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Historical economic and environmental policies influencing trace metal inputs in Montevideo Bay, Río de la Plata

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ABSTRACT

Montevideo Bay is located in the middle zone of the Rio de la Plata, and since the foundation of the city, several key economic and environmental policies affected the industry, and thus, metal inputs into this ecosystem. The aim of this study is to evaluate the sedimentary geochemical record of Montevideo Bay, in order to determine the historical inputs of anthropogenic metals to the system. In addition, environmental and economic policies of the country were taken into account to infer the relationship between them and the historic metal input. Concentrations of aluminum, chromium, copper, lead, scandium and zinc were analyzed and the EF and SPI indices were calculated. The analysis showed that since Montevideo foundation, metal concentrations increased in accordance with industry development, and the indices as well as the metal concentration represent a reliable footprint of the history of different economic and environmental policies influencing historical industrial activities.

1. Introduction

Estuaries are semi-enclosed coastal systems connected to the ocean and influenced by tides and the exchange of oceanic and freshwater from river discharges (McLusky & Elliot, 2004). In addition, these systems are subject to constant anthropogenic pressure, with population settlements on their coasts that grow faster than the world population of other eco-regions (Borja et al., 2012; Jordan, 2012). As a consequence, anthropogenic activities such as energy production, fisheries, and tourism among others, estuaries receive river inputs, urban and industrial effluents with sediments and pollutants that commonly lead to severe environmental degradation (McLusky & Elliot, 2004; Simpson et al., 2005; Borja et al., 2012; Jordan, 2012).

Sediments are the ultimate fate of most of the contaminants, thus becoming a source of pollution to the environment (Burton, 2002; Simpson et al., 2005). In particular, trace metals are significantly more abundant in the sediments since most of them are cations, and since sedimentary organic matter and clay exhibit a net negative charge, metals are adsorbed by the sediment (Horowitz 1985). There are several sources of these contaminants, such as mining/industrial activities, sewage sludge, pesticides, smelters and leaded gasoline and paints (Luoma & Rainbow, 2008; Wuana & Okieimen, 2011). In this sense, trace metals can be used as proxies for inferring human-induced change as an indicator of biological stress related to contaminants and ecosystem health (Du Laing, 2011; Birch, 2011), In contaminated sites, the most commonly found metals are cadmium (Cd), copper (Cu), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn). All above mentioned elements accumulate in sediments, are toxic and exert a potential effect on biological processes (Wuana & Okieimen, 2011; Luoma & Rainbow, 2008).

Montevideo Bay is a coastal system affected by several activities and industrial facilities such as the ANCAP-La Teja oil refinery, Batlle-UTE thermoelectric power plant and Montevideo harbor. Its main tributaries are Pantanoso, Miguelete and Seco streams (the latter currently flowing through an underground pipe). All systems are highly impacted by domestic and industrial effluents without treatment and solid waste disposal. Several studies classified this coastal system as highly degraded, especially the inner bay area with high levels of Cr, Pb and petroleum hydrocarbons in its sediments (Danulat et al., 2002; Gautreau, 2006; Muniz et al., 2002, 2004, 2006, 2015; Venturini et al., 2015). In addition, other historical studies reported high metal concentrations in sediment cores collected at the mouth of Miguelete and Pantanoso streams (Cranston & Kurucz, 2002; García-Rodríguez et al., 2010; Burone et al., 2011).

The aim of this study is to evaluate the geochemical record of the sedimentary column of Montevideo Bay, in order to determine the historic inputs of metals in the area and assess the environmental degradation evolved from such anthropogenic impacts. Consequently, concentrations of Al, Cr, Cu, Pb, Sc and Zn were analyzed. In addition, the Enrichment Factor (EF) (Szefer et al., 1998) and Sediment Pollution Index (SPI) (Singh et al., 2002) were calculated in order to establish the relationship between the environmental and economic policies of the country and the historical metal inputs.

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2. Material and methods

2.1. Study area

Montevideo Bay (34°52′18″ - 34°55′48″ S, 56°11′48″ - 56°14′42″ W) is located on the north coast of the Río de la Plata which is contained into the second largest river basin of South America (Fig. 1).

The first Spanish navigators considered Montevideo Bay as the natural harbor of the "New Continent". Despite this, due to the lack of metal wealth, the condition of city-harbor was explicitly denied when Montevideo was founded (between 1724 and 1726). After 1778, when free-trade was first decreed Montevideo harbor was recognized as such, and import/export of goods was only then allowed, although it had already been used by locals to market leather products clandestinely (Baracchini & Altezor, 2010). Thereafter, several key-events affected the dynamics and environmental conditions of Montevideo Bay (Table 1).

2.2. Collection of samples

In May 2010, a 149 cm long core (BAT 1) was collected with a 63 mm. internal diameter piston in the inner area of Montevideo Bay (near the Batlle thermoelectric power facility and Montevideo harbor) (Fig. 1). The core was longitudinally sectioned every 1 cm. and samples were preserved in the Oceanography and Marine Ecology Lab of Facultad de Ciencias, UdelaR.

2.3. Sedimentation rate

The sedimentation rate was determined based on unsupported ^{210}Pb activities using the CIC (Constant Initial Concentration) model (Appleby & Oldfield, 1978; Joshi and Shukla, 1991), and validated with ^{137}Cs data. In this sense, approximately 10 g of sediment were transferred into air-sealed cylindrical polyethylene containers for gamma counting in an EG&G ORTEC® low-background gamma spectrometer (hyperpure Ge, model GMX25190P).

The sedimentation rate was calculated using the following formula:

$$S = (\lambda \cdot D)/\mathrm{Ln}\left[\left(C_0{}^{210}\mathrm{Pb}\right)/\left(C^{210}\mathrm{Pb}\right)\right]$$

where S: sedimentation rate in $cm \cdot yr^{-1}$; λ: radioactive decay constant of ^{210}Pb (0.31076); D: distance between the core-top and the measured interval (cm); C_0^{210}Pb: count of unsupported ^{210}Pb at the core-top; C^{210}Pb: unsupported ^{210}Pb at the measured stratum.

Table 1
Chronology of events that influenced the dynamics and environmental conditions of Montevideo Bay.
Sources: Nahum, 1999; Baracchini & Altezor (2010), Burone et al. (2011), Muniz et al., 2011.

1781	First dock construction in Montevideo Bay
1834–1860	Proposals for managing industrial settlement in Montevideo (harmful to public health)
1839–1851	Uruguayan civil war ("Guerra Grande"). The port infrastructure built in Montevideo Bay surpasses all the work done in the area since the city foundation.
1870–1914	Beginning of the second industrial revolution. Changes in energy sources (replacement of steam for electricity and petroleum products), and new materials with the use of different metals
1901–1909	Montevideo harbor construction
1917–1930	Industrial exchange. Salting industry is replaced by the meat-packing industry and leather tanneries emerge in Miguelete and Pantanoso basins.
1930–1936	Construction of La Teja oil refinery and thermoelectric power station "José Batlle y Ordóñez". Both industries located on Montevideo Bay margin.
1947–1953	*Neobatllismo*. Boom of the ISI model (Import Substitution Industrialization). State lead economic development through nationalization, subsidization for national firms, increased taxation, and highly protectionist trade policies. Little international trade.
1973	End of ISI model. Beginning of Uruguayan dictatorship.
1980	Controls for the industrial waste disposal to the environment
2000	Important decrease in the leather industry since 2000
2004	Law 17.775 – gasoline and paint lead free.

The quality control of the method was evaluated through the determination of the radionuclides of interest (^{210}Pb, ^{226}Ra and ^{137}Cs) in three certified reference materials: IAEA-326 (soil), IAEA-327 (soil) and IAEA-385 (marine sediment).

2.4. Metal determination

Analyses were performed at the Marine Inorganic Chemistry Laboratory of the Oceanographic Institute at São Paulo University (IO-USP). The concentration of Al, Cr, Cu, Pb, Sc and Zn was determined using the partial digestion method USEPA 3050B (USEPA 1996). The method consists of a strong acid digestion with HNO_3 at high temperature and the addition of H_20_2 for the organic matter elimination. Then, the solution was filtered and diluted to 50 ml to be analyzed with a Varian Vista MPXICP-OES. For the analysis of Al, samples were diluted 1 to 100. Method accuracy was determined by analyzing the certificated reference material SS-2 EnviroMAT. Values obtained for the reference

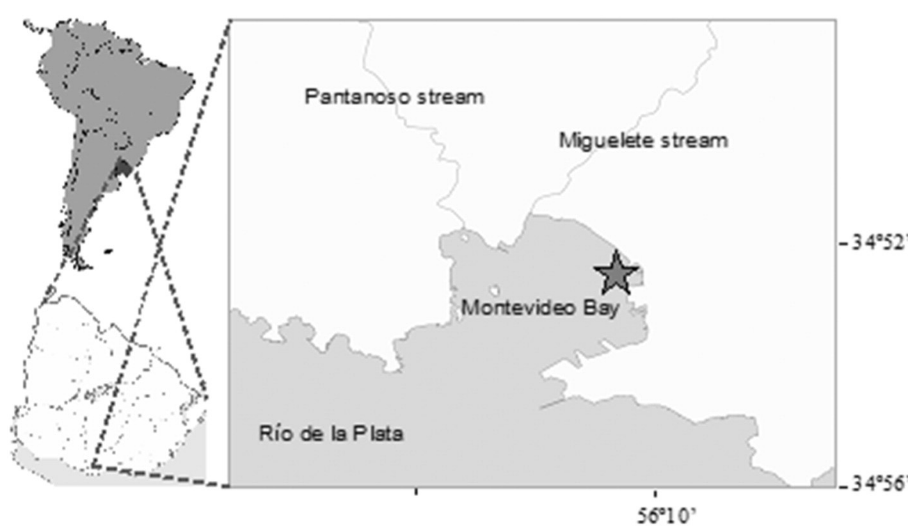

Fig. 1. Study area. The star indicates coring station in Montevideo Bay.

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