Chemosphere 184 (2017) 224–234

Contents lists available at ScienceDirect

Chemosphere

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

Comparative evaluation of sea-urchin larval stage sensitivity to ocean acidification

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HIGHLIGHTS

- CO_2-induced acidification changes the metal mobility from Brazilian and Spanish sediments.
- The pH reduction causes effects on embryo-larval development of sea urchins.
- The tropical sea urchin *Lytechinus variegatus* shows to be more tolerant to ocean acidification than *Paracentrutos lividus*.
- The $ICpH_{50}$ for the embryo-larval development was ranged from pH 7.30 to 6.79.
- The As dissolved in the elutriate sediment was correlated with the pH reduction and toxicity of the sediment.

ARTICLE INFO

Article history:
Received 14 March 2017
Received in revised form
16 May 2017
Accepted 1 June 2017
Available online 6 June 2017

Handling Editor: Jim Lazorchak

Keywords:
CO_2 enrichment
Paracentrutos lividus
Lytechinus variegatus
Toxicity tests
Metal mobility

ABSTRACT

Changes in the marine carbonate system may affect various calcifying organisms. This study is aimed to compare the sensitivity of embryo-larval development of two species of sea urchins (*Paracentrutos lividus* and *Lytechinus variegatus*) collected and exposed to samples from different coastal zone (Spain and Brazil) to ocean acidification. The results showed that the larval stages are very sensitive to small changes in the seawater's pH. The larvae from *P. lividus* species showed to be more sensitive to acidified elutriate sediments than larvae from *L. variegatus* sea urchin. Furthermore, this study has demonstrated that the CO_2 enrichment in aquatic ecosystems cause changes on the mobility of the metals: Zn, Cu, Fe, Al and As, which was presented different behavior among them. Although an increase on the mobility of metals was found, the results using the principal component analysis showed that the pH reduction show the highest correlations with the toxicity and is the main cause of embryo-larval development inhibition. In this comparative study it is demonstrated that both species are able to assess potential effects of the ocean acidification related to CO_2 enrichment by both near future scenarios and the risk associated with CO_2 leakages in the Carbon Capture and Storage (CCS) process, and the importance of comparative studies in different zones to improve the understanding of the impacts caused by ocean acidification.

1. Introduction

Changes in the marine carbonate system may affect various calcifying organisms. As CO_2 is added to seawater, there are increases in H^+ and bicarbonate $[HCO_3^-]$ and simultaneous decreases in water's pH and carbonate ion concentration $[CO_3^{2-}]$ (Orr, 2011). This imbalance in the chemistry of seawater can cause many impacts on the marine ecosystem, especially to the organisms that have calcareous skeletal structures.

CO_2 increases in the ocean may occur both by the capacity of CO_2 exchanges with its dissolved form between the atmosphere and surface seawater as well by CO_2 leaks during the carbon capture and storage (CCS) process. Previous studies have showed a 7.5% increases in greenhouse gases from 2005 to 2011, with carbon dioxide contributing 80% of this amount (IPCC, 2013). The seawater surface pH is predicted to have a reduction around 0.4 units by 2100 and 0.77 units by 2300 (Caldeira and Wickett, 2005; IPCC, 2007). Briefly, this reaction is because there is a natural equilibrium between the ocean and the atmosphere. When there is an excess of atmosphere CO_2 concentrations due to the anthropogenic

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http://dx.doi.org/10.1016/j.chemosphere.2017.06.001
0045-6535/

activities, the gas is absorbed by the ocean as a sink (Sabine et al., 2004), reacting with the seawater and consequently the pH decrease (Millero, 1995).

On other hand, the CCS could contribute 15–55% of the cumulative mitigation effort worldwide by 2100 (IPCC, 2005). This technique consists of the separation of carbon dioxide from industrial and energy-related sources, transport to an offshore geological formation, and long-term isolation from the atmosphere. However, CO_2 leakage may occur during this process, which may contribute with the imbalance of seawater's chemistry. In this context, many studies have been performed in order to analyze the impacts from changes in the marine carbonate system as well as pH reduction to the organisms (Moulin et al., 2011; De Orte et al., 2014a; Basallote et al., 2012, 2014, 2015; Rodriguez-Romero et al., 2014a, 2014b; Bautista-Chamizo et al., 2016; Wang et al., 2016).

According to Barry et al. (2011), for taxa affected by ocean acidification, individual physiological stress can lead to reduced growth, size, reproductive output, and survival. Reduced calcification rates have been also well established, particularly to corals and mollusks (Gazeau et al., 2007; Doney et al., 2009). Echinoderms appear less tolerant of low pH waters than many groups, as indicated by their conspicuous absence from habitats with naturally high CO_2 levels such as hydrothermal vents (Grassle, 1986) and they are highly variable in response, mainly due to the great variability in degree of calcification within the phylum (Wood et al., 2008).

As calcifying organisms tend to be more vulnerable to carbonate seawater alteration, early life stages, such as fertilization, embryogenesis, and larval development, are expected to be particularly sensitive to changes in environmental conditions (Bryrne, 2011; Havenhand and Schlegel, 2009; Havenhand et al., 2008; Raven et al., 2005; Ross et al., 2011). Studies have showed a decrease of fertilization and early development stages in sea urchins in low pH conditions (Kurihara et al., 2007; Havenhand et al., 2008; Moulin et al., 2011). Thus, it highlights the importance of studying the impact of pH decrease on early life stages once the developmental success of a population level depends on the survival of the embryos and larvae.

Another important point that should be considered is the habit of marine organisms. Coastal organisms are regularly experiencing hypercapnic conditions (elevated pCO_2 levels). This suggests that they might be pre-adapted to relatively high ambient pCO_2 levels (Portner et al., 2011). Nonetheless, it has been reported that since infauna organisms live in an environment that is often high in CO_2, they will be inherently more immune to ocean acidification than organisms that live on sediment surface (epifauna) (Widdicombe et al., 2011). Therefore, the region where organisms live and their habit are strongly correlated with the effect on changes in carbonate seawater to marine organisms.

Recently there has been a debate on whether the tropics or temperate zones are more vulnerable to climate warming (Ghalambor et al., 2006; Tewksbury et al., 2008) and the acclimation capacity of species that live in these zones (Vinagre et al., 2016). Considering that the ocean acidification would be one of the causes from the global warming, it is also very important to study its impacts on the organisms from different zones. Thus, comparative studies to analyze the impact from seawater pH changes and consequently ocean acidification to different species are highlighted.

This study aimed to compare the sensitivity of embryo-larval development of two sea urchins species (*Paracentrutos lividus* and *Lytechinus variegatus*) to ocean acidification. The species *Paracentrutos lividus* and *Lytechinus variegatus* are used in samples collected in Spain and Brazil, respectively. Both of these areas have projects with operating (in Rio de Janeiro and Bahia states, Brazil) and dormant (Ponferrada, Spain) status of CCS system, and can be impacted by the use of this technology (SCCS, 2017). Also, there is approved a storage area in the Gulf of Cádiz that could be used in the future for CCS (BOE, 2008). Experiments were performed in laboratory scale with a CO_2-bubbling system designed to conduct ecotoxicological assays. The pluteus larval stage was analyzed for 24 h (*L. variegates*) and 48 h (*P. lividus*) to sediment elutriates subjected to various pH treatments. The exposition time established for each species was related to time for them get themselves to the pluteus stage. Sediment samples were collected different areas located in Spain and in Brazil. The dissolved metal concentrations in the sediment elutriates were measured to assess possible interactions among the pH, dissolved metals and toxicity.

2. Materials and methods

2.1. Sampling

Sediment samples were collected from four sites in two different littoral areas. Two sampling sites are located in Santos Estuary and Bay, São Paulo –Brazil (Fig. 1), and the others two in Bay of Cadiz, Spain (Fig. 2).

The Santos Estuarine System is located on the central coast of the state of São Paulo, in southeastern Brazil. This region is of economic importance due to the industrial complex in the city of Cubatão, the Port of Santos, the potential for tourism, and the fisheries and natural resources provided by mangroves that occur within the estuary. The establishment of the sampling site in the Santos Estuary (CPI) is based on previous studies (Lamparelli et al., 2001; Abessa et al., 2005; Cesar et al., 2006, 2007; Torres et al., 2015) which show contamination gradients from the inner portions of the estuary to the external areas. In contrast, the site from Santos bay (PAI) is considered relatively clean when compared with the local guideline which establish values for dredged sediment (CONAMA 454, 2012), and has been used as a reference site in this area (Szalaj et al., 2016; Goulding et al., 2017).

The sampling sites in Spain are located in San Pedro River (RSP) and Trocadero (TRO) both in Bay of Cádiz. The sites are relatively protected areas connected to the Atlantic Ocean through intertidal channels and salt marshes. These areas are influenced by marine aquaculture, shipbuilding industry, and urban discharges among other anthropogenic activities (DelValls et al., 1998; Silva et al., 2012). The RSP shows low metal concentration, while in TRO is considered an area with intermediate metal concentration (Basallote et al., 2014). These values were also compared with the local guidelines which establish the concentrations of metals for dredged sediments considered to be no dangerous (CEDEX, 2015) (Table 2).

Collection procedures and transport of sediment samples

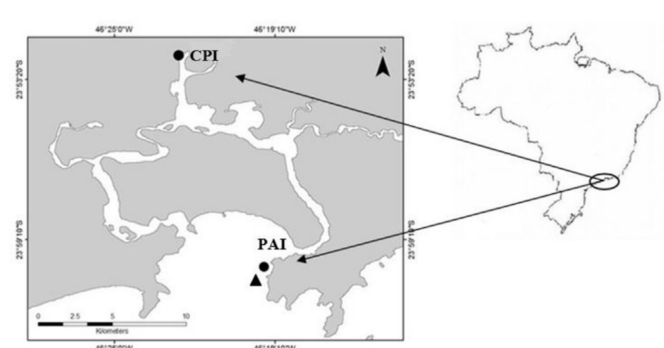

Fig. 1. Map showing the sediment sampling sites located in Piaçaguera Channel (CPI) and Palmas Island (PAI), Santos, Brazil. The triangle reflects the organisms collect site.