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Metals in Shrimp Farm Sediments, Sinaloa, Northwest Mexico

M. G. Frías-Espericueta,[1] J. I. Osuna-López,[1] D. Voltolina,[2]
E. M. Correa-González,[1] M. J. Armenta-Monje,[1] G. López-López,[1]
G. Izaguirre-Fierro[1]

[1] Environmental Studies Laboratory, Faculty of Marine Sciences, Autonomous University of Sinaloa, Post Office Box 1132, Mazatlán 82000, Sinaloa, Mexico
[2] Center of Biological Research of the Northwest, Environmental Studies Laboratory UAS-CIBNOR, Post Office Box 1132, Mazatlán 82000, Sinaloa, Mexico

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In 1985, the Mexican production of cultured shrimp was 200 tons, that by 2003 had increased to >50,000 tons produced mainly in coastal areas of the NW states of Sinaloa and Sonora, where it is an important component of the local economy (Miranda-Baeza et al. 2007). These farms are located close to estuaries or along the edges of coastal lagoons, which are their main water sources. This is of concern, because Soto-Jimenez et al. (2003) found evidence of important anthropogenic inputs of metals into one coastal lagoon in Sinaloa, and Frías-Espericueta et al. (2005) observed measurable metal concentrations in the shrimp muscles from some coastal lagoons of the Mexican NW.

Sediments act as traps for the metals introduced into the aquatic environment, and therefore are good indicators of metal pollution (Buchman 1989). However, there is no information on the sediments of Mexican shrimp farms. The purpose of this study was to assess the concentration of five metals (Cd, Cu, Ni, Pb and Zn) in the surface sediments of nine semi-intensive shrimp farms of Sinaloa.

MATERIALS AND METHODS

Five of the farms selected are located in the central part of Sinaloa and four are in the southern part (Fig. 1). Three ponds (≈5 ha) were chosen as representative of each farm because of their historic yield records (highest, average and lowest), and 6 sediment samples were obtained along each of three transects (left, center, right) of each pond.

The samples were obtained from the upper 5 cm layer of soil (Boyd et al. 1994), which is more active biologically and chemically, and has the strongest influence on water quality and associated biota, because most of the exchanges between sediments and water occur in this layer (Munsiri et al. 1995). All materials used for sampling and sample treatments were acid-washed as in Moody and Lindstrom (1977).

The samples were kept in coolers at 4°C until arrival to the laboratory, where each

Correspondence to: M. G. Frías-Espericueta

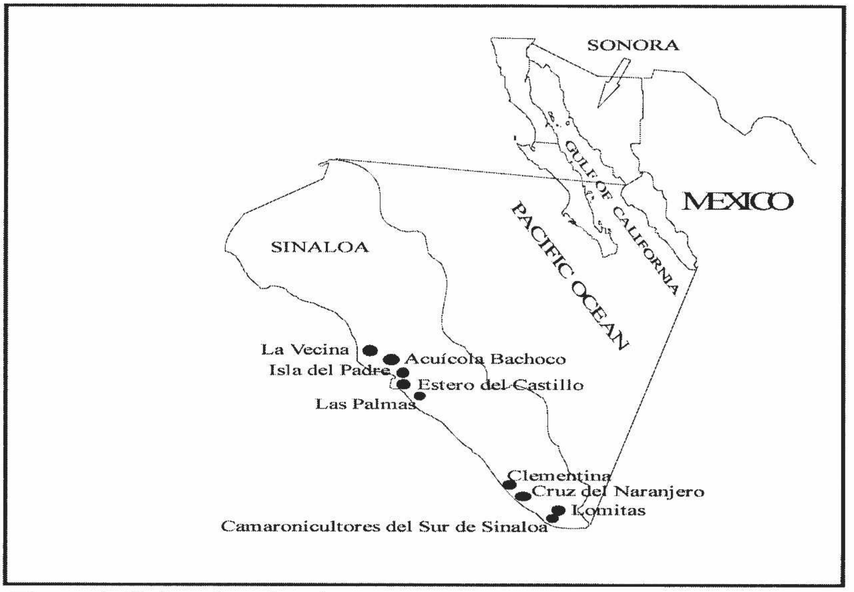

Figure 1. Shrimp farm locations.

sample was oven-dried (70°C), finely ground and combined with those from the same transect to yield one composite sample, for a total of three samples/pond and nine samples/farm.

Organic matter was measured with the Walkey-Black titration (Walkey 1947), and Cd, Cu, Ni, Pb and Zn concentrations were obtained with the standard additions method (Green-Ruiz and Páez-Osuna 2003): triplicate subsamples (two added with different known quantities of each metal) were digested with a concentrated nitric/hydrochloric acid mixture (3:1 v/v) (Breder 1982), slowly evaporated to dryness (90°C) and redissolved in 2M nitric acid. After this treatment, the samples were centrifuged and the concentrations at the five metals were determined in the liquid fraction by flame atomic absorption spectrophotometry.

The accuracy and precision of the method were evaluated using sediment homogenate BCSS-1 as reference material (UNEP 1995), that gave percentages of recovery within 87 and 108%. All data were normal and homoscedastic (Lilliefors' and Bartlett's tests). Therefore, the mean concentrations (as μg/g on a dry weight basis) of the transects of each pond were compared to those of the other ponds of the same farm by one-way analysis of variance, and the mean values of the nine farms were compared with the same test separating the significant differences with Tukey's multiple comparison tests (Zar, 1996).

RESULTS AND DISCUSSION

The differences among the three ponds of each farm were not significant ($p>0.05$) implying that, within the values obtained in this work, there is no relation between the historic yield records of each pond and the total metal content of its sediment. The mean values calculated for each farm and the results of their statistical comparisons are given in Table 1, which shows a general tendency to higher values in the farms of central Sinaloa.

When the organic content of the sediment is in excess, it may affect water quality and shrimp growth. All the values observed were below the upper limit of 10% (Boyd et al. 1994), but the organic contents of the two northernmost farms were close to that limit. All values of the central area were significantly higher than those of the southern farms.

The lowest metal concentrations were those of Cd, followed in progressively increasing order by Ni, Cu, Pb and Zn. Only the sediment of one farm (Cruz del Naranjero) had Cd values slightly higher than the maximum level of 1 µg/g for sediments mentioned by Buchman (1989), but this value was not significantly different from those of the rest of the farms, with the exception of the southernmost "Lomitas" farm, indicating that the most probable source of this metal are the weathered alluvial soils of the Sinaloa coastal plains.

The mean concentrations of Ni ranged from 6.08 to 12.35 µg/g, within the range of 7.50 µg/g mentioned by Merian (1991) for non-contaminated soils. As for all metals, the southernmost farm had the lowest value and those of the central region had significantly higher Ni concentrations than those of the southern part.

Only the farm "Las Palmas" had Cu and Zn values close or higher than the respective limits of 25 and 100 µg/g (Buchman 1989). This farm is located in soils of the Culiacán River deltaic system, that receives the drains of close to 330,000 ha of agricultural land, most of which is highly mechanized, intensively irrigated and with high rates of Cu and Zn-rich fungicide (©cupravit and ©zineb: Frías-Espericueta et al. 2004), as well as pesticide treatments (González-Farías et al. 2006).

All farms had Pb values above the permissible 10 µg/g, with means ranging from 10.8 µg/g in the "Camaronic. de Sinaloa" farm to the 31 µg/g determined in "Las Palmas". Vehicle emissions from the cities and the surrounding agricultural lands are the most probable source of Pb, since tetraethyl Pb was used until recent years as anti-knock agent in Mexican gasoline (Green-Ruiz and Páez-Osuna 2003). This is of ecological concern, because Pb accumulated by shrimps could induce pathological disorders in the shrimp itself, as well as in its consumers.

OM has a strong affinity for metals (Lin and Chen 1998). Therefore, a high content of OM in sediments may cause an increase of their metal content, that was confirmed by the significant positive correlations between OM and Cu, Ni ($p<0.05$) and in part Zn ($p<0.1$), but not for Cd and Pb (Table 2). The good, correlations between several metals indicate a common source of sediment enrichment with these metals.

Table 1. Mean concentrations of organic matter (OM in %) and of metals (μg/g, dry weight) in the surface sediments of nine semi-intensive shrimp farms of Sinaloa, NW Mexico.

Farm	OM	Cd	Ni	Cu	Zn	Pb
La Vecina	7.1cd (1.4)	0.7b (0.2)	11.0c (1.3)	19.5de (3.1)	60.3b (8.2)	25.4cd (2.7)
Acuícola Bachoco	8.1d (1.0)	0.9b (0.1)	10.7c (0.9)	17.1cd (2.8)	52.8b (3.6)	16.1ab (4.9)
Isla del Padre	6.4c (1.1)	0.6b (0.1)	11.2c (1.0)	18.8d (2.3)	54.1b (9.3)	19.4bc (5.2)
Estero del Castillo	6.5c (0.6)	0.7b (0.3)	12.0c (0.9)	19.4d (1.9)	58.4b (5.4)	19.5bc (3.9)
Las Palmas	4.2b (0.4)	0.9b (0.3)	12.4c (0.9)	22.2e (1.7)	103.7d (11.1)	31.0d (3.6)
Clementina	1.8a (1.2)	0.8b (0.2)	8.3b (2.1)	10.1ab (2.5)	36.8a (6.9)	20.7b (5.6)
Cruz del Naranjero	1.5a (0.4)	1.1b (0.8)	7.4ab (0.9)	14.7c (2.7)	73.1c (13.8)	29.9d (4.1)
Camaronic. de Sinaloa	2.7a (0.7)	0.5b (0.1)	7.6ab (1.6)	10.7b (2.1)	38.0a (13.6)	10.8a (1.8)
Lomitas	1.4a (0.3)	0.3a (0.2)	6.1a (1.5)	7.2a (0.9)	32.9a (4.3)	12.8a (5.1)

Standard deviations in parenthesis. Different letters indicate significant differences (one-way ANOVA, $\alpha = 0.05$); a≤ab≤b and a<b.

This is possibly due to their close association with the Ag and Au ores that are exploited in the mining districts of Cosalá and Mocorito (Central Sinaloa) and Mazatlán and Concordia (southern Sinaloa), which lie in the respective catchment areas of the Culiacán and Presidio Rivers systems. This would seem confirmed by the high values of Zn, Pb and Cu of the "Las Palmas" and "Cruz del Naranjero" farms, that are located in the respective deltaic soils of these rivers.

The nature of the Mexican soils, such as the lateritic soils of the Pacific coastal plains, and their weathering and erosion have been recognized as the most important metal sources of Mexican natural systems, although human activities may be equally important in agricultural areas, such as those of concerned by this study (Páez-Osuna, 1999).

Table 2. Correlation matrix between OM and metal concentrations in the surface sediments of nine shrimp farms of Sinaloa, NW Mexico. n=81

	OM	Cd	Cu	Ni	Pb	Zn
OM	--					
Cd	0.0126	--				
Cu	0.6721*	0.2045^{+}	--			
Ni	0.7370*	0.1775	0.8513 *	--		
Pb	0.0249	0.4057*	0.5027 *	0.3569*	--	
Zn	0.1903^{+}	0.3012*	0.7611 *	0.5581*	0.6841 *	--

* significant ($p<0.05$); $^{+}$ $p<0.1$.

In comparison to other Latin American shrimp farms, our results show higher Cd and Pb values, while Cu and Zn are intermediate between the data by Carbonell et al. (1998) and those by Sonnenholzner and Boyd (2000) (Table 3). However, we measured the total metals present in sediments, whereas the results of the latter of these studies concern the weak-acid extractable fraction, because this is supposed to be bioavailable to bottom-dwelling organisms such as shrimp and their natural food (Sonnenholzner and Boyd 2000).

Table 3. Metals (μg/g, dry weight) in sediments of Latin American shrimp farms.

Site	Cd	Cu	Pb	Zn	Reference
Nicaragua	0.07±0.02	42.2±7.8	6.8±3.3	90.5±6.4	Carbonell et al. (1998)
Honduras	0.06±0.02	38.8±6.6	7.9±2.4	86.8±15	Carbonell et al. (1998)
Ecuador		6.4±5	4.1±2.5	9.5±4.3	Sonnenholzner and Boyd (2000)
Sinaloa, Mexico	0.82±0.3	14.9±5.6	19.6±7	56.3±21	Present study

According to our results, it seems desirable to continue this line of research, because of the >750 farms in operation in the states of Sinaloa and Sonora, with estimated landings of close to 95,000 ton harvested in 2005 in 43,500 ha of shrimp farms, most of which located close to agriculture areas and to basins.

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