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High protein production of phytoplankton in the Amundsen Sea

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ABSTRACT

The Amundsen Sea polynya is one of the largest and most productive polynyas in the Southern Ocean and has recently experienced a rapid change in sea ice coverage. However, very little is known about current physiological status of phytoplankton and its quality as food for pelagic herbivores and consequently higher trophic levels in the Amundsen Sea. Using a ^{13}C isotope tracer technique, macromolecular production measurements of phytoplankton at eleven stations were conducted at three light depths (100, 30, and 1%) onboard R/V *ARAON* in the Amundsen Sea, 2012. The concentrations of major inorganic nutrients were replete at all the productivity stations and no substantial difference in macromolecular production was found between polynya and non-polynya regions. Distinct vertical trends were not observed in low-molecular-weight metabolites (LMWM) and polysaccharide productions, but weak vertical patterns in lipid and protein productions were found during our cruise period. The vertical patterns of lipids slightly increased with depth whereas decreased for protein synthesis in this study, and these vertical trends were not consistent with the results reported previously in the Arctic Ocean. Overall, phytoplankton allocated more photosynthetic carbon into proteins (60.0%) than other macromolecules in the Amundsen Sea, which is markedly higher than those reported previously in the Antarctic Ocean, ranging from 7 to 23%. The high protein synthesis appears to be sustained by high concentrations of major nutrients, which might be a strong factor for general patterns of macromolecular productions of phytoplankton in polar oceans, even under potential iron limitation.

1. Introduction

Although an increasing trend in the mean sea ice coverage was observed for the overall Antarctic Ocean (Turner et al., 2009; Zhang, 2007), a great interannual and regional variability in the amount and distribution of sea ice (Cavalieri and Parkinson, 2008) as well as environmental conditions (Montes-Hugo et al., 2009) were reported in recent decades. Based on satellite data, sea ice coverage increased in the western Ross Sea sector whereas it declined by about 7% per decade in the Bellingshausen-Amundsen Sea during the same period from 1979 to 2006 (Cavalieri and Parkinson, 2008; Stammerjohn et al., 2012). These changes of climate and sea ice conditions can alter the quantity, quality, and timing of primary production of phytoplankton and ice algae in polar oceans (Smith et al., 1998; Lee et al., 2008, 2012; Vernet et al., 2008). Consequently, changes in the seasonal distributions, geographic ranges, and nutritional structure of higher trophic levels are expected (Tynan and DeMaster, 1997; Moline et al., 2004; Yun et al., 2014). However, marine ecosystems can respond to the environmental conditions differently in different regions in the Antarctic Ocean (Montes-Hugo et al., 2009). The biomass of summer phytoplankton populations increased in the southern shelf region but decreased in the northern shelf region of the Western Antarctic Peninsula, which is associated with geographic differences in receding sea ice according to Montes-Hugo et al. (2009). In our study region, the Amundsen Sea contains one of the largest polynyas in the Southern Ocean, located in between Ross Sea and Bellingshausen Sea (Arrigo and van Dijken, 2003; Tamura et al., 2008). The daily rates of primary production in the Amundsen Sea polynya reaches up to 2.2 g C m^{-2} d^{-1} during spring and summer with absence of sea-ice which is comparable to that in the Ross Sea polynya (Smith and Gordon, 1997; Arrigo and van Dijken, 2003; Arrigo et al., 2008; Lee et al., 2012). Over recent decades, the rapid sea ice retreat and the fast melting of the Pine Island Glacier have been reported in the Amundsen Sea (Jacobs and Comiso, 1997; Jenkins et al., 2010). More recently, the Amundsen Sea has received more attention because of strong sensitivity of ice-shelf melting in Pine Island to atmospheric variability associated with a strong La Niña event (Dutrieux et al., 2014). A substantial flux of bioavailable iron and water

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column stability could be affected by the ice-shelf melting and marine glaciers (Yager et al., 2012). However, how this kind of change in the sea ice coverage affects physiological status and primary production of phytoplankton in the Amundsen Sea is not clear since very little is known about physical and chemical conditions and the marine ecosystem responses of this remote region.

The photosynthetic carbon partitioning by primary producers into different macromolecular classes such as proteins, lipids, polysaccharides, and low molecular weight metabolites (LMWM) can provide important clues to the environmental factors that control their physiological conditions and consequently productions (Morris, 1981; Smith et al., 1989, 1997a, b; Lee et al., 2012; Joo et al., 2014). In the Antarctic, there have been several studies of the photosynthetic carbon allocations mostly for ice algal assemblages (McConville et al., 1985; Gleitz and Kirst, 1991; Gleitz and Thomas, 1992; Ugalde et al., 2013). However, the number of such studies on phytoplankton is relatively limited (Oijen et al., 2004, 2005). The primary objectives of this study were to compare physiological conditions of phytoplankton in polynya and non-polynya regions with different physical-chemical conditions and to evaluate their ecological importance in the Amundsen marine ecosystem by determining carbon allocations into different macromolecules as photosynthetic end-products.

2. Materials and methods

2.1. Study area and samplings

All samples were obtained from 11 February to 14 March in 2012 onboard R/V *ARAON* during the second Antarctic cruise in the Amundsen Sea (Fig. 1). Macromolecular production measurements of phytoplankton were conducted when on-deck incubations were available during daytime at the stations. A total of eleven stations during the cruise period includes polynya (5 stations including Pine Island Polynya stations) and non-polynya (6 stations) regions (Table 1). The polynya was determined by definition of Arrigo and van Dijken (2003), estimated from satellite data [Special Sensor Microwave/Imager (SSM/I)] (Lee et al., 2012). Physical properties such as water temperature and salinity and water samples were obtained from a CTD/rosette sampler (SBE 911 Plus, Seabird Electronics Inc., Bellevue, USA) equipped with 24–10 L bottles.

2.2. Inorganic nutrient and chlorophyll-a analysis

Major inorganic nutrient concentrations (ammonium, nitrite+nitrate, phosphate and silicate) were analyzed onboard using a Bran and Luebbe model Quatro AA (Auto Analyzer) during the cruise (Lee et al., 2012). Water samples (0.3–1.0 L) for total chlorophyll-*a* (chl-*a*) concentrations of phytoplankton were filtered through Whatman glass fiber filters (GF/F; 24 mm) at macromolecular productivity stations. To obtain information on phytoplankton community compositions at sampling stations, size-fractionated chl-*a* concentrations were measured at three light depths (100, 30, and 1% penetration of the surface photosynthetically active radiation, PAR) determined from an underwater PAR sensor lowered with CTD/rosette samplers. Size-fractionated chl-*a* concentrations were determined on samples passed sequentially through 20 and 5 μm Nucleopore filters (47 mm) and Whatman GF/F (47 mm) (Lee et al., 2007). All total and size-fractionated chl-*a* concentrations were measured onboard using a Trilogy fluorometer (Turner Designs, Inc.) after calibration (Lee et al., 2012).

2.3. Productivity experiments for photosynthetic carbon allocation

Productivity experiments were conducted at three light depths (100, 30, and 1%) for photosynthetic carbon allocations, using a ^{13}C isotope tracer technique (Lee et al., 2008, 2009; Joo et al., 2014). Seawater samples of each light depth were transferred from the Niskin bottles to 8.8 L polycarbonate incubation bottles which were covered with screens (LEE Filters; Garneau et al., 2007) appropriate for each light depth. Then, an isotope-enriched (99%) solution of $NaH^{13}CO_3$ was added to the polycarbonate incubation bottles at final concentrations of ~0.2 mM ($^{13}CO_2$) (Hama et al., 1983). The bottles were incubated in a large polycarbonate incubator cooled with running surface seawater on deck under

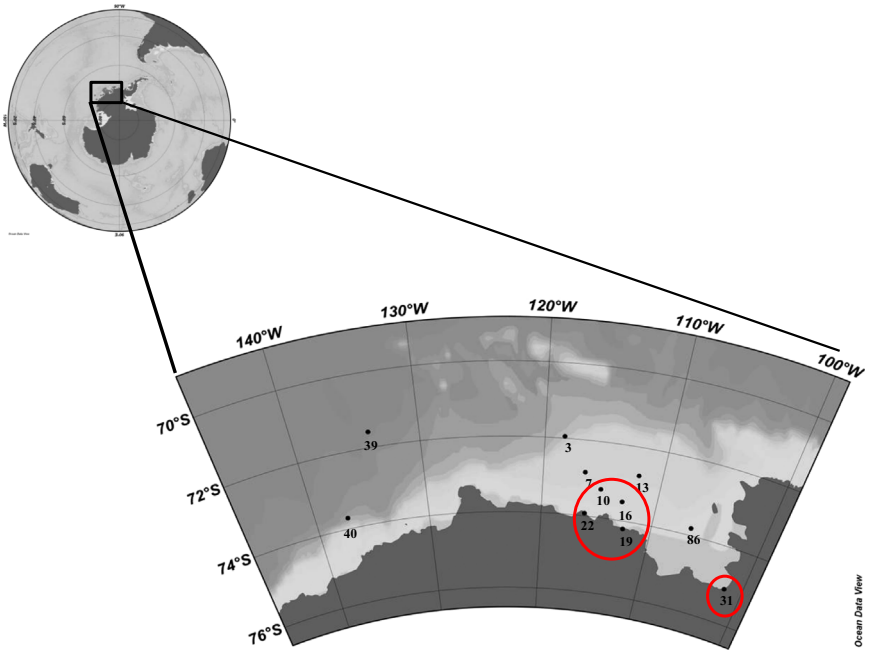

Fig. 1. Macromolecular production stations in the Amundsen Sea, 2012 (Polynya stations are indicated by circles).