

Using a mesocosm approach to evaluate marine benthic assemblage alteration associated with CO₂ enrichment in coastal environments

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ABSTRACT

The effects of acidification related to the CO₂ enrichment in the coastal environments on marine macrobenthic abundance, diversity and richness were analyzed in a medium-term (21 days) using mesocosm experiments. Two sampling sites located in the Bay of Cadiz – SW, Spain were selected and tested at pH values ranged from 7.9 to 6.0 (± 0.1). Moreover, variations in the concentrations of metals in the sediment samples were analyzed at the end of each experiment. The results showed low variation in the concentrations of metals in the sediment among the pH treatments. A significant decrease ($p < 0.05$) in the abundance, diversity and richness of assemblages were measured between the control and the lowest pH level in both sampling sites tested in this study (Rio San Pedro and El Trocadero). The majority of species were found in all samples except in pH 6.0 which only two species were found (*Hydrobia ulvae* and *Scrobicularia plana*) in Rio San Pedro sediment fauna. In general, the results of cluster analysis showed 60% and 40% similarity in all replicated tests in El Trocadero and Rio San Pedro of sediment fauna, respectively. The results of the Principal Component Analysis (PCA) showed that both sediment parameters and pH reduction can interfere in the benthic assemblage indices. Although the assemblages' indices have shown decreases only in the lower pHs, the organisms also could be impacted by chronic effects. Therefore, the extension of this study is important in order to improve the knowledge about the risks associated with CO₂ enrichment in on marine organisms.

1. Introduction

The increase of not only atmosphere pollution but also aquatic and land pollution has been associated mainly with the human activities (Passarelli et al., 2018; Komatsu et al., 2014). Among the contamination sources, CO₂ emissions from the burning of fossil fuel have been highlighted as one of the most major causes of atmosphere pollution and it is closely linked to global warming (IPCC, 2013). According to IPCC (2001), the climate change phenomenon is considered to be a consequence of increasing concentrations of greenhouse gases (mainly CO₂) in the atmosphere.

It is estimated that CO₂ concentrations in the atmosphere have risen from 280 ppm, dated in preindustrial time, to the current 401 ppm (Tans and Keeling, 2015). Additionally, it was registered that the surface waters of the ocean have taken up about 25% of carbon generated by human activities since 1800 (Sabine et al., 2004). Once dissolved in seawater, CO₂ is a weak acid which combines to form carbonic acid

(Gattuso and Hansson, 2011). Afterwards, it produces hydrogen ions (H⁺) and escalates the concentration of bicarbonate (HCO₃⁻) followed by the decreasing of pH and carbonate ions CO₃²⁻ (Millero, 1995; Caldeira and Wickett, 2005; Orr et al., 2005; Doney et al., 2009).

The Carbon Capture and Storage (CCS) process is considered one of the best choices for the reduction of atmospheric CO₂ emissions with reductions of 15% and 60% of current emissions by 2025 and 2050, respectively, as required by the United Nations Framework Convention on Climate Change, (1992). This process consists of separating carbon dioxide from industrial and energy-related sources, transporting it to an offshore geological formation, and isolating it from the atmosphere for the long term (London, 1996). However, the environmental risk related to this technique is needed to be fully understood as the potential impact of a large scale leak still remains largely unexplored hampered by complex ecological relationships (Blackford et al., 2015).

In this sense, CO₂ enrichment in the ocean may cause an imbalance in the carbonate cycles of aquatic ecosystems (Gattuso and Hansson,

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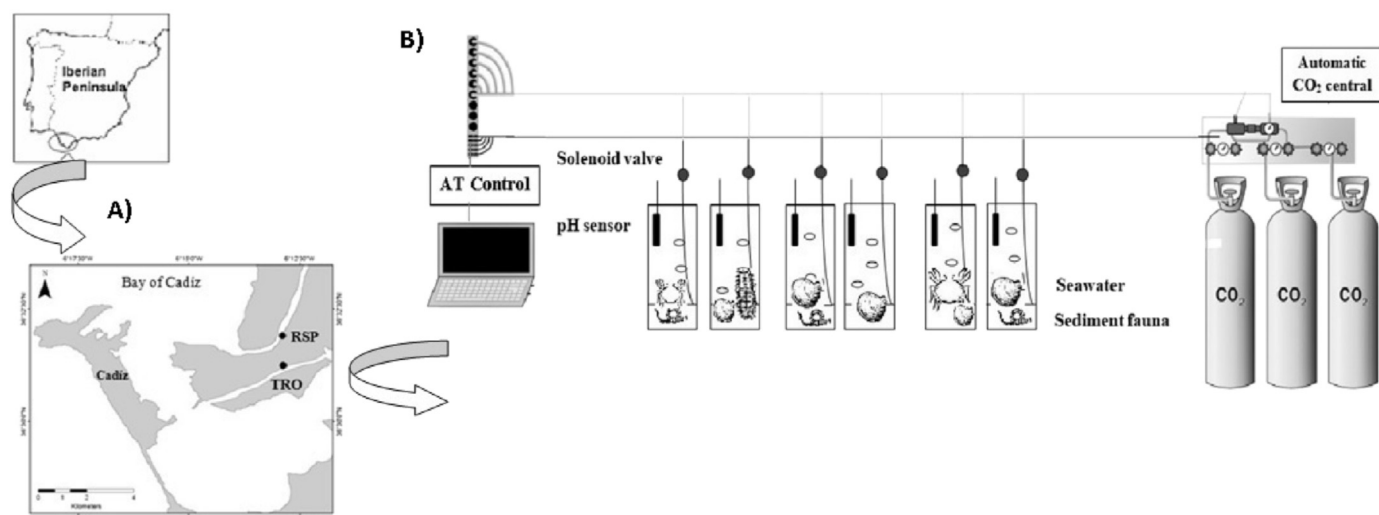


Fig. 1. A) Map of the location of water and sediment fauna sampling sites Río San Pedro (RSP) and Trocadero (TRO) in south of Spain. The samples were exposed to CO₂ enrichment using B) Schematic design of the CO₂ injection system used in the mesocosm experiments following Basallote et al. (2014).

2011; Widdicombe and Spicer, 2008). This imbalance has a consequence on pH decreases in the ocean and subsequently may cause adverse effects to the organisms (Moulin et al., 2011, 2014). At the same time, the effects of ocean acidification on the full range of different benthic organisms and ecosystems are poorly known and difficult to ascertain (Andersson et al., 2011). The present study provides thus more information about the possible impacts related to CO₂ enrichment on marine assemblage.

Previous studies have shown the effects of pH reduction to amphipods (Basallote et al., 2014; Passarelli et al., 2017a), fish larvae, polychaete, adults and juveniles clams (Basallote et al., 2012, 2015), sea urchin (Moulin et al., 2011, 2014; Passarelli et al., 2017b), algae growth (De Orte et al., 2014; Bautista-Chamizo et al., 2016) and bacteria (Borrero-Santiago et al., 2016). Nevertheless, there is little information about the impact of CO₂ enrichment in the ocean to whole benthic communities. Predicting potential impacts on ecosystem function should be based on research involving whole communities (Hawkins et al., 2008) and not only on individual level.

Environmental risk assessment involves several tools to analyze the impacts of pollution to the ecosystem. Benthic community alteration analysis has been useful to assess ecological status of aquatic ecosystems (Pereira et al., 2014) and it is the current basis for most biomonitoring programs (WFD 2000/60/EC; MSFD 2008/56/EC). Ecological monitoring using benthic structure analysis provides information on changes in species composition, abundance and diversity which may indicate adverse effect in communities (Silva et al., 2012; Chapman, 1990, 1996; DelValls et al., 1998; Long and Chapman, 1985).

The effects of ocean acidification on a population level may impair individual performance and survival causing consequences for populations and species that may include reduced abundance, productivity and resilience to disturbance, as well as increased likelihood of extinction (Barry et al., 2011). Furthermore, significant changes were previously reported in the structure and reduction diversity, abundance and biomass of the benthic communities exposed to low pH levels (Christen et al., 2013; Almagro-Pastor et al., 2015).

According to Widdicombe and Spicer (2008), CO₂ enrichment in the marine ecosystem could potentially reduce its biodiversity in a number of ways. Firstly, through a loss of those species which are sensitive to changes in CO₂ and pH. Secondly, sensitivity to acidification is a function of some organism taxonomic diversity and thirdly, the loss of keystone/critical species, or a reduction in their activity (e.g. predation, grazing, bioturbation), could reduce habitat complexity and also reduce the biological regulation of competition. Furthermore, these authors

highlighted that evidence from direct ‘relevant’ experimental observations is limited. Based on that, this study aimed to analyze possible macrobenthic structure alterations in relation to CO₂ enrichment in the ocean using sediments which are known for their toxicity and contamination levels. In order to do so, sediment fauna was collected in San Pedro River (RSP) and Trocadero (TRO), located in Bay of Cádiz, Spain and mesocosm experiments were performed using a pH range from 7.9 to 6.0 (± 0.1). The experiments lasted 21 days and the abundance, richness and diversity from the macrobenthic were calculated. Metals concentration in the sediment was also measured to assess possible interactions between changes in the pHs and bioavailability of these metals. An integrative approach based on the weight of evidence was used to identify the relation between the biological effects associated with acidification, and the variation in the concentration of metals in the sediment samples used in this study. The influence of pH was assessed by comparing natural pH in coastal areas (pH 8.1–7.8) with reduced pH values (pH 7.0–6.0) simulating possible scenarios of leakages from CO₂ storage and other natural and anthropogenic processes in the marine ecosystem.

2. Materials and methods

2.1. Approach

The research work was performed handling the macrobenthic fauna associated with sediments from San Pedro River (RSP) and El Trocadero (TRO), both located in the Bay of Cádiz (Fig. 1A).

The Bay of Cádiz is a salt marsh creek situated in the southwest of Spain. These areas have been studied in the last years to identify the level of metal contamination (Passarelli et al., 2017a, 2017b) and the benthic community structure (Silva et al., 2012). In this sense, the RSP has a low metal concentration, while the TRO is considered an area with moderate metal concentration (Basallote et al., 2014; Passarelli et al., 2017a) when compared with the local guidelines which establish the concentrations of metals for dredged sediments considered to be not dangerous (CEDEX, 2015).

Seawater from the surface (1 m depth), during high tide (salinity 32 ± 2 psu) was collected in the RSP, transported to the laboratory (Marine and Environmental Science Faculty, University of Cádiz) and placed in a 400-L tank with aeration. On the same day, during low tide, surface sediments (top layer from 0 to 5 cm depth) were taken using a 0.025 m² Van Veen grab. The contents of three sediment grabs (0.075 m²) were poured into a 25 L plastic aquarium

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