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Net community production in the northeastern Chukchi Sea

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ABSTRACT

To assess the magnitude, distribution and fate of net community production (NCP) in the Chukchi Sea, dissolved inorganic carbon (DIC), dissolved organic carbon (DOC) and dissolved organic nitrogen (DON), and particulate organic carbon (POC) and particulate organic nitrogen (PON) were measured during the spring and summer of 2004 and compared to similar observations taken in 2002. Distinctive differences in hydrographic conditions were observed between these two years, allowing us to consider several factors that could impact NCP and carbon cycling in both the Chukchi Shelf and the adjacent Canada Basin. Between the spring and summer cruises high rates of phytoplankton production over the Chukchi shelf resulted in a significant drawdown of DIC in the mixed layer and the associated production of DOC/N and POC/N. As in 2002, the highest rates of NCP occurred over the northeastern part of the Chukchi shelf near the head of Barrow Canyon, which has historically been a hotspot for biological activity in the region. However, in 2004, rates of NCP over most of the northeastern shelf were similar and in some cases higher than rates observed in 2002. This was unexpected due to a greater influence of low-nutrient waters from the Alaskan Coastal Current in 2004, which should have suppressed rates of NCP compared to 2002. Between spring and summer of 2004, normalized concentrations of DIC in the mixed layer decreased by as much as 280 μmol kg^{-1}, while DOC and DON increased by ~16 and 9 μmol kg^{-1}, respectively. Given the decreased availability of inorganic nutrients in 2004, rates of NCP could be attributed to increased light penetration, which may have allowed phytoplankton to increase utilization of nutrients deeper in the water column. In addition, there was a rapid and extensive retreat of the ice cover in summer 2004 with warmer temperatures in the mixed layer that could have enhanced NCP. Estimates of NCP near the head of Barrow Canyon in 2004 were ~1500 mg carbon (C) m^{-2} d^{-1} which was ~400 mg C m^{-2} d^{-1} higher than the same location in 2002. Estimates of NCP over the shelf-break and deep Canada Basin were low in both years, confirming that there is little primary production in the interior of the western Arctic Ocean due to near-zero concentrations of inorganic nitrate in the mixed layer.

1. Introduction

Arctic shelf seas contain some of the highest rates of primary production found in the ocean and play an important role in the cycling of carbon and nutrients in the Arctic Ocean. In the Chukchi Sea, nutrient-rich Pacific origin waters pass through Bering Strait (Fig. 1) to support a brief, but intense, photosynthetic season with rates of water-column primary production >300 g C m^{-2} yr^{-1} (Sambrotto et al., 1984; Hansell et al., 1993; Hill and Cota, 2005; Bates et al., 2005a). This production supports substantial benthic (Grebmeier et al., 1995) and pelagic biomass (Ashjian et al., 2008) that, in turn, supports higher trophic level organisms (e.g., fish, marine mammals, seabirds), including the native human population.

Primary production and net community production (NCP) in the northeastern Chukchi Sea are influenced by seasonal and interannual variability in light, ice and snow cover, as well as marine and coastal inputs. Because of the paucity of data in the region, the timing, extent, and controls of NCP are not well understood. This lack of understanding is particularly important because the Arctic Ocean has a heightened sensitivity to climate change, which could have an impact on ecosystems as warming and sea-ice loss continues (Walsh et al., 1990; Moritz and Perovich, 1996; Grebmeier and Whitledge, 1996; Manabe and Stouffer, 2000). It remains unclear how the warming of the atmosphere and sea-surface temperatures along with changes in stratification and thinning sea-ice might affect productivity and ecosystem dynamics in the region. Productivity over Arctic

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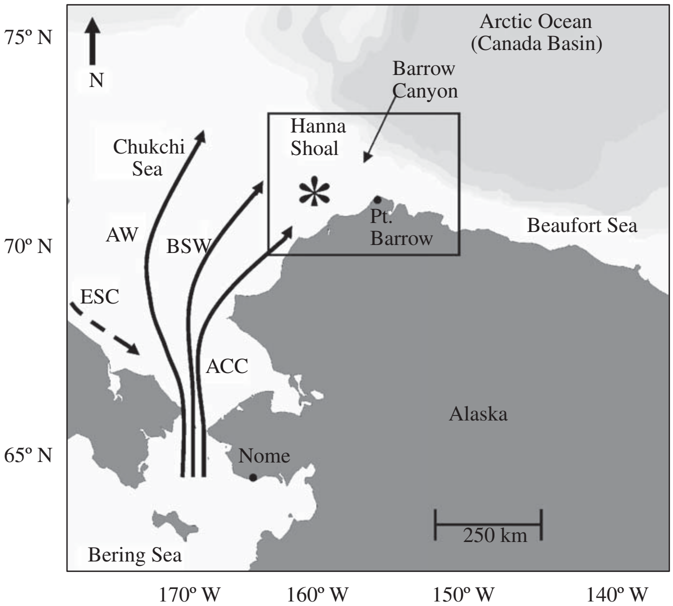

Fig. 1. Map of the western Arctic Ocean showing the northward flowing components of the major current system. The Alaska Coastal Current (ACC) dominates the eastern side of Bering Strait, while Bering Shelf Water (BSW) and Anadyr Current (AC) occupy the central and western channel of Bering Strait. The East Siberian Current (ESC) contributes some seasonal input to the region, but its impact is not well understood. The black box indicates the focus of the area in this study. The star is the approximate location of the head of Barrow Canyon and the biological hotspot in the region. A more detailed map showing the cruise track for spring and summer with station locations can be found at the SBI website (http://sbi.utk.edu/).

shelves could be enhanced in response to increased light availability as polar sea ice continues to diminish.

To date, limited *in vitro* measurements of primary productivity in the Chukchi Sea have been performed. Furthermore, it is difficult to extrapolate the measured rates, typically determined using dawn-to-dusk ^{14}C incubations (Williams, 1993), either spatially or temporally. An alternative approach to direct rate determinations involves observing changes in the *in situ* water-column inventories of the reactants and products (dissolved oxygen (DO), inorganic nutrients, dissolved inorganic carbon (DIC), dissolved organic carbon/nitrogen (DOC/N) and particulate organic carbon/nitrogen (POC/N) of photosynthesis. Estimates of NCP (Williams, 1993) can be determined from seasonal changes in DIC, thereby offering spatially and temporally integrative measures of productivity (Weiss et al., 1979; Codispoti et al., 1982, 1986; Karl et al., 1991; Chipman et al., 1993; Yager et al., 1995; Bates et al., 1998, 2005a; Lee, 2001; Lee et al., 2002).

As part of the Western Arctic Shelf–Basin Interactions (SBI) project (Grebmeier and Harvey, 2005), the timing, extent, and dynamics of production were evaluated during two cruises to the Chukchi Sea in 2004. In this study, the spatial and temporal patterns of NCP and its associated carbon parameters were observed over the northeastern Chukchi shelf and adjacent slope-basin of the Arctic Ocean and then compared to findings from similar cruises in the region in 2002 (Bates et al., 2005a).

A comparison of the 2004 hydrographic data with the results from 2002 revealed several similarities as well as some distinct differences in the two years. During both years dissolved inorganic nitrogen (DIN) (ammonium+nitrate+nitrite) was the limiting factor in phytoplankton growth, suggesting that the fixed-N transport through Bering Strait is a major control on biological productivity (Codispoti et al., 2009). We also found that the head of Barrow Canyon was a region of enhanced biological production over the northeastern shelf. In both years, particularly during summer, oxygen super-saturations were common in or just above the shallow nitracline with higher oxygen saturations observed in 2004 near Barrow Canyon (Codispoti et al., 2009). Finally, surface waters at the deepest stations occupied over the Canada Basin had near-zero concentrations of nitrate in both years indicating little to no potential for primary production in the Canada Basin.

In 2004, there was a greater influence of warm, relatively low-nutrient water from the Alaska Coastal Current (ACC) entering the region via Bering Strait (Codispoti et al., 2009). This increased inflow of ACC may have reduced photic zone nutrient concentrations. The differences in water temperature and nutrients were most pronounced in the upper ~100 m, and the increased influence of warm water in 2004 relative to 2002 was most evident in the area near and to the east of Barrow Canyon. Observations taken on the same days in late July–early August of both years showed that the surface layer was up to 5 °C warmer in 2004.

While the stronger inflow of Alaskan Coastal Water in 2004 may have reduced the autochthonous nutrient supply, rates of primary production and bacterial production were higher during 2004 (Kirchman et al., 2009). One possible explanation for this was an observed increased in light penetration in 2004, which may have allowed phytoplankton to increase utilization of nutrients deeper into the nutricline. In addition, more light combined with warmer water temperatures from the ACC could have enhanced NCP in the region. Sea ice over the northeastern shelf was thicker in 2004 than in 2002, but snow cover was significantly less and may compensated for the differences in ice thickness due to greater light penetration (Codispoti et al., 2009; Shirasawa et al., 2009). It is also possible that the rapid ice retreat and warmer temperatures in 2004 lead to an acceleration in the seasonal progression of biological processes such that the summer observations taken in 2004 might have existed a few weeks after the completion of the 2002 summer cruise. However, there is little doubt that hydrographic conditions in 2004 differed significantly from those in 2002, and this has given us a chance to analyze how these changes impacted NCP.

It has been hypothesized (Walsh and McRoy, 1986) that when the spring bloom occurs in the very cold waters of a shelf (<2 °C), zooplankton reproduction and growth are retarded, and the autotrophs are less susceptible to grazing. Hunt et al. (2002) followed with the suggestion that variability in ice extent, with impacts on SST and the timing of ice retreat, controls the structure of the ecosystem; these controls may be realized through retention of biomass in the upper layer (warm year) vs. the bottom waters (cold year) with a cascading effect through the ecosystem.

2. Hydrography and biogeochemistry

The continental margins of the western Arctic Ocean are important sites of biological activity as they are where the majority of primary production occurs in the Arctic. Ice algae and phytoplankton contribute significantly to primary production over the Chukchi shelf with ~90% of the total primary production occurring in the water column (Hill and Cota, 2005; Gosselin et al., 1997). Primary production in the water column is influenced by a variety of physical and biogeochemical factors including grazing, light, and sea-ice cover. However, the inflow of nutrient-rich Pacific water through Bering Strait has been considered the dominant mechanism controlling regional productivity.

Pacific and fluvial waters from the Bering Sea transit the narrow Bering Strait and fan out across the shallow (<60 m deep), broad Chukchi shelf (Fig. 1). The Bering Strait acts as a gateway for the influx of Pacific waters into the Arctic Basin (Coachman and