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Biomonitoring Total Mercury in the Persian Gulf Using Rock Oyster, *Saccostrea cucullata*

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ABSTRACT

This study is an attempt to evaluate the biomonitoring capabilities of rock oyster, *Saccostrea cucullata*, for mercury (Hg) pollution. The oyster and sediment samples were collected from 10 rocky habitats of Qeshm and Hormoz Islands in the Persian Gulf. The concentration of mercury in the shell and soft tissues of the oysters and sediments were analyzed using an advanced mercury analyzer. Biota-sediment accumulation factor (BSAF) was calculated based on the ratio of Hg concentrations in soft tissues to that in sediments. The results showed that the rate of mercury accumulation in the soft tissues of the oyster was significantly higher than that in its shell ($P < 0.05$). There was a significant correlation between mercury concentrations in the soft tissues and the sediments ($r = 0.75$). According to BSAF, soft tissues of the oyster were recognized as an appropriate indicator for biomonitoring mercury. The present study generally supports the usability of soft tissue of *S. cucullata* as a sensitive biomonitoring organ to warn mercury pollution in the Persian Gulf.

Keywords: *Saccostrea cucullata, Persian Gulf, Mercury, Biomonitoring.*

INTRODUCTION

Mercury is known as a highly-toxic environmental pollutant. Development of different industrial activities, regionally and globally have led to the increasing influx of mercury into the environment (Esmaili Sari *et al*. 2008; Zahed *et al*. 2010). The amount of mercury in aquatic habitats is anguished for poisoning food organisms which have long been used by people especially those living in coastal areas (Chouvelon *et al*. 2009). Due to its unique chemical properties, mercury has been used in various industries especially in pharmaceutical, medicinal, chemical, and electronic productions, in pesticides, dyes, (granule and pigments) and also in the processes of petrochemical industries. The establishment of these industries in the coastal areas resulted in the discharge of mercury into marine ecosystems (Mortazavi & Sharifian, 2011). Studies have shown that mercury can be easily accumulated in the body of different organisms and is magnified through its transfer from the lower to the higher trophic levels in a food chain (Hajeb *et al*. 2009; Leo *et al*. 2010). Through such a process, pollutants such as mercury, which are usually found at low concentrations in the environment, can reach to a poisoning level in sea food (Esmaili sari, 2004). Marine food is a rich source of protein, vitamins, micronutrients, and the beneficial long-chain polyunsaturated omega-3 fatty acids for human (Mortazavi & Sharifian, 2011). Sadly to say that the entrance of mercury into marine ecosystems is continuing through wet and dry depositions from anthropogenic sources as well as from natural origins (Carrasco *et al*. 2008). Thus, in most marine ecosystems which are located in the vicinity of industrial areas, especially those close to oil exploitation and processing plants, the continuous influx of pollutants does not allow organisms to eliminate the contaminants. This may terminate in local and global catastrophic events (Esmaili Sari *et al*. 2008; Ritthong *et al*. 2011).

Asia has experienced two documented environmental disasters related to mercury

poisoning: the first at the Minamata Bay of Japan in 1956 and the second in Iraq in 1971 (Esmaili Sari *et al*. 2008). Recent reports of mercury pollution in developed countries such as Canada and America, and in developing nations like Iran and Thailand especially in places near the chlorine-alkaline plants and oil processing centers showed that discharge of pollutants is still occurring (Garron et al. 2005, Mark 2001; Ritthong *et al*. 2011). The Persian Gulf suffers from chemical pollution mainly by heavy metals resulting from intensive oil and gas exploitation, agricultural activities, and growth of industrialization & urbanization (Tolosa *et al*. 2005).

The huge activities of oil and gas exploration together with industrialization, urbanization and agricultural activities in the study area made biomonitoring of this areas an indispensable task (Tolosa *et al*. 2005). Due to high evaporation of mercury, the analyses of water samples reveal the quality of environment only around the sampling time limit. By contrast, evaluation of this element using biomonitoring agents demonstrate the pollutants which are fixed in the body of organisms during the time (Adjei-Boateng *et al*. 2010). For an accurate estimation, a method is required to reveal the load of pollutants through a long-term exposure.

Bivalves have been nominated as biomonitoring agents for various kinds of organic and inorganic pollutants for about 40 years, mostly because of their filter-feeding behavior, easy access, being sessile and their capability for pollutant bioaccumulation in some parts of their body (Chouvelon *et al*. 2009; Alessia *et al*. 2006; Jeng *et al*. 2000; Yap *et al*. 2003). This is particularly useful for monitoring pollution within a certain time span (USEPA, 1988). Thus, in this study, the aim was to investigate biomonitoring of mercury by rock oyster, *Saccustra cucullatain,* in the intertidal coasts of the Persian Gulf.

MATERIALS AND METHODS

Seven sites in the Qeshm Island and three sites in the Hormoz Island were selected for sampling in the Persian Gulf (Fig. 1). Geographic position, local name and main characteristics of the sampling sites are shown in Table 1. A total of 20-27 rock oysters, *Saccostrea cucullata* of same size were collected from each site during low tides in May 2010. A stainless steel hammer and rod were used to detach the oysters from their rocky habitats. Five combined sediment samples were taken from the upper 3cm of surface sediments around each site by laboratory spatula. All samples were placed in polyethylene zip bags and kept in an icebox during the sampling period.

Sample preparation

The collected animals were transferred to the laboratory, rinsed with distilled water and all debris was removed. Soft tissues of samples were carefully removed with a teflon knife, weighted with an analytical balance (0.0001g) and kept at –20°C. The length of shells was measured with a pair of calipers. Samples were thawed at room temperature for further analysis. The shells were powdered using a mortar and pestle and then sediment samples and shell powders were sieved. All samples were oven dried and two grams of homogenized samples were kept in polyethylene zip bags and stored in a desiccator before analysis.

Sample analysis

Total mercury concentration of the dry samples was determined by an advanced Mercury Analyzer (AMA-254, LECO, USA) working with pre concentration by gold amalgamation, thermal desorption and UV determination at 254 nm. For the analysis, a calibration curve was constructed with standard materials. Low and medium ranges of samples (50±1mg) were precisly weighted in a nickel boat and automatically placed in the sampler (ASS -254). Total concentration of mercury (THg) was reported for each sample with AMA software. Accuracy of the analysis was checked by running three standard reference materials (SRM) from National Institute of Standard and Technology (NIST), namely SRM 1633b, SRM 2709, and SRM 2711). The recovery values of SRMs were obtained to be between 95.5 and -98.0%.

Statistical analysis

A Two-Way nested ANOVA (where the sites were nested within locations) was

applied to calculate the effects of location on mercury concentration in the soft tissues, shells, and sediments. Significant differences were followed by a Tukey *post hoc* test. Square root and logarithmic transformations were applied to the data to satisfy the assumption of normality. Bivariate relationships between mercury concentrations in the sediment and soft tissue were analyzed using Pearson's correlation. Probability of $P < 0.05$ was accepted for statistical significance. Values are reported as mean ± standard error (SE).

RESULTS

The concentration of total mercury (THg) in the soft tissues and shell of the oysters and the sediments ranged from 35.95 to 65.31, from 1.57 to 2.73 and from 1.13 to 8.85µg/kg dry weight (dw), respectively. The maximum and minimum levels of THg were observed in Kaveh and Naz sites, respectively. The level of THg was significantly higher in the soft tissues (50.89 ± 1.09 µg/kg dw) than in the shell of the oyster (2.31 ± 0.06 µg/kg dw) and in the sediments (3.24 ± 0.45 µg/kg dw) ($P < 0.05$) (Table 1). Analysis of total mercury (THg) in the soft tissue, shell and sediment of *Saccostrea cucullata* (Table 1) revealed that mercury levels in soft tissue were significantly ($P<0.05$) higher than that in shells in Qeshm and Hormoz Islands. In both locations mercury bioaccumulation in the soft tissue was higher than that in hard tissue. The concentrations of THg in the soft tissues of oyster and the sediments were significantly higher in Hormoz compared to Qeshm Island ($P < 0.05$) (Figures 1 & 2). Increased levels of THg concentrations were observed in the oyster shell in Qeshm Island compared to Hormoz (Figure 3).

The maximum levels of mercury in the shell and sediments were recorded in Kaveh and Laft while the minimum concentrations were measured in Shahshahid and Naz (Tables 2 & 3). Among the three sites of Hormoz Island, variations in the total mercury concentration in the soft tissues, shell and sediments were 71.7–165.5, 0.96–44.19 and 0.83–1.01µg/kg dw, respectively. The THg was significantly higher in the soft tissues (109.15 ± 5.84 µg/kg dw) than in the shells (0.90 ± 0.03 µg/kg dw) and sediments (18.84 ± 4.95 µg/kg dw) ($P < 0.05$).

The maximum concentrations of mercury in the soft tissues of *S cucullata* (165.50 ± 7.19) and in the sediments (44.193±1.548) were obtained in Khak-Sorkh from Hormoz Island (Figures 5 & 7). The THg concentrations in soft tissues, shells and sediments differed significantly ($P < 0.05$) in different sites of Qeshme Island (Figures 4 & 6).

Biota-Sediment Accumulation Factor (BSAF) in Qeshm Island (15.63) was higher than that in Hormoz Island (5.78) (Table 2). There was a significantly positive correlation ($r=0.75$) between the Hg levels in the soft tissues and the sediments (Figure 9).

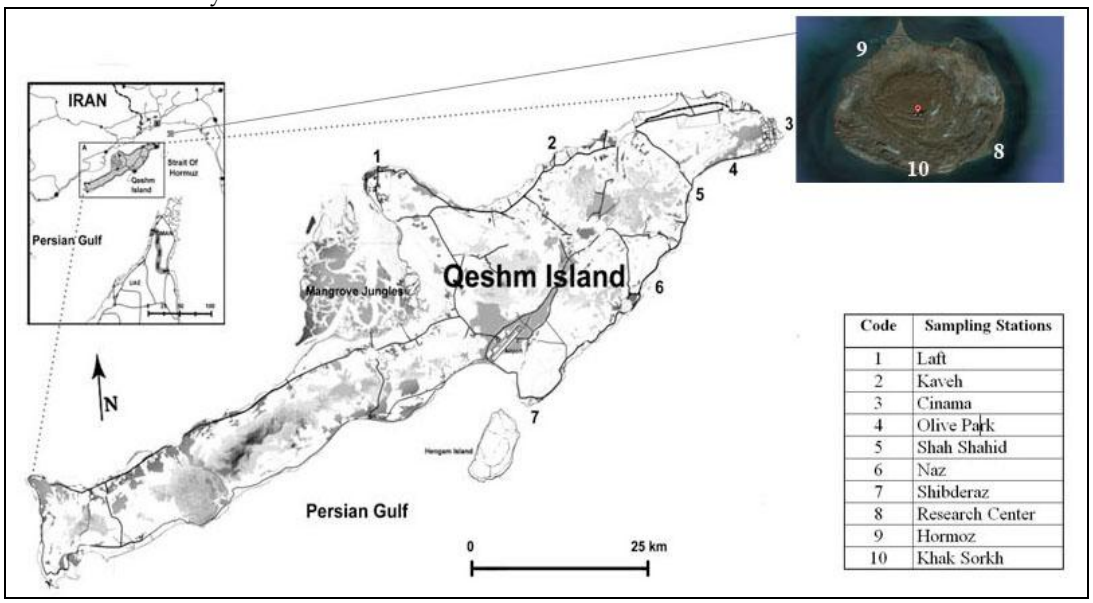

Fig. 1. Position of sampling sites in the Qeshm and Hormoz Islands

Table1. Positions and descriptions of sampling sites, number of samples analyzed (N) and shell length (mm) of the collected rock oysters (*S. cucullata*)

Location	Site no.	Local name	Latitude (N)	Longitude(E)	N	Shell length (mean)	Site description
Qeshm	1	Laft	26°56'37"	55°45'35"	27	48.84	Yachting area
	2	Kaveh	26°55'19"	55°57'17"	27	57.37	Busy jetty
	3	Cinema sahele	26°56'25"	56°16'31"	27	36.35	Urban area
	4	Park e Zaytoon	26°55'28"	56°16'04"	20	36.71	Less developed
	5	Shah shahid	2 6°53'27"	56°09'37"	25	50.52	Recreational
	6	Naaz Island	26°48'49"	56°06'56"	28	41.62	Pristine area
	7	Shibderaz	26°41'16"	55°55'45"	20	41.41	Pristine area
Hormoz	8	Research Center	27°02'49"	56°29'42"	21	43.31	Prisine area
	9	Hormoz	27°05'20"	56°26'39"	21	63.3	Urban area
	10	Khak sorkh	27°02'01"	56°27'34"	21	52.9	Mining area

Table 2. Mercury concentrations (µg/kg dw) in different samples and the BSAF values (data are mean±SE)

Location	Soft tissue	Shell	Sediment	BSAF
Qeshm	50.89 ±1.09	2.31 ± 0.06	3.24 ± 0.45	15.68
Hormoz	109.15± 5.84	0.90 ± 0.02	18.84 ± 4.95	5.780

Table 3. Mercury concentrations (mean µg/kg dry weight ± SE) in sediment, soft tissues (ST) and shell (SH) and the ratios of ST/SH in *S. cucullata*

Locations	Site no.	Site Name	sediment	ST	SH	(ST/SH)
Qeshm	1	Laft	8.85 ± 0.68	63.18 ± 10.09	2.29 ± 0.66	27.58
	2	Kaveh	4.84 ± 0.51	65.31 ± 11.80	2.73 ± 0.79	23.93
	3	Cineama Sahele	2.64 ± 0.75	55.91 ± 11.47	2.73 ± 0.77	20.47
	4	Park-e Zaytoon	1.57 ± 0.89	47.52 ± 1.87	2.21 ± 0.19	21.50
	5	Shah shahid	3.69 ± 1.75	37.07 ± 1.34	1.57 ± 0.12	23.61
	6	Naaz Island	1.13 ± 0.05	35.95 ± 1.32	2.63 ± 0.12	13.66
	7	Shibderaz	1.34 ± 0.57	49.63 ± 1.51	1.82 ± 0.12	27.26
Hormoz	8	Research center	0.967±0.048	71.75 ± 2.15	0.83 ± 0.03	86.45
	9	Hormoz	11.368±0.512	90.21 ± 3.80	0.89 ± 0.05	101.36
	10	Khak sorkh	44.193±1.548	165.50 ± 7.19	1.00 ± 0.05	165.50

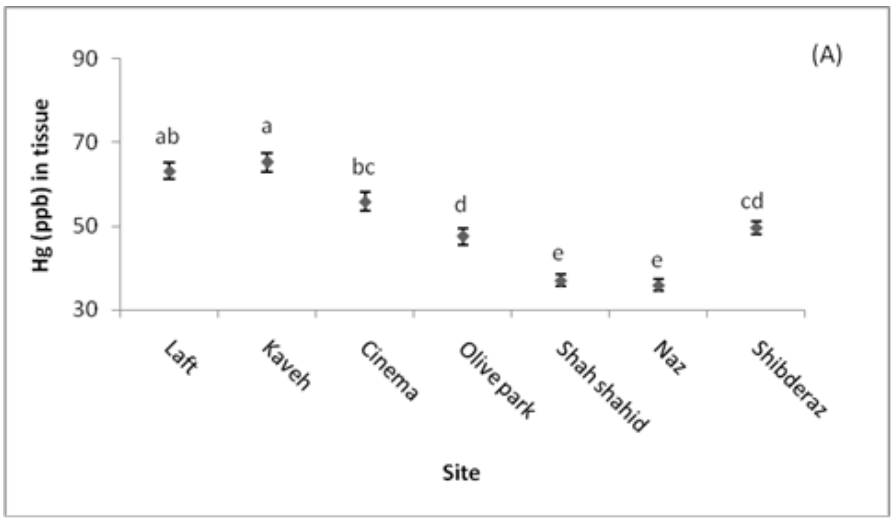

Fig 2. Varitaion of total mercury in the soft tissues of *S. cucullata* in different sampling sites of Qeshm Island

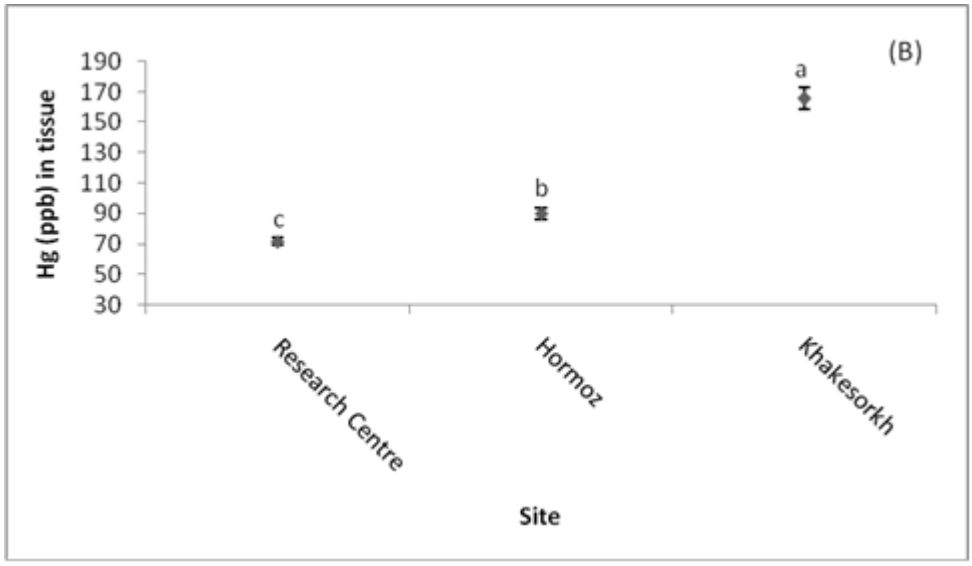

Fig 3. Varitaion of total mercury in the soft tissues of *S. cucullata* in different sampling sites of Hormoz Island

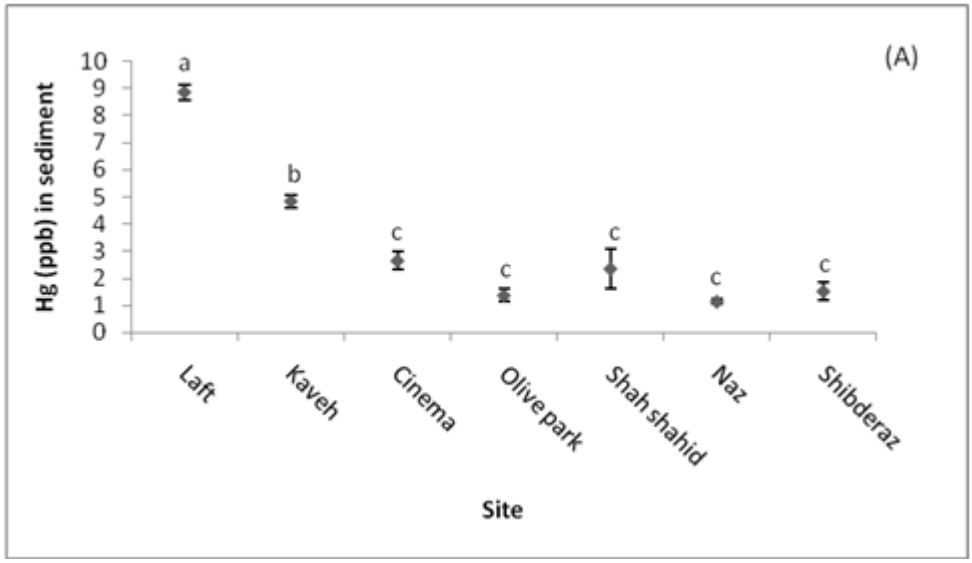

Fig 4. Varitaion of T_{Hg} µg/kg±SE in the sediment in different sites in the Qeshm

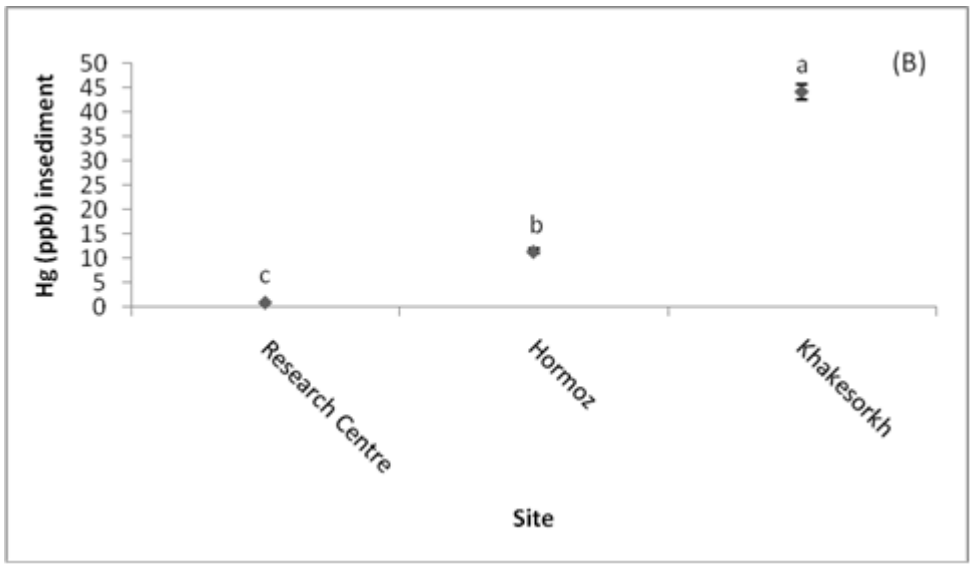

Fig 5. Variation of THg µg/kg ±SE in sediment in differen sites in the Hormoz

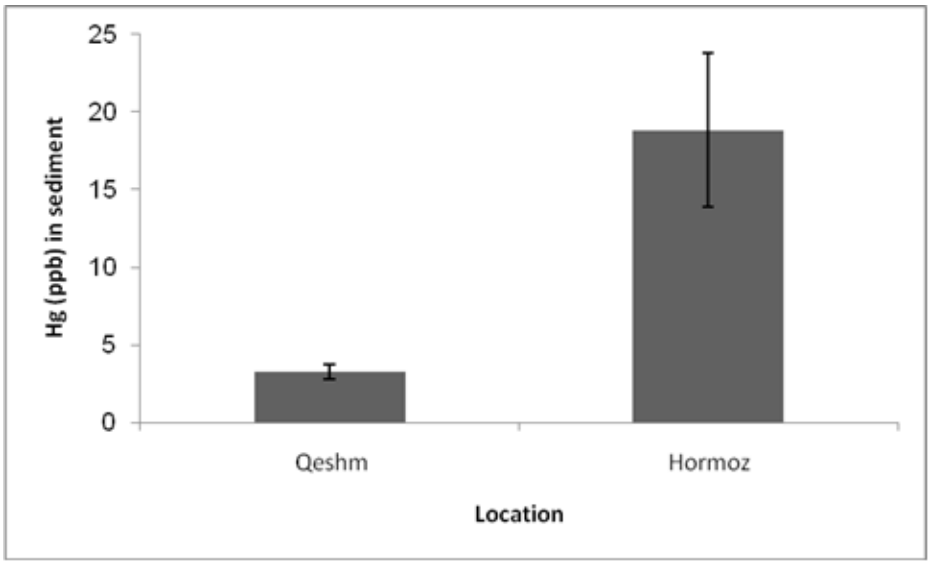

Fig 6. Mean total mercury (T_{Hg} µg/kg±SE in the sediment of two studied locations

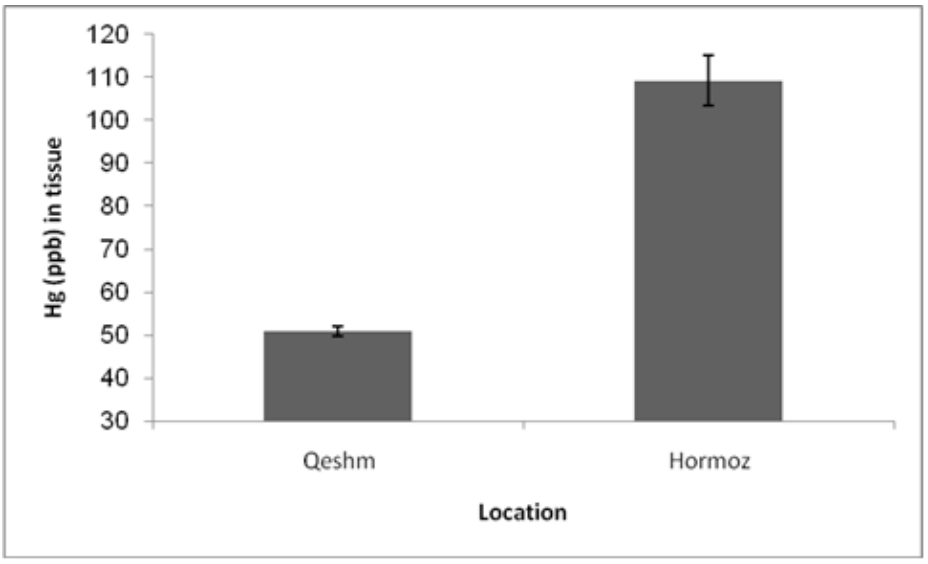

Fig 7. Comparison of mean T_{Hg} µg/kg ±SE in soft tissue between locations

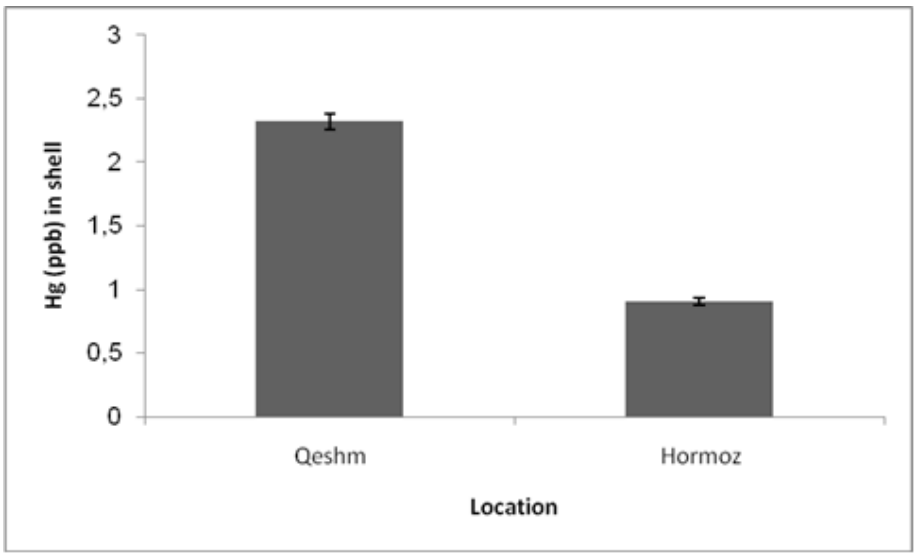

Fig 8. Comparison of mean T_{Hg} µg/kg±SE in the shell between locations

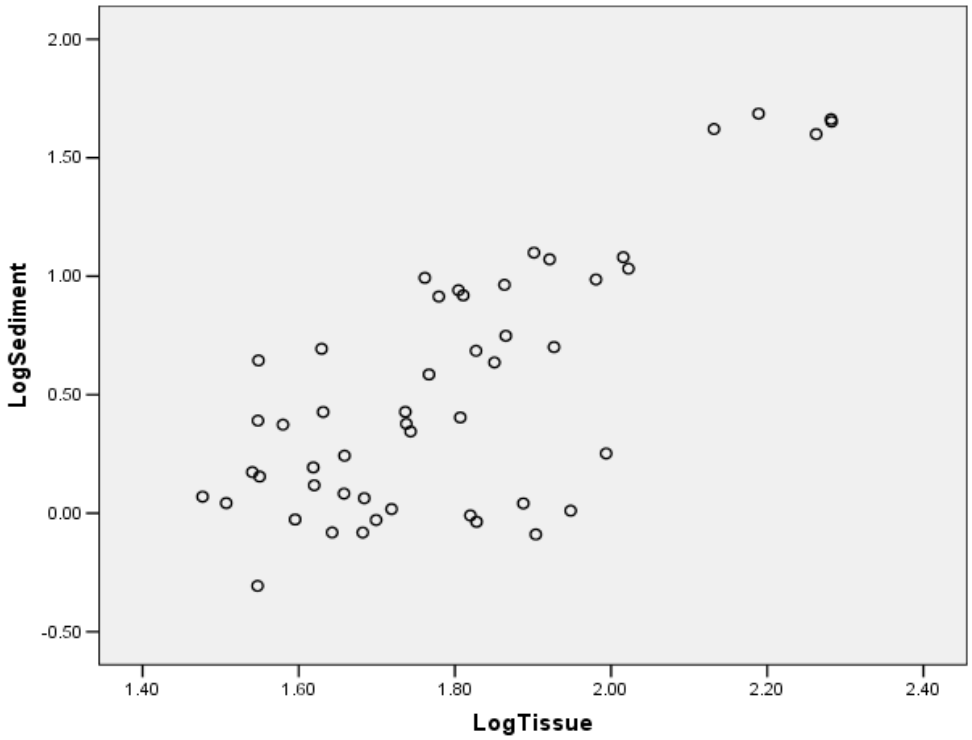

Fig 9. Correlation between concentration of total mercury in the soft tissues of *S. cucullata* and in the sediment (r=0.75, n=50, $P < 0.05$).

DISCUSSION

Oil exploitation has been practised in the southern part of Iran since 1908. The industry has developed since that time in other coastal countries of the Persian Gulf (Ghafariyan 2010). For more than one hundred years, oil and gas production, processing and transportation in the Persian Gulf has had significant impact on the marine ecosystem of the Gulf by releasing different types of organic pollutants. This has also influenced the marine organisms and habitats by producing low levels of highly-toxic inorganic elements and components (Agah *et al*. 2007).

The results obtained from a project conducted by USEPA (United States Environmental Protection Agency) revealed that every year, more than 13,250 kg of mercury is discharged into the water, solid waste and air in the US by the oil and gas production, processing and combustion activities. The concentration of mercury in crude oil was estimated to be 10 ppb (Mark 2001). It can be assumed that the Persian Gulf ecosystem has suffered from mercury pollution by oil and gas industries for more than a century. Although the mean concentration of mercury in crude oil is very low, some related industries such as petrochemical industry and chloride-alkaline industry are considered as the major sources of mercury (Christine *et al.* 2005; Mark 2001; Ritthong *et al.* 2011).

It is evident from the results of this study that mercury accumulation in soft tissues of the rock oyster was considerably higher than that in its shell in all the study sites. It has been found that non-essential elements can be stored in shells of mollusks for detoxification while the shell regulates the metabolism of some essential elements (Amiard *et al*. 2008; Einollahi Peer *et al*. 2010; Yap *et al*. 2003). In contrast, the present study revealed that accumulation of mercury as a nonessential element was very low in the shells of the oyster and the shell cannot act as a detoxification organ in this animal. Therefore, it seems that almost all mercury accumulates in the soft tissues of the oyster which can later be transferred to the consumers (Blackmore and Wang 2004). As a result, it is recommendable that the mercury concentration in soft tissues of oyster should be checked for human consumption.

A significantly positive correlation (r = 0.75, P < 0.05) was observed between the concentration of mercury in soft tissues of *S. cucullata* and in the sediments. On the basis of BSAF values, organisms or their organs are classified into three groups comprising macro- concentrators (BSAF > 2), micro concentrators (1< BSAF < 2) and non-concentrators (BSAF > 1) (Adjei-Boateng *et al*. 2010; Berandah *et al*. 2010; Soto-Jiménez *et al*. 2001)). According to the BSAF values obtained from this study (Table 2), having a high BSAF value, the soft tissue of *S. cucullata* was recognized as a target organ for biomonitring mercury in the selected study areas. There was a significant difference in the level of mercury between the sites located in Hormoz and Qeshm Islands. In Qeshm Island, the sites Kaveh and Laft were considered as highly-contaminated points, mainly because of heavy transportation and shipping. Due to low human activities, the amount of mercury in the areas of Shahshahid and Naz was considerably lower than that in other sites. There were also significant differences in the pollution levels among the three sites of Hormoz Island. The most contaminated site was Khak-sorkh where mining is the main activity (Kazemi *et al.* 2011). However, the main cause of pollution in Hormoz Island seems to be marine transportation. Due to the intense marine transportation through the strait of Hormoz, several sorts of pollutants can influence all areas of Hormoz Island (Ghafariyan 2010; Kazemi *et al*. 2011). Nevertheless, the increased level of mercury in the Research Center site which is located in a rural area suggests that all the sampling sites have been influenced somehow by common sources of pollutants.

Based on what is found here, the amounts of Hg in the oyster shell from Qeshm are higher than those from Hormoz. Previous studies showed that shell can absorb some material from the outer layer which is in direct contact with water or air (Peer *et al.* 2010; Esmaili sari *et al*. 2008; Mukhtasor *et al*. 2001). The significant differences in mercury concentrations in the shell samples in this study can be referred back to the differences in the surfaces of sampling sites. With the large surface area and high urban and industrial development in Qeshm, absorption of contaminated particulate materials from atmosphere can occur during the low tide period (Esmaili Sari 2004; Ghafariyan 2010; Kazemi *et al.* 2011).

The estimations here also indicated that the mean concentrations of mercury in the sediments of Qeshm and Hormoz Islands were lower than the permissible limits for this element (130ppb) suggested by Canadian Interim Sediment Quality Guidelines) (Canada, 2001). Regarding the toxicity of volatile and highly-toxic elements or components, periodic sampling and analysis of water and sediment cannot provide adequate information about the quality of ecosystems (Peer *et al*. 2010; 2004). Whereas, the pollutants can be collectively accumulated in the body of living organisms and illustrate the exact history of the pollution in the ecosystem at any point of time (Carrasco *et al*. 2008). Thus, biomonitoring of elements or components in the living tissues and organs is a useful approach for health assessment of any ecosystem.

This bivalve is widely distributed in the southern part of Iranian coastal areas and thus it can be considered as an important indicator of pollutants, even in low levels, in the Persian Gulf. Longer term monitoring and assessment of organic and metal pollutants would be necessary to precisely assess the level of pollution in the soft tissues, shell and the other parts of this animal. For continuous pollution biomointoring, protection of rock oyster habitats as biomonitoring sites is recommended.

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پایشگری زیستی جیوه کل (T_{Hg}) با استفاده از صدف صخره‌ای- خوراکی (*Saccustrea cucullata*) در سواحل خلیج فارس

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چکیده

این تحقیق توانایی پایشگری‌زیستی صدف صخره‌ای خوراکی *S. cucullata* را به منظور پایش آلودگی جیوه در سواحل خلیج‌فارس بررسی می‌نماید. در این مطالعه از ۱۰ ایستگاه در سواحل بین جزرومدی در مناطق قشم، هرمز، بندرلنگه و بندرعباس نمونه‌برداری از رسوبات و صدف‌ها انجام شد. غلظت جیوه در نمونه‌های رسوب، پوسته و بافت نرم صدف با کمک دستگاه آنالایزر جیوه تعیین شد. مقدار فاکتور BSAF براساس نسبت غلظت جیوه در بافت نرم به رسوبات مناطق محاسبه گردید. نتایج نشان داد که توان تجمع‌زیستی در بافت نرم بطور معنی‌داری بیشتر از پوسته صدف مورد مطالعه می‌باشد ($P<05$). بین مقدار جیوه در بافت نرم و مقدار جیوه در رسوبات زیستگاه صدف مورد مطالعه همبستگی مثبت و معنی‌داری بدست آمد ($p<۰/۰۵$ و $r=۰/۷۵$) براساس همبستگی مثبت و مقادیر BSAF ، مشخص شد که بافت نرم این صدف اندام مناسبی برای پایشگری‌زیستی می‌باشد. نتایج این تحقیق با اطمینان بالا توانایی بافت نرم صدف *S. cucullata* را بعنوان اندامی حساس و مناسب برای پایشگری‌زیستی جیوه در منطقه معرفی می نماید.

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