Bull Environ Contam Toxicol (2011) 86:410–414
DOI 10.1007/s00128-011-0223-1

Cadmium, Lead and Zinc Concentrations in Water, Sediment and Oyster (*Crassostrea virginica*) of San Andres Lagoon, Mexico

María de la Luz Vázquez-Sauceda · G. Aguirre-Guzmán · J. G. Sánchez-Martínez · R. Pérez-Castañeda

Received: 22 October 2010 / Accepted: 8 February 2011 / Published online: 19 February 2011

Abstract The spatial distribution of cadmium, lead and zinc concentrations in water, sediment and oysters from San Andres Lagoon was evaluated. Significantly higher cadmium (0.33 mg L^{-1}) and lead (0.70 mg L^{-1}) concentrations in water were observed in front of the mouth of Tigre river, whereas, zinc concentration (5.0 mg L^{-1}) was significantly higher in the south part of the lagoon. Similarly, lead and zinc values in sediment (1.01 and 9.29 µg g^{-1}, respectively) and oyster tissue (0.86 and 3.19 µg g^{-1}, respectively) were significantly higher in the south part of the lagoon. Levels of cadmium and lead in oyster tissue were positively related to those found in sediment. However, concerning zinc no evident relationship was found. Such differences in regression analyses may be explained by differential bioaccumulation of xenobiotic (cadmium, lead) and essential (zinc) metals.

Keywords Contamination · *Crassostrea virginica* · Heavy metals · Oyster

Heavy metals take part in different metabolic processes and are required by living organisms in trace amounts. However, high levels of heavy metals can become contaminant and induce adverse biological effects (Long et al. 1995). On the other hand, non-essential metals, i.e. not required for metabolism, are toxic even at very low levels (Wright and Welbourn 2001). Cadmium (Cd), lead (Pb) and zinc (Zn) are used in oil refineries, in steel production, fertilizers (Förstner and Wittmann 1979) and pesticides (Samyappan et al. 2007). Zinc can also be found in important quantities in detergents (Angino et al. 1970). Most heavy metals in coastal waters are leached to rivers by industrial, urban and agricultural discharges (Simpson 1994).

Previous studies indicate the presence of contaminants in coastal ecosystems in the Gulf of Mexico, among them heavy metals, which can affect not only aquatic organisms but also their habitats (Frías-Espericueta et al. 2009). San Andres Lagoon, located to the west of the Gulf of Mexico is exposed to heavy metal contamination because it is located in a cattle farming zone, where pesticides are used, which can leach to the water, and because there are urban discharges near the lagoon. This compounds the fact that coastal lagoons generally have a low water exchange (Kjerfve 1994), favouring the accumulation of heavy metals in the ecosystem, especially in bivalves.

Crassostrea virginica is an oyster species found in San Andres Lagoon, which forms oyster banks which can be as big as 2 km^2, supporting an important local fishery in the lagoon for the past several decades. Because of this, and considering the socioeconomic importance of the oyster fishery in this region, the present study evaluated the spatial variation of heavy metal levels (Cd, Pb and Zn) in water, sediment and oyster tissue from San Andres Lagoon.

Materials and Methods

Five sampling sites were selected comprising the main oyster banks in San Andres Lagoon, located on the Gulf of Mexico (Fig. 1). Weekly samplings were performed from April to September 2000 in each site in order to determine the heavy metal content (Cd, Pb and Zn) in water, sediment

M. L. Vázquez-Sauceda (✉) · G. Aguirre-Guzmán · J. G. Sánchez-Martínez · R. Pérez-Castañeda
Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Tamaulipas, Carretera Victoria–Mante km 5, Cd., Victoria 87000, Tamaulipas, México
e-mail: mvazquez@uat.edu.mx

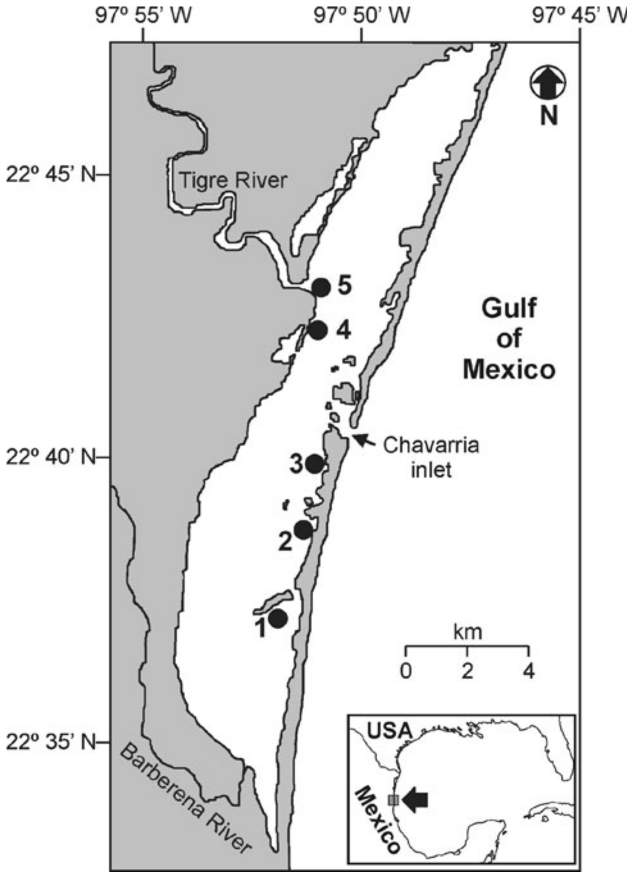


Fig. 1 Location of sampling sites in San Andres Lagoon, Tamaulipas

and oyster (*C. virginica*) tissue. Each site sample consisted of 500 g oyster tissue, 500 g sediment, and 500 mL water. Oyster tissue samples were obtained by free diving. Sediment was obtained with a 10 lb manual dredger, while water samples were obtained by immersing polyethylene flasks (500 mL) at a mean depth of 0.5 m. All the samples were place in polyethylene flasks, labeled and transported in iceboxes for their analysis in the laboratory.

Heavy metal (Cd, Pb and Zn) levels in water, sediment and oyster tissue samples were analyzed by atomic absorption, using a Perkin Elmer 5100 spectrophotometer. NIST standard reference materials were employed to verify the accuracy of the analytical technique: estuarine sediment (SRM-1646a), oyster tissue (SRM-1566b). The recoveries obtained with the reference materials for estuarine sediment were 93.3% Cd, 79.3% Pb and 88.5% Zn; while for oyster tissue were 89.11% Cd, 80.64% Pb and 99.4% Zn. The limits of detection were as follows: Cd (0.32 μg L^{-1}), Pb (2.5 μg L^{-1}), and Zn (0.20 μg L^{-1}) in water; Cd (0.009 μg g^{-1}), Pb (0.008 μg g^{-1}), and Zn (1.0 μg g^{-1}) in sediment; Cd (0.006 μg g^{-1}), Pb (0.005 μg g^{-1}), and Zn (0.1 μg g^{-1}) in oyster tissue.

The mean heavy metal values at each sampling site were compared using a one way ANOVA. When significant differences were detected, multiple comparisons were achieved using Tukey's test. Also, to evaluate the relation between heavy metal levels in sediment and oyster tissue, disaggregated linear regression analyses were done for each sampling site.

Results and Discussion

Most metal concentrations in water, sediment and oyster tissue from San Andres Lagoon showed significant differences among sampling sites. Levels of Cd and Pb in water were significantly lower ($p < 0.05$) than those observed in sediment and oyster tissue (Tables 1, 2 and 3), whereas Zinc concentration in water was lower than in sediment, but higher than in oyster tissue.

Significantly higher levels of Cd and Pb in water were usually recorded at site 5, located in front of the mouth of the Tigre river (Fig. 1), while the remaining sites were not significantly different from each other. This suggests that concentrations of Cd and Pb in the lagoon water could be related to inputs from the river, which may transport metals in fluvial sediments over long distances (Jaffé et al. 1995). The use of pesticides and fertilizers, derived from livestock and agricultural activities around the study area, could be an important source of these metals. In fact, pesticides and fertilizers contain lead (Hohl and Varma 2009) and cadmium (Bjerregaard and Andersen 2007) and have been considered as major sources of metal contamination in other coastal lagoons (Frías-Espericueta et al. 2009).

The highest Zn concentration in water was recorded at the southern part of the lagoon, particularly at site 1; however, it was not significantly different from values observed at sites 3 and 5 (Table 1). Zinc levels in San Andres Lagoon could be an indication of the presence of

Table 1 Mean (± SD) heavy metal levels (mg L^{-1}) in water at different sampling sites in San Andres Lagoon, Tamaulipas

Metal	Sampling site				
	1	2	3	4	5
Cd	0.32 ± 0.06	0.29 ± 0.06	0.30 ± 0.04	0.29 ± 0.07	0.33 ± 0.04
Pb	0.45 ± 0.22	0.40 ± 0.23	0.39 ± 0.17	0.52 ± 0.12	0.70 ± 0.11
Zn	5.00 ± 0.30	4.74 ± 0.42	4.84 ± 0.27	4.65 ± 0.45	4.92 ± 0.23

n = 24

Table 2 Mean (± SD) heavy metal levels (μg g^{-1}) in sediment at different sampling sites in San Andres Lagoon, Tamaulipas

Metal	Sampling site				
	1	2	3	4	5
Cd	1.08 ± 0.07	1.09 ± 0.12	1.07 ± 0.12	1.11 ± 0.11	1.08 ± 0.06
Pb	0.97 ± 0.11	1.01 ± 0.12	0.98 ± 0.20	0.89 ± 0.08	0.91 ± 0.07
Zn	9.29 ± 1.23	8.98 ± 0.97	8.83 ± 1.06	8.37 ± 0.73	8.54 ± 0.85

n = 24

Table 3 Mean (± SD) heavy metal levels (μg g^{-1}) in oyster tissue at different sampling sites in San Andres Lagoon, Tamaulipas

Metal	Sampling site				
	1	2	3	4	5
Cd	2.31 ± 0.18	2.25 ± 0.15	2.25 ± 0.15	2.21 ± 0.24	2.33 ± 0.20
Pb	0.85 ± 0.10	0.86 ± 0.09	0.73 ± 0.09	0.77 ± 0.08	0.80 ± 0.10
Zn	3.19 ± 0.13	3.10 ± 0.13	3.14 ± 0.06	3.00 ± 0.19	3.07 ± 0.13

n = 24

industrial discharges in the lagoon. However, sewage disposal could be another important source of Zn contamination (Basaham et al. 2009).

Cadmium concentrations in sediment and oyster tissue did not show significant differences between sites (Tables 2 and 3). On the other hand, the mean Pb levels in sediment were significantly lower in site 4, whereas the remaining sites were not significantly different from each other (Table 3). Oysters from sites 1 and 2 had significantly highest tissue Pb concentration, while the lowest Pb levels were observed in oysters from site 3 (Table 2). Pb levels in sediments of San Andres Lagoon were lower than those reported for other coastal lagoons from the Southern Gulf of Mexico, where concentration of lead ranged from 3.34 μg g^{-1} (Mandinga Lagoon in Veracruz) to 158.68 μg g^{-1} (Ilusiones Lagoon in Tabasco) (Villanueva and Botello 1992).

Zinc levels in sediment and oyster tissue were significantly higher ($p < 0.05$) at site 1 and lower at site 4 (Tables 2 and 3). Zn values in sediment (8.37–9.29 μg g^{-1}) were higher than those of water (4.65–5.00 mg L^{-1}) and oyster tissue (3.00–3.19 μg g^{-1}). This pattern is opposite to that reported for other coastal lagoons from the Gulf of Mexico where concentration of Zn in oyster tissue was higher that in sediment (Marín-Mézquita et al. 1997) indicating higher metal bioaccumulation in oysters and probably higher contamination levels in these ecosystems.

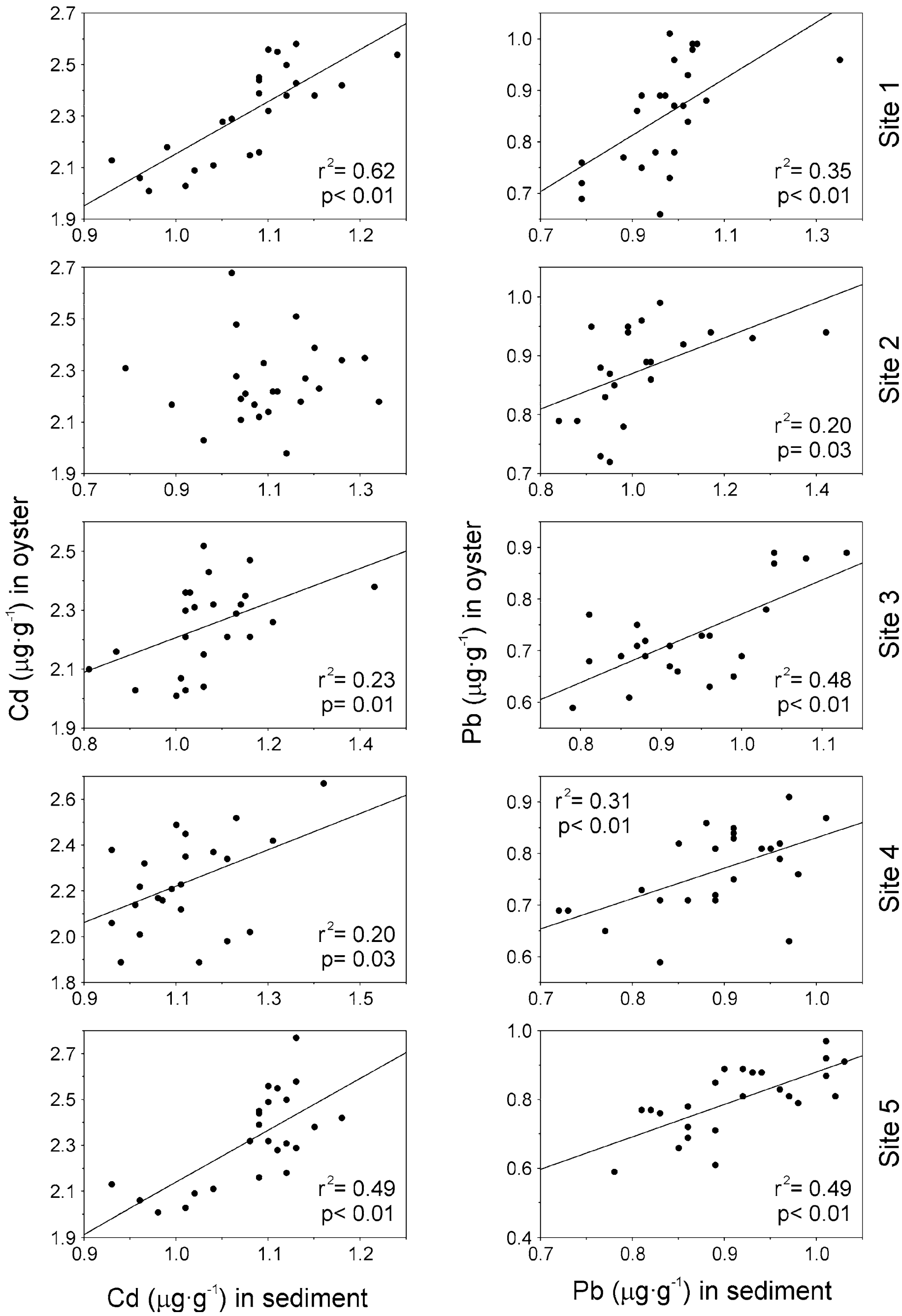
Concentrations of Cd, Pb and Zn in *C. virginica* were lower than those observed in *C. corteziensis*, an oyster of the Mexican Pacific coast, where metal tissue concentrations are up to 7.45 μg g^{-1}, 9.49 μg g^{-1} and 2,304 μg g^{-1} for Cd, Pb and Zn, respectively (Frías-Espericueta et al. 2009). In previous surveys in San Andres Lagoon (Vazquez et al. 1990) conducted 15 years before our study, the levels of Pb and Zn observed in *C. virginica* were 5.81 and 3,120 mg kg^{-1}, respectively, which were much higher than our findings (Table 3, Fig. 2). This suggests that the rate of bioaccumulation of Pb and Zn in oysters has decreased notably between 1985 and 2000. Furthermore, metal concentrations previously reported for water (1.38 mg kg^{-1} Pb, 5.12 mg kg^{-1} Zn) and sediment (11.8 mg kg^{-1} Pb, 10.1 mg kg^{-1} Zn) in this coastal lagoon (Vazquez et al. 1994) were also higher than those found in our study. Differences with respect to the previous studies may be attributable to the fact that our sampling was carried out after dredging and reopening of the Chavarria inlet, whereas the previous studies were performed when the inlet was semi-closed.

Significant positive relationships were observed between heavy metal levels (particularly Cd and Pb) in sediment and oyster tissue (Fig. 2). This pattern was observed in all sampling sites along the lagoon, excepting site 2 for Cd, which might imply that sediments are a major source of cadmium and lead to *C. virginica*. Similar results have been observed for other marine bivalves where metal concentrations in tissue are related to metal concentrations in sediments (de Astudillo et al. 2005); this is due to the ingestion of sediment particles by filter-feeding mollusks, which is an important mechanism for incorporation of metals into the oysters (Chapman 2002). On the other hand, the Cd concentration in *C. virginica* was significantly higher than in water and sediment indicating that the oyster is capable of accumulating this metal.

No relationships were observed between zinc levels in sediment and oyster tissue. This could be because zinc is an essential metal involved in physiological processes of invertebrates (Nieboer and Richardson 1980), thus it can be regulated by the oyster itself. In contrast, Cd and Pb are xenobiotic metals that tend to accumulate in organisms through bioaccumulation from water or food (Apeti et al. 2005).

It should be noted that metal concentrations in sediments were below established limits (ERL: effects range-low)

Fig. 2 Linear relation between heavy metal (Cd and Pb) levels in sediment (X) and oyster tissue (Y) at different sampling sites



where possible adverse biological effects can be expected (Long et al. 1995). According to these authors, ERL guideline values for Cd, Pb, and Zn are 1.2, 46.7 and 150 ppm (dry weight), respectively, which suggests that metal concentrations in the sediments of San Andres Lagoon would rarely be associated with adverse biological effects.

Acknowledgments We thank Government of Tamaulipas (Dirección de Desarrollo Pesquero) and fishermen from El Moron and Las Flores for field assistance. We also thank the staff at Laboratorio Ambiental Tamaulipas for their help with laboratory analyses.

References

Angino EE, Magnuson LM, Waugh TC, Galle OK, Bredfeldt J (1970) Arsenic in detergents: possible danger and pollution hazard. Science 168:389–390

Apeti DA, Johnson E, Robinson L (2005) Model for bioaccumulation of metals in *Crassostrea virginica* from Apalachicola Bay, Florida. Am J Environ Sci 1:239–248

Basaham AS, Rifaat AE, El-Mamoney MH, El-Sayed MA (2009) Re-evaluation of the impact of sewage disposal on coastal sediments of the Southern Corniche, Jeddah, Saudi Arabia. J King Abdulaziz Univ Mar Sci 20:109–126

Bjerregaard P, Andersen O (2007) Ecotoxicology of metals—sources, transport, and effects in the ecosystem 251–280. In: Nordberg GF,

Fowler BA, Nordberg M, Friberg L (eds) Handbook on the toxicology of metals. Academic Press, San Diego, p 1024
Chapman PM (2002) Integrating toxicology and ecology: putting the "eco" intoecotoxicology. Mar Pollut Bull 44:7–15
de Astudillo LR, Yen IC, Bekele I (2005) Heavy metals in sediments, mussels and oysters from Trinidad and Venezuela. Rev Biol Trop 53:41–53
Förstner U, Wittmann GTW (1979) Metal pollution in the aquatic environment. Springer, New York
Frías-Espericueta MG, Osuna-López I, Bañuelos-Vargas I, López-López G, Muy-Rangel MD, Izaguirre-Fierro G, Rubio-Carrasco W, Meza-Guerrero PC, Voltolina D (2009) Cadmium, copper, lead and zinc contents of the mangrove oyster, *Crassostrea corteziensis*, of seven coastal lagoons of NW Mexico. Bull Environ Contam Toxicol 83:595–599
Hohl H, Varma A (2009) Soil: the living matrix. In: Sherameti I, Varma A (eds) Soil heavy metals. Springer-Verlag, Berlin Heidelberg, p 492
Jaffé R, Leal I, Alvarado J, Gardinali P, Sericanos J (1995) Pollution effects of the Tuy River on the central Venezuelan Coast: antropogenic organic compounds and heavy metals in *Tivela mactroides*. Mar Pollut Bull 30:820–825
Kjerfve B (1994) Coastal lagoon processes. Elsevier oceanography series 60. Elsevier Science, Amsterdam, p 598
Long ER, Mcdonald D, Smith SI, Calder FD (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ Manage 19:81–97
Marín-Mézquita L, Baeza L, Zapata-Perez O, Gold-Bouchot G (1997) Trace metals in the American oysters, *Crassostrea virginica*, and sediments from the coastal lagoons Mecoacan, Carmen and Machona, Tabasco, Mexico. Chemosphere 34:2437–2450
Nieboer E, Richardson DHS (1980) The replacement of the nondescript term 'heavy metals' by a biologically and chemically significant classification of metal ions. Environ Pollut Bull 1:3–26
Samyappan K, Kumaar PS, Sarojini N (2007) Effect of heavy metal copper on the nutritive value in a freshwater field crab, *Spiralothelphusa hydrodroma*. Res J Agr Biol Sci 3:775–781
Simpson JH (1994) Introduction to the North Sea project. In: Charnock H, Dyner KR, Hurthnance JM, Liss PC, Simpson JS, Tett PB (eds) Understanding the North Sea system. Chapman & Hall, London, p 222
Vazquez F, Aguilera G, Delgado D, Márquez A (1990) Trace and heavy metals in the Oyster *Crassostrea virginica*, San Andres Lagoon, Tamaulipas, Mexico. Bull Environ Contam Toxicol 45:907–914
Vazquez FG, Aguilera LG, Sharma VK (1994) Metals in sediments of San Andres Lagoon, Tamaulipas, Mexico. Bull Environ Contam Toxicol 52:382–387
Villanueva FS, Botello AV (1992) Metales pesados en la zona costera del Golfo de México y Caribe Mexicano: una revisión. Rev Int Contam Ambient 8:47–61
Wright DA, Welbourn P (2001) Environmental toxicology. Cambridge University Press, New York