyga*	*C. signatus*	*P. sulcatus*
BSAFs	Ni	3.06	0.27	1.65
	V	0.06	0.21	0.23
BAFs	Ni	570.24	49.97	307.67
	V	2.94	10.78	12.00

The bioavailability of vanadium might be higher for *P. sulcatus* (Gastropoda) and *C. signatus* (Crustacea) with microphage-grazing and detritus-feeding strategies, respectively. The microbial biofilm and detritus are good source of heavy metals. Many studies have shown that microbial biofilms are efficient adsorbent of trace element from water column (van Hullebusch *et al.* 2003; Mages *et al.* 2004; Rhea *et al.* 2006). Given the feeding regime for *P. sulcatus*, this animal potentially has indirect bioavailability to the dissolved forms of heavy metals.

Efficacy of crustaceans, bivalves and gastropods as bio-indicators of mercury

The results that no significant differences were found in mercury levels in each species between locations mirror the results for this element levels in seawater and sea sediments. This lack of difference might be justified by the fact that mercury concentrations in both seawater and sediment were lower than the detection limit. In order to assess the efficacy of *C. callipyga* (Bivalvia), *P. sulcatus* (Gastropoda) and *C. signatus* (Crustacea) as bio-indicators for mercury, further studies are needed in areas with detectable limits of mercury in both seawater and sea sediments.

Efficacy of crustaceans, bivalves and gastropods as bio-indicators of nickel

The results that significant differences were found in the nickel levels in each species between locations, disagree the results for its levels in seawater and sea sediments. The results of present study suggest that *C. callipyga* (Bivalvia) followed by *P. sulcatus* (Gastropoda) and *C. signatus* (Crustacea) might not be reliable bio-indicators for nickel in seawater and sea sediments. Rainbow *et al.* (2000) reported no significant differences in nickel concentrations among studied locations in the Gulf of Gdansk, Poland in which the bioaccumulation of nickel by the mussel (*Mytilus trossulus*) and barnacle (*Balanus improvisus*) were not significantly different (Rainbow *et al.* 2000). In a study conducted in the northern Persian Gulf, significant difference was detected in nickel concentration in razor clam *Solen dactylus* between studied locations, even though, the concentrations of this element in the sediment samples were not significantly different (Saeedi *et al.* 2012). The results exhibiting that the ratio of nickel in soft tissues of *C. callipyga* was three times greater than its concentration in sediment (BSAFs), was in disagreement with those by Saeedi *et al*. (2012) who reported that nickel in sediment was higher than that in razor clam *Solen dactylus*. These results suggest that *C. callipyga* might be reliable accumulator of nickel. Soft tissues of marine molluscs are generally efficient accumulator of heavy metals (Yap & Cheng 2009). Usero *et al.* (2005) also reported significance difference in nickel bioaccumulation by 2 bivalves (i.e., *Donax trunculus*, *Chamelea gallina*), while no significant difference was found in the concentrations of nickel in the sediment samples between the polluted and non- polluted areas. Another study reported no significance difference in the nickel concentration in soft tissues of the gastropod, *Thais mutabilis*, and also sea sediments in intertidal zone of Bandar Abbas City, the Northern Persian Gulf (Astani *et al*. 2012). The conclusion from these studies is that further studies are needed to assess the efficacy of *C. callipyga* as bio-indicator of nickel.

Efficacy of crustaceans, bivalves and gastropods as bio-indicators of vanadium

The results that significant differences were found in the vanadium levels in each species between control and impacted locations are in disagreement with the results for its levels in seawater and sediments. This suggests that *C. callipyga* (Bivalvia), *P. sulcatus* (Gastropoda) and *C. signatus* (Crustacea) might not be reliable bio-indicators for vanadium in the seawater and sediments. The result that the concentrations of vanadium were remarkable in *P. sulcatus* and *C. signatus* might be driven by the fact that crustaceans and gastropods generally have high potential in accumulation of vanadium (Miramand, *et al.* 1980; Unsal 1983; Eisler 2009). Amiard *et al.* (2004) reported significant spatial variation in bio-accumulation of nickel and vanadium in South Coast of Brittany, France in 3 benthic invertebrates with different feeding guilds including mussels, *Mytilus edulis* (filter-feeder), periwinkles, *Littorina littorea* (grazing-feeder) and dogwhelks, *Nucella lapillus* (carnivore). However,

Khoshnood *et al.* (2010) reported no significant difference in the nickel and vanadium concentrations in soft tissues of the two fish species including oriental sole *Euryglossa orientalis* and deep flounder *Psettodes erumei* in the Northern Persian Gulf.

Efficacy of selected species for biomonitoring programs

Wide geographic distribution range and high abundance of an organism are the major features that make a species as a reliable bio-indicator for biomonitoring programs. Examined species in the present study had wide distribution ranges in the Persian Gulf and other tropical areas. The bivalve *C. callipyga* is native to the Red Sea and is an abundant species in the Indian Ocean including in the Persian Gulf and Oman Sea (Feulner & Hornby 2006; Nabavi *et al.* 2007). The gastropod, *P. sulcatus* is widely distributed in rocky shores of Indian Ocean, Indo-Pacific, Red Sea and the Persian Gulf (Bosch *et al.* 1995). Hermit crab *C. signatus* also has wide distribution in the Persian Gulf (Moradmand & Sari 2007) and Oman Sea (Hogarth 1988; Hosseini 2009).

CONCLUSION

The bioaccumulation potential of nickel and vanadium by *P. sulcatus* was remarkable with respect to its feeding mode. Given the wide distribution ranges of selected taxa and the potentials of *C. callipyga* and *P. sulcatus* for bioaccumulation of nickel as well as the potentials of *C. signatus* and *P. sulcatus* for bioaccumulation of vanadium, the results of the present study suggest that *C. callipyga* and *P. sulcatus* might be an efficient accumulator of nickel, while *P. sulcatus* and *C. signatus* as efficient accumulators of vanadium.

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