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Seasonal and event-driven changes in the phytoplankton communities in the Araçá Bay and adjacent waters

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ABSTRACT

Biomass and composition of phytoplankton are reported for the Araçá Bay (AB) and adjacent waters in the São Sebastião Channel (SSC) in relation to physical-chemical variables. The AB has unequivocal ecological and socio-economic importance but it is under current anthropic pressures that are expected to increase. Needed future management programs require establishing the natural scales of variability of the phytoplankton communities and main drivers. In this study, samplings were conducted every 5–6 weeks from September 2013 to August 2014 to evaluate the extent to which AB and SSC differ in time. The approach was: 1) to compare nutrient concentration and phytoplankton abundance and composition found at AB and adjacent SSC waters; 2) to associate significant changes in nutrient concentration and in phytoplankton composition with time and main meteo-oceanographic processes, such as changes in wind direction or intrusions of upwelled South Atlantic Central Water (SACW). Sampling design included two parallel sections of oceanographic stations (inside and outside AB) that were repeated in the morning and afternoon for 3 consecutive days. Temperature, salinity and chlorophyll-a fluorescence were measured vertically, and discrete water samples were collected for analyses of inorganic nutrients, chlorophyll (Chla) and enumeration of selected groups of phytoplankton. SSC water masses characteristics showed clear seasonality but also a significant hourly to daily variability driven by changes in wind speed and direction. Nutrients and Chla varied mainly on a scale of days, as did phytoplankton abundances and compositions and all variables compared were consistently higher at AB. Samplings were characterized in four groups: 1) warm and stratified waters, 2) cold and homogenous waters, 3) low salinity waters, and 4) an intermediary condition between groups 1 and 3. Diatoms were numerically important, including the potential bloom forming *Pseudo-nitzschia* spp, which were more frequent during warm and stratified conditions, when SACW intrusions were observed. Occurrences of *Asterionellopsis* spp and *Trichodesmium* spp were associated with changes in wind direction. Future monitoring programs in the region should combine short-time coastal observations and near-real-time regional hydrodynamic models. The results raise the awareness for the increasing urban expansion, inefficient sewage treatment and changes in the hydrodynamics of AB.

1. Introduction

In the global ocean, phytoplankton organisms are key in food webs and biogeochemical cycles (e.g., Boyd et al., 2010), therefore, quantitative assessments of their biomass and the understanding of processes governing their growth mechanisms are indispensable. Oceanographic features observed at large spatial scales, such as coastal upwelling or subtropical gyres, allow for some generalizations about the magnitudes and the spatial distributions of phytoplankton biomass, and to a certain degree, their expected taxonomic compositions (e.g., Cullen et al., 2002). In coastal waters, however, the variability of phytoplankton biomass tend to be site-specific due to a wide range of local disturbances (Cloern and Jassby, 2010).

At a given nearshore environment, the relative contributions of continental outflows and coastal and oceanic water masses will fundamentally alter the availability of light and nutrients for phytoplankton growth and will also modulate competition among species (D'Alelio et al., 2015) but the mixture and exchange rates of these waters largely depend on wind fields and bathymetry gradients (Thompson et al., 2009). In protected shallow bays, the residence times of water masses are likely to increase, which favors the input of nutrients from sediments and continental sources to the water column and

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hence phytoplankton growth, however, grazing pressure on phytoplankton organisms may also receive the additional contribution of benthic suspension-feeders (e.g., Cloern, 1982). Advection may become an important factor for the distribution of phytoplankton nearshore, especially in less protected and deeper zones (Cross et al., 2015) and may account for significant losses of organisms over time. In coastal seas, shallow and deeper areas will interconnect mainly through tidal and wind-driven currents, and a complex mosaic of horizontal and vertical fluxes will govern phytoplankton accumulation in time and space. Because of that, effective monitoring programs should consider local natural scales of variability of phytoplankton communities and also identify their main drivers.

Populated coastal areas are under the perpetual threat of nutrients build up originated from anthropogenic activities, which may initiate eutrophication in places with low hydrodynamics (Nixon et al., 2009). To a limited extent, local primary producers (e.g., macroalgae, phytoplankton, and microphytobenthos) present in enclosed and semi-enclosed waters can act as biological "filters" and increase the rates of nutrient cycling (McGlathery et al., 2007). Nonetheless, excessive or unbalanced nutrient concentrations additions to an area may stimulate phytoplankton blooms, including those of species considered harmful (e.g., Kononen, 2001), resulting in both environmental and economic impacts on coastal regions (Berdalet et al., 2017; Lundberg, 2005). Thus, it is crucial to comprehend how the phytoplankton communities naturally vary in these environments and the extent to which their variability is related to nutrient additions, especially in areas where human population or commercial activities are anticipated to increase (Castro et al., 2016).

The present work was motivated by the ecological and socio-economic importance of the Araçá Bay (AB) located in the central portion of the São Sebastião Channel (SSC), southeastern Brazil (Fig. 1), and it is part of the multidisciplinary Araçá Project (Amaral et al., 2016) that aims to understand the biodiversity and functioning of an ecosystem subjected to anthropic pressures. In spite of its small area (~509 m^2), the studies conducted in AB have so far provided invaluable biological data (Amaral et al., 2010; Checon et al., 2017; García et al., 2016), and both observations and experiments gave important insights on the ecological functioning of urbanized coastal regions (Gorman et al., 2017a; Pardal-Souza et al., 2017). The continued observation of AB, and the contiguous areas will be strategic to evaluate eminent problems derived from the predictable population expansion in the region (Turra et al., 2017) while providing a case study for other similar environments.

Studies about the dynamics of phytoplankton communities in SSC waters are scarce; the available reports describe the variability of biomass estimates (e.g., chlorophyll concentrations) during seasonal surveys (see Regaudie-de-Gioux et al., 2017) and mostly characterize SSC waters as meso-oligotrophic. These early works identified inputs of nutrients to SSC during intrusions of the South Atlantic Central Water (SACW), a cold oceanic water mass rich in nitrogen compounds that upwells in the southwestern Brazilian continental shelf and enters the SSC through a deep channel located in the south. However, nutrients may also advect from neighbor coastal environments by nearshore currents, and although no data is available to date, this is supported by the high hydrodynamics reported for SSC (Alcántara-Carrió et al., 2017b).

The water masses present in SSC will be forced into the AB by the tides (Siegle et al., 2017) and if nutrient-enriched, can contribute to the local sources provided by the small Mãe Isabel River, domestic sewage and diffused surface runoff (Gorman et al., 2017b), and the likely contributions from biological activities of the diverse AB benthic communities (e.g., Mermillod-Blondin et al., 2004). On the other hand,

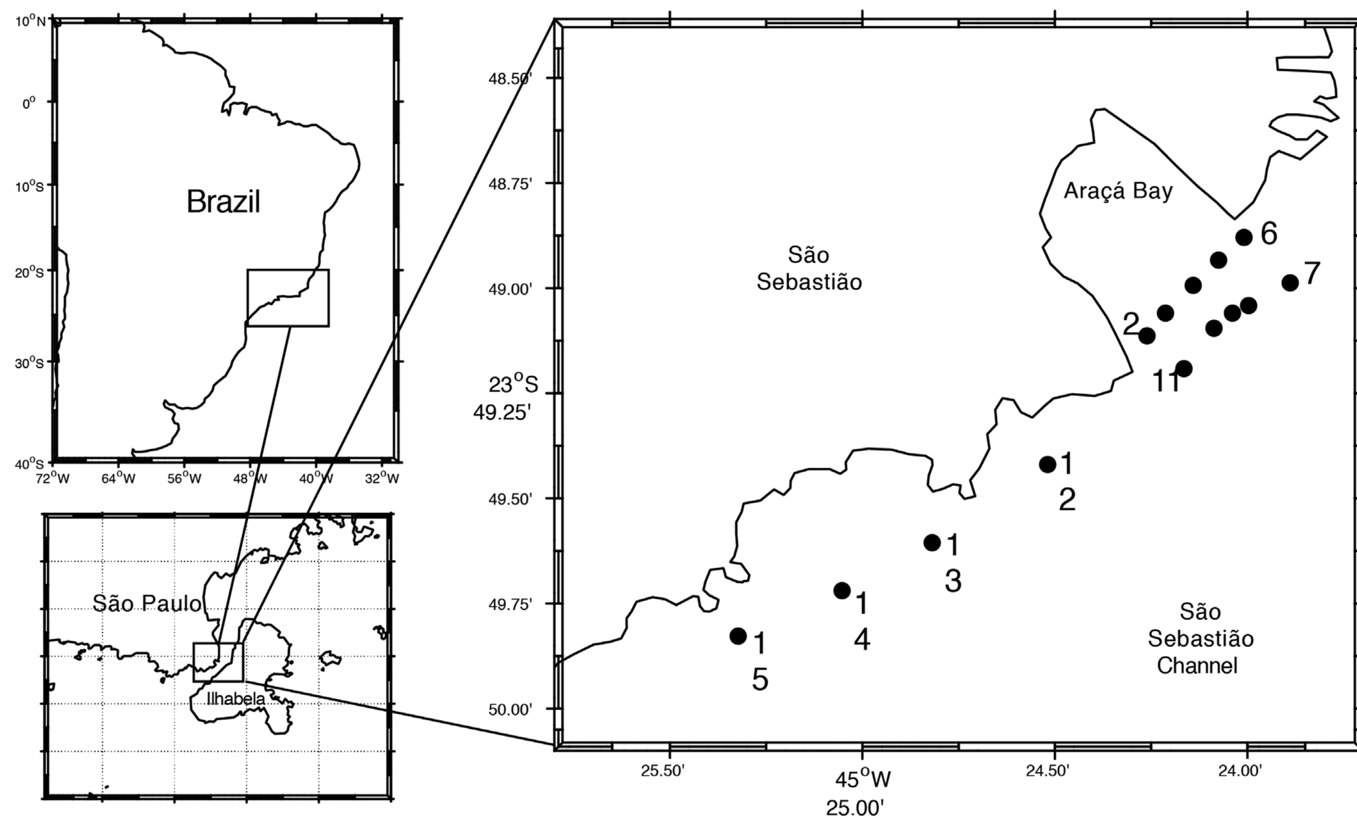

Fig. 1. Mean locations of the sampling stations (2–15) that were distributed into two sections parallel to the central axis of the São Sebastião Channel (SCC), southeastern Brazil, one inside the Araçá Bay (stations 2 to 6) and other just outside de Araçá Bay (stations 7 to 11) and in SSC (stations 12 to 15). Stations 1 and 16 are combinations of the same volume of water collected close to the positions of stations [2, 4 and 6] and [13 and 15], respectively. Each sampling lasted three or more days, and refer to the month and year of execution: September 2013, October 2013, December 2013, January 2014, February 2014, April 2014, May 2014, June 2014 and August 2014.