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Influence of oceanographic features on spatial and interannual variability of phytoplankton in the Bransfield Strait, Antarctica

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ABSTRACT

Spatial variability and interannual variability of phytoplankton biomass, estimated as chlorophyll-*a* (Chl-*a*) concentration and taxonomic groups, were analyzed in relation to environmental conditions in the Bransfield Strait (BS). This study is based upon both *in situ* (2003, 2004, 2005, 2008, 2009 and 2010) and satellite (2002–2010) data, during the austral summer. A thermohaline front was predominately observed between the colder and saltier waters under the influence of transitional water with Weddell Sea influence (TWW) in the southeastern BS, and the fresher and warmer waters associated with the presence of transitional water with Bellingshausen Sea influence (TBW) in the northwestern BS. Canonical correspondence analysis showed that the dominance of microplanktonic diatoms was associated with higher Chl-*a* within shallow upper mixed layers, with relatively strong pycnocline in the TBW, particularly close to the South Shetland Islands (SSI). Conversely, the TWW was primarily characterized by lower Chl-*a* within deeper mixed layers or a well-mixed water column and dominated by nanoplanktonic flagellates (including haptophytes and cryptophytes). Spatial variability based on both *in situ* and satellite data suggests that the Bransfield Strait acts as a typical Seasonal Ice Zone (SIZ) and the phytoplankton community there is governed by a combination of processes acting synergistically: the sea ice retreat, allowing for a penetration of light into the water column, and a relatively shallow upper mixed layer with strong pycnocline, primarily in the TBW, retaining organisms near the surface when light conditions are adequate. Interannual variability in Chl-*a* and species composition indicate an alternation between diatom-dominated and flagellate-dominated assemblages. These shifts are potentially related to the different stages of phytoplankton succession, as a result of varying water column physical features, principally influenced by the dynamic occupation of the TBW and TWW, that appear to modulate phytoplankton dynamics within the BS.

1. Introduction

The Southern Ocean is recognized as a pivotal component in the modulation of the global climate and in seawater ventilation through the thermohaline circulation (Sarmiento et al., 2004). In this polar region, phytoplankton standing stock and production can be associated with distinct biogeochemical provinces, where physical features exert a significant influence: the Polar Front zone (PFZ), the permanently open ocean zone (POOZ), the marginal ice zones (MIZ) and the coastal and continental shelf zones (CCS) (Arrigo et al., 1998; Tréguer and Jacques, 1992). In general, the continental shelves and marginal ice zones around Antarctica demonstrate a much higher phytoplankton biomass and productivity in comparison to deep pelagic areas (Arrigo et al., 1998).

The tip of the Antarctic Peninsula (AP) has long been a concern within the scientific community as it is one of the most susceptible regions in the world to global climate change (Steig et al., 2009; Turner et al., 2005). Environmental shifts within the AP have resulted in changes of biomass and composition within primary producers, particularly phytoplankton (Ducklow et al., 2007; Garibotti et al., 2005; Montes-Hugo et al., 2009; Schloss et al., 2012). Located to the northwest of the tip of the AP, the Bransfield Strait (BS) is a semi-enclosed sea, limited to the north by the South Shetland Islands (SSI) and to the south by the AP itself. The BS is also connected to the Weddell (east) and Bellingshausen (west) Seas, resulting in a complex circulatory system of surface waters within the Strait, with the Southern BS Current (SBSC) carrying waters advected from the Weddell Sea and the Gerlache Strait Current (GSC) carrying waters from the southwest (Jiang et al., 2013). As a result, the subsequent transitional waters can be detected within the surface layer: transitional water with Weddell influence (TWW) and transitional water with Bellingshausen influence (TBW), with each showing particular thermohaline structures (Fig. 1) (Amos, 2001; López et al., 1999; Sangrà et al., 2011, 2014; Zhou et al., 2006). The dynamic interaction between SBSC and GSC produces mesoscale processes, such as anticyclonic eddies, which become separated from those currents by

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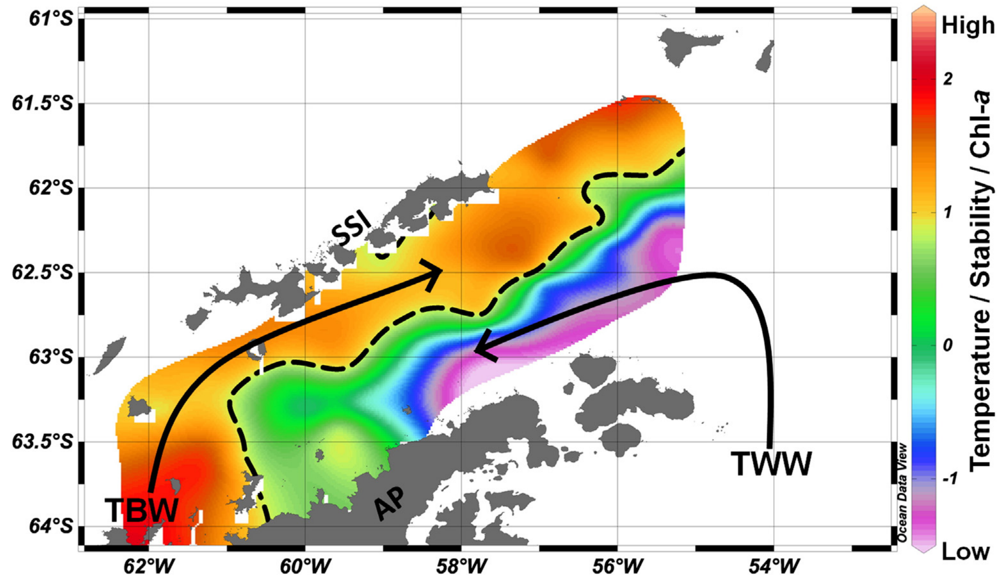

Fig. 1. Scheme of the main circulatory pattern, water column characteristics (temperature and water column stability) and Chl-*a* within the Bransfield Strait. Arrows represent the inflow of the TWW and TBW into the Bransfield Strait. Dashed line represents the Bransfield Front position, highlighting the dynamics between both transitional waters within the Bransfield Strait.

the establishment of two oceanographic fronts: the Bransfield Front (BF) and the Peninsula Front (PF) (Sangrà et al., 2011, 2014). The distribution of those waters, fronts, anticyclonic eddies and their respective thermohaline structures cause variations in the standing stock and composition of the phytoplankton community across the BS (García-Muñoz et al., 2013; Mura et al., 1995; Sangrà et al., 2014).

An eighteen-year research program conducted along the BS showed that the highest chlorophyll-*a* (Chl-*a*) was located close to the SSI and that upper mixed layer depth (UMLD) was negatively related with Chl-*a* (Hewes et al., 2009). In an eastern sector of the BS, the highest Chl-*a* was found at or near the surface decreasing toward the deeper layers at well stratified sites, with euphotic layers varying from 40 to 50 m. By contrast, weakly stratified sites, typically under Weddell Sea influence, were associated with low Chl-*a* and deeper euphotic zones (Holm-Hansen et al., 1997).

During the austral summers of 1995 and 1996, the phytoplankton community within the BS was predominately dominated by either the cryptophyte *Cryptomonas* sp. (1995) or by the colonial haptophyte *Phaeocystis cf. antarctica* and small flagellates (1996), with a considerable contribution of diatoms in both years (Rodriguez et al., 2002). In general, phytoplankton blooms around the AP are typically associated with the development of a shallow mixed layer (retaining phytoplankton within adequate light levels) and with iron availability (*e.g.*, Prézelin et al., 2000), and are reported to be typically dominated by diatoms and/or haptophytes (primarily *P. antarctica*). Nevertheless, several studies have highlighted the increasing importance of cryptophytes in the AP as they prevail over diatoms, particularly within ice melting regions (Moline and Prézelin, 1996; Moline et al., 2004). Several other studies have related the seasonal succession of phytoplankton along the west of the AP (wAP) to the timing of the sea ice retreat, particularly from the south of Gerlache Strait to Marguerite Bay (Garibotti et al., 2005; Prézelin et al., 2000), with some evidence found within the BS (Mendes et al., 2013; Varela et al., 2002). Firstly, diatom blooms attain higher biomass when the sea ice retreat is under way and, with a continued stratification, cryptophytes can numerically replace these diatoms (Ducklow et al., 2007). Finally, a phytoplankton community co-dominated primarily by very small diatoms and other unidentified flagellates are associated with low Chl-*a* (Garibotti et al., 2005; Moline and Prézelin, 1996). There are numerous sources in the literature on phytoplankton dynamics in some wAP systems, principally near Marguerite Bay (Prézelin et al., 2004 and references therein). However, the processes that modulate phytoplankton distribution in open sea regions and their relationship to the dynamics of the water masses, particularly within the BS, are poorly understood. As stated in Garibotti et al. (2005), it is not known if the phytoplankton composition changes from year-to-year in some regions within the wAP, and what kind of environmental variability is related to possible phytoplankton composition changes.

In the present study, microscopic data from four summer cruises to the BS (2003, 2004, 2008 and 2009) were analyzed in order to assess the variability in phytoplankton composition over spatial and interannual scales. These samplings can be considered as representative of the range of standing stock and community composition observed during the early and late 2000s in the region. In addition, satellite data, temperature and Chl-*a* derived from 2003–2010 were used to characterize several differences in the extent of sea ice and Chl-*a* during summer time. Our specific goals were: (1) to comparatively analyze the composition and biomass distribution of the phytoplankton groups during the four studied summers with available microscopic data; (2) to determine whether the phytoplankton community structure is stable or variable from year-to-year; and (3) to evaluate the ecological mechanisms regulating the spatial and interannual phytoplankton variability.

2. Material and methods

2.1. Sampling

Sampling and data collection procedures were conducted across the Bransfield Strait during the GOAL (High Latitude Oceanography Group) and SOS-CLIMATE (Southern Ocean Studies for Understanding Global Climate Issues) cruises during the late austral summers of 2003, 2004, 2005, 2008, 2009 and 2010 (Table 1), on board the Brazilian Navy R/V “Ary Rongel”, as part of the Brazilian Antarctic Program and the International Polar Year (IPY 2007–2008). Vertical profiles of temperature and salinity were taken with a SeaBird® 911+ CTD attached to a Carrousel system bearing 5-L Niskin bottles for water sampling. Water was collected from the surface and several depths for further laboratory analysis of phytoplankton biomass and composition (the later only for the summers of 2003, 2004, 2008 and 2009) and dissolved macronutrients.