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Abundance and distribution of benthic foraminifera as indicators of the quality of the sedimentary environment in a subtropical lagoon, Gulf of California

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ABSTRACT

Abundance and spatial distribution of benthic foraminifera were used to evaluate the impacts of anthropogenic activities on sediment quality in a coastal lagoon in the Gulf of California. In 1985 and 2013, 27 samples of superficial sediments were collected. The foraminifera genera *Ammonia*, *Cribroelphidium*, *Quinqueloculina* and *Peneroplis* were dominant in both years. The abundance of *Ammonia* increased from 41% to 60%, while *Peneroplis* abundance decreased from a maximum of 50% in 1985 to 7% in 2013. The greater abundance of *Ammonia* and the greater spatial coverage of *Ammonia* and *Cribroelphidium* suggest a marked environmental deterioration in the quality of the sedimentary environment, which contrasts with studies of trace elements in the sediment of this lagoon. The Foram Stress Index indicates that sediment quality has deteriorated over time, likely due to the effects of anthropogenic activities around the lagoon.

1. Introduction

Benthic foraminifera occur from the abyssal ocean to the intertidal coastal zone. The distribution, diversity and abundance of benthic Foraminifera are dependent on environmental parameters that determine their ecology (Murray, 2006). Urban development and consequent anthropogenic waste discharge (characterised by innumerable organic and inorganic substances) to the coastal zone have generated environmental pressure that modifies the distribution and association of benthic communities (e.g., Martins et al., 2016; Paquette et al., 2016; Dimiza et al., 2016; Musco et al., 2017; Tadir et al., 2017).

Benthic foraminifera are an excellent tool that can be used as an environmental tracer because of their adaptability and rapid response to anthropogenic waste discharge (Donnici et al., 2012; Martins et al., 2016; Dimiza et al., 2016; Paquette et al., 2016; Musco et al., 2017; Tadir et al., 2017). The degree of impact on the benthic environment may be reflected by changes in dominance, abundance and distribution of benthic foraminifera (e.g., Martins et al., 2016). In this sense, a temporal and spatial analysis of the distribution of benthic foraminifera (genera or species) and their relationship with abiotic and biotic parameters allows the identification of the locations and extent of anthropogenic impacts. Although there are countless global studies of benthic foraminifera in marine-terrestrial transitional environments (e.g., Tadir et al., 2017 and cited here), few studies have compared baseline conditions to human activity impacts in coastal zones (e.g., Thomas et al., 2000; Tsujimoto et al., 2006; Carnahan et al., 2009; Martins et al., 2013).

The lagoon of La Paz is an ecologically important habitat due to its endemic and commercially important species (Steinitz et al., 2006). The lagoon is located within the bay of La Paz, one of the most productive marine systems in the Gulf of California (Lluch-Belda et al., 2003). The population in the city of La Paz has increased by 140% (from 121,140 in 1980 to 290,288 in 2010), with a resulting increase in the demand for goods and services. Consequently, environmental pressure and deterioration of the lagoon have increased. We compared the dominance of benthic foraminifera genera collected in 1985 (Segura-Vernis and Carreño, 1991) and current data to evaluate changes in their abundance and temporal and spatial distributions. In addition, we applied the Foram Stress Index (FSI) to determine the degree to which the quality of the benthic environment has deteriorated in this subtropical lagoon over the past few decades.

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1.1. Study area

The lagoon of La Paz is relatively shallow, with an average depth of 2 m and a maximum depth of 8 m. The lagoon experiences temperatures ranging from 18 to 32 °C and surface salinities ranging from 33.5–39 from the winter to the summer. Annual gradients in temperature (14 °C) and surface salinity (8.5) are similar to those in other subtropical lagoons (Lankford, 1977). The salinity changes in the lagoon are isolated and regularly occurring because runoff is confined to the tropical stormy season during the summer.

The hydrodynamic conditions of the La Paz lagoon have been described by Obeso Niebla et al. (1993), Gómez Valdés et al. (2003), and Valle-Levinson et al. (2009). Residual tidal currents reach maximum speeds of ~6 cm s^{-1} in the main channel of the lagoon (Valle-Levinson et al., 2009) and flow towards the interior of the lagoon in the south margin and then out of the lagoon in the north margin, forming a cyclonic gyre. In the interior of the lagoon, there is an anticyclonic gyre in the southern margin and central part of the lagoon and a cyclonic gyre in the deeper region in the northern part of the lagoon. In both cases, residual tidal velocities are < 1 cm s^{-1} and increase to < 3 cm s^{-1} towards the central part of the lagoon (Gómez Valdés et al., 2003).

The distribution of the surface sediments describes two sediment textural groups in the lagoon: (1) muds located in the southern margin and central zone and (2) sands restricted to the channel and to the north margin of lagoon (Fig. 1; Green-Ruiz and Larrínaga-Cunningham, 1986; Pérez-Tribouillier, 2014). The distribution of the textural groups corresponds to the magnitudes of residual tidal velocities, except the northern margin of the lagoon where these velocities are < 1 cm s^{-1} and do not correspond to the grain size of medium to fine sands (e.g., Yordanova and Hohenegger, 2007). However, the sandy sediments of the northern margin of the lagoon originate from the coastal dunes of the sand bar of El Mogote (Fig. 1).

The distribution of mud has remained similar from 1985 and 2013 (Green-Ruiz and Larrínaga-Cunningham, 1986; Pérez-Tribouillier, 2014). Mud sediments are confined to the southern margin and inner-central part of the lagoon (segmented lines, Fig. 1). The spatial distribution of the organic carbon content (Fig. 2) is similar to the distribution of mud sediments, although the relative percentage of organic carbon has increased from 1985 to 2013 (0.03–0.89% for 1985, Green-Ruiz and Larrínaga-Cunningham, 1986; 0.30–2.2% for 1995, Méndez et al., 1998; 0.06–3.0% for 1996, Shumilin et al., 2001; and 0.12–6.9% for 2013, Pérez-Tribouillier, 2014).

Trace element concentrations (As, Cu, Cd, Pb, Se, Sb and Zn) in surface sediments remained unchanged for Sb (0.02–5.0 mg kg^{-1} and 0.1–5.2 mg kg^{-1}) and Zn (2.5–125 mg kg^{-1} and 9.8–120 mg kg^{-1}) in 1995 and 2013, respectively (Méndez et al., 1998; Shumilin et al., 2001; Pérez-Tribouillier et al., 2015). However, concentrations of As (0.83–44.4 mg kg^{-1} and 1.2–29.1 mg kg^{-1}), Cd (1.96–5.73 mg kg^{-1} and 0.12–1.2 mg kg^{-1}) and Pb (23.8–89 mg kg^{-1} and 3.5–36.8 mgkg^{-1}) decreased within the same period (1995–2013), while Cu levels (2.5–30.44 mgkg^{-1} and 2.6–70.2 mg kg^{-1}) increased (Méndez et al., 1998; Shumilin et al., 2001; Pérez-Tribouillier et al., 2015). The spatial distribution of As, Cd, Pb, Sb and Zn concentrations in the sediments was similar between 1996 and 2013, whereas that of Cu was greater in 2013 than in 1996 (Fig. 3).

2. Materials and methods

Sediments were collected on-board the vessel CICIMAR XII from 27 surface sampling stations in the La Paz lagoon during February 2013 (Fig. 1). All stations were georeferenced with GPS. To enable comparisons of foraminifera abundance and distribution, sampling sites were identical to those used in 1985 by Segura-Vernis and Carreño (1991). Samples were collected by free diving using a 25-ml polycarbonate tube. We only sampled the first centimetre of the surface sediment, until the 25-ml tube was full.

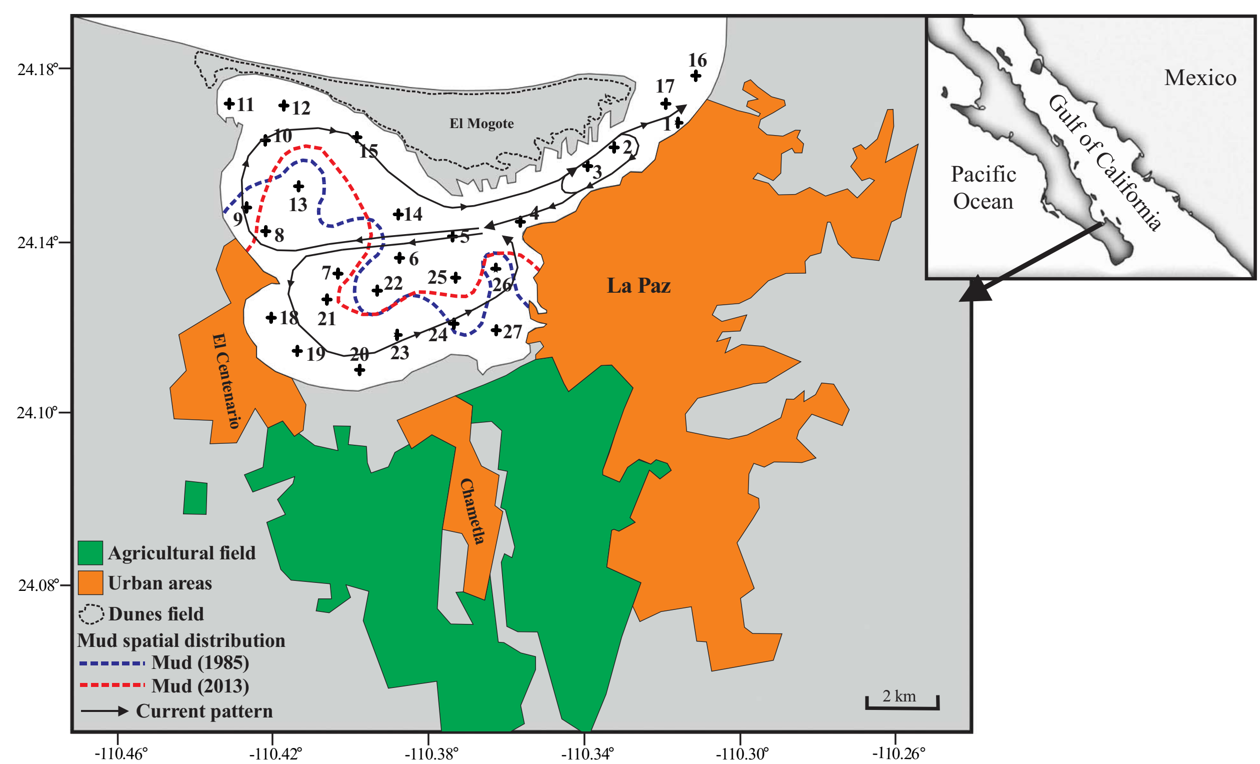

Fig. 1. Map of study area. Surface sediments collected from 27 sampling stations in 1985 and 2013. Green areas: agricultural fields. Orange areas: urban areas of La Paz and villages (Chametla and El Centenario). The segmented lines represent mud: blue segmented line - 1985 (Green-Ruiz and Larrínaga-Cunningham, 1986) and red segmented line - 2013 (Pérez-Tribouillier, 2014). Pattern of residual tidal currents: lines with arrowheads (Obeso Niebla et al., 1993; Gómez Valdés et al., 2003; Valle-Levinson et al., 2009). Field dunes: black segmented line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)