Metal concentrations in razor clam *Solen dactylus* (Von Cosel, 1989) (Bivalvia: Solenidae), sediments and water in Golshahr coast of Bandar Abbas, Persian Gulf

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Abstract

In a complementary field study, the concentrations of some metals (Cu, Ag, Pb, Zn, Ni, Co, Mn, Fe, As, Cd, Cr, Mg and Ba) were measured in clam *Solen dactylus*, sediments and water collected at two stations (Park-e-Qadir, 56° 20′ E, 27° 11′ and Nakhl-e-Nakhoda, 56° 23′ E, 27° 10′ N) of Bandar Abbas coastal waters of the Persian Gulf in November 2008 and February 2009 showing different contamination levels. Although there is little information on metal concentrations in macro-benthic animals in this area, this study, for the first time, reports the accumulation of some metals in *S. dactylus* in order to introduce this species as a bioindicator for this area. Results indicated that Mg and Fe were the two most abundant metals in clams and sediments. The maximum and minimum metal concentrations in clams belonged to Mg (3850-5040 μgg^{-1} dry wt) and Ag (0.30-0.40-0.58 μgg^{-1} dry wt), respectively. There was a significant relationship between the accumulation of metals in clams, sediment and water samples. A significant relationship between clam lengths and concentrations of Cu (positive) and Mg (negative) were observed. Our study also showed that variable metal concentrations were related to different sampling stations, seasons and their interactions as well. Bioaccumulation of metals in clams was significantly different for eight metal elements between start of the gametogenesis and ripeness stages. Our investigation indicated that the clam *S. dactylus* could be a useful bioindicator for Zinc.

Keywords: Metal, Bioaccumulation, Bioindicator, *Solen dactylus*, Sediment, Water, Persian Gulf

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Introduction

The Persian Gulf is one of the largest oil and gas resources in the world. This area represents a tropical case study mainly due to intensive oil extraction and related activities which can affect its pollution level. The industrial and urban activities in the tropical coastal zones increase the release of contaminants, which can be a threat for the marine ecosystems and have effects on marine diversity locally and globally (Metian et al., 2008).

In our studies, we are focusing on the determination of metal concentrations in some coastal marine species, particularly, in Bivalves and use of these organisms as bioindicators.

This kind of approach has been extensively applied in other marine environments using molluscs, oysters, as well as bivalve species. For example, Etim et al. (1991) have reported temporal trends in some heavy metal concentrations such as Zn, Ni, Pd, and Cd in the Cross River, Nigeria using the clam *Egeria radiata*. They showed that concentration of Ni and Zn was lower than the maximum permissible levels concentration in this area. Bilos et al. (1998) determined some metal concentrations including Cu, Cr, Mn, and Zn in Asiatic clams (*Carbicula fluminea*) which were collected at the Río de la Plata coast, Argentina to assess the amount of metal pollution in the area and compared to those reported for the other moderately polluted world rivers. Lu et al. (2005) worked on bioavailability of metals in sediment from northern San Francisco Bay and survival of clam *Macoma nasuta*. They concluded that survival of clams in sediments with high concentration of metals was decreased. Pourang et al. (2005) studied the trace element concentrations including Cd, Pb, Ni and V in fish, superficial sediments and water from northern parts of the Persian Gulf. They found that Cd concentration in sediment of all Northern parts of the Persian Gulf was higher than Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area Standard. Metian et al. (2008) worked on accumulation of metals and metalloid in scallop *Comptopallium radula* in New Caledonia. They demonstrated that Zn was mainly concentrated in the digestive gland (65%) and Co in Kidneys (81%). They concluded from their research that *C. radula* could be a valuable local biomonitor species for Ag, As, Cd and Fe. Yap et al. (2009) studied the concentration of some heavy metals in snail *Telescopium telescopium* as a biomonitor in the tropical intertidal area in Peninsular, Malaysia.

In their study, digestive gland had higher Zn concentration and shells demonstrated higher Pb concentration. Chouvelon et al. (2009) reported Hg concentrations and their risk assessment in several marine organisms in New Caledonia. Their study showed that Hg concentration in this area is high which would be dangerous to sea food consumers. Recent studies by Hédouin et al.(2006 and 2009) screened metal concentrations in a variety of bivalves, mainly oysters *Isognomon isognomon* and the edible clam *Garfarium tudium* showed that those marine organisms satisfied the basic ecological and ecotoxicological requirements to be met by a bioindicator species.We are particularly interested in the determination of metal concentrations in some marine organisms such as sessile benthic molluscs which inhabit in the Iranian coastal waters of the Persian Gulf. These organisms can be exploited for contamination determination of the area as potential bioindicators. The advantage of using such organisms for biomonitoring plans has been reported (Yap et al., 2009). *Solen dactylus* is an edible sessile clam which inhabits intertidal sandy-muddy beaches along the Oman Sea and the Persian Gulf (Saeedi et al., 2009). Heavy metal accumulations in edible marine organisms have always been threats for their consumers.In order to assess the magnitude of trace metal pollution in the Northern parts of the Persian Gulf, we have begun a research program aimed at investigation and recognition of coastal marine organisms as bioindicator species. The aim of this study was, therefore, to provide baselines information on the metal ion contamination status of the Persian Gulf coastal marine environment. A wide range of metal element bioaccumulations were determined in *S. dactylus*, water and sediments, and also the relationships between lengths and sexes of clams and the metal concentrations in them were studied. This study also determines the differences between metal concentrations in clam at two stations of the Iranian coastal waters of the study area in two different seasons (November 2008 and February 2009).

Materials and methods

Study area and sampling

Two sampling stations along the Golshahr coast of Bandar Abbas in the Persian Gulf were selected according to the contamination status by direct observation. pollutants (e.g. sewage and urban wastes) in the first station (Park-e-Qadir, $56^{\circ}\ 20^{/}$ E, $27^{\circ}\ 11^{/}$ N) were more than the second station (Nakhl-e-Nakhoda, $56^{\circ}\ 23^{/}$ E, $27^{\circ}\ 10^{/}$ N) (Figure 1). Anthropogenic inputs and occurrence of rubbish dump make the first station as a polluted station. Specimens of *S. dactylus* were collected by hand with a 0.5 m long metal wire forming a V shape at one end (Saeedi et al., 2009) during low tide. The sampling was done in November 2008 (start of gametogenesis, stages I and II) and February 2009 (ripeness stage, stage III A) (Saeedi et al., 2009) along two intertidal stations of Golshahr coast in Bandar Abbas. The specimens were kept in seawater of the sampling station for 24 hrs in order to purify or depurate the gut contents and mantle cavity (Hédouin et al., 2009), then they were frozen at -20°C in a refrigerator in Shahid Beheshti University Biosystematics' lab for future analysis.

150 to 300 g sediments (top 5 centimeter layer) were collected by acid-washed containers in the sampling stations and immediately transferred to the laboratory in acid-washed plastic bags and kept at -20°C for future metal analyses (Chen et al., 2007). 300 to 600 ml seawater samples were collected from the sea-surface at <1m depth by acid-washed containers and kept in the laboratory at 4°C.

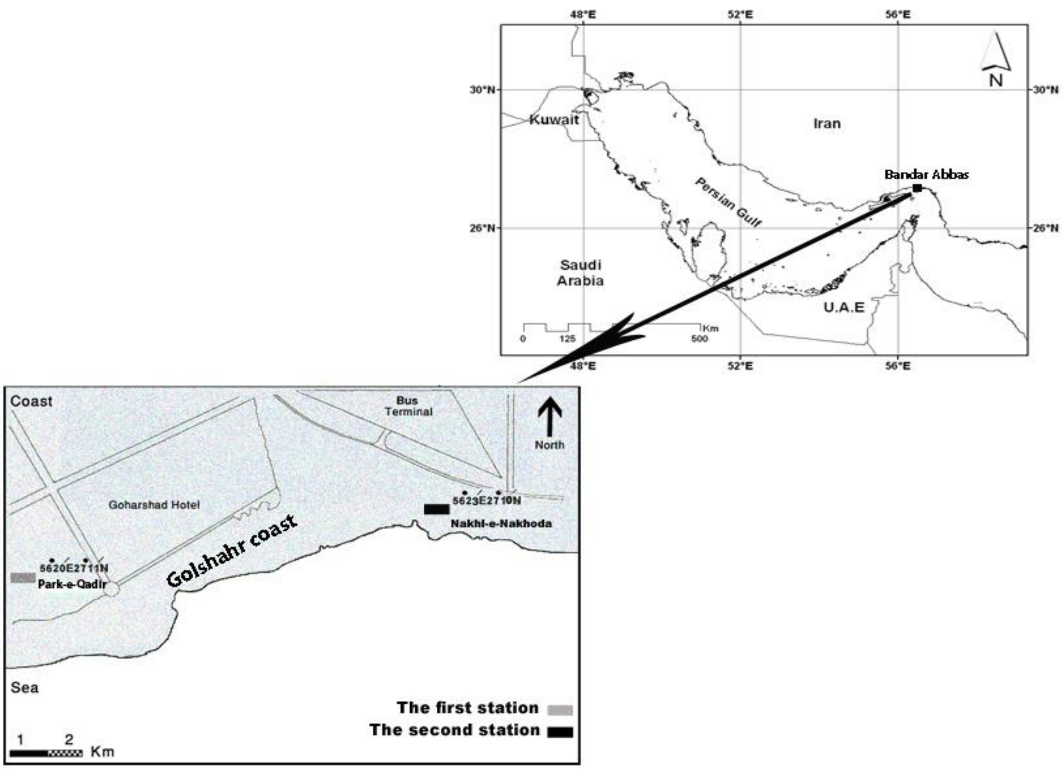

Figure 1: Field study area in Bandar Abbas, Persian Gulf. Inset shows the sampling sites: 'Park-e-Qadir' and 'Nakhl-e-Nakhoda'

Biometry and sample preparation for metal analysis

In total, 240 clams (*n*=60 per station per sampling month) were collected and studied during this study. The biometrical measurements including anterio-posterior length (length), dorso-ventral length (width) and the distance between two valves (diameter) to the nearest 0.1 mm and total weight (TW), wet weight of the soft parts (SPW) to the nearest 0.1 mg were measured using vernier calipers and a digital balance, respectively (Saeedi et al., 2009). Only adult samples with shell lengths longer than 45 mm were selected for analysis. Soft parts of clams were removed from the shells. Six length classes from 48 to 108 mm were selected and 10 clams for each one were pooled, weighed (wet wt) (Maanan, 2008), and dried at 60°C in the oven until reaching the constant weight (Hédouin et al., 2009). In February 2009, females, males and sex undetermined were pooled separately because we wanted to clarify metal concentration in different sexes. Dried samples weighed again (dry wt) and ground in an agate mortar for homogenization (Maanan, 2008). Sediments were dried at 60°C until reaching the constant weight, and then were sieved by a 1 mm mesh size before metal analysis (Hédouin et al., 2009). Dried biological samples of clams from 0.1 to 0.5 g and dried sediment samples about 0.5 g were digested using a 3:1 (v/v) 65% HNO_3 30% HCL mixture at room temperature overnight, then using a microwave for 30 min with constantly increasing temperature up to 150 °C for biological samples and up to 100 °C for sediment samples, then 15 min at this maximum temperature. All samples were then diluted to 30-50 ml with milli-Q water (Hédouin et al., 2009).

About 100 ml of water samples were filtered through 0.4 µm filter papers. Finally, elements were analyzed using an atomic absorption spectrophotometer certified ISO/IEC 17025. The sample concentrations are presented as μgg^{-1} dry wt (Yap et al., 2009) for clams and sediments and μgl^{-1} for water samples. For verification of the quality of metal analysis, all samples were reanalyzed in Acme Labs in Vancouver, Canada and used SRM (Standard Reference Materials).

Environmental factors measurement

Sea-surface temperature, Salinity, dissolved oxygen and pH were measured with 3 replicates at low tide during the study period separately in both stations.

Statistical analysis

SPSS version 17 and Excel 2007 software were used for statistical analysis and plotting all graphs. All data were checked for normality (Shpiro-wilk test) to use in future parametric tests. A two-way analysis of variance (ANOVA) was used to determine the effects of sampling season (sexual and rest stages) and to study stations as fixed factors on the variation of metal concentrations in the soft parts (Maanan, 2008). Pearson correlation between size and total different metal concentrations in soft tissues in each length class were used. Paired samples t-test was used to determine the differences of metal concentrations in clams in proliferation of gonad and ripeness stages (Chouvelon et al., 2009). An independent sample t-test was used to determine the significant differences of metal concentrations between male and female clams as well as metal concentrations in sediment and water between two stations. A non-parametric test Spearman's correlation was used to determine the relationship between the metal concentration in clams, sediment and water. The level of significance was set at $\alpha=0.05$.

Result

Metal concentrations in Clam Solen dactylus, sediment and water

A total of 240 clams, were collected and studied during this work (52 to 108 mm in length, 2.56 to 21.15g in weight). The element concentrations in *S. dactylus*, sediment and water are collected in tables 1 and 2. Concentrations of some metal elements in clams were under the detection limit (indicated as < in all tables) which restricted comparisons between them in the two stations. The maximum and the minimum average (±SD) of metal concentrations in clams in station 1 belonged to Mg (3850±589.06 in November 2008 and 5040±811 μgg^{-1} dry wt in February 2009) and Ag (0.58±0.23 in November 2008 and 0.40±0.00 μgg^{-1} dry wt in February 2009), respectively. The maximum and the minimum averages of metal concentrations in clams in the second station during the same periods of study also belonged to Mg (4317±676.51 in November 2008 and 4818±922.72 μgg^{-1} dry wt in February 2009) and Ag (0.40±0.16 in November 2008 and <0.3 μgg^{-1} dry wt in February 2009), respectively. As it is also shown in table 1, the maximum and the minimum averages of metal concentrations in sediment and water samples belonged to Mg and Ag, respectively. In general, the most abundant and typical metals in clams and sediments were Mg and Fe and in water it was Mg and Cu.The Zn concentrations in the clams were more than that in sediment and water samples, while for Pb and Fe the concentrations in sediments were higher than those in clams and in water (Tables 1 and 2). Also the average concentrations of Cu were high first in water (101±6.18 $\mu g l^{-1}$) and then in clam (8.50±0.70 $\mu g g^{-1}$ dry wt) and finally in sediment (6.75±1.50 $\mu g g^{-1}$ dry wt). Therefore, it is concluded that this clam might be a suitable bioindicator for Zinc based on the metal concentrations in clams more than their environment (Tables 1 and 2).In both the first and the second stations, there was a significant positive correlation between the metal concentrations in clam and sediment (Spearman's correlation, r=0.56 and 0.67, $p \leq 0.05$), clam and water (r=0.61 and o.86, $p \leq 0.05$) and sediment and water (r=0.66 and 0.68, $p \leq 0.05$). Figure 2 shows the mean of metal concentrations in clams at two different stations. The mean concentration of Mg in clams at Park-e-Qadir (station 1) was somehow similar (4594±929.58 $\mu g g^{-1}$ dry wt) to Nakhl-e-Nakhoda (station 2) (4585±826.48 $\mu g g^{-1}$ dry wt). The mean concentrations of Fe and Mn at station 2 in clams (1662±711.26 and 48±22.15 $\mu g g^{-1}$ dry wt) were higher than those at station 1 (494±428 and 16±12.53 $\mu g g^{-1}$ dry wt), whereas the mean concentration of Zn at the first station (81±16.38 $\mu g g^{-1}$ dry wt) was greater than that at the second station (61±6.43 $\mu g g^{-1}$ dry wt). Other metal concentrations in clams show little differences between two stations. Figure 3 presents the metal concentrations in sediments at both stations 1 and 2. The mean concentration of Mg in sediments at station 1 (15001±425 $\mu g g^{-1}$ dry wt) and station 2 (14851±6498 $\mu g g^{-1}$ dry wt) showed a little difference. The mean concentrations of Fe and Mn at the second station (13801±5190 and 504±215 $\mu g g^{-1}$ dry wt, respectively) were considerably higher than those at the first station (9051±1203 and 481±12 $\mu g g^{-1}$ dry wt, respectively). As it is shown in Figure 4, the mean concentration of Mg in water at two stations was nearly equal. The relationship between all metal concentrations in soft tissue of clams were studied and it was found that only Fe and Mn concentrations showed a significant positive correlation (r^2=0.97, $p \leq 0.05$) (Figure 5).

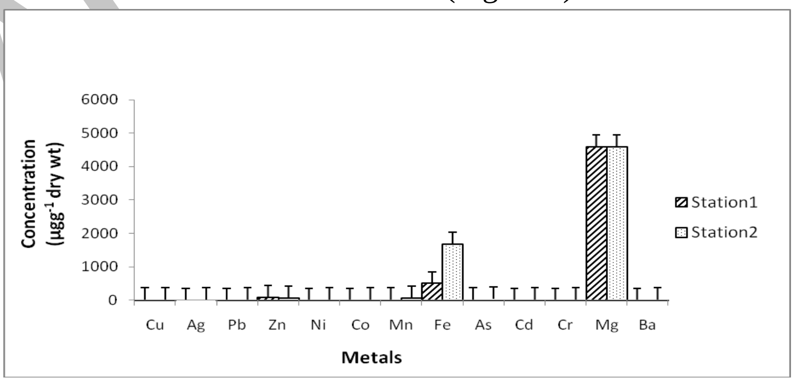

Figure 2: Average metal concentrations in clam at two different stations; Station 1, Park-e-Qadir and Station 2, Nakhl-e-Nakhoda, Bandar Abbas (Standard Bar: SE)

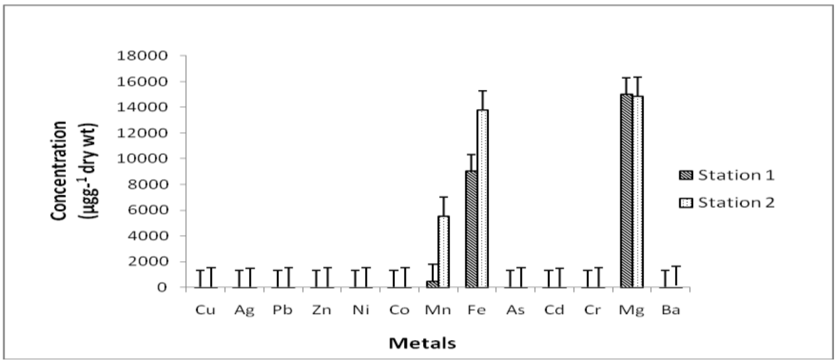

Figure 3: Average metal concentrations in sediment at two different stations; Station 1, Park-e-Qadir and Station 2, Nakhl-e-Nakhoda, Bandar Abbas (Standard Bar: SE)

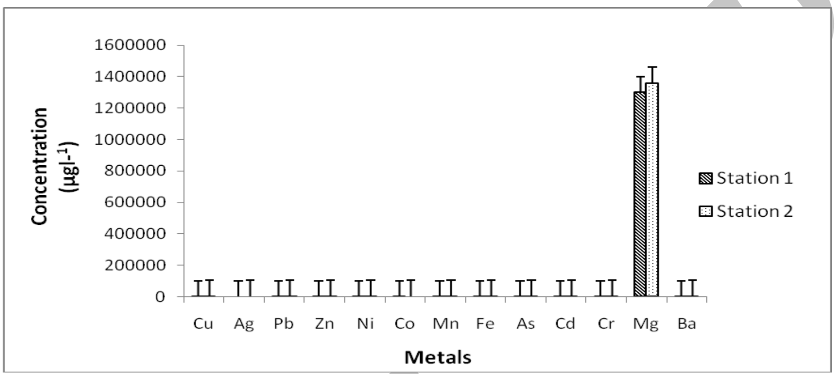

Figure 4: Average metal concentrations in water at two stations; Station 1, Park-e-Qadir and Station 2, Nakhl-e-Nakhoda, Bandar Abbas (Standard Bar: SE)

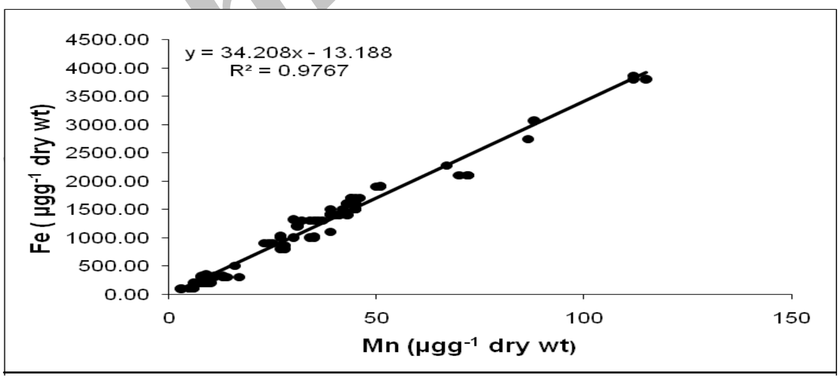

Figure 5 : Linear regression relationship between two metal elements; Mn and Fe, in *S. dactylus*, Bandar Abbas

Table 1: Element concentrations in different length classes of *Solen dactylus* (mean±SD; $\mu g g^{-1}$ dry wt, *n*=10), sediment (mean±SD; $\mu g g^{-1}$ dry wt, *n*=3) and water

Length Class	Mean Length (mm)	Weight (g)	Cu	Ag	Pb	Zn	Ni	Co	Mn	Fe	As	Cd	Cr	Mg	Ba
Park-e-Qadir															
1	64.83±3.2	5.33±0.8	24.00±2.0	0.50±0.0	<3	63.00±10.0	6.00±0.8	5.00±0.4	39.00±9.0	1100.00±135.0	25.00±4.0	<0.50[a]	5.00±0.4	4600.00±930.0	8.00±1.0
2	70.83±0.6	6.59±1.7	12.00±1.0	<0.30[a]	8.00±0.7	55.00±9.0	6.00±0.9	4.00±0.1	39.00±7.0	1500.00±127.0	30.00±5.0	<0.50[a]	5.00±0.2	4500.00±892.0	20.00±8.0
3	74.16±1.3	7.23±1.8	23.00±1.0	0.50±0.0	<3	60.00±12.0	4.00±0.3	2.00±0.2	24.00±3.0	900.00±68.0	26.00±5.0	<0.50[a]	3.00±0.3	3600.00±732.0	6.00±0.8
4	80.91±1.7	9.30±2.3	21.00±3.0	0.60±0.0	<3	63.00±11.0	5.00±0.3	4.00±0.2	34.00±3.0	1000.00±104.0	25.00±2.0	<0.50[a]	4.00±0.3	3800.00±692.0	8.00±0.7
5	91.91±2.4	12.37±3.2	18.00±2.1	0.60±0.0	<3	65.00±13.0	4.00±0..3	2.00±0.3	27.00±6.0	800.00±78.0	30.00±3.0	<0.50[a]	3.00±0.4	3500.00±661.0	6.00±0.9
6	106.16±1.7	19.57±4.6	23.00±2.1	1.00±0.0	5.00±0.8	73.00±11.0	3.00±0.1	10.00±0.9	16.00±2.0	500.00±39.0	26.00±6.0	1.00±0.0	3.00±0.5	3100.00±592.0	21.00±7.0
Sediment	-----	-----	5.00±0.7	<0.30[a]	4.00±0.6	14.00±1.0	29.00±7.0	13.00±1.0	472.00±29.0	8200.00±376.0	10.00±2.0	<0.50[a]	33.00±9.0	14700.00±2963.0	54.00±12.0
Water	-----	-----	94.60±18.0	0.14±0.0	1.60±0.0	13.20±0.0	5.60±0.8	1.87±0.2	45.99±13.9	25.00±7.9	83.70±19.0	1.00±0.0	5.60±1.2	1277689.00±2981.0	15.18±5.4
Nakhl-e-Nakhoda															
1	60.66±4.5	4.00±0.9	12.00±2.0	0.70±0.0	27.00±13.0	76.00±19.0	9.00±1.0	25.00±11.0	50.00±16.1	1900.00±293.0	29.00±5.0	<0.50[a]	8.00±0.7	5500.00±873.0	40.00±13.0
2	66.83±2.0	5.28±0.8	22.00±5.0	0.50±0.0	4.00±0.2	62.00±17.0	5.00±0.5	3.00±0.0	25.00±11.0	900.00±98.0	27.00±5.0	<0.50[a]	3.00±0.1	3600.00±732.0	7.00±2.0
3	81.08±1.5	9.27±2.7	12.00±2.0	<0.30[a]	<3	58.00±15.0	5.00±0.3	3.00±0.0	35.00±13.0	1300.00±123.0	35.00±8.0	<0.50[a]	4.00±0.2	4200.00±782.0	8.00±2.0
4	86.16±1.5	11.83±3.6	10.00±1.0	<0.30[a]	4.00±0.2	54.00±16.0	6.00±0.4	3.00±0.0	45.00±17.2	1500.00±129.0	27.00±7.0	<0.50[a]	6.00±0.3	4600.00±862.0	7.00±1.8
5	89.00±1.0	11.83±3.8	11.00±2.0	<0.30[a]	3.00±0.1	56.00±13.0	8.00±0.7	4.00±0.1	43.00±15.0	1600.00±162.0	32.00±9.0	<0.50[a]	6.00±0.3	4200.00±829.0	10.00±3.0
6	95.50±1.4	14.22±4.2	11.00±2.0	<0.30[a]	4.00±0.3	55.00±12.0	5.00±0.4	3.00±0.0	31.00±10.0	1200.00±121.0	31.00±11.0	<0.50[a]	3.00±0.0	3800.00±612.0	6.00±0.9
Sediment	-----	-----	8.00±0.9	<0.30[a]	7.00±0.9	22.00±8.0	46.00±17.0	15.00±3.0	509.00±107.0	13600.00±2734.0	7.00±0.8	<0.50[a]	49.00±10.0	15300.00±3726.0	107.00±29.0
Water	-----	-----	102.90±26.0	0.20±0.0	0.60±0.0	21.70±11.0	10.70±2.9	0.46±0.0	49.06±17.0	82.00±27.0	78.00±31.0	0.44±0.0	10.70±2.1	1321297.00±3017.0	24.34±14.0

a: Concentrations <detection limit;

Table 2: Element concentrations in different sex and length classes of *Solen dactylus* (μgg^{-1} dry wt, *n*=10), sediment (μgg^{-1} dry wt, *n*=3) and water (μgl^{-1}, *n*=3)

Length Class	Mean Length (mm)	Weight (g)	Cu	Ag	Pb	Zn	Ni	Co	Mn	Fe	As	Cd	Cr	Mg	Ba
Park-e-Qadir															
1 (M)	86.50±1.8	11.49±3.6	15.00±3.0	0.40±0.0	5.00±0.2	88.00±17.0	3.00±0.2	12.00±2.0	9.00±0.8	300.00±85.0	22.00±8.0	0.90±0.0	2.00±0.0	3800.00±991.0	1.00±0.0
1 (F)	93.50±2.1	13.91±0.9	32.00±8.0	0.50±0.0	6.00±0.3	107.00±29.0	<1[a]	12.00±3.0	3.00±0.2	100.00±41.0	17.00±3.0	1.10±0.0	<1[a]	5500.00±1021.0	<1[a]
2 (M)	106.25±1.8	17.57±0.9	25.00±6.0	0.40±0.0	5.00±0.2	75.00±15.0	2.00±0.1	12.00±2.6	9.00±0.9	200.00±61.0	24.00±8.0	1.50±0.0	<1[a]	3800.00±891.0	1.00±0.0
2 (F)	81.83±1.0	9.88±4.8	19.00±5.0	<0.30[a]	5.00±0.3	97.00±24.0	2.00±0.1	11.00±2.0	6.00±0.8	200.00±68.0	20.00±7.0	1.40±0.0	<1[a]	5900.00±1000.0	1.00±0.0
3 (M)	80.50±4.9	9.40±6.9	13.00±3.0	0.30±0.0	5.00±0.3	91.00±21.0	1.00±0.0	17.00±4.0	6.00±0.9	200.00±75.0	19.00±6.0	0.90±0.0	<1[a]	4500.00±749.0	1.00±0.0
3 (SU)	77.12±1.2	8.89±3.7	10.00±2.0	<0.30[a]	<0.30[a]	88.00±19.0	2.00±0.0	10.00±1.0	8.00±0.0	200.00±95.0	19.00±5.0	1.10±0.0	<1[a]	4800.00±698.0	1.00±0.0
4 (SU)	66.62±1.9	5.86±3.6	12.00±2.6	<0.30[a]	<0.30[a]	97.00±27.0	2.00±0.0	18.00±3.0	8.00±0.7	200.00±91.0	19.00±6.0	1.10±0.0	<1[a]	5800.00±1024.0	1.00±0.0
5 (SU)	73.00±1.3	7.55±3.3	21.00±7.0	0.50±0.0	<0.30[a]	101.00±34.0	2.00±0.1	18.00±3.2	8.00±1.0	300.00±101.0	21.00±6.0	1.50±0.0	1.00±0.0	5500.00±1092.0	2.00±0.1
6 (SU)	67.00±1.0	6.27±3.2	12.00±2.7	0.50±0.0	4.00±0.3	92.00±21.0	1.00±0.0	18.00±2.7	5.00±0.8	100.00±51.0	20.00±7.0	1.20±0.0	<1[a]	4900.00±1621.0	1.00±0.0
7 (F)	88.75±3.3	12.19±3.5	18.00±6.0	<0.30[a]	6.00±0.4	80.00±19.0	2.00±0.0	10.00±1.0	13.00±2.0	300.00±72.0	18.00±9.0	1.30±0.0	1.00±0.0	5900.00±1293.0	1.00±0.0
Sediment	---	---	6.00±0.6	<0.30[a]	7.00±0.5	19.00±7.0	42.00±12.0	28.00±9.0	488.00±96.0	9900.00±498.0	6.00±0.7	<0.5[a]	41.00±13.0	15300.00±4987.0	39.00±14.0
Water	---	---	109.00±35.0	0.17±0.0	1.63±0.6	14.01±9.1	6.21±1.9	1.91±0.2	47.04±23.0	27.00±11.4	82.45±23.4	1.44±0.8	5.63±2.1	1321243.00±3522 .0	16.32±8.9
Nakhl-e-Nakhoda															
1 (M)	96.25±4.3	92.50±1.4	15.00±3.7	0.30±0.0	6.00±0.3	57.00±120	5.00±0.3	9.00±0.8	41.00±11.0	1400.00±298.0	28.00±7.0	3.20±0.5	3.00±0.4	4300.00±721.0	5.00±0.2
1 (F)	92.50±1.4	11.25±4.5	18.00±4.6	<0.30[a]	6.00±0.5	66.00±16.0	16.00±3.0	25.00±7.0	112.00±39.0	3800.00±395.0	27.00±7.0	2.40±0.2	12.00±2.0	6800.00±1723.0	15.00±2.0
2 (M)	87.33±2.0	10.26±4.2	10.00±2.0	<0.30[a]	4.00±0.2	64.00±13.0	9.00±0.7	16.00±4.0	70.00±19.0	2100.00±725.0	26.00±60	3.20±0.4	7.00±0.9	5000.00±1002.0	12.00±1.0
3 (M)	81.66±2.8	8.84±4.0	12.00±3.0	<0.30[a]	5.00±0.3	69.00±17.0	6.00±0.3	14.00±3.0	45.00±18.0	1500.00±201.0	28.00±90	3.10±0.5	5.00±0.3	4500.00±1023.0	7.00±0.9
4 (SU)	70.00±3.5	5.53±4.0	10.00±1.0	<0.30[a]	5.00±0.5	65.00±12.0	5.00±0.3	15.00±3.0	36.00±17.0	1300.00±294.0	27.00±6.0	2.90±0.4	4.00±0.2	4200.00±982.0	6.00±0.7
5 (SU)	63.00±1.3	4.40±0.7	12.00±2.8	<0.30[a]	6.00±0.5	61.00±11.0	8.00±0.6	16.00±4.0	46.00±150	1700.00±429.0	26.00±10.0	3.20±0.5	5.00±0.1	4700.00±823.0	10.00±1.0
6 (SU)	57.50±2.6	4.08±1.3	11.00±2.0	<0.30[a]	6.00±0.4	56.00±9.0	6.00±0.3	18.00±6.0	39.00±17.0	1400.00±263.0	20.00±50	3.20±0.3	4.00±0.0	4200.00±1064.0	6.00±0.3
Sediment	---	---	8.00±0.9	<0.30[a]	7.00±0.8	21.00±4.0	45.00±14.0	19.00±5.0	498.00±72.0	14000.00±2893 .0	7.00±0.9	<0.5[a]	54.00±19.0	14400.00±6351.0	132.00±29.0
Water	---	---	98.46±41.0	0.23±0.0	0.62±0.0	22.74±10.4	11.21±3.7	0.32±0.0	51.00±24.0	89.83±29.0	83.34±26.0	0.47±0.0	11.62±4.3	1389188.00±3951.0	26.00±13.0

M: Male; F: Female; SU: Sex Undetermined; a: Concentrations <detection limit

Size and sex influences of clams on metal concentrations

A significant positive correlation occurred between the concentrations of Mg and Cu in clams and their lengths (r=0.63 and 0.59, $p \leq 0.05$).

Metal concentrations in both male and female clams were not significantly different during the study (Independent samplet-test, df=8, $p \geq 0.05$).

Metal concentrations were determined at the start of gametogenesis and the ripeness stages. A paired sample t-test was used to determine the relationship between two different sexual stages (after and before spawning). The test showed that there were significant differences between stages I and II (start of gametogenesis) and stage III A (ripeness) of gametogenesis (t=-6.18 to 4.43, df=11, $p \leq 0.05$).

Differences among sampling sites and seasons

The mean concentrations of all measured elements in clams varied considerably in terms of two sampling stations, two seasons and their interactions (Two-Way ANOVA, $p \leq 0.05$). Significant differences could be observed in Cu, Fe and Ba in sediment of the studied stations (Independent sample t-test, $p \leq 0.05$), while the concentration of these metal elements were higher in sediments of station 2. Our analysis in water also showed that only Fe had significant differences between the two stations (t=-4.76, $p \leq 0.05$). Significant interaction between two seasons and two sampling stations was detected (Two-Way ANOVA, df=2, $p \leq 0.05$).

Environmental factors measurement

Table 3 displays the environmental factors measurements during the periods of investigation. Temperature in February is less than November whereas other factors show a little change between two months. Therefore, due to the lack of differences in the values of environmental factors except temperature, investigations of their effects on the metals concentrations were not further pursued.

Table 3: Physical and chemical Sea-surface measurements during November 2008 and February 2009 in coastal waters of Bandar Abbas

Month	Temperature (^{o}C)	Salinity (psu)	Dissolved Oxygen (mg/l)	pH
November 2008	27	36.6	5.9	7.8
February 2009	23	37.2	5.8	7.6

Table 4: Metal concentrations ($\mu g g^{-1}$ dry wt) in some bivalves and their comparisons with the present study.

Species	Location	Cu	Ag	Pb	Zn	Ni	Co	Mn	Fe	As	Cd	Cr	Reference
Egeria radiata	Nigeria	---	---	0.3-3.6	96-172	0.6-4.5	---	---	---	---	0.1-0.6	---	Etim et al., 1991
Corbicula fluminea	Argentina	28-89	----	----	118-316	1-6	----	15-81	----	0.5-2.0	0.5-1.9	1.3-11	Bilos et al., 1998
Circentia callipyga	Qatar	8.35	3.0	1.4	69.1	23.9	4.4	17.7	517	156	1.1	0.9	de Mora et al., 2004
Saccostrea cucullata	Oman	60.9-276	----	0.3-0.6	391-1610	0.8-3.1	----	----	----	----	8.9-21.9	----	de Mora et al., 2004
Saccostrea cucullata	UAE, Oman Gulf	63.8	----	0.2	425	1.1	----	----	----	----	6.15	----	de Mora et al., 2004
Pinctada radiata	UAE, Persian Gulf	4.6-17.3	----	0.1-2.2	159-1430	0.5-7.0	----	----	----	----	2.7-9.9	----	de Mora et al., 2004
Pinctada radiata	Bahrain	3.1-4.4	----	0.3-3.9	1825-4290	0.7-0.8	----	----	----	----	3.6-3.7	----	de Mora et al., 2004
Perna perna	Senegal	7.2-7.7	----	----	64.5-121.6	----	----	----	----	----	0.7-2.3	----	Sidoumou et al., 2006
Crassostrea gasar	Senegal	47.1	----	----	2320	----	----	----	----	----	6.8	----	Sidoumou et al., 2006
Ruditapes decussatus	Egypt[a]	23.8	----	15.5	155.6	21.5	23.5	24	961.5	----	4.5	----	Gabr & Gab-Alla, 2008
Venrupis pullastra	Egypt[a]	23.2	----	18.5	132.2	27.5	30.5	26.5	1896.5	----	8.7	----	Gabr & Gab-Alla, 2008
Comptopallium radula	New Caledonia	3.7-3.9	0.0-5.2	----	176-183	12.8-13.8	1.7-1.9	5.9-6.0	221-289	44.7-86.9	1.1.3.5	3.2	Metian et al., 2008
Isognomon isognomon	New Caledonia	3.1-17.3	1.4-32.8	---	1718-13817	2.2-16	0.6-1.6	20.4-34.7	---	21.6-76.6	1.1-1.8	2.7-9	Hédouin et al., 2009
Gafrarium tumidum	New Caledonia	5.6-77.3	0.0-33.1	---	55.6-154	8.1-30.2	1.1-3.8	5.5-139	---	37.4-441	0.1-0.7	3.2-8	Hédouin et al., 2009
Solen dactylus	Iran, Northern Persian Gulf	13-20	0.3-1	4-7	60-92	2-8	5-16	8-56	210-1886	20-27	1-3	1-6	Present study

a: Contaminated Site

Table 5: Metal concentrations in marine sediment (μgg^{-1} dry wt) and seawater (μgl^{-1}) in different locations of the Persian Gulf and guidelines

	Location/Standards	Cd	Pb	Ni	References
Sediment					
	Global baseline values for metals in sediments	0.30	19	52	Bowen, 1979
	RSA, northeastern Iranian coast	1.25	25	103	ROPME, 1999
	Persian Gulf, Bahrain	0.40	12.30	15	ROPME, 1999
	Persian Gulf and Oman Gulf	0.02-0.21	0.25-99	0.74-1010	de Mora et al., 2004
	northwest Persian Gulf (Mahshahr Creeks)	0.27-1.00	7.09-29.72	65.57-171.41	Dehghan Madiseh et al., 2008
	northern Persian Gulf	2.89	90.47	64.89	Pourang et al., 2005
	northern Persian Gulf (Bandar Abbas)	<0.50	4-7	29-46	Present study
Water					
	MPL for aquatic life[a]	5	22	---	Gardiner & Mance, 1984
	ANZECC Guidelines[b]	2	5	15	Pourang et al., 2005
	northern Persian Gulf	0.44	5.38	2.79	Pourang et al., 2005
	northern Persian Gulf	0.83	1.11	8.43	present study

a: Maximum Permissible Levels

b: Australian Water Quality Guidelines for Fresh and Marine Waters, Australian and New Zealand Environment and Conservation Council (ANZECC)

Discussion

*Metal concentrations in biota, sediments and sea waters*The results showed that at two stations (Park-e-Qadir and Nakhl-e-Nakhoda) in Bandar Abbas (mean water temperature: 28.6±0.7°C; annual tidal range: -0.1- 3.88 m) the metal concentrations in razor clams, varied as follows:

Station 1:

Mg>Fe>Zn>Mn=As>Cu>Co>Ba=Pb>Ni>Cd>Cr>Ag, and

Station 2:

Mg>Fe>Zn>Mn>As>Co=Cu>Ba>Pb=Ni>Cr>Cd>Ag

The trends are reasonably consistent with the literature values reported earlier (e.g., Etim et al. (1991), Zn>Ni>Pb>Cd for clam *E. radiata*, and Metian et al. (2008), Zn>Cd>Co=Mn for scallop *C. radula*). Taking into account that sediments are a sink for marine contaminants (Salomons et al., 1987) and their elements' concentrations are often used to assess and monitor the contamination status. It is known that sediment-associated concentrations are not necessarily representative of the contaminant fraction (Hédouin et al., 2009). Therefore, to assess the difference in the contamination status of both stations, metal concentrations were analysed in clams, sediments and water (Tables 1 and 2). The concentrations of Mg and Fe in all clams and sediments and Mg and Cu in water at both stations were more than other metals which showed that these metals were the most abundant metals in this area as their natural abundance in the earth's crust. It is suggested that clams accumulate these metal elements in their body for some physiological requirements while bioaccumulating some of them more than their requirements according to their environmental pollutions (Bilos et al., 1998). This study indicated that this clam could be a valuable bioindicator for Zn after complementary and further studies; whereas, Metian et al. (2008) concluded that scallop *Comptopallium radula* would be a suitable bioindicator for Ag, As, Cd and Fe. *S. dactylus* is an edible clam (Saeedi et al. 2009); therefore, a study of the metal concentrations in this valuable species was necessary and vital for biomonitoring plans and management programs (as a bioindicator) and the risk assessment for humans (as an edible clam). According to low concentration of some metals in this clam comparing to its environment, this clam can be introduced as approximately safer seafood regarding other mentioned clams in other presented literatures. Clams accumulate Zinc in their bodies (54-107 $\mu g g^{-1}$ dry wt) more than sediments (14-22 $\mu g g^{-1}$ dry wt) and water (13-22 $\mu g l^{-1}$). Similar results were observed in the literature (de Mora et al. (2004) and Bilos et al., (1998)) for relatively high level of Cu and Zn accumulations in marine tissues while they did not follow the high concentrations of these metal elements in the environmental media. Cu and Zn metals are essential elements used in the structures of many metalloenzymes and metalloproteins such as haemocyanin and zinc fingers (Lippard and Berg, 1994). Based on the present findings and other studies, sessile bivalves such as *S. dactylus*, *S. cucullata* and *C. fluminea* distribute Zn metal in their bodies more than their environments. These metal distribution differences could be due to some physiological requirements, metabolic activities and body composition processes. However, the kind of phytoplankton which clams feed on is important for assimilation metals. As an illustration, in green mussel *Perna viridis* and the Manila clam *Ruditapes philippinarum* assimilated metals at a higher efficiency from the diatom diet (*Thalassiosira pseudonana*) than from inorganic sediment particles (Chong and Wang, 2000).

Mn, Pb, Ni and Fe concentrations in sediments were higher than in clams (Tables 1 and 2). De Mora et al. (2004) reported that *S. cucullata* concentrate lower values of Ni (0.80-3.14 $\mu g g^{-1}$ dry wt) than in the sediments (0.74-1010 $\mu g g^{-1}$ dry wt) in Oman and UAE. He suggests that nickel could not accumulate in those clams bodies; therefore, it does not play an integral role in their biological activities. In this study significant positive correlation were observed between the metal concentration in clams with sediments and water. *S. dactylus* is a filter feeder living in upper layers of sediments in a depth of 5-30 cm inside the canals (Saeedi et al., 2009). Therefore, some metals uptake from sediments and water into its body and accumulate in its tissues.

To compare the result of the present work with other investigations, the concentrations of accumulated metals in *S.*

dactylus are brought to table 4. Since oyster *Saccostrea cucullata* from remote areas such as the Oman Sea were shown to contain elevated Cd concentrations (8.9-21.9 μgg^{-1} dry wt) (de Mora et al., 2004), such a bioaccumulation ability, presumably, does not appear to relate to anthropogenic contamination of the environment. Cadmium is a non-biodegradable and non-beneficial heavy metal whose role in the cell is not known yet (Lal Shah, 2010). As it is shown in table 4, both clams *S. dactylus* (in this study) and *E. radiata* (from the contaminated site of Nigeria) encompass the maximum values of Fe concentrations (1886 and 1896 μgg^{-1} dry wt) in their body respectively. However, Ag concentrations in *S. dactylus* were the lowest among other clams reported in the literature (0.3-1 μgg^{-1} dry wt) (table 4). Ag concentrations were in studied sediment samples (~ 0.3 μgg^{-1} dry wt) which were lower than those reported earlier.Clams and sediments at station 2 contained more concentrations of Fe and Mn than station 1 which can show that concentration of metals in sediments and clams are correlated. Moreover, Fe and Mn showed a positive significant correlation in the clam body, whereas Etim et al. (1991) found no significant linear average relationship between any two of the metals studied. It can suggest that relationship between two metals in clam's body can describe some biological interactions between two metals in the clam's life.

According to table 5 the Cadmium concentration in sediment of northern Persian Gulf (all northern parts of the Persian Gulf) was 2.89 μgg^{-1} dry wt. (Pourang et al. 2005) which was higher than that in the Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area guideline (RSA) and other locations of the Persian Gulf. In this study Cd, Pb and Ni concentrations (~0.50, 4-7 and 29-46 μgg^{-1} dry wt) (Bandar Abbas, Northern Persian Gulf) reached less values among RSA and other locations of the Persian Gulf, except Ni concentrations in Bahrain (15 μgg^{-1} dry wt). Pourang et al. (2005) demonstrated that the highest concentrations of Ni (64.89 μgg^{-1} dry wt) in sediments were observed close to the southern coast of Qeshm Island and Bandar Lengeh of northern parts of the Persian Gulf, Iran. The concentration of Ni in sediments of Bandar Abbas in this study (29-46 μgg^{-1} dry wt) was less than Qeshm and Bandar Lengeh which are close to Bandar Abbas. Also the concentration of these three metals in seawater showed the lower value among other studies except Cd and Ni in the study of Pourang et al. (2005) (Table 5).

Metal concentration in different clam body sizes

In this work, the effect of body size (age) on metal concentrations in the clam *S. dactylus* has also been investigated. It is well known that body size reveals the metal concentrations in organisms and is related to the time courses of metal uptake. It is one of the most important parameters that reveal metal bioaccumulation in organisms (Hédouin et al., 2006 and 2009). The mechanisms of the effects of size are not fully understood; however, the body size is related to the age of the animal and more age means more time for exposure to contaminants. But two distinguished explanations are highlighted below: (1) the decreasing surface/ volume ratio of an organism with increasing body size, and (2) decreasing metabolic activity in larger (older) organisms (Hédouin et al., 2006). Both reasons would result in decreasing metal uptake with increasing individual size.

There was a positive significant correlation between the clam's length and the concentrations of Cu and Mg in clams, suggesting that the larger clams had a higher ability to concentrate the metal than smaller ones for Mg and Cu. Indeed, there is a positive correlation between the age of clams and the concentration of Cu and Mg. It is more likely to be an increase in physiological and biological requirements in clams during their growth; however, pollution levels and metal exposure time in clams can affect the bioaccumulation of some metals. Also according to the previous results in this study Fe and Mg had high concentrations in clams which can suggest that these are two important metals for clams' life or because of disability of clams to get rid of some metals easily. A significant negative relationship between size of clam *Gafrarium tumidum* in New Caledonia and concentrations of Cd, Cr, Co and Zn was reported by Hédouin et al. (2006) whereas the accumulation of Ag was positively correlated with size of clams. Bilos et al. (1998) demonstrated that Cu levels in Asiatic clam *C. fluminea* of Argentina significantly correlated with their size (positive) which indicated variable physiological requirements for this metal with age and showed a similar result of this study. Additionally, in view of Bilos et al. (1998) literature on Ag in bivalves, the latter observations suggest the occurrence of a specific detoxification mechanism that would be more efficient in older clams.

Metal concentration in different clam sexes

Male and female clams were studied separately for their metal concentrations. There was no significant difference between males and females. This species is a gonochoric clam which spends the ripeness stage of gametogenesise cycle in January and February and in this stage gonads are full of gametes whereas in September and October clams are in the first stages of gametogenesis with approximately empty gonads (Saeedi et al., 2009). When clams were analyzed for some metals concentration in two different sexual stages, a significant difference were observed after (stages I and II) and before spawning (stage III A). It would suggest that increasing the weight of clams and gametogenic materials can affect the metal concentrations in clams.

Metal concentration in different stations and seasons

Among the two factors considered (seasons and sampling sites) and their interactions, both factors determined the variability observed for all metals. Significant interaction between two seasons and two sampling stations was detected for all metals, suggesting that anthropogenic interference differences of measured concentrations were dependent upon the seasonal variation. Furthermore, distribution and variation of some metals in different stations is related to environmental factors and anthropogenic activities.

Only Cu, Fe and Ba sediment concentrations showed significant differences in the first and second station, surprisingly with maximum concentrations in the second station. Solely Fe concentrations in seawater presented a significant difference between two stations, with a maximum value at station 2. Metal accumulations were higher in station 2 (620-820 $\mu g l^{-1}$). It might be related to some natural factors like fewer water currents and different coastal topography. Also we need to attach so much importance to a bus terminal near station 2, while station one is only next to a park with litters from people. All these factors can make station 2 more polluted for some metals than station 1.

Even if these results are somewhat surprising, they demonstrate that the two sampling sites are consistent with the metal concentrations in the clams which can suggest clam *S. dactylus* as a reliable bioindicator for this area after several further studies on other organisms and the ecosystem.

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