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Phyto- and protozooplankton assemblages and hydrographic variability during an early winter survey in the Southern Brazilian Continental Shelf

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ABSTRACT

The distribution of phytoplankton and protozooplankton assemblages in relation to hydrographic variability across the southern Brazilian continental shelf were studied based on data collected during early winter (June/2012), complemented with MODIS-Aqua satellite imagery. The in situ data set was comprised by water column structure properties, dissolved inorganic nutrients (ammonium, nitrite, nitrate, phosphate and silicate), phytoplankton and protozooplankton composition and biomass [chlorophyll *a* (Chl *a*) concentration and carbon content]. Phytoplankton assemblages were assessed by both microscopy and HPLC-CHEMTAX approaches. A canonical correspondence analysis associating physical, chemical and phytoplankton composition data at surface revealed a tight coupling between the phytoplankton community and hydrographic conditions, with strong environmental gradients across three different domains: the pelagic, outer shelf Tropical Water (TW); the mid shelf domain under influence of Subtropical Shelf Water (STSW); and the inner shelf domain, mainly under influence of riverine outflow of the La Plata River Plume Water (PPW). Results showed that diatoms dominated the phytoplankton assemblages throughout the study region, but other groups were also important and varied according to the different water masses at surface. The low salinity and nutrient-rich PPW stimulated a high phytoplankton biomass and diversity of diatoms and dinoflagellates within the inner shelf region, with enhanced Chl *a* levels ($> 1.3\ mg\ m^{-3}$) and a great abundance of large and medium-sized diatoms (some of these appeared exclusively in PPW), as well as ciliates, dinoflagellates, raphidophyceans and cryptophytes. Conversely, smaller diatoms (e.g. *Rhizosolenia clevei*), picoplanktonic species (prochlorophytes and cyanobacteria) and a noticeable contribution of dinoflagellates and other flagellates, associated with lower Chl *a* levels ($< 0.93\ mg\ m^{-3}$), characterized the TW domain, where low nutrient concentrations and deep upper mixed layers were found. The transitional mid shelf domain showed intermediate levels of both nutrients and Chl *a* (ranging $1.06–1.59\ mg\ m^{-3}$), and phytoplankton showed a diversity of diatoms and dinoflagellates similar to PPW, and was mainly composed by those two groups. Considerably diverse and abundant phytoplankton communities were observed in early winter at that section of the southwestern Atlantic Ocean, particularly in areas under fresh water influence. In addition, the observed biomass levels of protozooplankton suggest their important role on top-down control processes in the region.

1. Introduction

Phytoplankton plays a key role in the dynamics of marine ecosystems, directly influencing both ecological and biogeochemical processes. However, the establishment and development of phytoplankton assemblages in the oceans are highly affected by hydrographical conditions, including both physical and chemical factors, through the so-called "bottom-up" effects. In the southwestern Atlantic waters, phytoplankton assemblages are generally patchily distributed and seem to be modulated, in part, by hydrographical conditions on both the shelf (Gonçalves-Araujo et al., 2016; Odebrecht and Djurfeldt, 1996) and oceanic habitats (Garcia et al., 2008; Gonçalves-Araujo et al., 2012,

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The shelf and shelf-break regions of southern Brazil are recognized as crucial nursery and fishing grounds, concentrating the most important areas of fishery activities in that sector of the southwestern Atlantic Ocean (Torquato and Muelbert, 2014). The region sustains high ichthyoplankton and fish densities and accounts for approximately half of the total Brazilian fish catches (De Macedo-Soares et al., 2014; Vasconcellos and Gasalla, 2001). Overall, the hydrographical conditions along the southern Brazilian continental shelf (SBCS) have been studied over the past decades, using in situ and/or historical hydrographic data (Möller et al., 2008; Piola et al., 2000, 2008a). Satellite images of sea surface temperature, chlorophyll concentration and salinity in the region (Ciotti et al., 2010; Gonzalez-Silvera et al., 2006; Piola et al., 2008b) have particularly allowed a synoptic description of physical and biological processes, such as displacements of the Brazil-Malvinas convergence zone, variability and temporal dynamics of phytoplankton biomass and the dynamics and influence of the Río de La Plata plume on the coast, along the Southwestern Atlantic margin.

During the autumn-winter seasons, the predominance of southwesterly (SW) winds force the La Plata River plume to drift northwards, beyond 26°S, whereas the dominant northeasterly (NE) winds during spring-summer time lead to the retraction of the plume south of 32°S and to an offshore expansion towards the shelf break (Möller et al., 2008). The plume waters flow northwards, transported by the Brazilian Coastal Current (BCC; Souza and Robinson, 2004) also known as the Rio Grande Current (RGC; Zavialov et al., 2002) up to the beginning of August, starting to retreat afterwards. On the other hand, the warm and salty Tropical Water (TW) is transported southwards by the Brazil Current (BC) at the outer shelf and shelf break off southern Brazil. As previously described, the BC reaches latitudes close to 38°S where it encounters the Malvinas/Falklands Current (MC) at the so-called Brazil-Malvinas (Falklands) Confluence (BMC) (Peterson and Stramma, 1991; Souza and Robinson, 2004). The Subtropical Shelf Water (STSW), generated by mixing between the offshore TW and fresh waters from the continental runoff, tends to be transported southwards, parallel to the BC down to the BMC location, where it may mix with other surface water masses such as the La Plata River Plume Water (PPW) and the original TW found at the BC retroflection region (Möller et al., 2008; Piola et al., 2008a). Another important water mass in the region is the South Atlantic Central Water (SACW), found in subsurface layers of the outer shelf and shelf break off southern Brazil, generally reported during the winter season (Möller et al., 2008). Episodic wind-induced upwelling events allow nutrient-enriched SACW to reach the euphotic layer and promote phytoplankton growth, mainly during the summer period (Brandini et al., 2014; Odebrecht and Djurfeldt, 1996). However, the SACW plays a minor role on phytoplankton dynamics within the SBCS during the winter time, when it is located in subsurface layers (Möller et al., 2008).

River plumes influence the hydrographical conditions through advection of low salinity waters to the marine environment (Möller et al., 2008). They also play an important role on local biogeochemical cycles, by carrying estuarine phytoplankton species to inner- and mid-shelf environments (Carreto et al., 2008). Due to the outflow of the nutrient-rich La Plata River, high phytoplankton biomass can frequently be observed in the SBCS in winter and beginning of spring (Garcia and Garcia, 2008; Gonzalez-Silvera et al., 2006). Opposite conditions are found in summer, when the plume is displaced offshore and south of the river mouth and does not reach the Brazilian continental shelf (Möller et al., 2008; Piola et al., 2008b). Seasonal variation in phytoplankton biomass across the region, with high chlorophyll *a* (Chl *a*) concentration at costal sites during winter periods, linked to waters from the La Plata River, have been already described (Ciotti et al., 1995; Garcia et al., 2008), but without details about the phytoplankton community composition. However, a recent study, further north, in the Southern Brazilian Bight (~26.7°S), found a phytoplankton community, with some influence from the La Plata River plume, with a great diversity of diatoms, during winter (Brandini et al., 2014). Other regional studies (most of them during spring and/or summer seasons) have concentrated only on the taxonomy and ecology of particular phytoplankton groups such as dinoflagellates (Haraguchi and Odebrecht, 2010; Islabão and Odebrecht, 2011), cyanobacteria/diatoms (Fernandes and Brandini, 2004; Odebrecht and Djurfeldt, 1996) and raphidophytes (Odebrecht and Abreu, 1995). Most studies have used Chl *a* as a proxy of bulk phytoplankton biomass and described the phytoplankton community only in terms of abundance, i.e., cell number/concentrations. However, cell abundance, alone, does not represent the importance of a species or group in terms of their relevance to trophic webs, unless data on cell sizes are also available. On the other hand, data on carbon biomass provide a robust quantification and allows for a partitioning of the plankton community into functional compartments, such as discriminating between autotroph (phytoplankton) and heterothroph (protozooplankton) biomass as well as into taxonomic/functional phytoplankton groups, which are much needed in ecosystem model parameterizations. Moreover, in this region there are almost no studies on the identification and biomass of the phyto- and protozooplankton communities (including diversity levels) and how these are associated with physical-chemical variables, particularly in winter, when the La Plata River plume is most prominent in coastal waters of the region.

This work therefore addresses the following question: what is the influence of La Plata River waters on the phytoplankton and protozooplankton communities, as compared to other water masses over the southern Brazilian shelf? To characterize this influence, on a spatial scale in the region, a research cruise was conducted in the early wintertime and the following specific goals were pursued: (I) to perform a classification of the water masses within the study region as well as evaluate the water column structure based on thermohaline properties (e.g. temperature and salinity profiles); (II) to assess the phyto- and protozooplankton communities within the region with respect to their biomass and taxonomic composition; and (III) to determine the association of phyto- and protozooplankton groups with the water masses found in the study region. Additionally, we offer a description of the seasonal evolution of phytoplankton biomass by means of sea surface Chl *a* estimates (SSC) obtained from ocean color images, in relation to sea surface temperature (SST), which can also be used as a tracer of the La Plata influence over the Brazilian shelf. This relationship (SST vs. SSC) was then compared with corresponding associations using surface in situ values of both temperature and Chl *a*.

2. Material and methods

2.1. Sampling

The in situ sampling was conducted onboard the Brazilian Navy R/V '*Cruzeiro do Sul*', in the framework of the ACEx/SIMTECO survey, between 12th–20th June 2012. The ACEx/SIMTECO survey was a joint campaign of the research projects "Atlantic Ocean Carbon Experiment" (ACEx) and "Integrated System for Monitoring of Weather, Climate and Ocean for Southern Brazil" (SIMTECO). A total of 31 oceanographic stations were occupied and distributed into 5 transects throughout the southern Brazilian continental shelf and shelf-break domains (25–34°S) (see Fig. 1a). Surface water samples were taken using 5L-Niskin bottles attached to a combined rosette CTD SeaBird® 911 carrousel system. An overview of the location of sampling stations, as well as the sampled or measured parameters at each station is provided in Table A.1, in the Supplementary material. Additionally, the ACEx/SIMTECO cruise also aimed at collecting simultaneous data on the coupled ocean-atmosphere system, including CO_2 fluxes determination in the region (Pezzi et al., 2016) as well as providing data for validation of regional numerical modeling exercises (Mendonça et al., 2017).