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Mercury assessment, macrobenthos diversity and environmental quality conditions in the Salado Estuary (Gulf of Guayaquil, Ecuador) impacted by anthropogenic influences

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ABSTRACT

Water and sediment quality, macrobenthos diversity and mercury levels were assessed in the Salado Estuary, Gulf of Guayaquil (Ecuador) during 2008, 2009 and 2014. Severe hypoxia, anoxia and large fluctuations of salinity occurred in an impacted sector within Guayaquil city relative to a mangrove area within the Salado Mangroves Faunal Production Reserve. Significant inter-site and temporal differences were observed for dissolved oxygen, salinity, total dissolved solids, percentage of silts and clays, and species diversity. Macrobenthos' species richness for both sectors was greater during 2008. Sediments revealed high concentrations of total mercury (THg) (1.20–2.76 mg kg^{-1} dw), exceeding Ecuador's SQG (0.1 mg kg^{-1} dw). Sediment THg were significantly lower in 2014 than 2008/09. Biota sediment sccumulation factor values for mussels (3.0 to 34), indicate high bioaccumulation potential from mercury-contaminated sediments. This work highlights the need to develop stronger environmental policies to protect the Salado Estuary from anthropogenic stressors.

1. Introduction

Estuarine ecosystems are natural systems that provide ecological and economical services to coastal communities (i.e., fisheries), critical nursery habitat and feeding grounds for many species of fish, crustaceans, molluscs and wading birds (Barbier et al., 2011; Cloern et al., 2016). Human activities in the watersheds around estuaries and the increasing demand for coastal resources, expose estuaries to anthropogenic contaminants and waste from industrial, agricultural and domestic sewage, which in turn, change the water chemistry, sediment quality, and the patterns of biodiversity of valued species that use these habitats (Gillet, 2003; Holland et al., 2004). The degree of watershed growth is also strongly correlated with fluctuations in water and sediment quality (i.e. dissolved oxygen (DO), pH, salinity, organic carbon content) (Fulton et al., 1993; Van Dolah et al., 1999; Calle, 2006; Clements and Rohr, 2009). Intertidal creeks are known for experiencing extreme fluctuations in environmental conditions, including salinity, DO, and temperature, and are the primary hydrologic link between non-point source pollution loadings and estuaries (Fulton et al., 1993; Holland et al., 1996). In Ecuador, estuaries are characterized by expansive intertidal and subtidal creeks within riverine mangroves (Monserrate and Medina, 2011) that have been severely affected by urban sprawl and growing industries, such that > 34 thousand ha of mangrove have been lost between 1984 and 2007 (CLIRSEN-PMRC, 2007). The Gulf of Guayaquil, which accounts for 80% of the total mangrove area of Ecuador, has been particularly hard hit. It harbors Guayaquil, a rapidly growing city of > 3.5 million inhabitants (Villacís and Carrillo, 2011) that constitutes the major center of industry and commerce in Ecuador.

Estuarine zones classified as urban and industrial by their watershed development, had significantly higher concentrations of organic and inorganic contaminants (Holland et al., 2004). One of the inorganic

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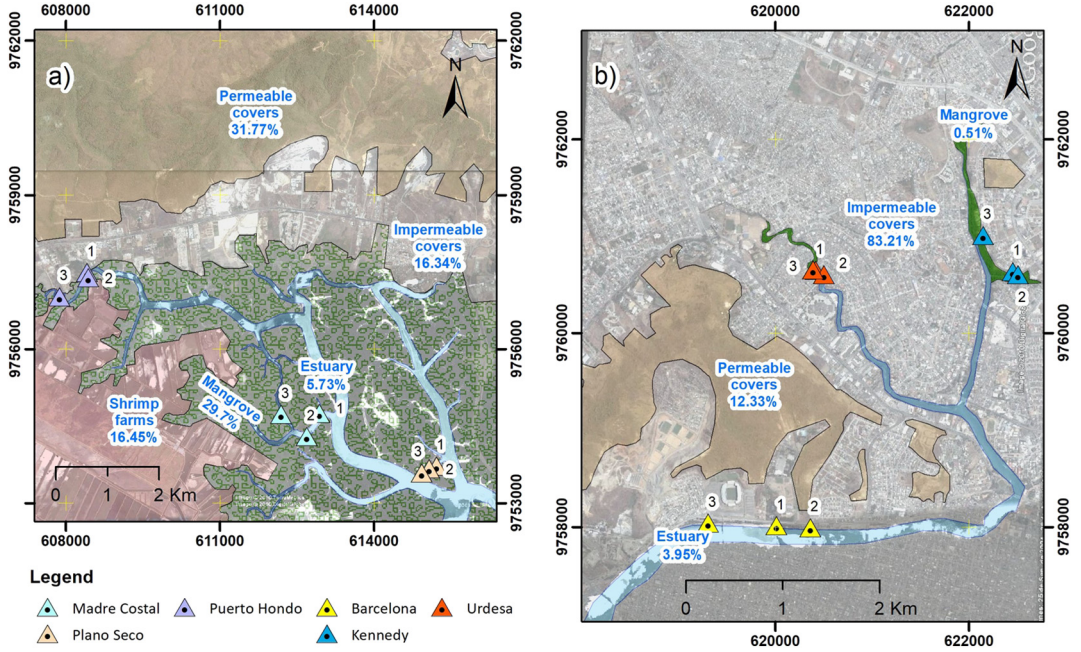

Fig. 1. Anthropogenic influences at the Salado Estuary and locations of sampling sites: a) sector of the Estuary within and in the Salado Mangroves Faunal Production Reserve Mangroves (RPFMS), where the green coverage depicts the remnants of mangrove forests in both the RPFMS, and around shrimp farms and urban settlements; b) sector of the Estuary (head of the Estuary) within the city boundaries of Guayaquil (SAC), in which a substantial area of land use and cover is dominated by impervious surface from urban and industrial settlements. Maps were modified from *Google Maps*, accessed December 15th 2010. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contaminants of concern is mercury (Hg) whose concentrations have increased globally as a result of industrial activities. Mercury has been known as a toxic and mobile contaminant that does not degrade in the environment, and it is very volatile with a long residence time in the atmosphere (Harris et al., 2007; Lindberg et al., 2007; Pacyna et al., 2016). In addition, Hg can be transported within air masses over very long distances far from an emission sources due to long-range atmospheric transport (Fitzgerald et al., 1998; Lindberg et al., 2007; Calle et al., 2015), and deposited in watersheds that play the role as sinks of atmospheric mercury (Grigal, 2002). Most Hg entering aquatic environments can be transformed by bacterial activity into its organic form, methylmercury (MeHg) (Hamdy and Noyes, 1975), and can be bioaccumulated in several organisms causing adverse effects on commercially and recreationally important species, such as shrimp, crabs, mussels, and fish (Scott et al., 1992; Diop et al., 2015; Zhang et al., 2017). Bivalves, including mussels have been used as indicators of coastal pollution in monitoring studies all over the world (Géret et al., 2002; Angelo et al., 2007; Cevik et al., 2008). Several studies have reported that mussels can bioaccumulate high concentrations of Hg and organic contaminants in their tissues (Domouhtsidou and Dimitriadis, 2000; Géret et al., 2002).

Despite several studies on macrobenthic fauna in the Gulf of Guayaquil (Villamar, 1989; Cruz, 1998; Cruz et al., 2003), there is little information about the diversity and abundance of the macrobenthos at the intertidal branches of the Salado Estuary, at either the head of the estuary (within the city of Guayaquil, SAC) or the Manglares El Salado Fauna Production Reserve (RPFMS) (Cruz, 1998; Twilley et al., 2001; Carvajal et al., 2006). Differences in the kind and abundance of macrobenthic organisms, between developed and undeveloped areas associated to agricultural, industrial and urban sprawl, have consistently proven to be a sensitive and integrative indicator of anthropogenic stress to estuarine systems, including tidal creeks (Pawhestri et al., 2015; Salcedo et al., 2017). Additionally, the community responses to envrironmental pollutants may vary depending on the specific chemicals and some species may be more tolerant than others (Diaz and Rosenberg, 1995; Bellante et al., 2016). Particularly, some oligochaetes and polychaetes have been used as environmental sentinels for estuarine ecosystem health based on their response to stress (Horne et al., 1999; Calle, 2006; Dean, 2008; Dauvin et al., 2016). In this context, an assessment of mercury and environmental quality conditions of the Salado Estuary is important to establish a mercury baseline and possible biological indicators of tolerance for this estuary. Therefore, the goals of this research were to determine: a) if the two sectors of the Salado Estuary the SAC and the RPFMS differ in environmental conditions between 2008 and 2009; b) if the distribution and abundances of macrobenthos are affected by the quality conditions of the Salado Estuary; c) if the concentration of total mercury is exceeding sediment quality guidelines; d) if the concentration of total mercury (THg) at Puerto Hondo varies temporally between 2008/09 and 2014; and e) the biota sediment bioaccumulation factors (BSAFs) using mussels (*Mytella strigata*).

2. Materials and methods

2.1. Study area

The Salado Estuary (SE, hereafter), is part of the Gulf of Guayaquil in South America, and is located west of the Guayas River, in the western reaches the Gulf of Guayaquil. The SE is 60 km in length and brings water from the Gulf to the city of Guayaquil. Its mouth at "El Morro Channel" is 3 km wide and forms several branches, secondary creeks and islands. Some of these branches located in the western portion of the main branch of the SE constitute the "Manglares El Salado Fauna Production Reserve" (known in Spanish as RPFMS) (Carvajal et al., 2006). Its main branch forms several small creeks that enter into the city of Guayaquil. This estuary at the city of Guayaquil (head of the estuary) used to be a place for recreation; a park where people could swim safely. However, human development of the land and the rapid growth of the city over the last 80 years have severely degraded its water and sediment quality (Twilley et al., 2001).

The SE was divided in two sectors: the head of the estuary, located within the city of Guayaquil (SAC), and the area within the RPFMS