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Low primary production in the Chukchi Sea shelf, 2009

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ABSTRACT

Using a ^{13}C–^{15}N dual tracer technique, phytoplankton production measurements were conducted along the entire Chukchi Sea shelf during the 2nd RUSALCA cruise from September 1 to 31, 2009, as a part of long-term ecosystem monitoring. The daily total nitrogen production rates ranged from 6.3 to 126.1 mg N m^{-2} d^{-1} in this study, which were significantly lower than those of previous studies in the region. The large difference in nitrate production rate between the northern and southern regions could be explained by different ambient nitrogen concentrations during the cruise period. Consistently, the overall daily carbon production rate in 2009 was low with a mean of 0.3 g C m^{-2} d^{-1} (SD = ± 0.2 g C m^{-2} d^{-1}). These lower rates of phytoplankton production were induced by a decrease in chlorophyll *a* concentration resulting from less widespread Anadyr Water, which is normally high in nutrients and phytoplankton biomass. In addition, high amounts of freshwater accumulated from the Siberian Coastal Current negatively affected phytoplankton production rates. Under the low nutrient and freshening conditions during this study, small phytoplankton were more abundant than those reported previously on the Chukchi Sea shelf. Because of large variations in production rates of phytoplankton caused by strong seasonal/interannual variations of environmental conditions, various long-term monitoring programs are important to understand marine ecosystem responding to ongoing environmental changes in the Chukchi Sea.

1. Introduction

The Arctic Ocean is experiencing remarkable changes related to its sea ice cover (Arrigo and van Dijken, 2011). Sea ice concentrations have decreased by approximately 9% per decade over the last three decades and have been accompanied by reductions in sea ice thickness and duration (Perovich and Richter-Menge, 2009). With sea ice thinning and melting, which results in increased areas of open water and a longer ice-free period, it is expected that the light-limited biological primary production rate will increase (Arrigo et al., 2008; Codispoti et al., 2009; Pabi et al., 2008). Arrigo et al. (2008) observed a 35 Tg C $year^{-1}$ increase in the annual primary production in the Arctic between 2006 and 2007, and approximately 30% of this increase could be explained by the increased water area in 2007. Cai et al. (2010) also observed increased biological CO_2 removal in the partially ice-covered basin areas, although CO_2 removal was not increased or possibly decreased in the ice-free basin. However, there are negative effects on primary production in the Arctic Ocean such as ocean acidification caused by increased atmospheric CO_2 and sea ice melting (Yamamoto-Kawai et al., 2009) or a deepening of the nutricline from the accumulation of surface freshwater in the Canada Basin (McLaughlin and Carmack, 2010). Thus, it is difficult to predict whether sea ice melting might enhance phytoplankton production under ongoing environmental changes in the Arctic Ocean.

Unlike ice-covered basins, shallow (< 100 m water depth) shelf regions of the Arctic Ocean are seasonally ice-free and sites for strong air–sea–ice exchanges, biological production, riverine discharges, and water-mass transformation (Aagaard et al., 1981, 1985; Macdonald and Wong, 1987). Particularly, the Chukchi Sea shelf is unique in that the northward transport of Pacific Waters through the Bering Strait profoundly influences regional circulation, water mass properties, and nutrient distributions (Walsh et al., 1989; Weingartner et al., 1998). In addition, the Chukchi Sea, as the only area of inflowing water to the Arctic Ocean, is a notable region to study because environmental changes in the Chukchi Sea are directly linked to ecosystems in the Arctic Ocean (Grebmeier et al., 2006a). Recently, several climate-induced environmental changes have been reported in the northern Bering and Chukchi seas (Overland and Stabeno, 2004; Grebmeier et al., 2006b; Bluhm and Gradinger, 2008), which could change the patterns and total amounts of primary production and subsequently the production at higher trophic levels (Grebmeier, 2012). According to Arrigo et al. (2008), increases in annual net primary production (NPP) by phytoplankton based on satellite ocean color data were particularly large on the continental shelves of the Beaufort, Chukchi, East

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Siberian, Laptev, and Kara seas. However, Lee et al. (2007) reported that the primary production rates from *in situ* measurements were up to three times lower than those previously reported from the shelf of the Chukchi Sea. In consistent, Lee et al. (2013) observed significantly lower chlorophyll *a* concentrations and primary production in the northern Bering Sea. Whether ongoing climate changes enhance or reduce the overall primary production in the Chukchi Sea is unknown. Thus, it is important to monitor how recent phytoplankton productions are changing under rapidly changing environmental condition on the Chukchi Sea shelf.

Previously, several interdisciplinary studies were conducted in the Chukchi Sea but could not include data from territorial waters of the Russian Federation, which are important to better understand the marine ecosystem under ongoing environmental conditions. Based on the Memorandum of Understanding for World Ocean and Polar Regions Studies between the NOAA (US) and the Russian Academy of Sciences in 2003, the first ecosystem-oriented RUSALCA (Russian-American Long-term Census of the Arctic) expedition, which is a joint US-Russian research program, was conducted in the entire Chukchi Sea from August 8 to August 24, 2004 (Lee et al., 2007). The exploration provided a good opportunity to measure the primary production of phytoplankton on the entire Chukchi Sea shelf, including relatively less studied territorial waters of the Russian Federation. Since 2004, the second ecosystem-oriented RUSALCA expedition was conducted in the Chukchi Sea from September 1 to 31, 2009, onboard the Russian vessel *Professor Khromov*. This study is a part of the second RUSLACA program. In this paper, we describe the general features of the carbon and nitrogen production rates of phytoplankton, discuss the factors driving primary production on the Chukchi Sea shelf, and compare our values with those reported previously in the region as a long-term monitoring program.

2. Materials and methods

2.1. Study area

Primary production rates were measured at 22 morning stations from a total of 115 stations for oceanographic samples (Fig. 1). These production stations were divided into two geographical regions: the northern (latitude > 69.5 °N) and southern regions (latitude < 69.5 °N) following Lee et al. (2014). The northern regions consisted of 11 stations surrounding Wrangel Island, including the East Siberian Sea and Herald Canyon (Stns. CEN4, LS3, LS1, SS5, SS4, WN3, WN1, HC49, HC24, HC60, and GD7). The stations in the Chukchi South and Bering Strait were included in the southern regions (Stns. CL1, CL3, CL6, CL7-A, CS1, CS4, CS8, CS12, CS16, BS2, and BS8).

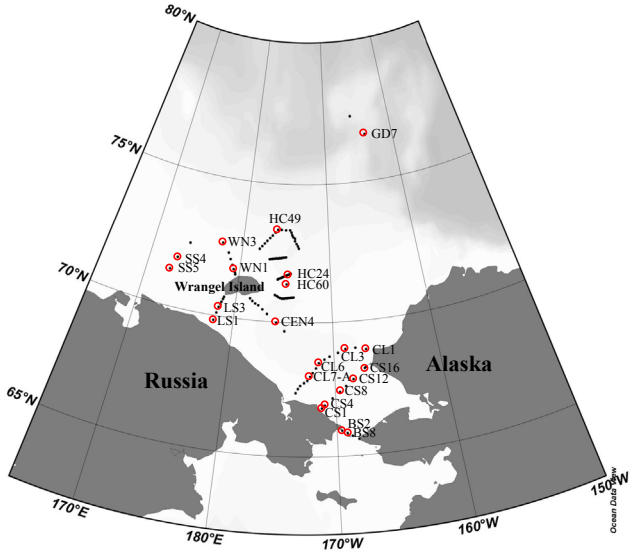

Fig. 1. The locations of the production stations in the Chukchi Sea shelf during the 2009 RUSALCA.

2.2. Hydrographic and water sampling

Water column profiles of temperature and salinity were obtained using a Seabird SBE 911 CTD profiler mounted on a rosette sampler equipped with 21 10-l Niskin bottles. CTD sensors were calibrated by the manufacturer prior to expedition. CTD salinity was calibrated by comparison with bottled seawater salinity analyzed using a salinometer. Euphotic depth (Z_{eu}) was defined as the depth receiving 1% of the surface PAR (photosynthetic active radiation). The mixed-layer depths (Z_m) were defined as the depth of a 0.05 kg m^{-3} increase in sigma-*t* from the 10-m value (Rintoul and Trull, 2001). An index of the vertical stratification of the water column (SI), in kilograms per cubic meter (kg m^{-3}), was determined as the difference in the density between the surface and the bottom depth. To assess the depth affected by freshening within the water column, the surface fresh layer (SFL) was defined as the thickness of the layer above the 31 isohaline (Coupel et al., 2011).

Discrete water samples for measurement of nutrient and total chlorophyll *a* concentrations were obtained from 6 to 8 depths. Samples for size-fractionated chlorophyll *a* concentrations were only obtained at three light depths (100, 30, and 1%). Water samples for the primary productivity experiments were collected at six photic depths (100, 50, 30, 12, 5, and 1% of surface irradiance) determined using an underwater PAR sensor (QSP-2300, Biospherical Instruments Inc.) lowered with CTD/rosette samplers.

2.3. Nutrients and chlorophyll a concentration

Dissolved inorganic nutrient concentrations (nitrite, nitrate, ammonium, silicate, and phosphate) were immediately analyzed onboard after collection using an automated nutrient analyzer (ALPKEM RFA model 300) following the method of Whitledge et al. (1981). The accuracy of the nutrients in the water samples was within ± 0.2 μM with a full-scale range of 5 V. Water samples (300 mL) for the total chlorophyll *a* concentrations were filtered through Whatman GF/F filters (24 mm). For size-fractionated chlorophyll *a* concentrations, 1-L water samples were passed sequentially through 20 and 5 μm Nuclepore filters (47 mm) and 0.7 μm Whatman GF/F filters (47 mm). The chlorophyll *a* concentrations were measured using a Turner Designs model 10-AU field fluorometer calibrated with commercially purified chlorophyll *a* (Turner Designs). The chlorophyll *a* concentration measurements followed the method outlined in Parsons et al. (1984).

2.4. Carbon and nitrogen uptake rate measurements

In situ carbon and nitrogen uptake rates of phytoplankton were measured using a ^{13}C–^{15}N dual tracer technique (Lee and Whitledge, 2005; Lee et al., 2007). Water samples were obtained in polycarbonate incubation bottles (1 L), which were covered with stainless steel screens to simulate each light depth. Labeled carbon ($NaH^{13}CO_3$), nitrate ($K^{15}NO_3$), and ammonium ($^{15}NH_4Cl$) substrates were inoculated immediately in the bottles. The bottles were then incubated in a large polycarbonate incubator cooled with running surface seawater on deck under natural light conditions for approximately 4–5 h. At the majority of sampling sites, incidental photosynthetic active radiation (PAR, 400–700 nm) was measured continuously with a Biospherical QSP-2200 surface PAR sensor next to our incubator.