Bull Environ Contam Toxicol (2010) 85:339–343
DOI 10.1007/s00128-010-0071-4

Mercury in Cultured Oysters (*Crassostrea gigas* Thunberg, 1793 and *C. corteziensis* Hertlein, 1951) from Four Coastal Lagoons of the SE Gulf of California, Mexico

C. C. Osuna-Martínez · F. Páez-Osuna · R. Alonso-Rodríguez

Received: 24 March 2010 / Accepted: 8 July 2010 / Published online: 10 August 2010

Abstract In order to determine the mercury concentrations in cultured oysters from coastal lagoons (SE Gulf of California), several individuals of *Crassostrea gigas* and *C. corteziensis* were collected and their mercury levels were measured with a cold vapor analyzer. The mean concentrations during the rainy and dry seasons, respectively, were 0.70 and 0.15 μg g^{-1} in *C. gigas* and 0.56 and 0.18 μg g^{-1} in *C. corteziensis.* During the rainy season, elevated mercury contents are apparently related to terrigen transport from the watershed, while during the dry season, the moderate levels are related to upwellings.

Keywords Mercury · Oysters · Coastal lagoon · *Crassostrea gigas* · *Crassostrea corteziensis*

Mercury is an element with one of the highest environmental risks and it is considered a global pollutant as a result of both natural origin and anthropogenic activities (Shah et al. 2010). Given the significant inputs of this metal into the environment, it is considered a "blacklisted" pollutant in terms of environmental damage and is a threat to human health. Its high mobility, persistence in the environment and lipophilicity justify the importance of environmental studies of Hg. On the SE Gulf of California coast (Sinaloa state), there are important fisheries, including shrimp, lobster, fish and oysters. The impact exerted by human activities has come about from several factors: changes in land use, alteration of wetlands and coastal lagoons by dam construction for irrigating purposes and electricity production, conversion of wetlands into shrimp farms, eutrophication of coastal lagoons, loss of habitats due to urban and tourist developments, and pollution by municipal and agroindustrial waste. In this region, published studies concerning Hg levels in mollusks (Jara-Marini et al. 2008) are scarce, although there are works involving shrimp (Ruelas-Inzunza et al. 2004) and fish (Ruelas-Inzunza et al. 2008). Potential sources of Hg pollution in the SE Gulf of California region are represented by waste effluents from intensive agriculture, where Hg compounds are used as fungicides, urban sewage and effluents from the sugar cane industry. Another important source of Hg in agricultural ecosystems is the use of Hg seed dressings, the production of which was discontinued in countries like Poland; in other countries, these Hg dressings are still used (Shah et al. 2010). In the studied region, agriculture is the main economic activity, with 1.5 million ha and more than 8 million t of 68 different crops produced each year.

The Pacific or Japanese oyster (*C. gigas*) is the most widely cultivated oyster species worldwide. It has been introduced for cultivation in many countries. In Mexico, its introduction occurred in 1973. Oyster culture has been developed to a commercial scale, and at the present time, this activity represents approximately 1,600 metric t of production annually for Mexico. For the purposes of assessing coastal water quality, oysters of the *Crassostrea* genus have already been proposed as sentinel organisms for marine ecotoxicological tests, because they are very sensitive to pollutants and provide a rapid response (Páez-Osuna et al. 1995). Another oyster from the genus

C. C. Osuna-Martínez
Posgrado en Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Mazatlán, Sinaloa, Mexico

F. Páez-Osuna (✉) · R. Alonso-Rodríguez
Instituto de Ciencias del Mar y Limnología, Unidad Académica Mazatlán, Universidad Nacional Autónoma de México, P.O. Box 811, 82000 Mazatlán, Sinaloa, Mexico
e-mail: paezos@servidor.unam.mx

Crassostrea that is cultivated in this area is the mangrove oyster *C. corteziensis*, which is a native and brackish species that occurs principally associated with the roots of the red mangrove *Rhizophora mangle*. Its distribution area extends along the tropical Pacific, from Mexico to Peru (Páez-Osuna et al. 1995). Additionaly, *C. corteziensis* is widely utilized for human consumption and has important commercial value. As the cultivation of these organisms is carried out inside coastal lagoons, the oysters are susceptible to contamination by heavy metals such as Hg. The present work is aimed at measuring the concentrations of Hg in the soft tissue of *C. gigas* and *C. corteziensis* specimens from Sinaloa coastal lagoons because of the importance of oysters as cultured products for human consumption and as useful biomonitors of the quality of lagoon waters where they are produced.

Materials and Methods

The present study was performed at four oyster farms in four coastal lagoons in the Sinaloa state, SE Gulf of California, Mexico: El Colorado (EC), Santa María-La Reforma (SMLR), Altata (ALT) and Ceuta (CEU) (Fig. 1). A total of six samples of cultured oysters of *C. gigas* and two samples of *C. corteziensis* (species restricted to only one farm) were collected in duplicate. In order to conduct the sample pretreatment, a depuration of 36 h with lagoon water from the mouth of every lagoon was made. Once cleaned, the oyster shells were measured (mm) and weighed (total and soft tissue, g). The condition index (CI) was determined by: CI = [soft tissue dry wt (g) × 1000]/ shell dry wt (g) (Walne and Mann 1975). The soft tissue of the groups (each pool of 25 oysters) was extracted, homogenized, freeze-dried over 72 h (−49°C and 133×10^{-3} mbar) and then ground in an automatic agate mortar. Finally, they were kept frozen until their digestion (<3 months). The glassware and other utensils were previously washed according to Jara-Marini et al. (2008).

Samples were digested by a microwave system (Model MARS-X) in one step: 5 mL of concentrated HNO_3 were added to 0.25 ± 0.003 g of tissue and the mixture was heated to 100°C for 5 min, to 120°C for 5 min and to 140°C for 10 min. The digested samples were then stored in polyethylene containers. Analyses were carried out by reducing the Hg compounds with $SnCl_2$ followed by Hg detection using cold vapor atomic absorption spectrometry (Jara-Marini et al. 2008). Certified mussel material (Standard Reference Material® 2976, from NIST) was analyzed for metal quality control purposes, and there was

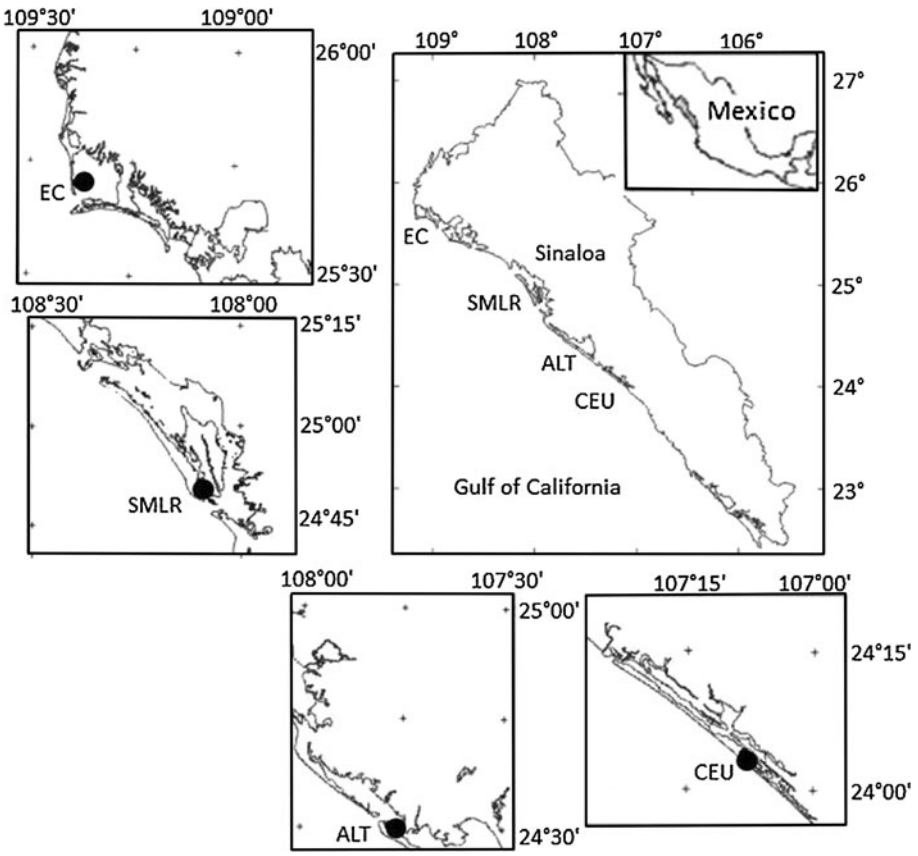

Fig. 1 Location of the study area: coastal lagoons from Sinaloa, where cultured oysters were collected. The point (*filled circle*) indicates the approximate position of the farms

satisfactory agreement between the analytical results (0.063 ± 0.009 μg g^{-1} dry wt) and the certified value (0.061 ± 0.003 μg g^{-1} dry wt). The limit of detection was 0.05 μg g^{-1}; the precision, estimated as the coefficient of variation, was below of 4.0% for the levels found. Additionally, each set of 14 samples included one blank. In order to extrapolate from the limited number of samples from each site that were analyzed (duplicates), the 'bootstrap' method was employed (Efron and Tibshirani 1991). Then, an analysis of variance was performed, which showed significant differences among the mean Hg concentrations.

Results and Discussion

Aside from the species, the body size of oysters is one of the most important factors that affect the metal accumulation rates in biological tissues (Meyer et al. 1998); therefore were collected specimens of similar sizes of both species (Table 1). However, the soft tissue weight was higher in samples from the dry season, when the condition index is greater. This phenomenon has been observed before, such as with *C. rhizophorae* (Rebelo et al. 2005). A linear model was applied in which the metal concentration in the tissues was plotted as a linear function of the condition index (Fig. 2), and the results showed that Hg was negatively correlated to the CI ($r = 0.86$; $p < 0.05$).

For *C. gigas* in all of the coastal lagoons, higher mean concentrations of Hg were found during the rainy season (0.70 ± 0.24 μg g^{-1}) compared with the dry season (0.15 ± 0.07 μg g^{-1}), as well as for *C. corteziensis* in the CEU lagoon, where the mean concentrations were 0.56 ± 0.03 and 0.18 ± 0.03 μg g^{-1} for the rainy and dry seasons, respectively. This may be explained by the transport of materials from the watershed to the lagoons through rain (runoff). In a similar study of the Moroccan coastal region, Maanan (2008) found higher Hg concentrations in samples from the rainy season, which is in agreement with our results. However, another factor to consider is the maturation phase of the oysters, which influences the seasonal fluctuations of metal concentrations in these organisms (Frías-Espericueta et al. 1999). The reproductive state and body size exerts an important influence on the accumulation and variability of trace metals (Páez-Osuna et al. 1995). Frías-Espericueta et al. (1999) studied the reproductive cycle of *C. corteziensis* in San Blas estuary, Nayarit. They observed that the resting and maturation phases occurred in November and March–April, respectively. They found that the highest concentrations of some metals occurred when the oysters were in the resting phase, and lower concentrations of the same metals were found when the oysters were engaged in gametogenic activity.

The Hg concentrations in the samples of both cultured oysters are illustrated in Fig. 3. The highest value was

Table 1 Morphometric data of collected organisms

Coastal lagoon	Season	Species/group	Length	*Total weight	*Soft tissue weight	CI
EC	Rainy	Cg/A	90 ± 9	73.3 ± 12.0	11.4 ± 2.8	36.8 ± 9.0
	Rainy	Cg/B	92 ± 7	75.8 ± 12.1	11.2 ± 2.9	34.7 ± 9.0
SMLR	Rainy	Cg/A	79 ± 6	54.9 ± 6.4	7.9 ± 1.6	33.6 ± 6.8
	Rainy	Cg/B	76 ± 8	51.4 ± 5.8	7.7 ± 1.9	35.2 ± 8.7
	Dry	Cg/A	79 ± 7	55.5 ± 11.4	12.1 ± 3.5	55.8 ± 16.1
	Dry	Cg/B	81 ± 7	56.7 ± 11.5	12.2 ± 2.7	54.8 ± 12.1
ALT	Dry	Cg/A	93 ± 9	63.1 ± 7.8	13.7 ± 2.6	55.5 ± 10.5
	Dry	Cg/B	92 ± 6	63.4 ± 7.4	13.3 ± 2.5	53.1 ± 10.0
CEU	Rainy	Cg/A	84 ± 6	61.4 ± 12.5	8.8 ± 2.8	33.5 ± 10.6
	Rainy	Cg/B	86 ± 7	57.8 ± 7.9	6.6 ± 2.1	25.8 ± 8.2
	Dry	Cg/A	97 ± 10	47.7 ± 5.9	10.6 ± 2.2	57.1 ± 11.9
	Dry	Cg/B	99 ± 8	50.8 ± 8.1	10.9 ± 2.2	54.6 ± 11.0
	Rainy	Cc/A	75 ± 6	63.0 ± 9.3	7.7 ± 1.9	27.8 ± 6.9
	Rainy	Cc/B	79 ± 7	65.0 ± 9.8	8.3 ± 2.2	29.3 ± 7.8
	Dry	Cc/A	82 ± 10	71.6 ± 14.8	13.7 ± 3.8	47.3 ± 13.1
	Dry	Cc/B	84 ± 8	74.8 ± 13.0	14.8 ± 4.3	49.3 ± 14.3

Length (mean ± SD, mm); total and soft tissue weight (mean ± SD, g); CI ± SD

Cg C. gigas; *Cc C. corteziensis*; *SD* standard deviation

* On the wet weight basis

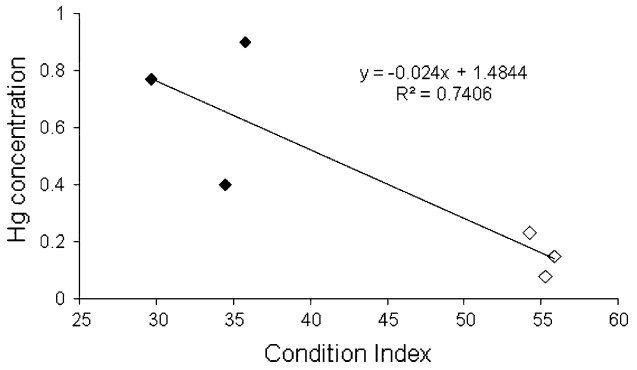

Fig. 2 Linear regression relating tissue Hg concentrations (μg g^{-1}dry wt) to CI in *C. gigas* ((*diamond*) dry and (*filled diamond*) rainy season)

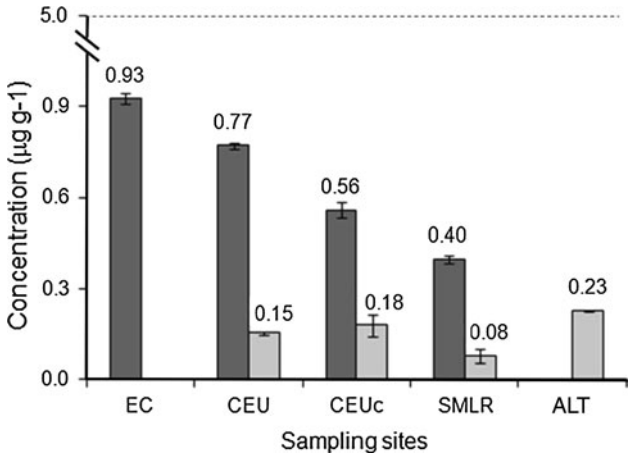

Fig. 3 Mercury concentrations in the oysters (*C. gigas*, except CEUc, which is *C. corteziensis*) from the coastal lagoons (mean ± SD, μg g^{-1} dry wt) and their comparison with the maximum tolerable value (*dashes*), *filled square* rainy and *grey square* dry season

found during the rainy season at the EC lagoon (0.93 μg g^{-1}), and the lowest was found during the dry season at the SMLR lagoon (0.08 μg g^{-1}). The average Hg concentration trend during the rainy season was EC > CEU > SMLR, which can be explained because the oyster farms in the EC and CEU lagoons are located at the inner portion of the water body, while in SMLR, the farm is set adjacent to the mouth of the lagoon. This situation influences the different availability of contaminants in the lagoons. On the other hand, during the dry season, the mean Hg concentration trend was ALT > CEU > SMLR. As mentioned, the location of the oyster farm in ALT is the closest to the mouth of the lagoon, so in this case, it is difficult to explain. Nevertheless, as has been determined for metals like Cd, spring upwellings could increase Hg bioavailability during this season. The surface distribution pattern may be altered in upwelling regions due to the input of Hg-enriched water from depth (Lares et al. 2002). Such enhancement of Hg concentration by the onset of upwellings has been reported in coastal regions of the North Pacific Ocean (Conaway et al. 2009). The Gulf of California is characterized by the presence of upwellings along its eastern coast, normally from February to April (Staines-Urías et al. 2009). Consequently, during upwelling periods, oysters from farms located at the inlet of lagoons probably exhibit higher Hg levels than those from farms located in the inner waters.

Although the highest Hg concentrations were found during the rainy season in all of the coastal lagoons, the Hg concentrations of all the samples were below the maximum tolerable in seafood (5 μg g^{-1} dry wt = 1 μg g^{-1} wet wt) according to the WHO (2003) and the Official Mexican Standard (NOM-031-SSA1-1993) (Fig. 3). The Expert Committee on Food Additives (FAO/WHO) has established regulatory guidelines regarding the dietary intake of Hg. It recommends a provisional tolerable weekly amount of Hg intake of 5 μg/kg body weight (WHO 2003), equivalent to 350 μg Hg/week for a 70 kg person. According to the results of this study, during the rainy season, the mean concentration of Hg in both cultured species was 0.66 μg g^{-1} = 660 μg kg^{-1} dry wt, equivalent to 132 μg kg^{-1} wet wt. Therefore, *ca.* 2.6 kg is the total weekly maximum amount of oysters that could be consumed by a 70 kg person without exceeding a body mercury concentration of 5 μg kg^{-1} weekly basis, which is improbable.

In the case of the CEU samples, both species were collected from the same farm (site); therefore, they were under the same water conditions and levels of Hg exposure. Although there was a limited number of samples collected (n = 4), the analysis of correlation of Hg content between the two *Crassostrea* species revealed a significant ($p < 0.05$) correlation. The equation was $Y = 0.616\ X + 0.084$ ($r = 0.99$), where Y and X are the metal concentrations in the soft tissues of *C. corteziensis* and *C. gigas*, respectively. This equation may be useful in the intercomparison of Hg levels between different sites involving these two species in monitoring programs.

Table 2 shows a comparison between Hg concentrations in oysters of the genus *Crassostrea* from different sites around the world and the values found in this study. The contents of Hg in the cultured oysters from coastal lagoons of Sinaloa during the dry season were lower or comparable to the concentrations of Hg reported for other estuaries. However, the concentrations of Hg found during the rainy season were higher or similar, with the exception of Minamata Bay (Japan), to the maximum levels reported in all of the other coastal ecosystems. From this work, emerge the need of researching the mechanisms and sources of Hg associated with the enrichment of Hg in cultured oysters in both seasons; which apparently is connected in rainy months with material transported from the watershed, while in dry season is related to upwellings in the Gulf of California.

Table 2 Mercury range concentrations (μg g^{-1} dry wt) in *Crassostrea* species from Mexican and other world regions

Species	Concentration	Study area	Ref.
C. rhizophorae	0.27–2.21	Channel of Santa Cruz, Brazil	1
C. virginica	0.02–0.03	Murrells Inlet and North Inlet, South Caroline, USA	2
C. tulipa	0.12–0.21	Benya, Ningo lagoons, Ghana	3
C. talienwhanensis	0.02–0.06	Bohai Sea, China	4
C. gigas	10.0*	Minamata Bay, Japan	5
C. gigas	0.04–0.10	Chi-ku, Tai-shi, Tapeng Bay, Taiwan	6
C. gigas	0.02–0.84	Oualidia lagoon, Morocco	7
C. gigas	0.23*	Guaymas lagoon, Mexico	8
C. corteziensis	0.03–0.08	Urías lagoon, Mexico	9
C. gigas	0.06–0.91	Coastal lagoons, SE Gulf of	10
C. corteziensis	0.16–0.58	California, México	

(1) Meyer et al. (1998); (2) Kawaguchi et al. (1999); (3) Otchere et al. (2003); (4) Wang et al. (2005); (5) Eisler (1987); (6) Chen and Chen (2003); (7) Maanan (2008); (8) Green-Ruiz et al. (2005); (9) Jara-Marini et al. (2008); (10) This study; *Only the mean value was available

Acknowledgments The authors thank H. Bojórquez-Leyva for assistance in the laboratory, G. Ramírez-Reséndiz for the preparation of figures and C. Ramírez-Jáuregui for bibliographic support.

References

Chen CY, Chen MH (2003) Investigation of Zn, Cu, Cd and Hg concentrations in the oyster of Chi-ku, Tai-shi and Tapeng Bay, Southwestern Taiwan. J Food Drug Anal 11(1):32–38

Conaway C, Black FJ, Gault-Ringold M, Pennington JT, Chávez FP, Flegal (2009) Dimethylmercury in coastal upwelling waters, Monterey Bay, California. Environ Sci Technol 43:1305–1309

Efron B, Tibshirani R (1991) Statistical data analysis in the computer age. Science 253:390–395

Eisler R (1987) Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. Biological Report US Fish and Wildlife Service 85 (1.10)

Frías-Espericueta MG, Osuna-López JI, Páez-Osuna F (1999) Gonadal maturation and trace metals in the mangrove oyster *Crassostrea corteziensis*: seasonal variation. Sci Total Environ 231:115–123

Green-Ruiz C, Ruelas-Inzunza J, Páez-Osuna F (2005) Mercury in surface sediments and benthic organisms from Guaymas Bay, east coast of the Gulf of California. Environ Geochem Health 27:321–329

Jara-Marini ME, Soto-Jiménez MF, Páez-Osuna F (2008) Trace metal accumulation patterns in a mangrove lagoon ecosystem, Mazatlan Harbour, SE Gulf of California. J Environ Sci Health A Tox Hazard Subst Environ Eng 43:1–11

Kawaguchi T, Porter D, Bushek D, Jones B (1999) Mercury in the American oyster *Crassostrea virginica* in South Caroline, USA, and public health concerns. Mar Pollut Bull 38(4):324–327

Lares ML, Flores-Muñoz G, Lara-Lara R (2002) Temporal variability of bioavailable Cd, Hg, Zn, Mn and Al in an upwelling regime. Environ Poll 120:595–608

Maanan M (2008) Heavy metal concentrations in marine molluscs from the Moroccan coastal region. Environ Poll 153(1):176–183

Meyer U, Hagen W, Medeiros C (1998) Mercury in a northeastern Brazilian mangrove area, a case study: potential of the mangrove oyster *Crassostrea rhizophorae* as bioindicator for mercury. Mar Biol 131:113–121

Otchere FA, Joiris CR, Holsbeek L (2003) Mercury in the bivalves *Anadara* (Senilia) *senilis*, *Perna perna* and *Crassostrea tulipa* from Ghana. Sci Total Environ 304(1–3):369–375

Páez-Osuna F, Frías-Espericueta MG, Osuna-López JI (1995) Trace metal concentrations in relation to season and gonadal maturation in the oyster *Crassostrea iridescens*. Mar Environ Res 40(1):19–31

Rebelo MF, Amaral MCR, Pfeiffer WC (2005) Oyster condition index in *Crassostrea rhizophorae* (Guilding, 1828) from a heavy-metal polluted coastal lagoon. Braz J Biol 65(2):345–351

Ruelas-Inzunza J, García-Rosales SB, Páez-Osuna F (2004) Distribution of mercury in adult penaeid shrimps from Altata-Ensenada del Pabellón lagoon (SE Gulf of California). Chemosphere 57:1657–1661

Ruelas-Inzunza J, Meza-López G, Páez-Osuna F (2008) Mercury in fish that are of dietary importance from the coasts of Sinaloa (SE Gulf of California). J Food Composit Anal 21(3):211–218

Shah AQ, Kazi TG, Baig JA, Afridi HI, Kandhro GA, Arain MB, Kolachi NF, Wadhwa SK (2010) Total mercury determination in different tissues of broiler chicken by using cloud point extraction and cold vapor atomic absorption spectrometry. Food Chem Toxicol 48:65–69

Staines-Urías F, Douglas RG, Gorsline DS (2009) Oceanographic variability in the southern Gulf of California over the past 400 years: evidence from faunal and isotopic records from planktic foraminifera. Palaeogeogr Palaeoclimatol Palaeoecol 284(3–4):337–354

Walne PR, Mann R (1975) Growth and biochemical composition in *Ostrea edulis* and *Crassostrea gigas.* Proceedings of the 9th European Mar Biol Symp: 587–607

Wang Y, Liang L, Shi J, Jiang G (2005) Study on the contamination of heavy metals and their correlations in mollusks collected from coastal sites along the Chinese Bohai Sea. Environ Int 31:1103–1113

WHO (2003) Summary and conclusions of the sixty-first meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), JECFA/61/SC, Rome