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REVIEW

Influence of summer conditions on surface water properties and phytoplankton productivity in embayments of the South Shetland Islands

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Abstract

Phytoplankton productivity in glaciomarine embayments of the West Antarctic Peninsula is constrained because of extensive thermohaline variability, which is due to seasonal sea-ice and glacial melting. To determine whether or not this affects the biology of the water column, we explored the influence of surface water properties on phytoplankton productivity in four embayments of the South Shetland Islands (SSI) during late summer of 2013. We analyzed hydrographic, climatic, and primary productivity satellite data (wind velocity, sea-ice cover, and chlorophyll-a), in situ CTD measurements of physical and chemical characteristics, new estimates of net primary production (NPP), and surface water samples for chlorophyll-a, nutrients, biogenic silica, and plankton composition. Sea-ice cover at the SSI was ~ 20% during February. Long-term satellite wind data (2010–2015) showed that during February 2013 the average wind velocity was ~ 2 m s^{-1} higher than the long-term mean with two low sea surface temperature events occurring simultaneously at all sites. The CTD profiles did not show vertical salinity changes, although salinity was highly correlated with the percentage of integrated nanoplankton Chl-*a*, which represented > 50% of the total integrated Chl-*a* in all the embayments. Phytoplankton was the major contributor to the integrated carbon biomass of the upper water column, where centric diatoms predominated. The contribution of microzooplankton and bacterioplankton at the different sites explained NPP values and the trophic mode at each site. Specifically, NPP at Fildes Bay exhibited an autotrophic productivity mode in contrast to Collins Bay, where both heterotrophic and autotrophic modes alternated, mainly due to weekly changes in community respiration rates.

Keywords South Shetland Islands · Antarctica · Chlorophyll-*a* · Net primary production · Biogenic silica · Nutrients · Phytoplankton

Introduction

The decrease of glacier ice mass, the reduction of the sea-ice season (Cook et al. 2005; Martinson et al. 2008; Stammerjohn et al. 2008), and the increase of precipitation along

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the West Antarctic Peninsula (WAP) (Thomas et al. 2008) have impacts on the thermohaline structure of the water column, the circulation of water masses and stratification, constraining the ability of primary producers to incorporate carbon from the atmosphere. In terms of salinity, the Southern Ocean (SO) is the most affected, exceeding the trends observed in other oceans (Rhein et al. 2013). In fact, it has been reported that, within the glaciomarine environments of the WAP, biomass and composition of phytoplankton have decreased (Garibotti et al. 2005; Ducklow et al. 2007; Montes-Hugo et al. 2009; Schloss et al. 2012). On the other hand, at Palmer Station, sea-ice associated with increased seasonal concentration of chlorophyll-*a* (Chl-*a*) and characterized by a high proportion of diatoms likely favorable for the Antarctic krill has increased since 2009 (Schofield et al. 2017).

The glaciomarine embayments of the South Shetland Islands (SSI) in the WAP constitute a key natural laboratory to study the effects of local climate and seasonal melting on aquatic productivity. These coastal ecosystems are extremely sensitive to climate variations due to the presence of vast glaciers, whose fluctuations could affect the hydrography and biological production because of increased seasonal freshwater flux into the surface ocean. In fact, the WAP has been identified as the fastest warming region of the Southern Hemisphere and the region of greatest warming in the world, with increases of both atmospheric and oceanic temperatures of 5 and 1 °C, respectively, over the past 50 years (Meredith and King 2005; Abram et al. 2013). In this region, the increase in heat is associated with warm, saline Upper Circumpolar Deep Water (UCDW) that penetrates onto the WAP shelf (Schofield et al. 2017). This heat supply by UCDW is associated with stronger winds over the SO (Thompson and Solomon 2002; Marshall 2003), which, accompanied by increased summertime surface-ocean heating (Meredith and King 2005), has caused strong retreats in the seasonal sea-ice cover (Stammerjohn et al. 2008) and an 87% reduction of glaciers in the area (Cook et al. 2005).

Montes-Hugo et al. (2009) estimated a ~ 12% decrease in phytoplankton blooms due to increased glacial melt on phytoplankton communities in the WAP during 1998–2006. Their study demonstrated that the magnitude of phytoplankton blooms has changed latitudinally, especially at the northern WAP, and is associated with more cloudy days, greater upper mixed layer depth, stronger intensity winds, and shorter sea-ice seasons along the marginal ice zone. The decline of sea-ice in the Antarctic ecosystem and associated physical space–time changes in its structure and functioning are believed to be the determining factor in reductions throughout the pelagic food web (Schofield et al. 2010; Saba et al. 2014). By contrast, the opposite trend of increasing phytoplankton biomass over time reflects increased duration and area of ice-free water during the summer season in the southern areas of the WAP (Montes-Hugo et al. 2009). Similarly, the 20-year time series collected by the Palmer Long-Term Ecological Research program (United States Palmer Research Station) to assess long-term patterns and stability in the coastal phytoplankton communities in the WAP (Schofield et al. 2017) showed a significant increase in the seasonally integrated concentration of Chl-*a*, with diatoms being the dominant phytoplankton group. In general, the continental shelves and marginal ice zones around Antarctica display a much higher phytoplankton biomass and productivity than open ocean regions (Arrigo et al. 1998). Phytoplankton composition (Villafañe et al. 1995; Kang et al. 2002; Schloss et al. 2014) in combination with Chl-*a* and primary production estimates (Holm-Hansen and Mitchell 1991; Varela et al. 2002; Holm-Hansen and Hewes 2004) have shown that summer phytoplankton is dominated by microphytoplankton > 20 µm in different ecological regions of the Drake Passage, Bransfield Strait, and the WAP, with a strong spatial salinity gradient between the different water bodies (Hewes et al. 2009). Chl-*a* biomass at the South Shetland Islands (SSI) rarely shows concentrations higher than 3 mg m^{-3} (Hewes et al. 2009), although the largest phytoplankton bloom recorded over the last 20 years had a maximum of 20 mg m^{-3} in coastal waters of southern King George Island in January 2010 (Schloss et al. 2014).

Recently, oceanographic research has focused on examining the possible impact of climate change on the phytoplankton inhabiting the waters of the SO south of the Subtropical Front (Deppeler and Davidson (2017). During the past two decades, the consequences of rapid recent warming and freshening on marine productivity of several areas close to the SSI have been investigated. Phytoplankton blooms were monitored long term (Schloss et al. 2014) to observe their seasonal variability (Hewes et al. 2009), community composition (Schofield et al. 2017) and physiological responses due to changes in light, vertical mixing (Schloss and Ferreyra 2002; Schloss et al. 2002) and salinity effects (Hernando et al. 2015). The influences of local weather on physical and chemical changes in the water column and on the phyto- and zooplankton communities of coastal glaciomarine environments of the SSI remain unresolved.

In this study, we explored the influences of surface water properties on primary productivity proxies (BSi, Chl-*a*, carbon biomass, and phytoplankton abundances) during late summer in four glaciomarine embayments of the SSI, an area with abrupt changes due to extended glacial and sea-ice melt. Our analysis focused on ice coverage, wind field data, as well as in situ measurements of water physical–chemical properties from 1 to 50 m depth (sea surface temperature, dissolved oxygen, salinity, fluorescence, pH, and turbidity), and chemical–biological characteristics from 1 to 25 m depth (nutrients, BSi concentration, Chl-*a* concentration, net primary production (NPP), carbon biomass, and phytoplankton,