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Effects of coastal upwelling on the structure of macrofaunal communities in SE Brazil

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ABSTRACT

The effects of coastal upwelling on the structure of macrofaunal communities were investigated in two shallow bays in SE Brazil. Water, sediment and fauna samples were collected at four time-points corresponding to austral summer, fall, winter and spring, respectively. Water column temperature and salinity profiles indicated that upwelling occurred in summer–spring (December and November), but not in fall–winter (April and August). The structure of macrofaunal communities differed consistently between these periods. The sediment content of labile organic matter did not vary as a function of upwelling and could not explain the changes in macrofaunal communities. Rather it appeared that macrofaunal community structure was determined by organic matter quality (i.e. phytoplankton composition), physical disturbance regimes and bottom-water temperature. Physical disturbance caused by S–SE winds, warm water temperatures (up to 26 °C) and resuspension-driven phytoflagellate blooms during non-upwelling were associated to higher density (2511–2525 ind m^{-2}) and dominance of small opportunistic species such as spionid, paraonid and capitellid polychaetes. In contrast, stable hydrodynamic conditions, diatom blooms and lower water temperatures (down to 18 °C) during upwelling resulted in lower density of macrofauna (796–1387 ind m^{-2}) and a shift in species composition to relatively large-sized magelonids and carnivorous polychaetes. Therefore, organic matter quality, physical disturbance regimes, and bottom-water temperature were the major factors regulating the life-cycles, composition and density of macrofaunal communities in these less productive subtropical upwelling systems.

1. Introduction

Benthic macrofauna (i.e. animals retained by a 0.5 mm mesh) are important components of the food-webs in coastal marine ecosystems. They assimilate energy contained in organic detritus and thereby act as a second trophic level transferring energy from primary production to animals of higher trophic levels, such as commercially important benthic megafauna including prawns, crabs and demersal fishes (De Léo and Pires-Vanin, 2006; Rocha et al., 2003). In tropical and subtropical zones, marine ecosystems function under meso-oligotrophic conditions, and the limited input of organic detritus derived from phytoplankton greatly affects the structure of benthic macrofaunal communities. Under these conditions benthic macrofauna are typically characterized by high diversity, but low biomass of individuals (Alongi, 1989; Sanders, 1968). In meso-oligotrophic areas, primary productivity and the input of organic detritus to the seabed are strongly dependent on nutrients regenerated in the water and sediment, discharged by run-off from land or transported with oceanic water to the coast during upwelling events (Braga and Müller, 1998; Silveira et al., 2000).

The coastal areas of SE Brazil are strongly influenced by a seasonal upwelling of a deep, cold and nutrient-rich water mass; the South Atlantic Central Water (SACW) (Castro-Filho et al., 1987). During late spring to early summer in November–December, predominant winds from the E–NE quadrant induce the upwelling of SACW from the continental slope towards the coast by Ekman transport (Castro-Filho et al., 1987). SACW is therefore often registered up to 10 m depth along the coast below a strong thermocline in mid-water (Braga and Müller, 1998; Castro-Filho et al., 1987). SACW flows towards the coast in close contact with the sea bottom and becomes enriched with inorganic nutrients produced by organic matter mineralization in the water column and sediments. Thus, besides having a low temperature compared to surface water, SACW typically has low oxygen and high nitrate levels (Braga and Müller, 1998). When SACW with up to ~5 μM nitrate reaches the euphotic zone, it triggers phytoplankton blooms and the sediments may temporarily receive increased amounts of labile organic matter (Aidar et al., 1993; Sumida et al., 2005), providing a rich source of energy to the benthic fauna. Furthermore, upwelling conditions during spring–summer are characterized by more stable environmental conditions, i.e. calm winds and hydrodynamics, compared to non-upwelling

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conditions in the rest of the year, when frequent passage of cold fronts causes stronger hydrodynamic forcing and sediment resuspension in the coastal zone (Gaeta et al., 1999; Mahiques et al., 1998).

SACW upwelling may influence benthic fauna communities along SE Brazilian coasts by changing the amount and quality of food delivered to the sediments. The phytoplankton biomass in spring–summer during coastal upwelling ranges from 3 to 12 mg chlorophyll m^{-3} in SE Brazil (Aidar et al., 1993; Gonzalez-Rodriguez et al., 1992). Other important coastal upwelling zones in the eastern boundary Pacific and Atlantic Oceans are extremely productive and phytoplankton biomass reaches levels up to 5-fold higher compared to those in SE Brazil (Chavez and Messié, 2009; Pennington et al., 2006). Much is known about how increased primary productivity affects benthic fauna in high-productive upwelling areas (Levin et al., 2009), but limited information is available on the ecological community structure of benthic macrofauna in less productive upwelling systems along SE Brazilian coasts (Quintana et al., 2010; Venturini et al., 2011).

This study investigates the effects of a seasonal upwelling on the availability of labile organic matter (i.e. microalgal-derived material) and associated impacts on the structure of macrofaunal communities along two shallow coastal bays in SE Brazil. We hypothesized that summer upwelling events increases labile organic matter content in the sediment resulting in high density of organisms and shifts in dominance of macrofaunal species compared to non-upwelling seasons. To test this hypothesis, benthic macrofauna, sediment and water parameters were sampled four times during a year in two shallow-water bays (4–19 m depth), representing summer, fall, winter and spring. SACW upwelling was assessed by temperature and salinity profiles in the water column. Labile organic material was measured as chlorophyll-a concentrations in the sediment. Temporal changes in density and species distribution of macrofauna were detected by multivariate analysis and coupled to concurrent changes in environmental data.

2. Material and methods

2.1. Study area

The study area is located in Ubatuba at the Tropical/Subtropical boundary in SE Brazil (Fig. 1). Ubatuba is composed of several small enclosed bays and is surrounded by the Serra do Mar mountain chain, which extends to the shore throughout most of the region and limits the extension of intertidal flats and drainage systems (Mahiques et al., 1998). The coastal water (CW) in Ubatuba has a salinity of 32–36 and temperatures of ≥25 °C (Castro and Miranda, 1998). Since there are only few, small-sized rivers present in the coastal bays, the freshwater and nutrient run-off is minimal, resulting in meso-oligotrophic characteristics of the CW (Castro and Miranda, 1998; Gaeta et al., 1999). Nutrient concentrations (e.g. nitrate, ammonium, phosphate) are low during most of the year and the phytoplankton is dominated by nanoflagellates (Aidar et al., 1993; Gaeta et al., 1999). In spring–summer, however, the upwelling of the cold and nutrient-rich SACW (salinity ≤ 36.4 and temperatures ≤ 20 °C) to the euphotic zone and higher rainfall can drive sporadic blooms of opportunistic diatoms (Aidar et al., 1993; Castro-Filho et al., 1987; Gaeta et al., 1999). Sporadic nutrient enrichment of the water column may also occur during short-term sediment resuspension events, which are frequent during passage of cold fronts (i.e. strong S–SE waves, 4–6 times per month) in the period without SACW upwelling. These resuspension events can also increase water column nutrient levels, stimulate primary productivity and influence the depth distribution of organic matter into the sediments (Aidar et al., 1993; Gaeta et al., 1999; Quintana et al., 2010; Galluci and Netto, 2004). The physical disturbance level and potential for sediment resuspension in Ubatuba bays are determined by the shape of the shoreline and the orientation to the open sea (Burone et al., 2003; Mahiques et al., 1998). Bays oriented in S–SE direction are more exposed to

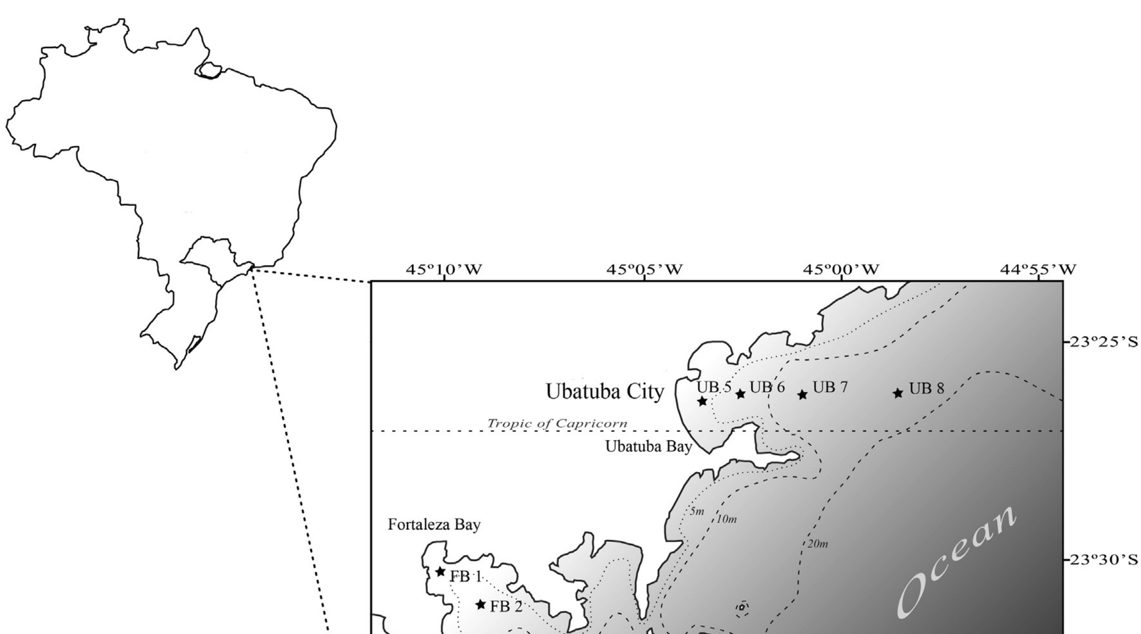

Fig. 1. Map of the study area with the sampling stations located at Sao Paulo State coast in Fortaleza (F1, F2, F3 and F4) and Ubatuba (U5, U6, U7 and U8) bays.