Quaternary Science Reviews 160 (2017) 138–149

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Sedimentary record of recent climate impacts on an insular coastal lagoon in the Gulf of California

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ARTICLE INFO

Article history:
Received 17 October 2016
Received in revised form
21 December 2016
Accepted 2 January 2017

Keywords:
Gulf of California
Climate variability
Coastal lagoon sediments
^{210}Pb dating
Anthropocene
Inorganic geochemistry

ABSTRACT

Sedimentary records are useful to evaluate environmental changes, either from natural or anthropogenic causes, such as global and climate change. The recent changes in accumulation rates and geochemical characteristics (grain size distribution, elemental composition, organic carbon and carbonate concentrations) recorded in a sediment core from San Jose Island Lagoon (SJIL, Gulf of California) were evaluated to determine its relationship with anthropogenic impacts and climatic variability. The ^{210}Pb-derived chronology was corroborated with $^{239+240}$Pu and ^{137}Cs stratigraphic markers. The mass accumulation rate increased up to ~3 times during the past ~100 years (0.16 ± 0.03 to 0.51 ± 0.06 g cm^{-2} yr^{-1}). The contents of terrigenous and marine (salinity) indicator elements, as well as fine-grained sediments, also increased considerably, although no anthropization evidences were observed; indeed, the enrichment factor of trace elements indicated that the ecosystem is still a pristine environment. By using multivariate statistical techniques, we inferred that the larger input of fine-grained terrigenous sediments could be related to the enhancement of soil erosion from the catchment, under the influence of higher rainfall rates, especially during the last 20 years. In addition, the higher concentrations of salinity indicator elements most likely resulted from higher evaporation rates in the lagoon, caused by higher minimum atmospheric temperatures. We concluded that recent climate variability has become the main driver for sedimentary geochemical changes in San Jose Island Lagoon. These observations confirmed the usefulness of ^{210}Pb-dated geochemical sediment records to study the impacts of recent climate variability where long-term environmental data is scarce or non-existent.

1. Introduction

Sedimentary records are environmental archives commonly used to reconstruct anthropogenic impacts and past climatic conditions. ^{210}Pb is a natural radionuclide, member of the ^{238}U radioactive series, which is widely used to date sediments deposited over the last 100–150 years to document the impacts of global change (e.g., pollution, sea level rise, eutrophication; Ruiz-Fernández et al., 2014).

Globally, humans are leaving a stratigraphic signature in sediments owing to the increasing use of metals and minerals, fossil fuels, agricultural fertilizers, and transformation of land and nearshore, leading to the establishment of a new geological time unit known as Anthropocene (Waters et al., 2016). In the tropical Eastern Pacific and Western Atlantic, sedimentary cores have been used to show increasing trends of sediment accumulation rates and pollutants during the 1970s–1980s, related to human activities such as industrial and urban development, and landscape disturbances such as agriculture (Santschi et al., 2001; Ruiz-Fernández et al., 2009, 2012; Díaz-Asencio et al., 2014; Aronson et al., 2014).

Coastal lagoons are among the most productive marine systems and one of the most heavily impacted aquatic ecosystems on Earth, mainly due to population growth (Kennish and Paerl, 2010). In 2015 the world population was ~7.3 billion people (UN, 2015) and in 2000 about 30% of global population inhabited in low elevation

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http://dx.doi.org/10.1016/j.quascirev.2017.01.002
0277-3791/

coastal zones (<10 m of altitude; Neumann et al., 2015).

In Mexico, sedimentary reconstructions of recent environmental conditions of coastal lagoons are scarce and include some lagoons in the states of Sinaloa (Ruiz-Fernández et al., 2002, 2003), Veracruz (Ruiz-Fernández et al., 2012, 2014) and the Gulf of Tehuantepec (Ruiz-Fernández et al., 2004, 2009). In general, sedimentary records show sediment supply changes as a consequence of land use change due to deforestation, industrialization and urbanization in the coastal area. Activities such as land clearing, water impoundment and agriculture fertilization also affect fluxes of nutrients (e.g., Ohuira Lagoon, Sinaloa; Ruiz-Fernández et al., 2009) and metals (Gulf of Tehuantepec, Ruiz-Fernández et al., 2004). However, natural stressors can also exacerbate ecosystems degradation, especially hurricanes and major storms which can significantly increase coastal erosion and flooding (Kennish and Paerl, 2010).

The Gulf of California is complex in terms of climate variability, as it is located between tropical and subtropical climate regimes (Páez-Osuna et al., 2016). This region is highly impacted by tropical cyclones that can contribute with 20–69% of the annual rainfall (Latorre and Penilla, 1988; Farfán et al., 2013) and sedimentation rates can be tripled during these events (Silverberg et al., 2007). Climatic conditions in this large marine ecosystem are influenced by large-scale variability such as El Niño and La Niña events (ENSO; Farfán et al., 2013). In this study we assessed the recent changes in accumulation rates and geochemical properties of a sediment core from the Gulf of California in relation with climatic parameters.

2. Regional setting

San Jose Island (SJI) is located in the southwestern part of the Gulf of California (24° 52′– 25° 06′ N; 110° 43′ – 110° 35′ W). This work was carried out in a semi-enclosed lagoon of about 86 ha (24°52′29.7″ N, 110°33′3.3″ W; Fig. 1), bordered landward by mangroves and seaward by a narrow sand bar. It is connected to the sea by a long and narrow channel at the north-northwest, and a small intermittent outlet at the southwest (Morquecho, 2008; Morquecho et al., 2012). The maximum lagoon water depth ranges from 0.3 m in the west to 8 m in the east. The climate in the study area is warm and very arid, with mean annual air temperatures ranging from 13.7 °C to 31.0 °C, with a well-defined rainy season from July to October (Ruiz et al., 2006) which accounts for a mean annual rainfall between 125 and 400 mm and an annual evaporation between 2000 and 2200 mm (UNAM, 1990). Surface water temperature ranges from 16.5 to 32.0 °C, and salinity ranges from 34.6 to 34.9 (Montoya-Campos, 2009; Sotelo, 2014). Mesotrophic and temporal eutrophic conditions are observed during dry months, when temperatures are low and upwelling processes occur (Quezada, 2008). SJI is dominated by Cretaceous granite (Puy-Alquiza, 1992) but in the lagoon area granite is overlain by volcanic and sedimentary rocks of the Oligocene- Miocene Comondú Group (Umhoefer et al., 2001, 2007).

SJI is occupied by only about 70 inhabitants established in the northern part (Espinosa-Gayosso and Alvarez-Castañeda, 2006). Between the late 18th century and the early 19th century, salt extraction was an important activity in SJI, and there are still traces of gold and silver extraction (CONANP, 2002). Since 1978, SJI is a natural protected area and the main economic activities are local fishing and ecotourism (Morquecho, 2008; Morquecho et al., 2012).

3. Materials and methods

3.1. Sampling

A push sediment core (San Jose core) was collected by scuba

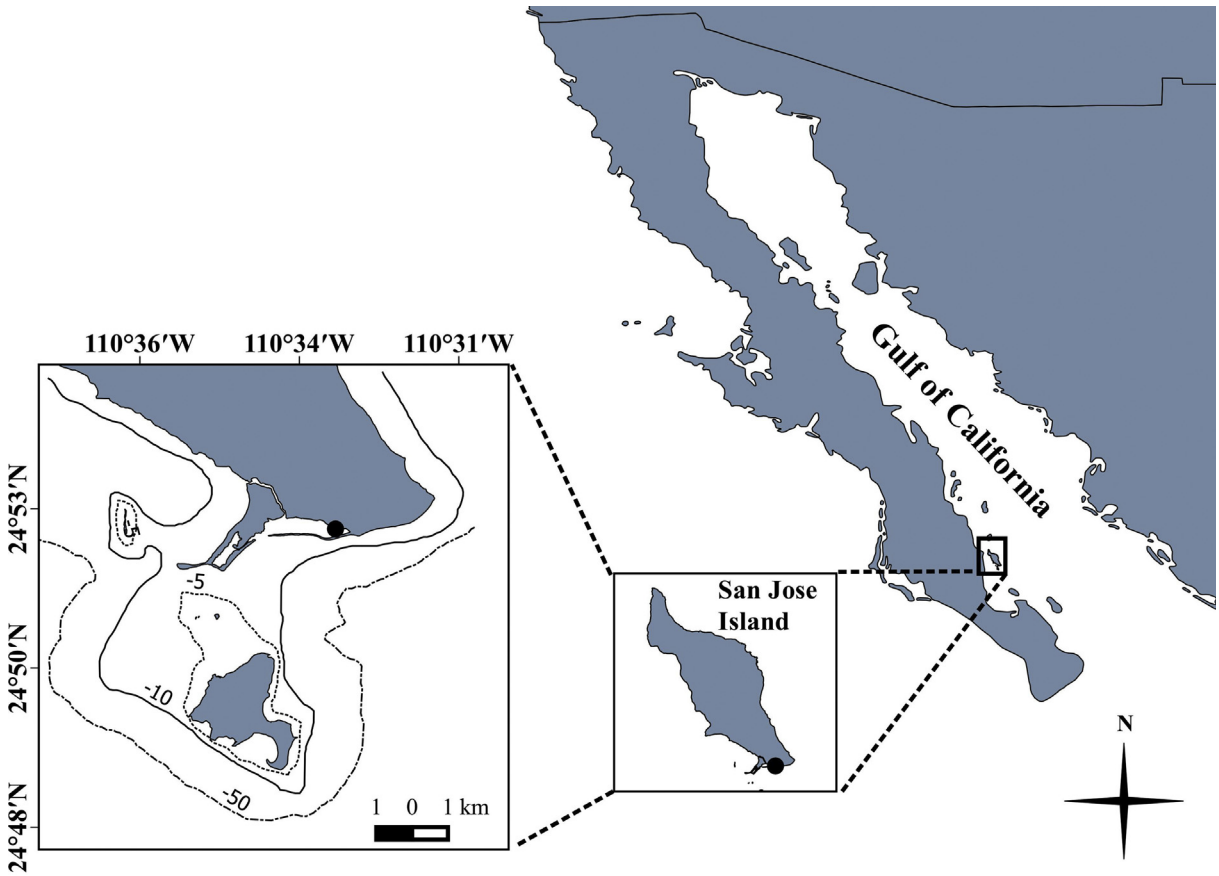

Fig. 1. San Jose Island and sediment core collection site (●). Isobaths are in meters.