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Physical-biological coupling in the Amundsen Sea, Antarctica: Influence of physical factors on phytoplankton community structure and biomass

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A B S T R A C T

To understand the spatial distribution of phytoplankton communities in various habitats in the Amundsen Sea, western Antarctica, a field survey was conducted at 15 stations during the austral summer, from December 2013 to January 2014. Water samples were analyzed by microscopy. We found high phytoplankton abundance and biomass in the Amundsen Sea polynya (ASP). Their strong positive correlation with water temperature suggests that phytoplankton biomass accumulated in the surface layer of the stratified polynya. In the ASP, the predominant phytoplankton species was *Phaeocystis antarctica*, while diatoms formed a major group in the sea ice zone, especially *Fragilariopsis* spp., *Chaetoceros* spp., and *Proboscia* spp. Although this large diatom abundance sharply decreased just off the marginal sea ice zone, weakly silicified diatoms, due to their high buoyancy, were distributed at almost all stations on the continental shelf. *Dictyocha speculum* appeared to favor the area between the marginal sea ice zone and the ASP in contrast to cryptophytes and picophytoplankton, whose abundance was higher in the area between the continental shelf and the open ocean of Amundsen Sea. Several environmental factors were found to affect the spatial variation of phytoplankton species, but the community structure appeared to be controlled mainly by the seawater density related to sea-ice melting and water circulation in the Amundsen Sea.

1. Introduction

The Southern Ocean is a net sink for atmospheric CO_2 uptake at annual timescales. With its high primary productivity (Arrigo et al., 2008), it accounts for 20% of CO_2 uptake in the global ocean (Takahashi et al., 2009). Phytoplankton blooms occupy local areas of reduced ice cover that generally form due to offshore katabatic winds and seasonal ice melt and appear in the austral summer in coastal polynyas (Tremblay and Smith, 2007). The higher insolation and thinner sea ice during the growth season allow the penetration of sufficient irradiance to drive photosynthesis in this continental shelf area. The seasonal variation of phytoplankton biomass and primary production in Antarctic shelf waters play an important role in the biogeochemical cycles of the Southern Ocean (Hoppema and Anderson, 2007).

Studies of the dynamics of phytoplankton in Antarctic coastal waters have shown that both diatoms and the prymnesiophyte *Phaeocystis antarctica* form massive blooms during different seasons and in different areas (Arrigo et al., 1999; Smith et al., 2010). The dominance of these two major groups and the controlling mechanisms differ from year to year, which complicates predictions regarding their distribution (Smith Jr et al., 2006). Most studies have thus far focused on regions in the Ross Sea, the Weddell Sea, and eastern Antarctica (Arrigo et al., 1999; Lancelot et al., 1993; Wright et al., 2010).

The Amundsen Sea polynya (ASP) is the most productive of the 37 identified coastal polynya systems in the Antarctic when assessed per unit area (Arrigo and van Dijken, 2003). The Amundsen Sea is a current hot spot of rapidly thinning ice shelves in Antarctica, a phenomenon attributed to global warming (Pritchard et al., 2012; Rignot et al., 2008). The basal melting of ice shelves in the ASP is accelerated by the intrusion of modified circumpolar deep water (mCDW) (Rignot et al., 2013), which could lead to changes in water column stratification and water circulation, coastal upwelling, and iron (Fe) supply (Gerringa et al., 2012; Rignot et al., 2013; Wang et al., 2014).

In recent studies, the distribution and physiology of the phytoplankton community have been assessed based on measurements of photosynthetic pigments using CHEMTAX (CHEMical TAXonomy) and phytoplankton biomass and primary production derived from satellite data in the Amundsen Sea (Arrigo et al., 2012; Fragoso and Smith Jr, 2012). The results of those studies have shown that the distribution of phytoplankton in the Amundsen Sea is influenced by

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water column stratification, Fe supply, and grazing (Alderkamp et al., 2012b; Mills et al., 2012). In most of these studies, high-performance liquid chromatography (HPLC) was used to examine major species, such as *Phaeocystis antarctica* and diatom groups. Phytoplankton responses to environmental changes are found to differ in terms of both the various groups and individual species (Rose et al., 2009; Xu et al., 2014). Thus, both the distribution and response of whole phytoplankton assemblages, including minor groups, in the rapidly melting Amundsen Sea need to be understood before phytoplankton responses to rapid climate change can be accurately predicted. Accurate information on the phytoplankton communities can be acquired by microscopy. Although this approach is time-consuming and requires a high level of expertise, it provides the basic and detailed information needed to understand phytoplankton ecology and physiology.

We herein provide a first step towards an improved understanding of the spatial variation of phytoplankton species in the Amundsen Sea. In this microscopy-based study, the distribution of the phytoplankton communities was investigated in four distinct habitats [the oceanic area (OA), the ASP, the marginal sea ice zone (MSIZ), and the Dotson ice shelf (DIS)] to elucidate its spatial distribution in response to the changing physical and chemical environment occurring in response to the rapidly melting Amundsen Sea.

2. Materials and methods

2.1. Field survey and sample processing

A field survey was conducted onboard the Korean IBRV Araon in the ASP and the surrounding seas during the austral summer from 31 December 2013–14 January 2014 (Fig. 1). Vertical profiles of sea water temperature, salinity, water pressure, water density (sigma-t), and photosynthetic available radiation (PAR) were obtained at 15 stations from casts of a Seabird 911plus model CTD (Sea-Bird Electronics, USA). The mixed layer depth (MLD) was defined as the depth at which the density change exceeded 0.05 kg m^{-3} relative to the reference value at 10 m depth (Venables and Moore, 2010). The euphotic depth was estimated as the depth at which the PAR was 1% of its surface value. Sea ice concentration data were obtained from the Nimbus-7 scanning multichannel microwave radiometer and Defense Meteorological Satellite Program special sensor microwave/imager–special sensor microwave imager/sounder passive microwave data (Cavalieri et al., 1996).

Water samples collected from 4 to 5 layers in the upper 100 m were either analyzed for nutrients and chlorophyll-a (Chl-a) concentrations or used for microscopy. The samples were obtained using a 10 L PVC Niskin water sampler attached to a CTD rosette system. The analyzed nutrients were nitrate+nitrite, ammonium, phosphate, and silicate. Their concentrations were measured onboard using a Bran and Luebbe model Quatro auto-analyzer according to the manufacturer's instructions (Lee et al., 2015). Chl-a was determined onboard at each depth using samples immediately filtered through glass-fiber filter paper (47 mm; Gelman GF/F), extracted with 90% acetone for 24 h (Persons et al., 1984), and then measured in a fluorometer (Trilogy, Turner Designs, USA), previously calibrated against pure Chl-a (Sigma).

To estimate phytoplankton abundance, water samples from the Niskin bottles were subsampled using 200 mL high-density polyethylene bottles, preserved with glutaraldehyde (final concentration 1%), and stored at 4 °C until processed as follows: Sample volumes of 50–150 mL were filtered through Nuclepore filters (0.8 µm pore size, black, 25 mm diameter) until 5 mL were remaining in the filtration tower.

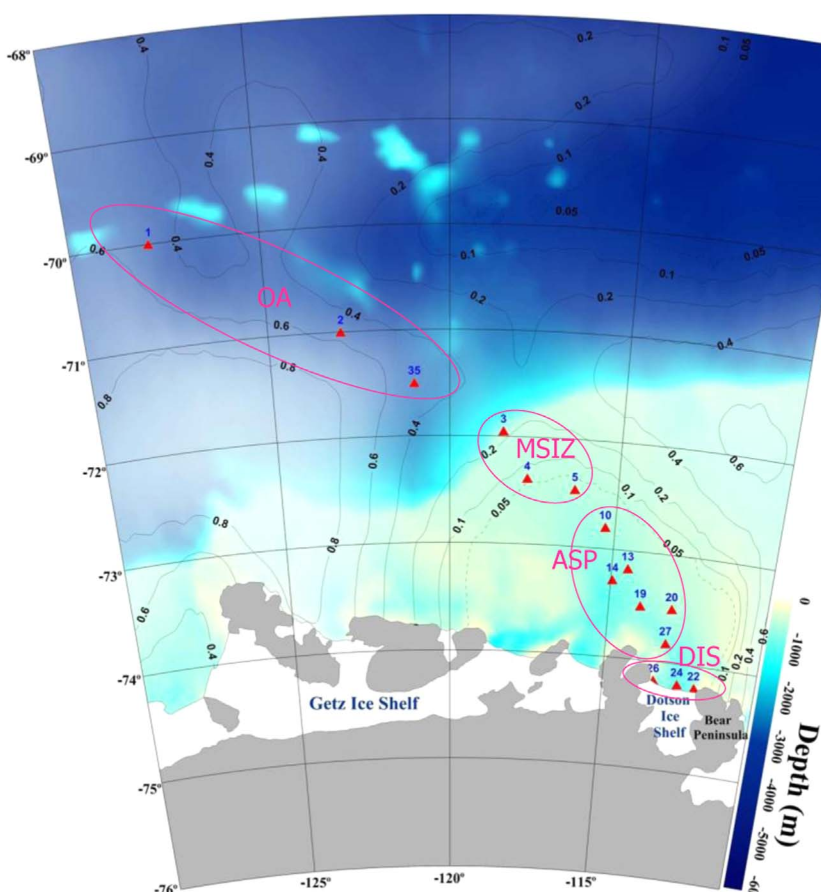

Fig. 1. Sampling stations and the mean sea ice concentration (grey contour line, ×100%) from December 31, 2013 to January 14, 2014 with bathymetry of the study area, which was geographically divided into 4 habitats: oceanic area (OA), marginal sea ice zone (MSIZ), Amundsen Sea polynya (ASP), and Dotson Ice Shelf (DIS) in the Amundsen Sea, Antarctica.