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Distribution and bioconcentration of heavy metals in a tropical aquatic food web: A case study of a tropical estuarine lagoon in SE Mexico

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A B S T R A C T

Despite the increasing impact of heavy metal pollution in southern Mexico due to urban growth and agricultural and petroleum activities, few studies have focused on the behavior and relationships of these pollutants in the biotic and abiotic components of aquatic environments. Here, we studied the bioaccumulation of heavy metals (Cd, Cr, Ni, Pb, V, Zn) in suspended load, sediment, primary producers, mollusks, crustaceans, and fish, in a deltaic lagoon habitat in the Tabasco coast, with the aim to assess the potential ecological risk in that important wetland. Zn showed the highest concentrations, e.g., in suspended load (mean of 159.58 mg kg^{-1}) and aquatic consumers (15.43–171.71 mg kg^{-1}), particularly Brachyura larvae and ichthyoplankton (112.22–171.71 mg kg^{-1}), followed by omnivore *Callinectes* sp. crabs (113.81–128.07 mg kg^{-1}). The highest bioconcentration factors (BCF) of Zn were observed for planktivore and omnivore crustaceans (3.06–3.08). Zn showed a pattern of distribution in the food web through two pathways: the pelagic (where the higher concentrations were found), and the benthic (marsh plants, sediment, mollusk, fish). The other heavy metals had lower occurrences in the food web. Nevertheless, high concentrations of Ni and Cr were found in phytoplankton and sediment (37.62–119.97 mg kg^{-1}), and V in epiphytes (68.64 mg kg^{-1}). Ni, Cr, and Cd concentrations in sediments surpassed international and national threshold values, and Cd entailed a “considerable” potential risk. These heavy metals are most likely transferred into the food web up to fishes through the benthic pathway. Most of the collected fishes are residents in this type of habitat and have commercial importance. Our results show that the total potential ecological risk in the area can be considered as “moderate”. Nevertheless, heavy metal values were similar or surpassed the values from other highly industrialized tropical coastal regions.

1. Introduction

The accelerating growth of urban areas near aquatic environments (rivers and lagoons) in developing countries, combined with the poor control of wastewater and the uncontrolled increase in industrial and agricultural activities, have raised serious concerns about the generation of pollutants such as heavy metals (Rai, 2008; Wang et al., 2010). Heavy metals are natural constituents of the environment, but the increase in their concentrations resulting from various human activities (e.g. industry and oil extraction) has been reported extensively in nearly all coastal environments (Mohammed et al., 2011).

Heavy metal pollution in southern Mexico has been associated with agrochemical use, urban expansion, and particularly petroleum extraction (Gu et al., 2014). Most of these pollutants are transported by runoff to rivers and are finally deposited in water bodies with low hydrological dynamics such as coastal lagoons where accumulation occurs primarily in sediments (Lester, 2014; Melgar et al., 2008). Important bioenergetic fluxes

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in coastal lagoons are dependent on sediments (Jara-Marini et al., 2009), and therefore biota is susceptible to the accumulation of pollutants therein (Ip et al., 2005; Song et al., 2014; Wen-Xiong, 2002).

The biotic components of tropical coastal lagoons include many economically important organisms such as fish, crustaceans and mollusks. These organisms have close relationships in these habitats, and use them as areas for growth, reproduction and larval and juvenile recruitment (Arévalo-Frías and Mendoza-Carranza, 2012; Day et al., 2012). The occurrence and bioaccumulation of the many pollutants through the food webs could constitute a risk to human health (Comby et al., 2014).

While some studies have analyzed the behavior and relationships of heavy metals in the biotic and abiotic components of aquatic environments (Aderinola et al., 2009; Jara-Marini et al., 2009; Mathews and Fisher, 2008), most of the research on these pollutants has focused on isolated components, e.g. sediments (Aprile and Bouvy, 2008; Soto-Jiménez and Páez-Osuna, 2001), water (Melgar et al., 2008; Zhang and Liu, 2002), plants (Bayen, 2012; Dahmani-Muller et al., 2000; Samecka-Cymerman and Kempers, 2001) and fish (Canli and Atli, 2003; Malik et al., 2010; Vinodhini and Narayanan, 2008). The bioavailability and the potential for bioaccumulation and biomagnification of heavy metals in all components of an ecosystem are high; and dietary exposure is the primary route for the transfer of heavy metals in aquatic food webs (Croteau et al., 2005; Jara-Marini et al., 2009), hence the importance to understand the pollutant dynamics in the aquatic environments.

The coastal zones of southern Mexico, especially the Grijalva-Usumacinta delta, the second most important in North America, have many aquatic ecosystems, such as freshwater and coastal lagoons, streams and rivers, that support a high diversity of aquatic communities (Arévalo-Frías and Mendoza-Carranza, 2012; Novelo-Retana, 2006; Toledo, 2003). However, the accelerating urban growth, and agricultural and industrial activities such as intensive petroleum extraction in the Grijalva-Usumacinta basin, are potential sources for a diversity of pollutants (Geissen et al., 2010; Melgar et al., 2008).

The hydrological dynamics of the Grijalva-Usumacinta basin has strong implications for the reallocation, dispersion and sedimentation of pollutants in the aquatic environments of the region (Muñoz-Arriola et al., 2011; Sánchez-Hernández et al., 2013; Zhao et al., 2010). The lower part of the Grijalva-Usumacinta basin contains an extensive wetland area, the Centla Wetlands Biosphere Reserve (CWBR) (Instituto Nacional de Ecología, 2000; Yáñez-Arancibia et al., 2009). As in other wetlands, the high diversity and density of the plant communities produce extensive areas with low hydrological dynamics and high rates of sediment retention, which make them potential pollutant sinks (Bayen, 2012; Dachs et al., 2000; Jurado et al., 2007). Here, we studied the bioaccumulation of heavy metals in a lagoon of CWBR taking into account abiotic components (suspended load in water, and sediment), plants (marsh plants), and consumers (mollusks, crustaceans, and fish) of different trophic levels (omnivores, planktivores, herbivores, detritivores, zoobenthivores and piscivores). Furthermore, we compared our results with international threshold values in order to make an estimation of the ecological risk in the study area.

2. Material and methods

2.1. Study area

The Centla Wetland Biosphere Reserve (CWBR) is situated in the southern coastal plain of the Gulf of Mexico (Fig. 1). CWBR comprises an extensive wetland system in Mexico and is one of the most extensive wetlands in North America, with a surface area of 302 706 ha (Instituto Nacional de Ecología, 2000; Vega, 2005). The CWBR receives high hydrological inputs from the continent toward the coast from the two largest rivers in Mexico, the Grijalva and the Usumacinta, with fluvial discharges of 27 013 and 55 832 hm^3, respectively (Vega, 2005). The Grijalva-Usumacinta drainage basin in the CWBR contains 28% of all the surface water of Mexico (Toledo, 2003; Yáñez-Arancibia et al., 2004). Important urban (e.g. Villahermosa, Tenosique and Frontera), agricultural and petroleum-extraction areas are located along the two rivers (Toledo, 2003; Tudela, 1990). Petroleum exploitation is an important economic activity in the Grijalva-Usumacinta basin and hundreds of accidents have led to severe environmental problems in the region (Ortiz-Salinas et al., 2012). The climatic condition in the region is humid tropical, with annual rainfall ranging from 1100 to 2000 mm, and with a mean annual temperature exceeding 25 °C. The area is dominated by dry (March–May) and rainy (June–September) periods, but additionally another climatic condition in the region related with the influence of northerly winds is the winter storm period (October–February) (Yáñez-Arancibia and Day Jr., 1982).

2.2. Sampling location

The San Pedrito Lagoon (SP) in the CWBR (18°20′36″N, 92°33′50″W, Fig. 1) is an inner lagoon of deltaic origin with a surface of 1360 ha and an average depth of 1.5 m. The vegetation is characterized by the presence of the American eelgrass *Vallisneria americana* and emergent swamp vegetation dominated by the Common reed *Phragmites australis*, the Southern cattail *Typha domingensis*, and sparse patches of the Alligator flag *Thalia geniculata* (Novelo-Retana, 2006; Sepúlveda-Lozada et al., 2015). The lagoon is connected by two narrow channels with the Usumacinta River, which joins the Grijalva River before flowing into the Gulf of Mexico (Mendoza-Carranza et al., 2010). The lagoon is ca. 26 km from the mouth of the river and is influenced by brackish water, especially during the dry season (Mendoza-Carranza et al., 2010; Rodríguez, 2002). Water temperature in tropical lagoons is usually higher than 21° C (De la Lanza-Espino and Montes, 1999), nevertheless during the dry season it can reach 27 to 31° C (Albarran-Melze et al., 2009). Since SP is located at the lower part of the Usumacinta-Grijalva basin it is strongly influenced by all the human activities upriver, from wastewater discharges of big cities as Villahermosa to petroleum exploitation and extraction, the latter especially in the southern part of the reserve (Macuspana and Centla municipalities).

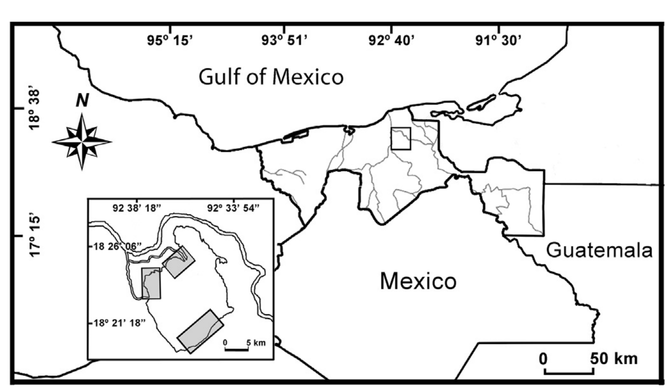

Fig. 1. Maps of the study area illustrating the sampling areas (grey).