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Heavy metals in the habitat and throughout the food chain of the Neotropical otter, *Lontra longicaudis*, in protected Mexican wetlands

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Abstract Top predators like the Neotropical otter, *Lontra longicaudis annectens*, are usually considered good bioindicators of habitat quality. In this study, we evaluated heavy metal contamination (Hg_{tot}, Pb, Cd) in the riverine habitat, prey (crustaceans and fish), and otter feces in two Ramsar wetlands with contrasting upstream contamination discharges: Río Blanco and Río Caño Grande in Veracruz, Mexico, during the dry, the wet, and the *nortes* seasons. Most comparisons revealed no differences between sites while seasonal differences were repeatedly detected for all of the compartments. Higher concentrations of Pb during the dry season and of Cd during the wet season in otter feces mirrored differences detected in the most seasonally consumed prey. Compared with fecal methylmercury values reported for the European otter (0.25–0.75 mg kg^{-1}) in unprotected areas, the Hg_{tot} levels that we measured were lower (0.02–0.17 mg kg^{-1}). However, Pb (117.87 mg kg^{-1}) and Cd (9.14 mg kg^{-1}) concentrations were higher (Pb, 38.15 mg kg^{-1} and Cd, 4.72 mg kg^{-1}) in the two Ramsar wetlands. Protected areas may shelter species, but those with water-linked diets may suffer the effect of chemicals used upstream.

Keywords Neotropical otter · *Lontra longicaudis annectens* · Heavy metals · Feces · Mexico · Ramsar protected wetlands

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Introduction

A common belief (and the reason for their existence) is that protected areas (Primack et al. 2001) provide better conditions for the persistence of species than unprotected ones. The Ramsar Convention on Wetlands (Ramsar, Iran, 1971) was established to protect sites of particular interest due to their biodiversity and the ecosystem services they provide. Species inhabiting these protected ecosystems should therefore have optimal living conditions.

Heavy metals in the environment have repeatedly been reported to have an effect on the physiology and survival of animals (Chen et al. 2009; Rowsell et al.

2010). Due to the biomagnification effect (US EPA 1997), top predators are especially vulnerable to the effects of these contaminants as a result of bioaccumulation (Cervantes and Moreno-Sánchez 1999) and their persistence throughout the food chain without degradation (Erlinge 1968).

A recent study on heavy metals bioaccumulated by the Eurasian otter, *Lutra lutra* (Delibes et al. 2009), showed that some contaminated habitats may function as ‘ecological traps’ or ‘attractive sinks’ (Schlaepfer et al. 2002; Battin 2004). The animals are unable to detect residual quantities of chemicals in these habitats, and these compounds can reduce the animals’ breeding success and/or increase their mortality. The most important conclusion of that study was that, even though otters are usually considered indicators of good water quality, their premature recolonization of sites where toxic spills have occurred casts doubt on their usefulness as bioindicators (Delibes et al. 2009). Otters may instead be good biomonitors (Zhou et al. 2008) and reveal contamination changes over time and space in protected wetlands.

Land use (and the associated use of water) in the upper sections of a basin affects the amount of heavy metals running throughout the river to the lower sections (Chen et al. 2009; Ruelas-Inzunza et al. 2009). The amount, however, changes throughout the year (Ruelas-Inzunza et al. 2009) due to variations in the volume of the stream or river (about half the concentration of Hg_{tot} and Pb during the rainy season compared with the dry season). This may result in a differential risk of poisoning throughout the year for the organisms living in the lower sections of a river.

Feces have been used to measure the exposure of wildlife to heavy metals in the environment (Mason and MacDonald 1986; Mason and Ratford 1994; Delibes et al. 2009). The relationship between the amounts defecated and absorbed gives an idea of the potential effect on the organism. Quantifying heavy metal concentrations in the feces collected in different areas gives an idea of the daily consumption of contaminants by a species (Mason and MacDonald 1986; Mason and Ratford 1994; Delibes et al. 2009). Additionally, measuring the concentrations of contaminants in the different compartments and elements of the trophic chain may allow for comparisons not only of the consumption by the predator but also of the quality of the habitat in which the predators and their prey are living.

In this study, we ask whether differences in land use in the upper sections of basins result in differential habitat quality in two Ramsar protected wetlands. Total mercury (Hg_{tot}), lead (Pb), and cadmium (Cd) in different compartments of the habitat (soil, water) and the trophic chain (fish and crustaceans) of the Neotropical otter (*Lontra longicaudis annectens*) were measured. Because of seasonal changes in the volume of the rivers (Vázquez-Sauceda et al. 2005; Ferreira et al. 2009), samples were taken seasonally from all of the compartments to quantify potential changes in heavy metal ingestion by the otters throughout the year.

Materials and methods

Study area

Two rivers and their lagoons thought to have contrasting contamination levels were selected (Fig. 1): Río Blanco (RB) and Río Caño Grande (RCG) in the state of Veracruz, Mexico. Both of these wetlands are habitats for the Neotropical otter. RB is born in the lower slopes of the Pico de Orizaba volcano and runs eastwards to the Gulf of Mexico. Although there is a large wastewater treatment plant in the area for both industrial and domestic wastewater (Fideicomiso del Sistema de Aguas Residuales del Alto Río Blanco, FIRIOB), its capacity is limited. Consequently, there is effluent discharge from small communities and some industries along the Orizaba-Córdoba industrial corridor into the upper sections of the RB before it drains into the Tlalixcoyan lagoon of the Alvarado complex (18° 44′00" to 18°52′15" N; and 95°44′00" to 95°57′00" W; Flores-Coto and Méndez-Vargas 1982; Fig. 1). This series of lagoons contains the largest mangrove forest in the state (Portilla Ochoa 2003), and of the wetland sites (Ramsar) in Mexico; it is classified as the second highest priority for conservation. Before it drains into the lagoon, the riverine vegetation of RB is dominated by pasture and agricultural land (Reséndez-Medina 1973). RB is considered one of the most contaminated rivers in Mexico (Comisión Nacional del Agua 2005) with concentrations of pollutants above the maximum permissible level for human use and the protection of wildlife (Cervantes and Moreno-Sánchez 1999;

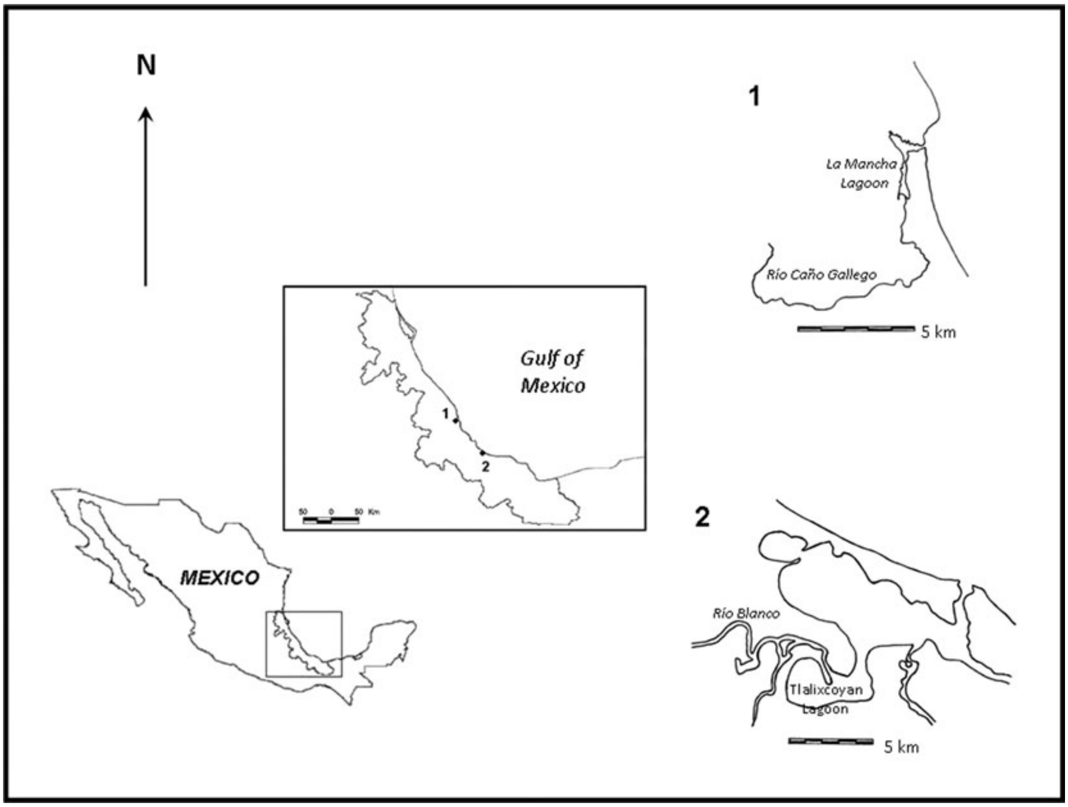

Fig. 1 Study location in the state of Veracruz, Mexico. Heavy metals (total mercury, lead, and cadmium) were measured for water and sediment from the rivers and throughout the food chain (crustaceans and fish) of the Neotropical otter. Fecal samples were used to monitor heavy metal consumption by the otter. Two protected wetlands thought to have contrasting degrees of contamination were selected: *1* Rio Blanco and Tlalixcoyan Lagoon, with heavy contamination sources in the upper basin (large cities and industry) and *2* Rio Caño Grande and La Mancha Lagoon with very low human activity

NOM-001-SEMARNAT-1996; NOM-127 SSA I-1994) in continental waters.

The RCG rises in the Manuel Díaz mountain range and drains into the La Mancha Lagoon. Located in the central part of the state (19° 34" to 19° 42" N; and 96° 23" to 96° 27" W) some of its water is rerouted to irrigate sugar cane plantations and then returned to the main stream of the river. It was decreed a Ramsar site because of the variety of wetlands and terrestrial ecosystems it runs through, including coastal dunes and lowland forests (Moreno-Casasola 2003). The dominant vegetation in the riverine zone before the stream arrives at the lagoon is *Rhizophora mangle, Laguncularia racemosa, Avicennia germinans,* and *Conocarpus erectus* mangrove (Barreiro-Güemes and Balderas-Cortés 1991). There were no previous reports of contaminants in this river.

The climate of both sites is subhumid and hot, with summer rains.

Sample collection and analysis

Sampling was done between May 2008 and February 2009 during the dry, rainy, and *nortes* seasons (the latter is characterized by strong winds from the north, rain, and low temperatures between November and March).

Paired sampling stations 1 m from the shoreline and separated by 1.5 km were set up on the wetland. We followed the protocols of the US Geological Survey for the collection of samples for the evaluation of heavy metals (ADEQ 1995). Briefly, 0.5 L of water was collected in polypropylene flasks and acidified with 1 ml of concentrated HNO_3. Sediment was collected from a depth of 3 cm with a plastic spoon.

For the sediment, Marine Sediment Reference Material (PACS-2) was used and, for tissue, Dogfish Muscle Certified Reference Material (DORM-2) from the National Research Council Canada.

Potential prey (fish and crustaceans) and otter feces were collected along the area delimited by outermost pair of sampling stations. Potential prey was collected with the help of local fishermen. Otter feces were located by walking along the riverbanks or searching for them from a boat. Each sample was kept refrigerated until processed. Prey tissue was homogenized with an Ultra Turrax T-25 basic IKA-Werke using subsamples of muscle, skin, bone, and inner organs (whole weight tissue). Sediment and fecal samples were dried in an oven at 40 °C until dehydrated and then pounded to a fine powder.

Samples were digested in a microwave oven (CEM Corp. MARS-X) using the 3015 US EPA method (1994). Briefly, 1 g of sample (wet base) or 0.25 g (dry base) and 5 ml (50 %) of nitric acid were placed in the Teflon® digester vessels and processed at 100 °C for 6 min, 150 °C for 6 min and 175 °C for 15 min. 3 ml of H_2O_2 (30 %) were added, and the samples were redigested again using the same digestion program. Digested samples were dissolved to 50 ml with distilled water and kept frozen until analysis.

Levels of total mercury (Hg_{tot}), lead (Pb), and cadmium (Cd) were measured with a lamp Atomic Absorption Spectrometer (Perkin Elmer 1100 B, with a specific cathode lamp). For QA/QC purposes, blanks, duplicates, and references (DORM-2 dogfish muscle and PACS-2 marine sediment reference materials for trace metals from the National Research Council Canada) were analyzed for each metal. Mean percent recovery for Hg in tissue was 81 % and in sediment, 92 %, and the mean relative percent difference was 15 %. For Pb, mean percent recovery for tissue and sediment was 80 %, and mean relative percent difference was 6 %. For Cd, mean percent recovery in tissue was 90 % and in sediment, 78 %, and the mean relative percent difference was 5 %. Detection limits were: water ($Hg_{tot=}$0.48, Pb=2, and Cd=0.016 μg mL^{-1}), sediment ($Hg_{tot=}$ 0.088, Pb=0.18, and Cd=0.003 mg kg^{-1}), feces, and prey tissue ($Hg_{tot=}$0.044 mg kg^{-1}, Pb=0.036 mg kg^{-1}year, Cd=0.0015 mg kg^{-1}).

After testing for normality, for each sample type, concentrations were compared between sites and seasons using two-way ANOVAs with interaction. When the distribution was not normal, we used the ANOVA option of the generalized linear models specifying a Poisson distribution and correcting for overspread data (Crawley 1993). Statistical analyses were done with STATISTICA 7.1 software (StatSoft 2006).

Heavy metal absorption index

The quantity of heavy metals absorbed was calculated using the absorption percentages of each metal reported for mammals (Mason and MacDonald 1986). According to these authors, 10 % of Pb and 5.5 % of Cd ingested are absorbed by the intestinal wall, and the rest is excreted. It has been reported that about 95 % of methylmercury is absorbed through the intestinal wall in mammals (Chen et al. 2009). Because in this study only Hg_{tot} concentrations were measured, it was not possible to estimate the amount of mercury that was absorbed.

To obtain a daily average of Pb and Cd excretion by the otters at each site, the average amount of feces produced daily by the European otter (0.070 kg; Mason and MacDonald 1986) was multiplied by the average concentration of the metals measured in the feces.

Results

All three metals were detected in all of the compartments sampled at both sites of the study area (RB and RCG), during all three sampling seasons.

Heavy metals in the water (Fig. 2)

Hg_{tot} differed between wetlands (χ^2=15.055, P<0.001) with mean concentrations of 0.001 mg L^{-1} in RB and 0.0004 mg L^{-1} in RCG and among seasons (χ^2=70.145, P<0.001) and was higher during the dry season (0.001 mg L^{-1}). Lead (χ^2=11.165, P=0.003) and Cd (χ^2=7.008, P=0.03) were different among seasons, and were significantly higher during the wet (0.188 mg L^{-1}) and dry seasons (0.032 mg L^{-1}), respectively. The site× season interaction was significant in all comparisons.

Heavy metals in the sediment (Fig. 3)

The concentrations of Hg_{tot} ($F_{2,36}$=22.801, P<0.001), Pb ($F_{2,36}$=5.407, P=0.008), and Cd ($F_{2,36}$=5.783, P=0.006) differed among seasons. While the maximum concentrations of Hg_{tot} (0.398 mg kg^{-1}) and Pb (38.701 mg kg^{-1}) were recorded during the dry season, the maximum concentration of Cd (6.333 mg kg^{-1}) occurred during the *nortes* season. Cadmium differed between wetlands as well ($F_{1,36}$=4.348, P=0.004) with mean concentrations of 5.878 mg kg^{-1} in RCG and

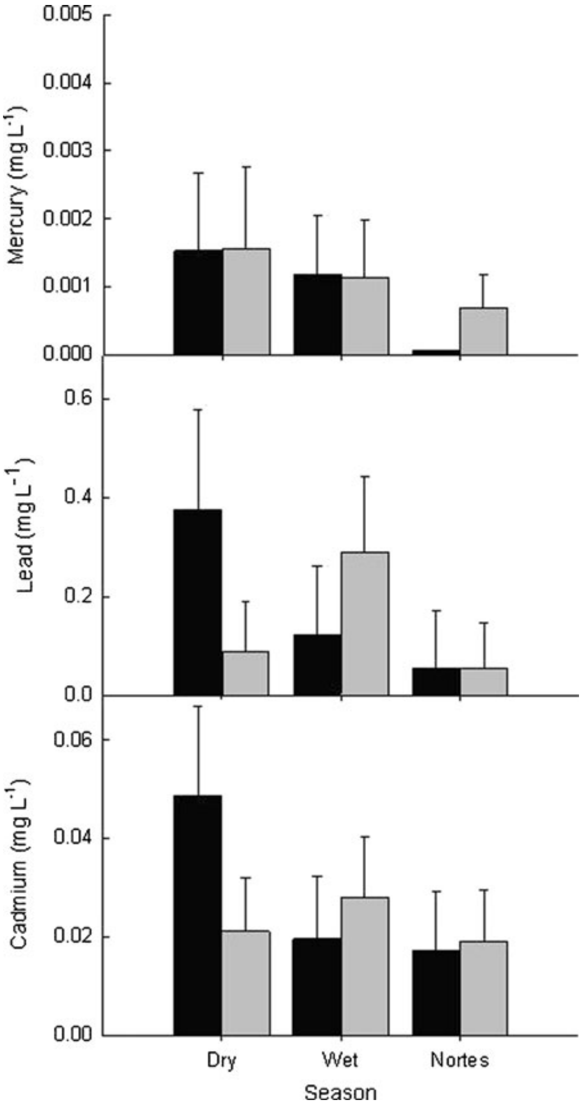

Fig. 2 Heavy metal concentration (milligrams per kilogram) per season in water samples from two water bodies located in Veracruz, Mexico. The *gray bars* are the values (mean±standard error) measured in Rio Blanco (RB), and the *dark bars* are those measured in Rio Caño Grande (RCG)

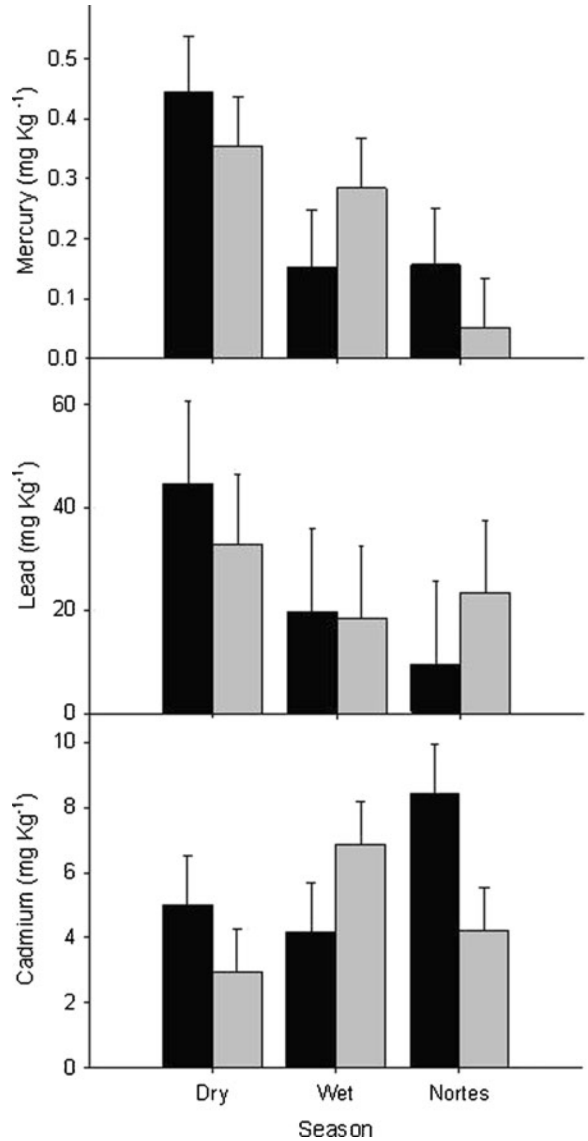

Fig. 3 Heavy metal concentration (milligrams per kilogram) per season in sediment samples from two water bodies located in Veracruz, Mexico. The *gray bars* are the values (mean± standard error) measured in Rio Blanco (RB) and the *dark bars* are those measured in Rio Caño Grande (RCG)

4.682 mg kg^{-1} in RB. The site×season interaction was significant for Hg_{tot} and Cd.

Heavy metals in potential prey (fish and crustaceans) (Fig. 4)

In crustaceans, differences in Pb were detected only among seasons (χ^2=22.844; P<0.001). It is worth noting that Pb concentrations were lower (with an average of 0.133 mg kg^{-1}) in crustacean tissue during the *nortes* season, compared with the very high concentration (50.334 mg kg^{-1}) during the dry season. In contrast, Hg_{tot} was rather high for all seasons, considering the higher toxicity of this metal. There was no site× season interaction for any of the metals in potential prey.

In fish, Hg_{tot} differed between wetlands (χ^2=4.027, P=0.044), with mean concentrations of 0.078 mg kg^{-1} in RCG and 0.051 mg kg^{-1} in RB and among seasons (χ^2=25.244, P=0.001) with higher concentrations

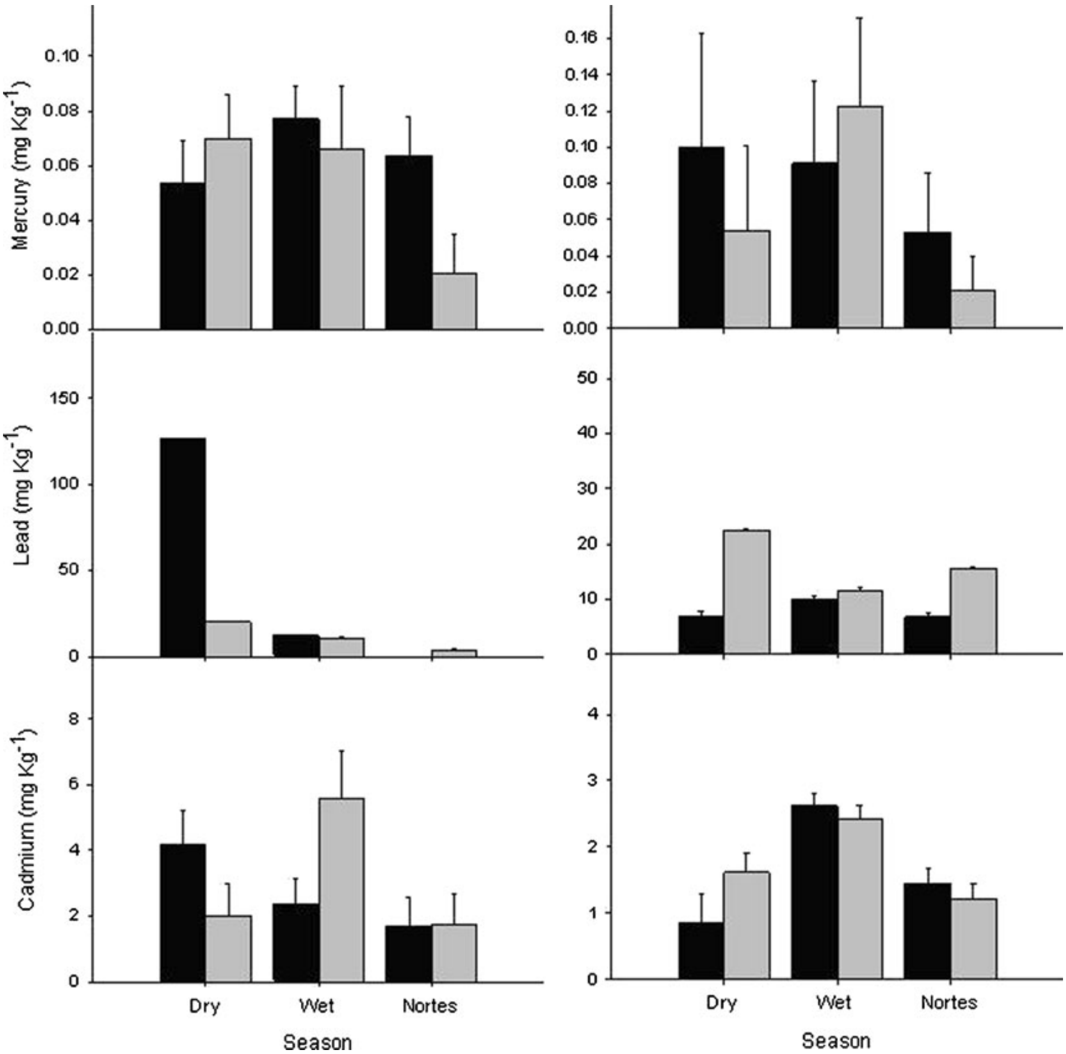

Fig. 4 Heavy metal concentration (milligrams per kilogram) per season in samples of crustaceans (river shrimp, crab, and crayfish; *left side*) and fish (*right side*) for two water bodies located in Veracruz, Mexico. The *gray bars* are the values (mean±standard error) measured in Rio Blanco (RB) and the *dark bars* are those measured in Rio Caño Grande (RCG)

during the wet season (0.150 mg kg^{-1}). The site× season interaction was also significant.

Pb concentration did not differ between sites or among seasons, and there was no significant interaction between the two factors. Cd differed only among seasons (χ^2=12.109, P=0.002) and was higher during the wet season (2.525 mg kg^{-1}).

Heavy metals in feces (Fig. 5)

Hg_{tot} differed between wetlands ($F_{1,26}$=157.664, P< 0.001) with mean concentrations of 0.088 mg kg^{-1} in RB and 0.058 mg kg^{-1} in RCG. The site×season interaction was significant. In contrast, only seasonal differences were found for Pb ($F_{2,26}$=40.578, P<0.001), with higher concentrations occurring during the dry season (66.693 mg kg^{-1}) and for Cd ($F_{2,26}$=6.056, P=0.006) during the wet season (0.690 mg kg^{-1}).

Heavy metals absorption index

Table 1 reports the estimated amounts of Pb and Cd absorbed daily by the otters for each season.

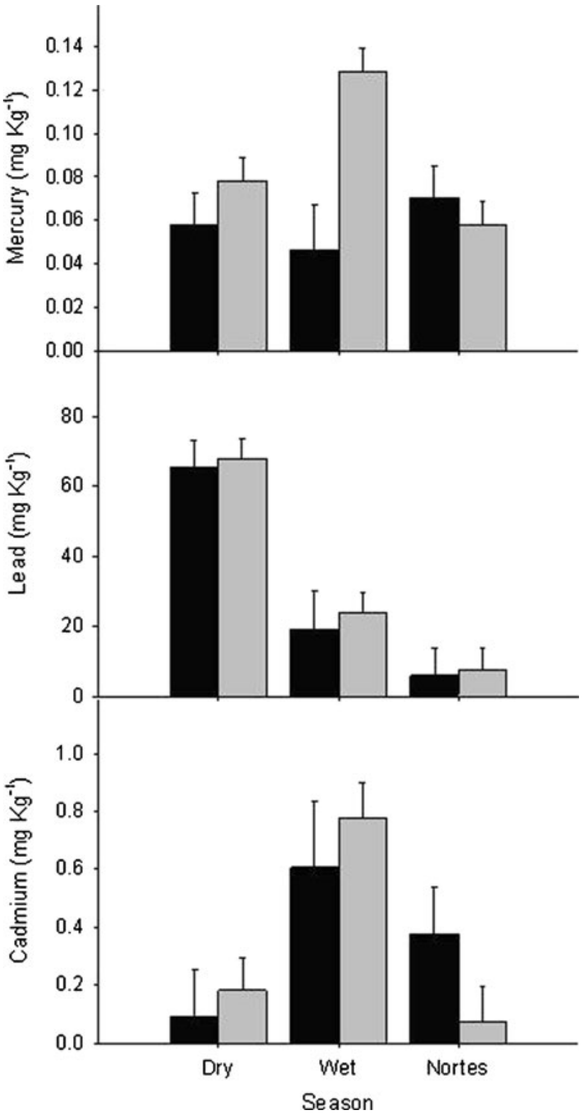

Fig. 5 Heavy metal concentration (milligrams per kilogram) per season in samples of feces of Neotropical otters inhabiting two water bodies located in Veracruz, Mexico. The *gray bars* are the values (mean±standard error) measured in Rio Blanco (RB) and the *dark bars* are those measured in Rio Caño Grande (RCG)

Discussion

Contrary to what we expected, differences were found only for Hg_{tot} and Cd in a few of the compartments of the two supposedly contrasting sites. Moreover, protected Ramsar wetlands are not free of contaminants, and one of the top predator species inhabiting them, the Neotropical otter, seems to be consuming significant amounts of heavy metals.

Table 1 Estimated concentrations of lead and cadmium absorbed (milligrams) daily by the Neotropical otter in different seasons at two sampling sites: Río Blanco and Río Caño Grande

River	Season	Lead (Pb) (10 %)[a]	Cadmium (Cd) (5.5 %)[a]
Río Blanco	Dry	0.529	0.006
	Wet	0.186	0.025
	Norte	0.059	0.007
Río Caño Grande	Dry	0.508	0.006
	Wet	0.150	0.016
	Norte	0.046	0.009

[a] Percent absorption reported by Mason and MacDonald 1986

Heavy metals in the water and sediment

Elevated concentrations of Hg_{tot} in the water from RB are easily explained by: (1) the discharge of this metal in effluents from the industrial complex located upstream; (2) the discharge of municipal wastewater into the river without proper treatment; and (3) the runoff from agricultural lands and large pastures along the river, where fertilizers and pesticides are used (Förstner and Wittmann 1981). In contrast, there are no such activities in the upper RCG basin, and this could explain the lower concentration of Hg in that wetland.

Although there are no previous reports of contaminants in RCG, the highest concentrations of Cd in sediment were found there. This could be the result of this river's low water flux as it receives the runoff from the extensive sugar cane plantations that surround the study area (Marin 2007; Ferreira et al. 2009). It is known that, compared with other crops, sugar cane plantations are treated with the largest amounts of fertilizers and pesticides (Corbi et al. 2008) and that these agricultural inputs are highly toxic to aquatic environments, wildlife, and human beings. It is also known that fertilizers and pesticides contain heavy metals (El Gharmali et al. 2002; Li and Wu 2008).

Seasonal differences were observed in all of the compartments, with higher concentrations during the dry season except for Pb in water (higher in the wet season) and Cd in sediment (higher in *nortes*). Higher concentrations of pollutants in rivers during the dry season are related to the lower water level that is characteristic of this time of the year (Vázquez-Sauceda et al. 2005; Ferreira et al. 2009) and also to the high evaporation caused by the elevated temperatures typical of a hot, subhumid climate (Travieso-Bello and Campos 2006), resulting in the slower movement of chemical compounds.

The higher concentrations of Pb in the sediment during the dry season are probably related to the lower water flux of that season (Vázquez-Sauceda et al. 2005; Ferreira et al. 2009). Even though gasoline in Mexico has been lead free since the early 1990s, the use of leaded gasoline prior to this and the oil from the motorboats that are used on both rivers could be the source of the lead detected in the water and sediment (Villanueva and Vázquez-Botello 1992; Portilla Ochoa 2003; Moreno-Casasola et al. 2006).

Heavy metals in potential prey (fish and crustaceans)

The wet and *nortes* seasons increase the dilution of contaminants but can also transport greater amounts of the contaminants from the highlands to the lower basin (Moreno-Casasola et al. 2006; Ruelas-Inzunza et al. 2009). This could explain the high concentrations of Hg_{tot} and Cd measured in fish during this season.

The lack of difference in the concentrations of Hg_{tot}, Pb, and Cd bioaccumulated by crustaceans at the two sampling sites could be the result of the detritivorous diet of these organisms, which would reflect the contaminants in the sediments (Morel et al. 1998; Blackmore 2001) and for which there was no difference in heavy metal content between sites (except for Cd). This conclusion is supported by the fact that the Pb concentration in crustaceans was higher during the dry season, when it was also higher in the sediments.

The higher Hg_{tot} concentration measured in fish is probably the result of longer exposure to the metals (compared with the crustaceans) due to their longer lifespan. It would have been interesting to analyze the Hg levels for different species of fish in the context of their feeding habits, considering that predators, carrion eaters, and detritivorous fish are expected to have higher concentrations of contaminants than herbivorous fish (Blackmore 2001).

For both wetlands, the highest concentrations of Pb and Cd measured in crustaceans (126 and 7.5 mg kg^{-1}) and fish (79.79 and 6.26 mg kg^{-1}) exceeded the maximum permitted levels for consumption by humans as set forth in the Official Mexican Standards (1.0 and 0.5 mg kg^{-1}, respectively). This represents a potential problem for the health of the Neotropical otter and a significant risk for the human population that makes use of these resources both as hobby food and for daily consumption. A recent study in Luxembourg focused on the evaluation of heavy metals in the prey fish of the European otter (Boscher et al. 2010). There, the highest Hg concentration was 0.535 mg kg^{-1}; that of Pb was 0.181 mg kg^{-1}, and for Cd it was 0.104 mg kg^{-1}, one and two orders of magnitude lower than our values. Even though their results are reported in wet weight, the Luxembourg otters are probably exposed to lower contaminant concentrations.

Heavy metals in feces

The high concentration of Hg_{tot} in otter feces year round is of particular concern as these values indicate elevated absorption throughout the year. The Hg_{tot} levels detected in the feces of the Neotropical otter (0.02–0.17 mg kg^{-1}) are, however, lower than those of methylmercury (0.25–0.75 mg kg^{-1}) reported for the European otter (*L. lutra*; Mason and MacDonald 1986). Since these values are for samples taken from a number of sites in England, Mason and MacDonald (1986) suggested that they should be considered normal values for this species, and we use them as a reference. The highest concentrations of Pb (117.87 mg kg^{-1}) and Cd (9.14 mg kg^{-1}) recorded in our study sites were, however, higher than the highest reported by those authors for *L. lutra* (Pb, 38.15 and Cd, 4.72 mg kg^{-1}) for a series of European sites.

The higher concentration of Pb in feces during the dry season corresponded to higher concentrations of this metal in crustaceans, while Cd in feces was higher in the wet season, as found for fish. This reflects the proportion of the otter's diet made up by these prey (40–54 % fish and 30–44 % crustaceans; Macías-Sánchez and Aranda 1999; Gallo-Reynoso et al. 2008) and indicates this otter may be having a problem in terms of accumulation of these contaminants.

Seasonal differences in the concentration of heavy metals in the different prey suggest differences in the amounts of type of prey ingested by the otter throughout the year. This means that the risk of poisoning by each metal may be season-specific. For example, Pb concentrations were higher in the feces during the dry season, when there are more births and a higher probability of maternal transfer to the pups (Basu et al. 2005;

Croteau et al. 2005; Yates et al. 2005; Scheulhammer et al. 2007). Because Cd is higher in the wet season, it might not affect nursing pups.

Heavy metal absorption index

The absorption indices revealed that at both sites the Neotropical otter is at risk of poisoning and that the risk varies depending on the season. As otter prey, crustaceans contribute the higher amounts of Pb and Cd. Because of their larger body size, males consume more food each day than females do (otters eat 1 to 1.5 kg of food per 10 kg of body weight every day, Mason and MacDonald 1986) so heavy metal bioaccumulation is potentially higher in males, and they might be at greater risk than females.

It has been calculated that the average otter in the Guadiamar River, which was recolonized by European otter populations after a toxic spill, consumes 3–4 mg of Pb and 0.25 mg of Cd daily (Delibes et al. 2009). Using the same type of calculations, an average Neotropical otter at the Veracruz sites would be consuming 3.347 mg of Pb and 0.349 mg of Cd every day. Given that 10 % of Pb and 5.5 % of Cd consumed are absorbed, this would represent a yearly absorption of 122.17 mg of Pb and 8.28 mg of Cd. A recent study in the Loire River catchment, France, where liver bioaccumulation of heavy metals in otters killed by road traffic was analyzed, indicated concentrations of 1.0 mg kg^{-1} for Pb, 0.3 for Cd, and 8.2 mg kg^{-1} of Hg (Lemarchand et al. 2010). In Oregon and Washington, a similar study of male river otters, *Lontra canadensis*, reported concentrations of 0.5 mg kg^{-1} of Cd in juveniles and 1.18 mg kg^{-1} in adults, with concentrations of Hg_{tot} as high as 12.6 mg kg^{-1} (Grove and Henny 2008). Since the liver and kidneys are where the greatest amounts of contaminants accumulate (after that which is eliminated in growing hair; Mason et al. 1986), Neotropical otters in Veracruz may be bioaccumulating at least an order of magnitude more of heavy metals than the animals studied in France and the USA.

Even though we expected higher concentrations of heavy metals in RB due to the presence of industry as an important source of upstream contamination, in general, the heavy metal concentrations in the habitats and compartments of the sites did not bear out this expectation. This lack of difference between rivers is likely associated with the lower water flux and the very high organic content of the sediments in the mangrove (Golia et al. 2008) of RCG. Both of these conditions facilitate heavy metal accumulation (mainly through adsorption and immobilization by sediments), even though heavy metal input may have been lower at RCG. Therefore, the results of this study support the idea that atmospheric input, water flux, and sediment characteristics could result in similar contamination levels in basins with contrasting land uses (Golia et al. 2008).

The levels of Hg_{tot} measured in crustaceans and fish did not exceed the maximum permitted levels for human consumption (1.0 mg kg^{-1}), but the detection of Hg in the samples collected indicates the need for a monitoring program owing to the potential health risks to people. The daily diet of the local inhabitants is based on potentially contaminated resources, and this could lead to future health problems (NOM-027-SSA1-1993; NOM-029-SSA1-1993; Chen et al. 2009; White et al. 2009) resulting from the potential bioaccumulation of metals in the liver, tissues, kidneys, bone marrow, and brain. Of particular concern is the potential vertical transfer from mothers to their offspring, both in otter and in human populations (Basu et al. 2005; Croteau et al. 2005; Yates et al. 2005; Scheulhammer et al. 2007).

It has been mentioned that the synergistic effects of several metals in a single individual are to be expected, and there is a call for studies on these problems (Walker et al. 2001). Also, since the study areas are designated as Ramsar sites, these wetlands are expected to be in better shape than other sites where the Neotropical otter occurs. Water in both wetlands, however, exceeded the maximum permitted levels of heavy metals for human consumption (NOM-001-SEMARNAT-1996; NOM-127 SSA I-1994), and this indicates that otters living within protected areas are not necessarily sheltered, as these sites receive water from contaminated sources located far away.

Conclusions

Protected wetlands are thought to shelter wildlife associated with aquatic ecosystems. This study indicates, however, that water coming from transformed areas that are upstream brings contaminants into the habitat and trophic chains of organisms inhabiting RAMSAR sites. Heavy metals such as Pb, Cd, and

Hg_{tot} were detected in similar concentrations in the habitat and along the trophic chain of the Neotropical otter in the two protected sites studied. Even though upstream land uses suggested otherwise, lower water flux and higher organic matter content in the sediment of the more conserved site resulted in similar concentrations of metals. We also found that seasonal differences in the diet modify the amounts of contaminants ingested, which may have an effect on the development or nourishment of pups. Compared with the European otter studied in unprotected and contaminated sites, the Hg_{tot} levels detected in the feces of *L. longicaudis* are lower than those of methylmercury. However, the highest concentrations of Pb and Cd recorded in the Ramsar sites studied were higher than the highest reported for *L. lutra* in the contaminated areas in Europe.

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References

ADEQ. (1995). *Manual de Campo para el Muestreo de la Calidad del Agua*. Tucson: Arizona Water Resources Research Center, University of Arizona.

Barreiro-Güemes, T., & Balderas-Cortés, J. (1991). Evaluación de algunas comunidades de productores primarios de la laguna de La Mancha, Veracruz. *Anales del Instituto de Ciencias del Mar y Limnología, 18*, 229–245.

Basu, N., Scheuhammer, A., Grochowina, N., Klenavic, K., Evans, D., O'Brien, M., et al. (2005). Effects of mercury on neurochemical receptors in wild river otters (*Lontra canadensis*). *Environmental Science and Technology, 39*, 3585–3591.

Battin, J. (2004). When good animals love bad habitats: ecological traps and the conservation of animal populations. *Conservation Biology, 18*, 1482–1491.

Blackmore, G. (2001). Interspecific variation in heavy metal body concentrations in Hong Kong marine invertebrates. *Environmental Pollution, 114*, 303–311.

Boscher, A., Gobert, S., Guignard, C., Ziebel, J., L'hoste, L., Gutleb, A. C., et al. (2010). Chemical contaminants in fish species from rivers in the North of Luxembourg: Potential impact on the Eurasian otter (*Lutra lutra*). *Chemosphere, 78*, 785–792.

Cervantes, C., & Moreno-Sánchez, R. (1999). *Contaminación ambiental por metales pesados. Impacto en los seres vivos*. México: AGT Editores.

Chen, Y. C., Dionne, M., Mayes, B. M., Ward, D. M., Sturup, S., & Jackson, B. P. (2009). Mercury bioavailability and bioaccumulation in estuarine food webs in the Gulf of Maine. *Environmental Science and Technology, 43*, 1804–1810.

Comisión Nacional del Agua. (2005). *Estudio Técnico para la Supresión y Establecimiento de Veda en la Zona Hidrológica denominada Río Papaloapan*. México: Comisión Nacional del Agua.

Corbi, J. J., Trininho-Strixino, S., & dos Santos, A. (2008). Environmental evaluation of metals in sediments and dragonflies due to sugar cane cultivation in Neotropical streams. *Water, Air, and Soil Pollution, 195*, 325–333.

Crawley, J. M. (1993). *Methods in ecology. GLIM for ecologists*. Blackwell Scientific Publications, Oxford, UK.

Croteau, M. N., Luoma, S. N., & Stewart, R. (2005). Trophic transference of metals along freshwater food webs: Evidence of cadmium biomagnification in nature. *Limnology and Oceanography, 50*, 1511–1519.

Delibes, M., Cabezas, S., Jiménez, B., & González, M. J. (2009). Animal decisions and conservation: The recolonization of a severely polluted river by the Eurasian otter. *Animal Conservation, 12*, 400–407.

El Gharmali, A., Rada, A., Meray, M., & Nejmeddine, A. (2002). Study of the effect of earthworm *Lumbricus terrestris* on the speciation of heavy metals in soils. *Environmental Technology, 23*, 775–780.

Erlinge, S. (1968). Territoriality of the otter *Lutra lutra* L. *Oikos, 19*, 81–98.

Ferreira, C. M., Barbosa, S. C. T., Barletta, M., Dantas, D. V., Kehring, H. A., Seixas, T. G., et al. (2009). Seasonal differences in mercury accumulation in *Trichiurus lepturus* (Cutlassfish) in relation to length and weight in a Northeast Brazilian estuary. *Environmental Science and Pollution Research, 16*, 423–430.

Flores-Coto, C., & Méndez-Vargas, L. (1982). Contribución al conocimiento del ictioplancton de la Laguna de Alvarado, Veracruz. *Anales del Instituto de Ciencias del Mar y Limnología, 9*, 141–160.

Förstner, U., & Wittmann, G. T. W. (1981). *Metal pollution in the aquatic environment*. Berlin: Springer.

Gallo-Reynoso, J. P., Ramos-Rosas, N. N., & Rangel-Aguilar, O. (2008). Depredación de aves acuáticas por la nutria neotropical (*Lontra longicaudis annectens*), en el río Yaqui, Sonora, México. *Revista Mexicana de Biodiversidad, 79*, 275–279.

Golia, E. E., Dimirkou, A., & Mitsios, I. K. (2008). Influence of some soil parameters on heavy metals accumulation by vegetables grown in agricultural soils of different soil orders. *Bulletin of Environmental Contamination and Toxicology, 81*, 80–84.

Grove, R. A., & Henny, C. J. (2008). Environmental contaminants in male river otters from Oregon and Washington, USA, 1994–1999. *Environmenatl Monitoring and Assessment, 145*, 49–73.

Lemarchand, C., Rosoux, R., & Berny, P. (2010). Organochlorine pesticides, PCBs, heavy metals and anticoagulant rodenticides in tissues of Eurasian otters (*Lutra lutra*) from upper Loire River catchment (France). *Chemosphere, 80*, 1120–1124.

Li, D. P., & Wu, Z. J. (2008). Impact of chemical fertilizers application on soil ecological environment. *Chinese Journal of Applied Ecology, 19*, 1158–1165.

Macías-Sánchez, S., & Aranda, M. (1999). Análisis de la alimentación de la nutria *Lontra longicaudis* (Mammalia: Carnivora) en un sector del río Los Pescados, Veracruz, México. *Acta Zoologica Mexicana, 76*, 49–57.

Marin, G. L. (2007). *Aproximación ecotoxicológica a la contaminación por metales pesados en la laguna costera Mar Menor*. Ph. D. dissertation. School of Biology, Universidad de Murcia.

Mason, C. F., & MacDonald, S. M. (1986). Levels of cadmium, mercury and lead in otter and mink faeces from the United Kingdom. *Science of the Total Environment, 53*, 139–146.

Mason, C. F., & Ratford, J. R. (1994). PCB congeners in tissues of European otter (*Lutra lutra)*. *Bulletin of Environmental Contamination and Toxicology, 53*, 548–554.

Mason, C. F., Last, N. I., & Macdonald, S. M. (1986). Mercury, cadmium, and lead in British otters. *Bulletin of Environmental Contamination and Toxicology, 37*, 844–849.

Morel, F. M. M., Kraepiel, A. M. L., & Amyot, M. (1998). The chemical cycle and bioaccumulation of mercury. *Annual Review of Ecology and Systematics, 29*, 543–566.

Moreno-Casasola, P. (2003). *Ficha Informativa de los Humedales de Ramsar* (FIR).

Moreno-Casasola, P., Salinas, G., Amador, L., Juárez, A., Cruz, H. H., Travieso-Bello, A. C., et al. (2006). El proyecto comunitario de conservación y producción. In P. Moreno-Casasola (Ed.), *Entornos Veracruzanos: la costa de La Mancha* (pp. 95–112). México: Instituto de Ecología AC.

NOM-001-SEMARNAT-1996. (1996). *Norma Oficial Mexicana. Límites máximos permisibles de contaminantes en las descargas de aguas residuales en aguas y bienes nacionales*. México: Secretaría de Medio Ambiente y Recursos Naturales.

NOM-027-SSA1-1993. (1993). *Norma Oficial Mexicana NOM-027-SSA1-1993, Bienes y Servicios. Productos de la pesca. Pescados frescos-refrigerados y congelados. Especificaciones sanitarias*. México: Secretaría de Salud.

NOM-029-SSA1-1993. (1993). *Norma Oficial Mexicana NOM-027-SSA1-1993, Bienes y Servicios. Productos de la pesca. Crustáceos frescos-refrigerados y congelados. Especificaciones sanitarias*. México: Secretaría de Salud.

NOM-127-SSA1-1994. (1994). *Norma Oficial Mexicana NOM-027-SSA1-1993, Salud Ambiental, Agua para uso y consumo humano-límites permisibles de calidad y tratamientos a que debe someterse el agua para su potabilización*. México: Secretaría de Salud.

Portilla Ochoa, E. (2003). *Establecimiento de Unidades de Gestión Ambiental en el Humedal de Alvarado, Veracruz, México: Base para su Ordenamiento Ecológico y Social. Reporte académico semestral North American Wetlands Conservation Council (NAWCC)*. México: Área Biología de la Conservación, Instituto de Investigaciones Biológicas, Universidad Veracruzana.

Primack, R., Rozzi, R., & Feinsinger, P. (2001). Establecimiento de áreas protegidas. In R. Primack, R. Rozzi, P. Feinsinger, R. Dirzo, & F. Massardo (Eds.), *Fundamentos de Conservación Biológica: Perspectivas Latinoamericanas* (pp. 449–475). México: CFE.

Reséndez-Medina, M. A. (1973). Estudio de los peces de la Laguna de Alvarado, Veracruz, México. *Revista de la Sociedad Mexicana de Historia Natural, 34*, 183–281.

Rowsell, F. V., Tangney, P., Hunt, C., & Voulvoulis, N. (2010). Estimating levels of micropollutants in municipal wastewater. *Water, Air, and Soil Pollution, 206*, 357–368.

Ruelas-Inzunza, J., Páez-Osuna, F., Zamora-Arellano, N., Amezcua-Martínez, F., & Bojórquez-Leyva, H. (2009). Mercury in biota and superficial sediments from Coatzacoalcos Estuary, Gulf of Mexico: Distribution and seasonal variation. *Water, Air, and Soil Pollution, 197*, 165–174.

Scheulhammer, A. M., Meyer, M. W., Sandeheinrich, M. B., & Murray, M. W. (2007). Effects of environmental methylmercury on the health of wild birds, mammals and fish. *Ambio, 36*, 12–18.

Schlaepfer, M. A., Runge, M. C., & Sherman, P. W. (2002). Ecological and evolutionary traps. *Trends in Ecology & Evolution, 17*, 474–480.

StatSoft. (2006). *STATISTICA (data analysis software system), version 7.1*. Tulsa, OK: Statsoft.

Travieso-Bello, A. C., & Campos, A. (2006). Los componentes del paisaje. In P. Moreno-Casasola (Ed.), *Entornos Veracruzanos: La costa de La Mancha* (pp. 245–280). México: Instituto de Ecología AC.

U.S. Environmental Protection Agency. (1994). *Method 3015. Microwave assisted acid digestion of aqueous samples and extracts*. Washington, DC, USA: EPA.

U.S. Environmental Protection Agency. (1997). *Method 3052 Microwave assisted acid digestion of siliceous and organically based matrices*. Washington, DC, USA: EPA.

Vázquez-Sauceda, M. L., Aguirre-Guzmán, G., Pérez-Castañeda, R., Rábago-Castro, J., & Sánchez, J. B. (2005). Contenido de cadmio y plomo en agua, ostión y sedimento de la laguna de San Andrés, Aldama, Tamaulipas. *Ciencia y Mar, 9*, 3–9.

Villanueva, F. S., & Vázquez-Botello, A. (1992). Metales pesados en la zona costera del Golfo de México y Caribe Mexicano: Una revisión. *Revista Internacional de Contaminación Ambiental, 8*, 47–61.

Walker, C. H., Hopkin, S. P., Sibly, R. M., & Peakall, D. B. (2001). *Principles of ecotoxicology*. London: Taylor and Francis.

White, L. H. A., Hook, G. R., Greening, G. E., Gibbs-Smith, E., & Gardner, J. P. A. (2009). Human dietary exposure to heavy metals via the consumption of greenshell mussels (*Perna canaliculus* Gmelin 1791) from the Bay of Islands, northern New Zealand. *Science of the Total Environment, 407*, 4348–4355.

Yates, D. E., Mayack, D., Munney, K., Evers, D., Major, A., Kaur, T., et al. (2005). Mercury levels in mink (*Mustela vison)* and river otter (*Lontra canadensis)* from northeastern North America. *Ecotoxicology, 14*, 263–274.

Zhou, Q., Zhang, J., Fu, J., Shi, J., & Jiang, G. (2008). Biomonitoring: an appealing tool for assessment of metal pollution in the aquatic ecosystem. *Analytica Chimica Acta, 606*, 135–150.