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Spring time production of bottom ice algae in the landfast sea ice zone at Barrow, Alaska

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ABSTRACT

The primary production of bottom ice algae is an important food source for sympagic, pelagic and benthic organisms in the Arctic Ocean as well as Antarctic Ocean. Using ^{13}C-^{15}N isotope tracers, the recent ice algal production at Barrow during the spring season was lower in 2003 than three decades ago, although the maximum chlorophyll-a concentration for the bottom ice algae was similar to the values from previous studies. Estimated recent new and total production rates of the ice algae were 0.8 g C m^{-2} yr^{-1} and 2.0 g C m^{-2} yr^{-1} respectively, while the rates of water column phytoplankton were 0.2 g C m^{-2} yr^{-1} and 0.7 g C m^{-2} yr^{-1} for the spring sampling period in 2003. The ice algae contributed 74% of the pelagic primary production under the landfast sea ice at Barrow before the phytoplankton spring bloom. At the end of the season in 2003, a high carbon allocation of lipids in the ice algae was found. Three possible explanations- nutrient depletion, increasing light, and/or changes in species composition- were suggested for the high carbon incorporation into lipids. This high lipid synthesis of the bottom ice algae might be significant to zooplankton and benthic fauna grazers because lipids are the most energy dense biomolecules.

1. Introduction

In addition to phytoplankton in the water column, ice algae within sea ice provide an additional source of primary production in the Arctic Ocean (e.g., Michel et al., 2002; Jin et al., 2006) as well as in the Antarctic Ocean (Arrigo et al., 1997; Lizotte, 2001). Among the various types of sea ice communities, bottom-ice communities are generally most productive in fast-ice both in the Arctic (Smith et al., 1987; Jin et al., 2006; Renaud et al., 2007) and in the Antarctic (Günther and Dieckmann, 1999; Arrigo, 2003). The contribution of ice algae to total primary production ranges from less than 1% in coastal regions (Rysgaard et al., 2001) to nearly 60% in the central ice-covered Arctic Ocean (Gosselin et al., 1997). Although the ecological impact of ice algal production appears to vary widely from region to region, it is potentially important because the bottom ice algae bloom starts a couple of months earlier in spring than phytoplankton bloom (Apollonio, 1965; Michel et al., 1996). Thus, an important food source is provided for sympagic organisms, under ice amphipods and pelagic copepods (Lizotte, 2001; Michel et al., 2002).

Recently, temperature in the Arctic has been changing at a very rapid rate. Higher temperatures have decreased the ice extent and sea-ice thickness in the Arctic Ocean over the past 40 years and have produced more open water, especially in coastal regions (Rothrock et al., 2003; Comiso, 2006; Nghiem et al., 2007). Serreze et al. (2003) and Comiso (2006) found that Arctic sea ice extent and area during the recent 4 years (2002-2005) were at their lowest levels recorded since 1978. Moreover, increased precipitation and earlier snow-melt onset are predicted in the future during winter due to the enhanced temperature in the Arctic (Lynch et al., 2004). Therefore, timing and length of the ice algal spring bloom could be changed by ongoing climate events (Lavoie et al., 2005). Although ice algae and phytoplankton provide a food source for higher trophic levels in the Arctic Ocean, we still do not know if the predicted climate change will increase or decrease food availability because little is known about ecosystem responses of this remote region. More studies of seasonal and annual production rates and physiological conditions of ice algae and phytoplankton are needed to improve our understanding of the impacts of current and future climate changes on the marine ecosystems in the Arctic communities.

The primary objective of this study was to determine the relative importance of ice algae and phytoplankton primary production during the spring growing season in the landfast sea ice zone of Barrow, Alaska in the western Arctic Ocean. The second objective was to compare the bloom patterns and amount of carbon production of ice algae between this and previous studies. Finally, the third objective was to evaluate possible changes in the physiological condition of sea ice algae through

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the growing season by determining carbon allocation into different macromolecules as photosynthetic end-products.

2. Materials and methods

Samplings on the landfast sea ice at Barrow were undertaken 6 times (12-16 February, 1-6 April, 28 April-1 May, 20-22 May, 27-30 May, and 9-11 June) in 2003. Chlorophyll-a data of pelagic and ice algae in 2002 from Kyung-Hoon Shin (pers. comm.) were used for comparison.

2.1. Study area

The sampling sites on the sea ice were located approximately 1.0 km offshore from the Naval Arctic Research Laboratory, Barrow, Alaska (Fig. 1). The sites were located approximately mid-way between the shore and the active pressure ridge. The surface of the sea ice was rather smooth and the water depth at the sampling sites was approximately 4-5 m below the ice. The sea ice gradually breaks up by mid-July (Alexander et al., 1974). Currents in this coastal area vary seasonally and the current speed estimated by Alexander et al. (1974) ranged from 25 to 200 cm s^{-1} in summer during ice free periods.

2.2. Sampling of ice cores and water

Ice cores were extracted with an 8 cm-diameter SIPRE ice corer and small holes (diameter <0.5 cm) for the temperature sensor (accuracy of 0.05 °C) were drilled every 10 cm apart from the bottom to the top of the ice cores. The ice cores were sectioned into 10 cm lengths for melting in the laboratory to determine the bulk salinity using a YSI model 85 meter (accuracy of ±2%) as well as chlorophyll-a and nutrient measurements. The bottom 10 cm section of the ice was further sectioned into 3 and 7 cm lengths for more detailed analysis.

Snow thickness was determined at 10 locations around the sampling site. The light intensity under the ice was measured with a LICOR 4π light sensor (LI-1400) facing upward through a 9-10 cm-diameter ice hole and a surface radiation reference (LI-190 quantum sensor) which was used to correct the light intensity. The light intensity was measured at noon during the productivity experiment. Because the light intensity measurements could have been biased by the ice hole even though the zenith angle of the sun was low, the measured intensity values (Table 1) were only used as a relative reference. Water samples under the ice were collected by a small water sampler through the 25 cm diameter ice hole followed by YSI model 85 temperature and salinity measurements. All samples were stored in dark containers during transfer to the laboratory and the ice samples were thawed in the dark at room temperature overnight, which might affect nutrient concentrations in the melted samples. Salinity was measured with a conductivity meter and nutrient samples were frozen without filtering for later analysis of nitrate, ammonium, silicate, and phosphate concentrations using an automated nutrient analyzer (ALPKEM). Pigment samples were filtered onto Whatman GF/F filters (24 mm), frozen for return to the laboratory, and subsequently extracted in a 3:2 mixture of 90% Acetone and DMSO (Dimethyl Sulfoxide) for 24 hours (Shoaf and Lium, 1976), and centrifuged. Concentrations of chlorophyll-a were measured using a Turner Designs model 10-AU fluorometer which had been calibrated with commercially purified chlorophyll-a preparations (Parsons et al., 1984). After measuring chlorophyll-a concentrations, 100 μl of 10% HCl solution was added into the extracted solution and stored in a test tube rack for about 90 seconds to degrade chlorophyll-a into phaeopigments. A final fluorescence reading was taken after the acidification (Parsons et al., 1984).

2.3. Carbon and nitrogen uptake rates of ice algae at the bottom of the sea ice in 2003

Immediately after the bottom 3 cm skeletal layers containing ice algae were obtained by a SIPRE corer, each layer was cut into several pieces under low light intensity (1% of surface irradiance) and placed in a polycarbonate incubation bottle (500 ml). Each bottle was topped up with 350 ml of cold filtered seawater (GF/F) and inoculated with labeled nitrate ($K^{15}NO_3$), ammonium ($^{15}NH_4Cl$), and carbon ($NaH^{13}CO_3$) substrates (Hama et al., 1983; Dugdale and Goering, 1967). The ^{13}C enrichment was ca. 5-10% of the total inorganic carbon in the ambient water and an amount equal to 10-15% of the ambient nitrate or ammonium concentration was added to each treatment

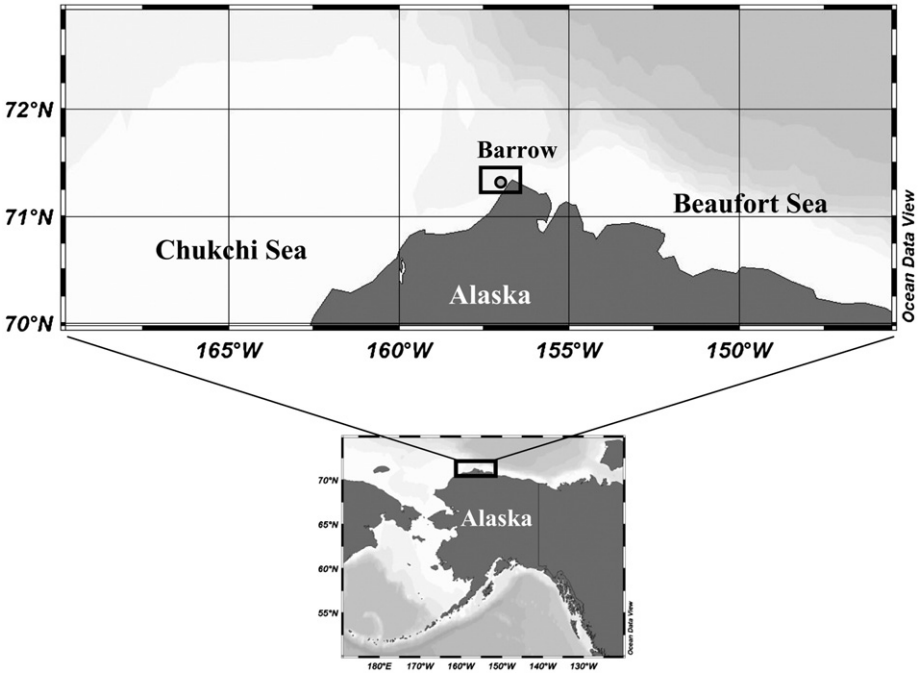

Fig. 1. Location of the primary sampling site near the Naval Research Laboratory at Barrow, Alaska.