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Lead in clams and fish of dietary importance from Coatzacoalcos estuary (Gulf of Mexico), an industrialized tropical region

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Abstract With the aim of knowing seasonal variability of lead in fish and bivalve species from Coatzacoalcos estuary, biota collected during three seasons was examined. In muscle tissue of fish, the highest level (5.4 μg g^{-1}) was found in the longnose gar *Lepisosteus osseus* from San Francisco stream (a highly impacted site); the lowest value (0.2 μg g^{-1}) was registered in yellowfin mojarra *Gerres cinereus* from Ostión lagoon (control site). In bivalves, concentrations in soft tissue ranged from 1.5 μg g^{-1} in *Polymesoda caroliniana* from Calzadas river, to 0.1 μg g^{-1} in *Corbicula fluminea* from Hidalgotitlán (control site).

Keywords Lead · Fish · Clams · Coatzacoalcos estuary

Industrial development associated to a rapid population growth has resulted in a severe stress on the environmental quality of diverse aquatic systems like coastal lagoons, bays and estuaries. On the basis of the elevated productivity of estuaries, human settlements have proliferated worldwide around them; on the other hand, estuaries characteristics as water supply, sites for effluent disposal and ease for product transportation make them suitable for the establishment of diverse industries. It has been widely documented that trace metals occur naturally in the environment (Forstner and Wittmann 1979); however, anthropogenic activities mobilize them in such a high extent that their supply is higher than from natural sources. In the specific case of Pb, it has been estimated that the ratio of anthropogenic to natural emission rates is about 17 (Nriagu and Pacyna 1988). Facilities related to petrochemical manufacture may cause significant inputs of heavy metals due to effluent discharges (Croudace and Cundy 1995); within this context, biota from impacted estuaries might accumulate trace metals amounts that could reach levels above safe limits and constitute health risks. Depending on the season, the Coatzacoalcos estuary may reach up to 40 km upstream; nevertheless, the lower Coatzacoalcos river has been highly industrialized since the 1970s and currently accounts for 65 petrochemical plants that produce more than 15 million tons of petrochemical products (Rosales-Hoz et al. 2003a, b). Therefore, in this paper the seasonal variability of lead in a variety of fish and bivalve species from the industrialized part of the Coatzacoalcos estuary was examined.

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Materials and Methods

The portion of the Coatzacoalcos river where samples were collected is located at 17°46′ and 18°10′ N, and 94°25′ and 94°31′ W (Fig. 1). The Coatzacoalcos estuary has an estimated length of 45 km. In the upper estuary, width and depth reach 213 and 18 m, respectively; in the river mouth, width and depth reach 530 and 11 m, respectively (Rosales-Hoz et al. 2003a, b). In the course of the main water body, several rivers discharge their waters, contributing to the load of contaminants to the estuary:Coachapa river, Uxpanapa river, San Francisco stream, Calzada river, and Teapa stream.

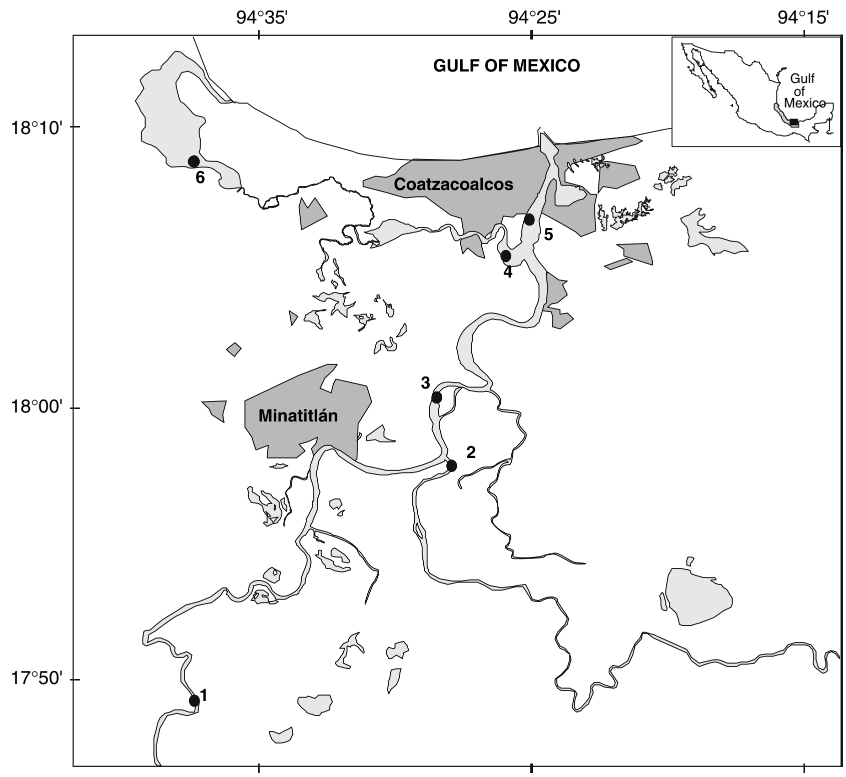

Fig. 1 Location of sampling sites in the Coatzacoalcos estuary (*1* Hidalgotitlán, *2* Uxpanapa river, *3* San Francisco stream, *4* Calzadas river, *5* Coatzacoalcos river, *6* Ostión lagoon)

The weather of the area is classified as Am(i) g (hot and humid with summer rains), with an average temperature of 24°C (Báez et al. 1975). Three defined seasons are encountered in the region:from June to September heavy rains occur in the catchment area; from October to February strong winds from the north ("Nortes") are frequent; the hot season ranges from March to April and saline waters can be detected 40 km upstream. Because of the proximity of the study area to the major oil resources in the Gulf of Mexico, industrial development has occurred in the past 40 years. Currently, it is considered that the most important industrial centers in Mexico are located in this area. As a major petrochemical production center, it is regarded as the most polluted coastal area in Mexico (Botello and Páez-Osuna 1987). Sampling was carried out between May 2005 and January 2006. The sites where specimens were collected covered selected stations along the Coatzacoalcos estuary, from the mouth and up to the cities of Coatzacoalcos (pop. 267,000) and Minatitlán (pop. 153,000) (INEGI 2005); in order to contrast results, bivalve specimens from a less impacted area upstream (sampling site 1) and some fish species (sampling site 6) were also collected (Fig. 1). In order to avoid contamination of samples, glassware and other plastic utensils were previously washed according to Moody and Lindstrom (1977). Fish samples were collected by local fishermen; depending on availability, bivalve molluscs were collected by hand during low tide in selected areas of the Coatzacoalcos estuary. Biological information of collected specimens is provided in Table 1. After taxonomic identification of organisms, soft tissue of bivalves was separated from the shells; in relation to fish, muscle, gills and liver were separated for the analyses. Samples were freeze-dried for 72 h (–49°C and 133×10^{-3} mBar) then ground in an agate mortar.

Powdered samples were acid digested (5 ml of quartz distilled concentrated nitric acid) using teflon vials with caps (Savillex) at 120°C for 3 h (MESL 1997). Digested samples were stored in polyethylene containers for further analysis. Two aliquots of each tissue were analyzed. Analyses of Pb were made by graphite furnace atomic absorption spectrophotometry (GFAAS) in a Varian SpectrAA220 equipment (Rothery 1988). Precision and accuracy of the analytical method were assessed by using reference material MA-B-3/TM (IAEA 1987); a satisfactory agreement between the analytical results and the certified values was obtained. Blanks were run with every batch of eleven samples. Significant differences ($p < 0.05$) of lead concentrations among specimens from the different seasons were defined by a one-way ANOVA and a Bonferroni-post test using GraphPad Prism 4.0 (Graph Pad Software, San Diego, CA, USA).

Results and Discussion

Lead concentrations (μg g^{-1} dry weight) of collected specimens are provided in Table 2. In relation to fish, it can

Table 1 Biological information (means ± SD) of collected fish and clams from Coatzacoalcos estuary (Gulf of Mexico)

Common name	Species	Habitat	Site (N)	Date	Weight (g)	Length (cm)
Fish						
White stardrum	*Stellifer fuerthii*	M	2(9)	05/2005	43 ± 21	20 ± 3
Tilapia	*Oreochromis* sp	F, E	2(7)	05/2005	76 ± 32	19 ± 2
Finescale sleeper	*Gobiomorus polylepis*	M, E	2(7)	05/2005	133 ± 70	31 ± 7
Yellowfin mojarra	*Gerres cinereus*	M	2(4)	05/2005	49 ± 19	20 ± 3
Largehead hairtail	*Thrichurus nitens*	E	5(6)	05/2005	328 ± 97	96 ± 8
White snook	*Centropomus viridis*	E	2(5*)	05/2005	880 ± 244	58 ± 8
Tilapia	*Oreochromis* sp	F, E	1(8)	05/2005	116 ± 9	23 ± 1
Longnose gar	*Lepisosteus osseus*	F	3(6*)	05/2005	578 ± 179	61 ± 6
Cichlid	*Cichlasoma* sp	F	2(6)	05/2005	17 ± 5	12 ± 1
White snook	*Centropomus viridis*	E	6(5*)	09/2005	327 ± 25	37 ± 1
White snook	*C. viridis*	E	4(7*)	09/2005	437 ± 44	37 ± 3
Finescale Sleeper	*Gobiomorus polylepis*	M, E	2(8)	09/2005	206 ± 78	29 ± 4
Tilapia	*Oreochromis* sp	F, E	2(10)	09/2005	415 ± 9	27 ± 1
Yellowfin mojarra	*Gerres cinereus*	M	2(10)	09/2005	184 ± 60	23 ± 3
Yellowfin mojarra	*G. cinereus*	M	6(4)	09/2005	140 ± 41	21 ± 3
White snook	*Centropomus viridis*	E	2(5*)	01/2006	846 ± 434	46 ± 8
Catfish	*Ictalurus punctatus*	E, F	1(6*)	01/2006	508 ± 153	36 ± 3
Longnose gar	*Lepisosteus osseus*	F	1(5*)	01/2006	411 ± 75	43 ± 3
Finesclae sleeper	*Gobiomorus polylepis*	M, E	5(4)	01/2006	377 ± 185	32 ± 5
White mullet	*Mugil curema*	E	2(4)	01/2006	301 ± 55	32 ± 4
Clams						
Asiatic clam	*Corbicula fluminea*	F	1(6)	05/2005	3 ± 2	2 ± 0.3
Carolina marsh clam	*Polymesoda caroliniana*	F	4 7)	05/2005	19 ± 5	4 ± 0.3
Carolina marsh clam	*Polymesoda caroliniana*	F	4(7)	09/2005	47 ± 16	5 ± 0.5
Carolina marsh clam	*Polymesoda caroliniana*	F	4(7)	01/2006	47 ± 20	4 ± 0.8

* Individual samples; *E* estuarine waters, *F* freshwaters, *M* marine waters (Fischer et al. 1995a, b)

be seen that, with the exception of *Centropomus viridis* and *Gobiomorus polylepis*, specimens from the different seasons did not belong to the same species. In tropical and subtropical latitudes, intraspecific comparisons are sometimes difficult to achieve given the fact that species diversity is higher than in temperate regions. In this sense, Rainbow and Phillips (1991) suggest that metal concentrations be compared directly between organisms of the same species; but comparisons of interspecific data may still be undertaken. Concerning bivalves, the Carolina marsh clam *Polymesoda caroliniana* was collected in a single site during the three sampling periods; the other bivalve, the Asiatic clam *Corbicula fluminea* was only available during the hot season in the upper estuary (Hidalgotitlán-control site).

Lead concentrations (in µg g^{-1} dry weight) ranged by a magnitude order in analyzed biota. In fish, the sequence of metal concentration was muscle > gills > liver. In muscle, the highest level (5.4) was found in the longnose gar *Lepisosteus osseus* from San Francisco stream (a highly impacted site by an oil refinery), contrastly, the lowest value (0.2) was registered in the yellowfin mojarra *Gerres cinereus* from Ostión lagoon (control site); in gills, lead varied from 3.5 in *G. cinereus* to 0.5 in tilapia *Oreochromis sp*. from Uxpanapa river; in liver, lead concentrations were higher (2.1) in the catfish *Ictalurus punctatus* and the white snook *Centropomus viridis* from Hidalgotitlán and Ostión lagoon (control sites), the lowest value (0.4) was found in *Cichlasoma sp*. from Uxpanapa river (Table 2).

In a study with *Gerres sp*. from Coatzacoalcos estuary, Pérez-Zapata et al. (1984) detected 2.8 µg g^{-1} in muscle, while in the present research lead concentrations reached 4.1 µg g^{-1} in muscle of *Gerres cinereus*.

In another study with fish *Lutjanus analis* from an oil and gas platform area in the Campeche Sound (Gulf of Mexico), Vázquez et al. (2001) recorded an average lead concentration of 4.68 µg g^{-1} in muscle tissue. The referred values and the current results give the idea that the Coatzacoalcos estuary area is impacted by industrial activities; in this sense, Rosales-Hoz et al. (2003a, b) concluded that following intensive industrialization of the Coatzacoalcos river, estuarine sediments show elevated concentration of

Table 2 Lead concentrations (means ± standard deviation, in μg g^{-1} dry weight) in fish and clams from Coatzacoalcos estuary (Gulf of Mexico)

Species	Site	Date	Muscle	Gills	Liver
Fish					
Stellifer fuerthii	2	05/2005	1.7 ± 1.8	1.1 ± 0.3	1.8 ± 2.2
Oreochromis sp	2	05/2005	1.0 ± 0.1^{g}	0.5 ± 0.1	<DL
Gobiomorus polylepis	2	05/2005	1.5 ± 0.7	2.2 ± 0.8	0.7 ± 0.3^{d}
Gerres cinereus	2	05/2005	4.1 ± 3.0	2.3 ± 0.9	NA
Thrichurus nitens	5	05/2005	3.7 ± 1.3	1.9 ± 1.1	1.8 ± 0.8
Centropomus viridis	2	05/2005	3.9 ± 3.7	<DL^{e}	1.1 ± 0.5
Oreochromis sp	1	05/2005	4.9 ± 2.4^{f}	0.9 ± 0.2	<DL
Lepisosteus osseus	3	05/2005	5.4 ± 3.1	0.6 ± 0.1	0.9 ± 0.4
Cichlasoma sp	2	05/2005	4.6 ± 1.3	1.1 ± 0.3	0.4 ± 0.3
Centropomus viridis	6	09/2005	1.8 ± 0.7	1.1 ± 0.2^{f}	2.1 ± 1.0
C. viridis	4	09/2005	1.6 ± 0.9	1.2 ± 0.2^{f}	1.8 ± 0.8
Gobiomorus polylepis	2	09/2005	1.5 ± 0.6	2.4 ± 0.2	1.7 ± 0.4^{c}
Oreochromis sp	2	09/2005	1.0 ± 0.7^{g}	1.6 ± 0.4	1.2 ± 6.1
Gerres cinereus	2	09/2005	1.0 ± 1.0	3.5 ± 2.8	0.9 ± 0.2
G. cinereus	6	09/2005	0.2 ± 0.1	1.4 ± 0.2	0.9 ± 0.2
Centropomus viridis	2	01/2006	<DL	1.4 ± 0.5^{f}	1.3 ± 0.6
Ictalurus punctatus	1	01/2006	<DL	0.6 ± 0.4	2.1 ± 1.1
Lepisosteus osseus	1	01/2006	1.0 ± 0.1	0.6 ± 0.3	0.6 ± 0.2
Gobiomorus polylepis	5	01/2006	1.3 ± 0.2	1.6 ± 0.7	<DL^{d}
Mugil curema	2	01/2006	2.1 ± 1.1	2.0 ± 0.5	1.1 ± 0.2
Clams					
Corbicula fluminea	1	05/2005	0.1 ± 0.003*^{b}	–	–
Polymesoda caroliniana	4	05/2005	1.5 ± 0.5*^{a}	–	–
P. caroliniana	4	09/2005	0.6 ± 0.3*^{b}	–	–
P. caroliniana	4	01/2006	0.6 ± 0.1*^{b}	–	–

*Soft tissue; *NA* not available; detection limit (DL) 0.0014 μg g^{-1}; with the exception of clams, for a given tissue within the same species, different letters denote significant differences ($p < 0.05$)

a range of metals (including lead), compared with sediments upstream of the industrialized area.

In bivalves, lead concentrations in soft tissue ranged from 1.5 μg g^{-1} in *Polymesoda caroliniana* from Calzadas river, to 0.1 μg g^{-1} in *Corbicula fluminea* from Hidalgotitlán (control site). In a study with the oyster *Crassostrea virginica* from Mandinga (an impacted site with industrial discharges) and Tampamachoco lagoons (Gulf of Mexico), Rosas et al. (1983) recorded 3.03 and 1.86 μg g^{-1}, respectively; it can be seen that in comparison to the highest value in *P. caroliniana* (present study), lead concentrations are of the same magnitude order.

Meteorological and hydrographic conditions as well as industrial activity in the studied estuary are not stable, as a consequence, levels of metals in environmental compartments are variable; additionally, lead concentrations in fish could also be explained by ecological factors as their habitat preferences (i.e. marine, estuarine and freshwaters species) that leads fish species to migrate seasonally within the estuary. During the rainy season, freshwater species occur in a wider area of the estuary; on the contrary, in the dry season, marine and estuarine species are better represented in the estuary. In Coatzacoalcos estuary, polluted as well as moderately polluted sites are encountered; consequently, studied fish accumulate and depurate Pb. Though tissues depurate at different rates, depuration rate of whole fish is inversely proportional to the body size (Maiti and Banerjee 2005). In this context, it was observed that in *Lepisosteus osseus*, high amounts of epidermal mucus were evident during dissection of specimens; it may constitute an indication of lead depuration. Varanasi and Markey (1978) found that in salmonids, epidermal mucus may play an important role in excretion of lead and cadmium.

It has been documented that lead concentrations in surficial sediments from Coatzacoalcos estuary change throughout the year, highest levels were recorded during the dry season (Bahena-Manjarrez et al. 2002). In the present study, two fish species (the white snook *Centropomus viridis* and the finescale sleeper *Gobiomorus* *polylepis*) and one clam species (the Carolina marsh clam *Polymesoda caroliniana*) were collected during the three seasons. Lead concentrations in the soft tissue of clams and muscle tissue of fish showed a declining pattern, being the dry season the time when highest levels were recorded. In this sense, Rosales-Hoz et al. (2003a, b) concluded that levels of Zn, Cu and Cr in waters of Coatzacoalcos estuary are higher during the dry season (April) when dilution is minimal and low levels of TOC are present. Statistical analyses defined significant differences in average lead concentrations with time, in the clam *P. caroliniana*, metal concentration during the dry season was significantly ($p < 0.05$) higher than in *P. caroliniana* of the rest of the sampled periods and *Corbicula fluminea* from the control site during the dry season. While *P. caroliniana* from the second and third sampling period were practically the same weight (47 g) and showed the same lead concentration (0.6 μg g^{-1}); in specimens (19 g) from the first sampling period, lead concentration raised to 1.5 μg g^{-1}. Apparently, this is a consequence of tissue dilution, though physiological differences could also account for such behaviour. Concerning liver of fish *Gobiomorus polylepis*, lead concentration during the rainy season was significantly ($p < 0.05$) higher than in the other sampling periods. In relation to gills of *Centropomus viridis*, lead values were significantly ($p < 0.05$) lower during the dry season than the rest of the sampling periods and control site.

Legal limits for human consumption in fresh fish (NOM-027-SSA1-1993) and clams (NOM-031-SSA1-1993) in Mexico is 1.0 ppm (fresh weight), if a 75% humid content is considered for analyzed species, values above limits were recorded in muscle tissue of four fish species and none of the clams. It is worth mentioning that lead values above legal limits were recorded only during the dry season (Table 2). Studies in biota with lead concentrations above safe limits for human consumption in the Gulf of Mexico are scarce; in fish, elevated concentrations were reported in muscle of *Lutjanus analis* (4.68 μg g^{-1}) and gonada of *Syacium gunteri* (5.2 μg g^{-1}) from the Campeche Sound (Vázquez et al. 2001). In bivalves, lead concentrations above legal limits were recorded in the soft tissue of the oyster *Crassostrea virginica* from San Andrés lagoon, Tamaulipas (5.85 μg g^{-1}) (Vázquez et al. 1990) and Términos lagoon, Campeche (5.80 μg g^{-1}) (Ponce 1988).

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