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Assessment of the health quality of Ria de Aveiro (Portugal): Heavy metals and benthic foraminifera

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ABSTRACT

This work analyses the distribution of heavy metals in the sediments of Ria de Aveiro (Portugal) assessed by total digestion and sequential chemical extraction of the sediments. The influence of environmental parameters on the living benthic foraminiferal assemblages was studied. The most polluted parts in the Ria de Aveiro are areas where the residence time is high and cohesive sediments are deposited. Organic matter, which is an excellent scavenger for a number of metals, is in general more abundant in the finer deposits of this lagoon, which act as sinks of anthropogenic pollutants. This condition is observed in Aveiro canals and Murtosa channel where sediments with the highest concentrations of Zn, Pb, Cu, and Cr are found. The sediments of Murtosa channel are also enriched in As, Co and Hg. In Aveiro canals the enrichment of heavy metals is mostly related to the past industrial production at their margins (ceramic and metallurgy), whereas in Murtosa channel with effluent discharges of the Chemical Complex of Estarreja. Foraminiferal density and diversity reach higher values near the lagoon mouth under higher marine influence and decline in general under very low-oxygen conditions. Some species seems to be indifferent to the increasing of TOC (e.g. *Haynesina germanica* and *Ammonia tepida*) and some have an opportunistic behaviour in areas with very depressed levels of oxygen (e.g. *A. tepida* and *Quinqueloculina seminulum*) whereas other species can better tolerate sulphide/reducing conditions (e.g. *H. germanica*, *Bolivina ordinaria*, *Buliminella elegantissima*, *Bulimina elongata/gibba* and *Nonionella stella*) a widespread condition in this lagoon. Foraminiferal density and some species are negatively correlated with concentrations of heavy metals. A most sensitive group of species to higher concentrations of heavy metals is identified (such as *B. ordinaria*, *B. pseudoplicata* and *B. elongata/gibba*) and another one of more tolerant species (such as *H. germanica A. tepida* and *Q. seminulum*). Foraminifera are more tolerate higher available concentrations (AC) of Zn in any phase than higher AC of Cu adsorbed do clay minerals (F1) and associated with Fe and Mn oxides (F2) and of Pb in F2; the phase F2, probably the most mobile phase, and even phase F1 seems to be more toxic than the increasing of metals in organic matter (F3).

1. Introduction

1.1. Study area

The Ria de Aveiro is a temperate, coastal lagoon located on the NW coast of Iberian Peninsula (Fig. 1). It is connected with the Atlantic Ocean through an artificial inlet opened in 1808. Its

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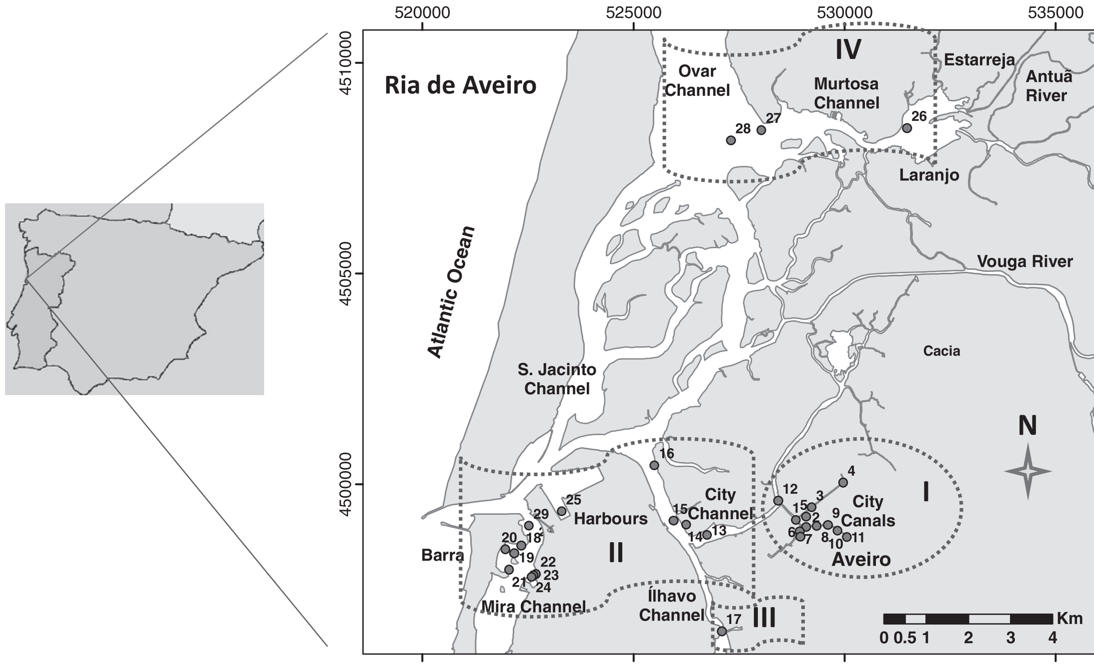

Fig. 1. The study area in Ria de Aveiro. Sampling sites are signed as well as the main study lagoonal zones: (I) in the City canals; (II) in Aveiro harbour area, near the lagoon mouth; (III) in Ílhavo channel, near the Vista Alegre plant; (IV) and in Murtosa channel.

dimensions are 45 km long and 10 km wide and it covers an area between ~66 and ~83 km^2, at low and high tide (spring tide), respectively (Dias et al., 2000). The lagoon is composed of several large channels, such as S. Jacinto, Ílhavo, Mira, City, Ovar, and Murtosa, and by a complex network of branches, bays and narrow channels. Two main rivers supply freshwater to the lagoon: Vouga (50 m^3/s) and Antuã (5 m^3/s, average flow) rivers (Moreira et al., 1993). Furthermore, other small rivers such as Boco river, in the southern of the Ílhavo channel, and the Caster river, in the northern of the S. Jacinto channel also contribute in the overall freshwater budget (Dias et al., 2000). The influence of rivers is higher in the northern and inner parts of the lagoon (Vaz and Dias, 2008). The water depth is generally lower than 3 m, and in the northern part of the lagoon close to 1 m (Lopes et al., 2006). The deepest areas correspond to the inlet and close to the lagoon's mouth, at its western boundary, where the water depths may reach 20 m. The water circulation in the lagoon is tide-dominated and mainly influenced by the lunar semi-diurnal constituent (M2), with 88% of the total tidal energy (Dias, 2001). The mean tidal range is approximately 2.0 m, with minimum tidal range of 0.6 m (neap tides) and the maximum tidal range of about 3.2 m (spring tides) (Dias et al., 1999). The tidal currents velocities, near the mouth, can be higher than 2 m/s (Dias et al., 2000; Vaz and Dias, 2008) but they are weak in the many innermost small canals and mudflats. Nevertheless, the lagoon can be considered, in general, a well-mixed system (Dias et al., 1999). The population living around the lagoon and its channels is over 250,000 inhabitants that entails the generation of large amount of wastes and worse the environmental quality of the lagoon itself. Pastorinho et al. (2012) have considered the Ria de Aveiro as a mildly polluted lagoon with localized areas of intense pollution.

1.2. Benthic foraminiferal responses to coastal pollution

Degradation of the coastal ecosystem due to anthropic activities is a worldwide environmental concern. The success of any pollution control and natural resource management strategy in the coastal zone is linked to the use of a comprehensive and inexpensive monitoring method. The European Union's Water Framework Directive (MSFD) aims to achieve a good ecological status in all European water bodies (i.e., rivers, lakes and coastal waters) by 2020 and requires that the assessment of the ecological status of a system be accomplished primarily utilizing biological indicators (bioindicators). Among these bioindicators, benthic foraminifera are among the most abundant microorganisms found in the surface sediments in the shallow and marginal marine environments; they are very sensitive to environmental changes and can provide information about the heath quality of the ecosystem where they inhabit (Schönfeld et al., 2012). Benthic foraminifera have been therefore widely applied as bio-indicators of pollution in a wide range of marine and transitional marine environments (for reviews see: Alve, 1991, 1995; Yanko et al., 1994, 1999; Martin, 2000). Studies of pollution effect on benthic foraminifera and their possible use as pollution indicators begun in the early 1960s by Resig (1960), Zalesny (1959) and Watkins (1961). During the last four decades, many studies have addressed the response of benthic foraminifera to heavy metal pollution (Armynot du Châtelet and Debenay, 2010; Frontalini and Coccioni, 2011).

It has been suggested that the disturbance of coastal environments caused by oil, sewage, garbage, pesticides, toxic chemicals, heavy metals, radioactive wastes, thermal, dredging, coolants and fertilizers can affect foraminiferal assemblages by modifying their community structure and specimen's morphology and cytology and test chemistry (Yanko et al., 1999). Faunal assemblages rather than individual species of foraminifera might be diagnostic environmental bioindicators. Foraminifera respond to pollution as well as to the environmental gradients (i.e., salinity) and stress (i.e., fluctuations of physico-chemical water parameters) either by changes in the density and diversity of the assemblage or by changes in the assemblage composition.

Increasing in metals concentrations may lead to (1) increasing delay before production of new chambers, explaining dwarfism in polluted areas; (2) increasing delay before reproduction and decreasing number of juveniles, explaining low density; and (3) increasing proportion of deformed tests (Le Cadre and Debenay, 2006). While building up their tests, benthic foraminifera selectively consume metallic ions present in the surrounding water and sediments or together with food (Yanko et al., 1998; Lea and