ARTICLE IN PRESS

Ocean and Coastal Management xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

Food web of a subtropical tidal flat, Atlantic Southwestern: Temporal and spatial variability of the primary organic sources

L.S.H. Soares*, L.P.L. Arantes, M.C.J. Pucci

Departamento de Oceanografia Biológica, Instituto Oceanográfico, Universidade de São Paulo, Praça do Oceanográfico, 191, São Paulo, SP, CEP 05508-120, Brazil

ARTICLE INFO

Keywords:
Producers
Carbon and nitrogen stable isotopes
Coastal system
Southeastern Brazil

ABSTRACT

Trophodynamic parameters have been used as input data for trophic models and are used as indicators to support ecosystem management decisions. To understand the ecosystems' trophic structure and functioning, it is important to identify the major primary carbon sources within a food web. This study aimed to investigate the spatial and temporal variability in isotopic composition of the basal sources of the food web of the Araçá Bay (23°49′S; 45°24′W) ecosystem. This site is a sheltered tidal flat and presents a sharp seasonal change in water temperature and salinity. Samples of 15 basal sources were analysed for $\delta^{13}C$ (n = 187) and $\delta^{15}N$ (n = 180) values and also for the C:N ratio, in January–March (austral summer) and June–July (austral winter) 2013, in the continental, intertidal (mangrove patches and soft and rocky bottoms) and sublittoral regions. The isotope values and C:N ratios were, in general, in the range of those available in previously published studies. C_3 and C_4 plants, green macroalgae and surface sediment organic matter (SSOM) did not present significant changes in the $\delta^{13}C$ and $\delta^{15}N$ values with time. For suspended particulate matter (SPM), microphytobenthos (MPB) and turf-forming algae, $\delta^{13}C$ values were higher in the summer than in the winter; also in the summer, red macroalgae showed higher $\delta^{15}N$ values. Spatial variability was investigated for SPM, SSOM and MPB. $\delta^{13}C$ values were significantly higher for SSOM and MPB in the intertidal region than in the sublittoral but for SPM there was no difference among regions. Values of $\delta^{15}N$ were higher for MPB in the intertidal region than in the sublittoral, and were higher for SPM in the sublittoral region than in the intertidal and continental regions. The $\delta^{13}C$ associated to C:N values of SSOM indicated a coupling of the marine sublittoral region and the land organic matter of an adjacent island and the SPM $\delta^{15}N$ variability pointed out a continental land-sea connection. Some mechanisms could explain the isotopic temporal and spatial shifts and sources of organic C in the study area: the seasonality of hydrodynamics and of phytoplankton size structures and biomass; the steady low concentration of nitrate and the episodic ammonia inputs; terrestrial runoff. Our results can contribute to the construction and understanding of a trophic model of the Araçá Bay ecosystem, and also for its management, considering the seasonal hydrodynamics, the coupling of marine sublittoral region in the São Sebastião channel and terrestrial organic matter from São Sebastião Island, as well as the continental land-sea connection. We suggest a monitoring program based on SPM, bottom detritus and *Ulva fasciata*, important primary organic sources for the Araçá Bay food web.

1. Introduction

Marine management and conservation require a good knowledge of the ecosystems' trophic structure and functioning, and trophodynamics parameters have been used as sources in ecosystems models as well as indicators to support conservation management plans (eg., Möllmann et al., 2014; Young et al., 2015). Concerning to this approach, carbon and nitrogen stable isotope analysis are considered a powerful tool to study trophic interactions and energy pathways in aquatic food webs, recording both sources and trophic position information in nearshore systems (Bowen and Valiela, 2008; France, 2014; Layman et al., 2012; McKinney et al., 2010). In addition, isotope analysis has been used for studying land-sea couplings (McClelland et al., 2016; Valiela et al., 2014) and contribution of materials from anthropogenic sources (Costanzo et al., 2005; Dvorak et al., 2016; Heaton, 1986; Kendall, 1998; Lemesle et al., 2015; McClelland et al., 1997).

This study was conducted in the Araçá Bay (23°49′S; 45°24′W), a tidal flat comprising a soft bottom, rocky shore, mangrove patches, a small stream, islands and an adjacent sublittoral region in the channel between the continent and São Sebastião Island (Amaral et al., 2010).

Abbreviations: MPB, Microphytobenthos; SPM, Suspended particulate matter; SSOM, Surface sediment organic matter

* Corresponding author.
E-mail address: lsoares@usp.br (L.S.H. Soares).

https://doi.org/10.1016/j.ocecoaman.2018.01.035
Received 28 July 2017; Received in revised form 22 January 2018; Accepted 31 January 2018
0964-5691/

Please cite this article as: Soares, L.S., Ocean and Coastal Management (2018), https://doi.org/10.1016/j.ocecoaman.2018.01.035

Seasonal variations in the hydrographic conditions occur in the channel propagating through the bay (Dottori et al., 2015; Siegle et al., this issue) and variability in nutrient availability in scale of hours to days was reported (Giannini and Ciotti, 2016). Although it is a hotspot for benthic biodiversity studies and part of two Brazilian government protected areas, in recent decades, Araçá Bay has been subject to various anthropogenic impacts, such as sewage release and oil spills (Amaral et al., 2010).

Producers' $\delta^{13}C$ and $\delta^{15}N$ values can vary in response to a many factors, seasonally (Farquhar et al., 1989) or on both seasonal and monthly scales (Claudino et al., 2013). In coastal systems studies, it is important to focus on the variables that can affect the base of the food web, that is, terrestrial vs. marine inputs, seasonality, macrophytes importance and changes in the phytoplankton community (e.g., Michener and Kaufman, 2007). In the case of the studied area, the primary sources of organic matter in the food web may include continental inputs, suspended and sediment organic matter and a variety of primary producers (C_3 and C_4 terrestrial plants, C_3 mangrove plants, seagrasses, macroalgae, microphytobenthos and phytoplankton).

Changes in the $\delta^{13}C$ and $\delta^{15}N$ of primary food sources and consumers have been reported in many coastal systems correlated to temporal and spatial variability (Carlier et al., 2007; Chouvelon et al., 2012; Faganeli et al., 1988; Kürten et al., 2013; Michener and Kaufman, 2007). $\delta^{13}C$ values of phytoplankton vary greatly between geographic regions, due to the variation in isotopic composition of the dissolved inorganic carbon pool with temperature and location, as well as with the phytoplankton species size, composition and growth rates (Michener and Kaufman, 2007, and references therein). Carlier et al. (2007) pointed out that the continental inputs did not contribute significantly to the benthic trophic network of Bay of Banyuls-sur-Mer. In the North Sea, Kürten et al. (2013) showed that spatial difference in the $\delta^{15}N$ of primary consumers between two sites of contrasting hydrography were attributed to the seasonal changes of primary production. Spatiotemporal changes in the $\delta^{13}C$ and $\delta^{15}N$ of primary sources were registered in the Brazilian coastal systems (e.g., Claudino et al., 2013; Corbisier et al., 2014; Gorman et al., 2017): in the Patos lagoon estuary, south Brazil, overall, the $\delta^{13}C$ values of food sources were higher in the mudflat than in the marsh creek, whereas $\delta^{15}N$ values were higher in the marsh creek for most primary producers (Claudino et al., 2013); in the Cabo Frio upwelling system, ^{15}N-depleted and ^{13}C-enriched organic matter were identified in the benthic assemblages of the inner shelf in comparison to the outer (Corbisier et al., 2014); in the Araçá Bay, $\delta^{13}C$ and $\delta^{15}N$ values of *Ulva fasciata* showed spatial variation across the bay, as well between seasons (Gorman et al., 2017).

This study aims to describe the main basal sources for the Araçá Bay food web and their spatiotemporal changes, based on $\delta^{13}C$ and $\delta^{15}N$ natural abundance measurements and on C:N ratios. We investigated the hypothesis that spatial and seasonal variations may occur, especially for suspended particulate matter, driven by the local hydrodynamics.

2. Methods

2.1. Study area

This study was undertaken in Araçá Bay (23°49′S; 45°24′W), located on the southeastern coast of Brazil, in São Paulo State (Fig. 1). It is a small (approximately 750 m wide and 750 m long) subtropical flat, protected from the incident swell by the São Sebastião Island, with large areas exposed during the low tides (Amaral et al., 2010; Dottori et al., 2015). The bay encompasses sandy beaches, small rocky shores and small patches of mangrove, being delimited from the adjacent port of São Sebastião by a rockfill (Contente and Rossi-Wongtschowski, 2017).

Araçá Bay is situated on the mainland side, narrow (about 1.9 km width) and central part of the São Sebastião Channel (Fig. 1). On the opposite side of the channel, São Sebastião Island (approximately 28 km long and 337.5 km^2) is covered by Tropical Atlantic Forest and is a barrier between Araçá Bay and the open sea. This island also acts as an important source of organic matter and nutrients, carried by the action of streams and rainwater leaching, into the channel and transported mainly towards the east and northeast (Alcántara-Carrió et al., 2017; Dottori et al., 2015).

Araçá Bay is a dynamic environment, mainly driven by the local currents of semi-diurnal tides, remote winds and frontal systems. Local currents movement in the São Sebastião Channel occur mostly towards the northeast, although superficial water flow can change towards the southwest in the spring and summer months (Castro et al., 2008, personal communication[1]). The physical properties of water in Araçá Bay are impacted directly by the hydrodynamics of the channel and by the seasonal influence of the South Atlantic Central Water (SACW) at the entrance of the bay, determining changes in temperature and salinity. The presence of the SACW waters, with low temperature and high salinity, is more frequent during the spring and summer months (Castro, 2014). The nutrient variability is associated with seasonal hydrodynamics and influences the concentration of the chlorophyll *a*, although the channel waters are considered oligo-mesotrophic year-round (Gianesella et al., 1999; Giannini and Ciotti, 2016).

The local climate is subtropical, with a mean annual air temperature of 23.3 °C and an average of 1800 mm of annual rainfall. A rainy season occurs between October and March (monthly mean of rainfall: 197 mm), while a less pronounced rainy period occurs from April to September (monthly mean of rainfall: 102 mm) (CEBIMar/USP; INMET).

Araçá Bay has a high richness of species inhabiting the soft bottom, the rocky bottom, and the small patches of mangrove of the intertidal region, as well as the sublittoral region (Amaral et al., 2016a) and supports a small-scale artisanal fishery (Avila-da-Silva et al., 2016). However, it is vulnerable to contamination from domestic sewage discharge (by a small stream, Mãe Isabel, and a submarine outfall) and frequent oil spills from an important oil harbour nearby (Amaral et al., 2010).

Detailed environmental and geographical characterisation of Araçá Bay is available in Contente and Rossi-Wongtschowski (2017), Giannini and Ciotti (2016) and Siegle et al. (this issue).

2.2. Field and laboratory work

Samples of representative primary producers and organic matter were collected, in a minimum of three replicates, during the daytime in the austral summer (January–March 2013) and winter (June–July 2013), in the continental, intertidal and sublittoral regions (Fig. 1). Samples for suspended particulate matter analysis were obtained in three regions (continental, intertidal and sublittoral), for microphytobenthos and sediment organic matter analysis, in two (intertidal and sublittoral), and for other primary producers in only one region (continental or intertidal). Table 1 contains the number of the samples of each primary source per region and time and in the Supplements 1A and 1B, additional information of the samples. Specific treatments for each group of basal sources are described below.

For suspended particulate matter analysis, samples of water were collected in the continental region and in the intertidal region during the low tides. Samples were obtained at 2 points along the Mãe Isabel stream (continental) in summer and winter (n = 6) and in the contiguous region of the stream (intertidal) only in winter (n = 4). Water samples were also collected along the 5, 10 and 20 m isobaths of the sublittoral region, in the two seasons considered (n = 36) (Table 1; Supplements 1A and 1B). SPM was collected by filtering seawater,

[1] Prof. Dr. Belmiro Mendes de Castro – Oceanographic Institute/University of São Paulo (IOUSP).