Bull Environ Contam Toxicol (2012) 88:962–966
DOI 10.1007/s00128-012-0607-x

Oyster *Saccostrea cucullata* as a Biomonitor for Hg Contamination and the Risk to Humans on the Coast of Qeshm Island, Persian Gulf, Iran

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Received: 7 September 2011 / Accepted: 17 March 2012 / Published online: 20 April 2012

Abstract A total of 174 individuals of rocky oysters (*Saccostrea cucullata*) and 35 surface sediment samples were collected from seven stations off the intertidal zones of Qeshm Island, Persian Gulf, in order to study the concentration of mercury in oysters' tissues, and to investigate whether mercury concentrations in the edible soft tissues are within the permissible limits for public health. The average mercury concentrations were found as 3.44, 50.66 and 2.29 μg kg^{-1} dw in the sediments, soft tissues and shells of the oysters, respectively. Results indicated that the levels of mercury in sediment differed significantly between the stations. In addition, results confirmed that the soft tissues of oysters could be a good indicator of mercury in the aquatic system. In comparison with food safety standards, mercury levels in oysters were well within the permissible limits for human consumption.

Keywords Mercury · Surface sediment · *Saccostrea cucullata* · Qeshm Island · Persian Gulf

Mercury, given its high toxicity even at at low concentrations, mobilization as methylated forms, and ability to enter into biological communities, is a significant known threat to both living organisms and human health. In marine environments, the dominant distribution of mercury is in sediments (Odzak et al. 2000). This sediment may in fact serve as a source of mercury to filter feeders, among them bivalves (Rojas de Astudillo et al. 2005). Bivalves such as oysters are one of the best bioindicators of pollution for marine monitoring studies (Gagnaire et al. 2004). Several monitoring programmes (such as U.S. Mussel Watch, French RNO, and RINBIO) are focused on this concept (Ke and Wang 2001; Yap et al. 2004). This can be attributed to the fact that oysters have a wide geographical distribution in the coastal zone, and a sedentary nature; they can be easily identified and collected, and are resistant to a variety of environmental conditions (Gagnaire et al. 2004).

Oysters and other bivalves are suspension feeders that filter water, and they may accumulate certain contaminants, such as metals, within their tissues (Sajwan et al. 2008). Therefore, they can serve as biomonitoring agents to assess environmental pollution. Oysters are widely consumed by humans as food and consequently marketed commercially (Garcia-Rico et al. 2001). They are considered to be excellent sources of food protein and fiber (Zireva et al. 2007). However, from the viewpoint of public health, it is important to know that consumption of seafood contaminated with mercury over the long term can be harmful and therefore recognition of mercury levels in oyster species is necessary for assessing public health.

The present study was designed to determine mercury concentration in oyster (*Saccostrea cucullata*) tissues and sediments from Qeshm Island, and to investigate whether local mercury levels are within permissible limits for public health. We also compared mercury concentrations in soft tissue (ST) with the shell (SH), and examined the relationship between mercury concentrations in these tissues with mercury levels in the sediment. Other major objectives were to evaluate this oyster species for its application in serving as a biomonitor for mercury, and to determine if there was any public risk from the consumption of oysters harvested from the Qeshm Island coastal region.

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Materials and Methods

Seven stations were selected along the intertidal zones of Qeshm Island (Persian Gulf) in May 2010 (Fig. 1). About 20–28 *S. cucullata* samples of similar sizes were collected from each sampling site to avoid environmental variations and/or sample bias. Details of the oyster samples, including number of oysters analyzed, shell lengths, and site descriptions, are given in Table 1. In addition to the oysters, the top 3–5 cm of surface sediment was also collected from each oyster sampling site. Five replicates of sediments were sampled from each station. The samples were placed in a plastic zip bag and transported to the laboratory in ice. The samples were then stored at −20°C until further analysis. Then the frozen oysters were scattered on paper towels and thawed partially at room temperature before opening.

In the laboratory, the ST of oysters was carefully separated from the SH. Then the SH length of each individual was measured by caliper. After cleaning shells with a jet of tap water, they were washed with double distilled water (DDW) and 0.5 % of concentrated HNO_3. In the next stage, all oyster samples were dried in an oven at 105°C for 72 h until constant dry weights (dw). Sediment samples were also dried in an oven at 105°C for 16 h until constant dry weights (dw) were reached. Then SH samples were powdered by a mixer mill and stored in acid-washed polythene bags. After that about 0.5 g of each sample was weighed and the total mercury of the ST, SH, and sediment was measured by an AMA254 Advanced Mercury Analyzer (LECO Corp., USA) according to ASTM standard No. D6722. In order to assess the analytical capability of the proposed methodology, the accuracy of total Hg analysis was checked by running three samples of Standard Reference Materials (SRM), National Institute of Standards and Technology (NIST), SRM 1633b, SRM 2709, and SRM 2711 in seven replicates (Al-Majed and Preston 2000). Recovery was between 95.3 % and 101 %. The detection limit of the instrument used was 0.001 μg g^{-1} of dry weight. One-way analysis of variance (ANOVA) and least significant difference (LSD) tests were performed to determine any significant differences in mercury concentrations in the sediments. A *t* test was used to determine mercury concentration mean differences between soft tissues and shells of oysters. Differences were considered significant only when *p* values were lower than 0.05. Prior to analysis, data were inspected for homogeneity of variance (Levene's test). For correlation analysis, sediment and ST data were transformed logarithmically to ensure normal distributions. Then, correlation analyses were performed for mean mercury concentrations in sediments with mean mercury concentrations in ST or SH was tested. All statistical calculations were carried out using Statistics for Windows (Version 10, Wilkinson 2000) and SPSS statistical software (version 17.0).

In this study, a coefficient of variation (CV) value was applied to investigate the degrees of variability of mercury concentrations in total SH and total ST of *S. cucullata*. The CV value was calculated using this equation:

$$\mathrm{CV}\% = (\text{standard deviation/mean}) \times 100$$

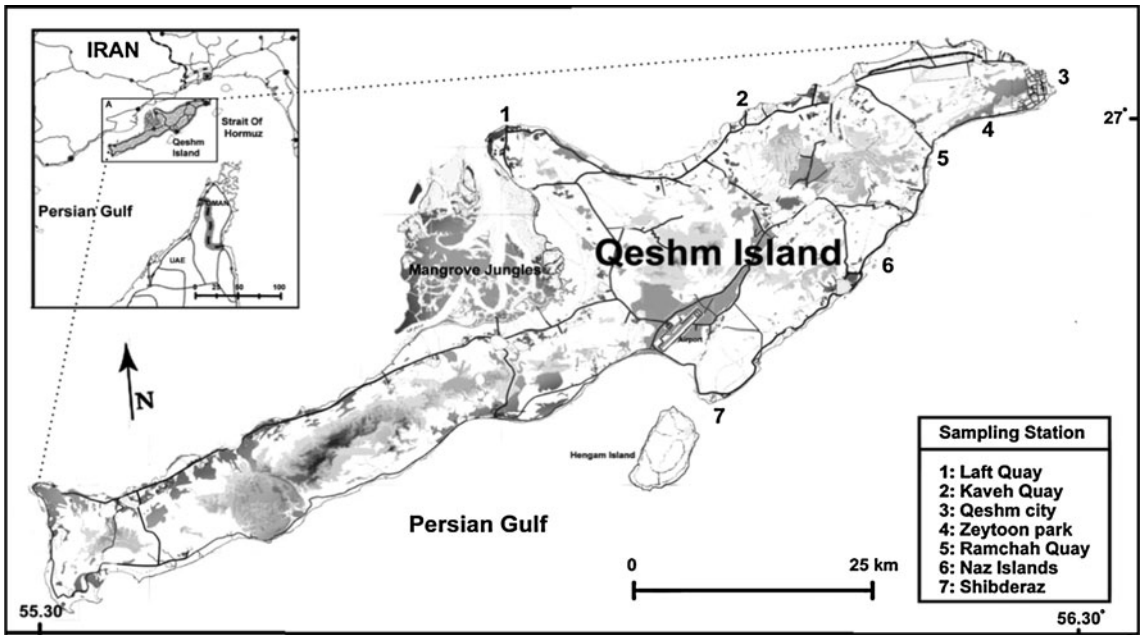

Fig. 1 Sampling stations along the coast of Qeshm Island, Persian Gulf

Table 1 Positions, number of samples analyzed (N), shell length (mm) of oysters and descriptions of sampling sites of *S. cucullata* collected from the coast of Qeshm Island, Persian Gulf

Station	Location	Latitude(N)	Longitude (E)	N	Shell length [mean (min–max)] (mm)	Shell height mean (min max) (mm)	Shell width mean (min–max)(mm)	Site description
1	Laft Quay	26°56′37″	55°45′35″	27	48.84 (33.45–64.73)	1.42 (1.06–1.91)	37.17 (28.18–42.34)	A busy jetty and shipping activities
2	Kaveh Quay	26°55′19″	55°57′17″	27	57.37 (36.75–81.39)	1.71 (1.44–2.02)	38.25 (24.21–44.11)	A jetty
3	Qeshm city	26°56′25″	56°16′31″	27	36.35 (28.09–49.73)	1.18 (1.01–1.34)	29.01 (21.22–34.78)	Urban area
4	Zeytoon Park	26°55′28″	56°16′04″	20	36.71 (22.66–51.51)	1.22 (0.98–1.53)	28.65 (20.33–36.12)	Urban area
5	Ramchah Quay	26°53′27″	56°09′37″	25	50.52 (37.93–67.19)	1.54 (1.32–1.79)	34.60 (24.59–44.26)	Recreational area
6	Naz Islands	26°48′49″	56°06′56″	28	41.62 (31.26–78.23)	1.31 (1.12–1.66)	33.76 (20.14–42.36)	Pristine area
7	Shib deraz	26°41′16″	55°55′45″	20	41.41 (34.65–48.44)	1.52 (1.32–1.76)	31.04 (21.66–36.12)	Pristine area

Results and Discussion

The mercury concentrations ranged from 1.13 to 8.85 μg kg^{-1} dw in the various stations (Table 2). An analysis of variance and the LSD test were applied to determine any significant differences in mercury concentrations among the stations. Results of Levene's test for Hg concentrations indicated a homogeneity of variances across groups ($S = 1.49$; $p = 0.218$). The results of ANOVA showed significant differences ($F = 55.07$; $df = 6, 28$; $p < 0.05$) in the Hg concentrations among the seven stations. The results of the LSD test revealed a significant difference ($p < 0.05$) at the 95 % confidence level in the mercury concentrations between stations 1 and 2 with the others (Table 3). Among the seven sites, sediment samples from the station 1 showed the highest mean Hg concentrations, whereas the lowest concentration of mercury in sediment was found in station 6. Similarly, there was an enrichment of Hg in the sediments located on the northern stations compared with those on the southern stations. These differences can be explained in part by municipal and industrial activities from Hormozgan province (Sarafraz et al. 2007). In addition, the high level of mercury in stations 1, 2, and 5 could be due to higher levels of human activities, such as shipping, sailing, and yachting (Pirrone et al. 2010). Whereas one source of mercury is oil, and this area has been polluted by petroleum (Agah et al. 2007). Therefore, it may be assumed that the low concentration of mercury in the other stations comes from petroleum resources.

The mercury concentrations ranged 36.0–65.3 μg kg^{-1}dw in the ST, and from 1.57 to 2.73 μg kg^{-1} dw in the SH of *S. cucullata* (Table 2). Analysis of mercury concentrations in the ST and SH of oysters by the independent *t* test revealed a significant difference ($t = 11.2$, $p < 0.05$, $df = 6$) between the tissue types. Mercury concentrations in the ST were 13.3 times higher than those in the SH of *S. cucullata.* These results indicate that the ST had higher affinities for Hg than the SH. The higher level of mercury in the ST may be due to

Table 2 Hg concentrations (mean ± standard error, μg kg^{-1} dry weight) in sediment and total soft tissue (ST) and shell (SH) and ratios of ST/SH of *S. cucullata* samples from the coast of Qeshm Island, Persian Gulf

Station	Sediment	ST	SH	Ratio (ST/SH)
1	8.85 ± 0.68	63.2 ± 10.1	2.29 ± 0.66	27.6
2	4.84 ± 0.51	65.3 ± 11.8	2.73 ± 0.79	23.9
3	2.64 ± 0.75	55.9 ± 11.5	2.73 ± 0.77	20.5
4	1.57 ± 0.89	47.5 ± 1.87	2.21 ± 0.19	21.5
5	3.69 ± 1.75	37.1 ± 1.34	1.57 ± 0.12	23.6
6	1.13 ± 0.05	35.9 ± 1.32	2.63 ± 0.12	13.7
7	1.34 ± 0.57	49.6 ± 1.51	1.82 ± 0.12	27.3

Table 3 Analysis of differences between means of mercury concentrations in sediment from seven stations along the coast of Qeshm Island by one-way ANOVA and the LSD (least significant difference) test

	Station1	Station 2	Station 3	Station 4	Station 5	Station 6	Station7
Station 1	1.00	4.01*	6.2*	7.5*	6.5*	7.7*	7.3*
Station 2		1.00	2.2*	3.5*	2.5*	3.7*	3.3*
Station 3			1.00	1.3*	0.29	1.5*	1.1*
Station 4				1.00	0.97	0.23	0.15
Station 5					1.00	1.2*	0.82
Station 6						1.00	0.38
Station 7							1.00

* Significant difference at the 0.05 level

the high metal binding capacity of metallothionein in the ST (Engel 1999). Nevertheless, several authors (Rojas de Astudillo et al. 2005; Sajwan et al. 2008) had shown that the ST of oyster was not a concentrating organ of mercury contamination in coastal waters.

Analysis of the variability of mercury concentrations in ST and SH (Table 4) indicated a lower degree of variability in the ST (CV = 28.3 %) than in the SH (CV = 35.3 %). The results indicated lower degrees of variability of mercury in the ST than in the total SH of *S. cucullata*. The lower degrees of mercury variability (CV) in the total ST of *S. cucullata* suggest greater precision when ST is used as a biomonitoring material for mercury.

A significant positive correlation ($r = 0.75$, $p < 0.05$) was found in mercury concentration between the ST and sediments (Fig. 2). On the contrary, there was no correlation ($r = 0.02$, $p > 0.05$) between Hg in sediment and shell of *S. cucullata* (Fig 3). The positive correlation in mercury concentration between the ST and sediments, higher mercury concentrations in the oyster ST than the SH and also the lower degrees of mercury variability (CV) in the ST of *S. cucullata* together indicate that it is generally a more sensitive and precise biomonitoring material for mercury than the SH of *S. cucullata*. However, the findings of the current study do not support the previous reports on mercury concentrations in oysters and sediments (Rojas de Astudillo et al. 2005; Affizah et al. 2009). In these studies no significant correlation was found ($p > 0.05$) in mercury concentrations between ST of oysters and sediments. Also, it may be important to determine the genetic makeup of populations of *S. cucullata* throughout its geographic distribution in the Persian Gulf to determine the degree of similarity, as this has been stated to be a vital benchmark for a good biomonitor (Yap et al. 2002). It is important to have an overall picture of the mercury levels present in the analyzed species from a public health perspective. To achieve this, it was first necessary to convert concentrations to wet weight values using a dry weight/wet weight ratio (0.22 ± 0.01). The results showed that the mercury concentration range in the ST of *S. cucullata* varied between 7.90 and 14.4 μg kg^{-1} wet wt. The present values exhibited that in comparison with guidelines established by the FDA (2001), concentrations of total mercury in oyster

Table 4 Comparison between coefficients of variation (%) of Hg concentrations in total soft tissue and total shell of *S. cucullata*

Hg	N	CV (%)
Soft tissue (ST)	174	23.8
Shell (SH)	174	35.3

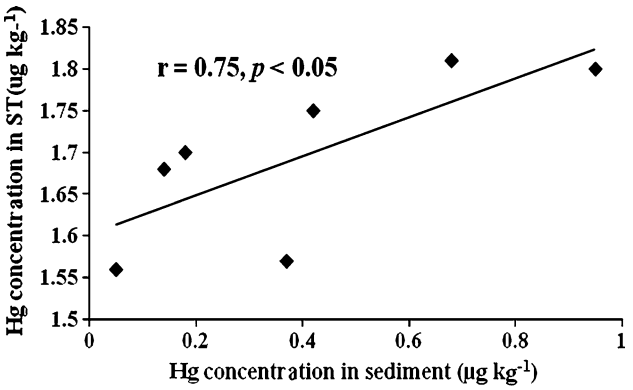

Fig. 2 Correlation of Hg between $\log_{10}$ (mean) soft tissue and $\log_{10}$ (mean) sediment of *S. cucullata* (n = 7)

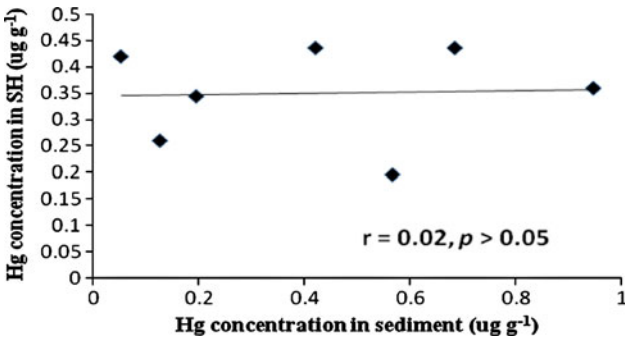

Fig. 3 Correlation of Hg between $\log_{10}$ (mean) shell and $\log_{10}$ (mean) sediment of *S. cucullata* (n = 7)

Table 5 Guidelines on mercury for seafood safety set by different countries

Standard	Country	Hg (μg/g)	Reference
FDA (Food and Drug Administration)	USA	1	FDA (2001)
EU Commission	Europe	0.5	EU Commission (1881)
NHMRC (National Health Medical Research Council)	Australia	1	Peerzada et al. (1993)

tissue were less than limit. In addition, data indicated that the concentrations of mercury in oyster tissue did not exceed the maximum permissible levels for seafood set by the EU Commission Regulation (EC) No (1881) and Australia's National Health Medical Research Council (NHMRC; Table 5). Mercury can directly affect the central nervous system of adults and may cause neurodegenerative diseases, such as Alzheimer's and Parkinson's disease, as well as psychological, renal, and immunological problems in all humans (Mercola and Klinghardt 2001).

In an assessment of the exposure risk to mercury from the consumption of oysters, knowing the amount of mercury ingested is important. For example, if an adult consumed 2.5 g/day of *S. cucullata* from the Qeshm Island coastal area at an average ST mercury concentration of 50.7 μg kg^{-1}, he would invest approximately 0.127 μg of mercury each day. If he consumes the oysters for 1 week, he would obtain 0.89 μg Hg. According to the recommended level of the Joint FAO/WHO expert committee for provisional tolerable weekly intake, maximum weekly intake for an adult with a body weight of 60 kg is 300 μg (Nasreddine and Parent-Massin 2002). This indicates that it is unlikely that the consumption of oysters from the Qeshm Island coastal area will result in any symptoms of acute toxicity due to mercury. In summary, this study has shown that the total ST of *S. cucullata* is a sensitive and precise biomonitoring material for mercury along the coast of Qeshm Island. In addition, from the viewpoint of public health, the low levels of mercury that are present in the ST of these oysters should not be harmful to human consumers, and the oysters may be regarded as being safe to eat.

Acknowledgments This study was supported by the Ministry of Science and Technology, Iran, which provided partial funding for this project. We thank Miss Gafari, Miss Ebrahimi, and Mrs. Mortazavi from the Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University for their kind assistance in the collection of oyster samples.

References

Affizah N, Vedamanikam V, Shazilli N (2009) Concentration of arsenic and mercury in theoyster (*Crassostrea iredalei*) from Setiu lagoon, Terengganu. Toxicol Environ Chem 91:259–265

Agah H, Leermakers M, Elskens M, Fatemi SMR, Baeyens W (2007) Total mercury and methyl mercury concentrations in fish from the Persian Gulf and the Caspian Sea. Water Air Soil Pollut 181:95–105

Al-Majed N, Preston M (2000) Factors influencing the total mercury and methyl mercury in the hair of the fishermen of Kuwait. Environ Pollut 109:239–250

Engel D (1999) Accumulation and cytosolic partitioning of metals in the American oyster *Crassostrea virginica*. Mar Environ Res 47:89–102

EU Commission Regulation (EC) No. 1881/2006

FDA (2001) Guidance documents for trace elements in seafood. Center for Food Safety and Applied Nutrition Food and Drug Administration, Washington, DC

Gagnaire B, Thomas-Guyon H, Renault T (2004) In vitro effects of cadmium and mercury on Pacific oyster, *Crassostrea gigas* (Thunberg), haemocytes. Fish Shellfish Immunol 16:501–512

Garcia-Rico L, Ruiz RER, Jimenez JV (2001) Determination of total metals in cultivated oysters (*Crassostrea gigas*) from the northwest coast of Mexico by microwave digestion and atomic absorption spectrometry. J AOAC Int 84:1909–1913

Ke C, Wang WX (2001) Bioaccumulation of Cd, Se, and Zn in an estuarine oyster (*Crassostrea rivularis*) and a coastal oyster (*Saccostrea glomerata*). Aquat Toxicol 56:33–51

Mercola J, Klinghardt D (2001) Mercury toxicity and systemic elimination agents. J Nutr Environ Med 11:53–62

Nasreddine L, Parent-Massin D (2002) Food contamination by metals and pesticides in the European Union. Should we worry? Toxicol Lett 127:29–41

Odzak N, Zvonaric T, Kljakovic Gaspic Z, Horvat M, Baric A (2000) Biomonitoring of mercury in the Katela Bay using transplanted mussels. Sci Total Environ 261:61–68

Peerzada N, Watson D, Guinea M (1993) Mercury concentrations in oysters from the coastline of Northern Territory, Australia. Bull Environ Contam Toxicol 50:158–163

Pirrone N, Cinnirella S, Feng X, Finkelman R, Friedli H, Leaner J, Mason R, Mukherjee A, Stracher G, Streets D (2010) Global mercury emissions to the atmosphere from anthropogenic and natural sources. Atmos Chem Phys 10:5951–5964

Rojas de Astudillo L, Chang Yen I, Bekele I (2005) Heavy metals in sediments, mussels and oysters from Trinidad and Venezuela. Rev Biol Trop 53:41–51

Sajwan KS, Kumar KS, Paramasivam S, Compton SS, Richardson JP (2008) Elemental status in sediment and American oyster collected from Savannah marsh/estuarine ecosystem: a preliminary assessment. Arch Environ Contam Toxicol 54:245–258

Sarafraz S, Khani M, Yaghmaeian K (2007) Quality and quantity survey of hospital wastewaters in Hormozgan province. IJEHSE 4:43–50

Wilkinson JM (2000) What do we know about herbal morning sickness treatment? A literature survey. Midwifery 16:224–228

Yap CK, Tan SG, Ismail A, Omar H (2002) Genetic variation of green-lipped mussel *Perna viridis* (Linnaeus) from the west coast of Peninsular Malaysia. Zool Stud 41:376–387

Yap C, Ismail A, Tan S, Rahim Ismail A (2004) Assessment of different soft tissues of the green-lipped mussel *Perna viridis* (Linnaeus) as biomonitoring agents of Pb: field and laboratory studies. Water Air Soil Pollut 153:253–268

Zireva D, Fanadzo M, Mashingaidze A (2007) Effect of substrate quality and shelf position yield of mushroom (*Pleurotus sajor-caju*). Pak J Biol Sci 10:3458–3461