Journal of Marine Systems 176 (2017) 54–63

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Bacterial and primary production in the Greenland Sea

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ARTICLE INFO

Keywords:
Bacterial production rate
Organic material
DOC
Terrestrial DOC
Microbial loop
Temperature
Mineral nutrients
Marine
Net primary production
Satellite
Greenland Sea
East Greenland current
Arctic Ocean

ABSTRACT

Bacterial production rates were measured in water profiles collected in the Greenland Sea and adjacent areas. Hydrography and nutrients throughout the water column were measured along 75°N from 12°W to 10°E at 20 km distance intervals. Net primary production rates from satellite sensed data were compared with literature values from ^{14}C incubations and used for regional and seasonal comparisons.

Maximum bacterial production rates were associated with the region close to the edge of the East Greenland current, and the rates decreased gradually towards the center of the Greenland Sea central gyre. Integrated over the upper 20 m the maximum bacterial production rate was 17.9 mmol C m^{-2} day^{-1}, and east of the center of the gyre the average integrated rate was 4.6 mmol C m^{-2} day^{-1}. It is hypothesized that high bacterial production rates in the western Greenland Sea were sustained by organic material carried from the Arctic Ocean by the East Greenland Current.

The depth profiles of nitrate and phosphate were very similar both sides of the Arctic front, with 2% higher values between 500 m and 2000 m in the Arctic domain, and a N/P ratio of 13.6. The N/Si ratio varied by depth and region, with increasing silicate depletion from 1500 m depth to the surface. The rate of depletion from 1500 m depth to surface in the Atlantic domain was twice as high as in the Arctic domain.

Net primary production rates in the area between the edge of the East Greenland current and the center of the Greenland Sea gyre was 96 mmol C m^{-2} day^{-1} at the time of the expedition in 2006, and 78 mmol C m^{-2} day^{-1} east of the center including the Atlantic domain. Annual net primary production estimated from satellite data in the Greenland Sea increased substantially in the period between 2003 and 2016, and the rate of increase was lowest close to the East Greenland Current.

1. Introduction

The Greenland Sea receives large input of water from the Arctic Ocean by the East Greenland Current (Fig. 1). Both the Arctic Ocean and the East Greenland Current surface water contain elevated concentrations of DOC compared to adjacent sea regions (Amon et al., 2003; Benner et al., 2005). A large fraction of the TOC found in the Arctic Ocean is of terrestrial origin and enters through river runoff (Amon, 2003; Benner et al., 2005). The organic carbon carried from the Arctic Ocean into the East Greenland Current may conceivably contribute to elevated bacterial production on its way southwards, and bacterial production rates in the Greenland Sea have been observed to be higher than in the adjacent Norwegian Sea (Børsheim, 2000). The present study was undertaken to investigate more in detail the gradient of bacterial production rates in the vicinity of the East Greenland Current, and to compare these rates with net primary production and nutrients in the region. The motivating hypothesis for the work was that input of organic matter from the East Greenland Sea Current in the western part of the Greenland Sea may stimulate bacterial production and that stimulated bacterial production reduce availability of mineral nutrients for net primary production.

The Greenland Sea is located between the continental shelf of Greenland and a row of seamounts known as the Mohn and Knipowitch ridges situated approximately midway between Greenland and Norway. The seamounts govern the location of the Arctic Front, which is the interface between the northern extension of the warm, saline Atlantic Current waters and the colder, fresher waters in the Greenland Sea (Blindheim and Østerhus, 2005). Part of the Atlantic Current enters the Arctic Ocean on the eastern side of Fram Strait, while a smaller part is redirected southward towards the Greenland Sea either before or shortly after entering the Fram Strait (Rudels et al., 2000). This Atlantic Water mixes with Arctic water of the East Greenland Current to form recirculating Atlantic Water (Blindheim and Rey, 2004). The Greenland Sea central gyre rotates cyclonically around approximately 75°N 2-3 W° with a diameter of ca 200 km (Gascard et al., 2002).

The East Greenland Current water is characterized by lower salinity and higher dissolved organic carbon (DOC) than the Greenland Sea waters (Amon et al., 2003). The elevated concentrations of DOC in the

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http://dx.doi.org/10.1016/j.jmarsys.2017.08.003
Received 7 April 2017; Received in revised form 6 July 2017; Accepted 28 August 2017
Available online 06 September 2017
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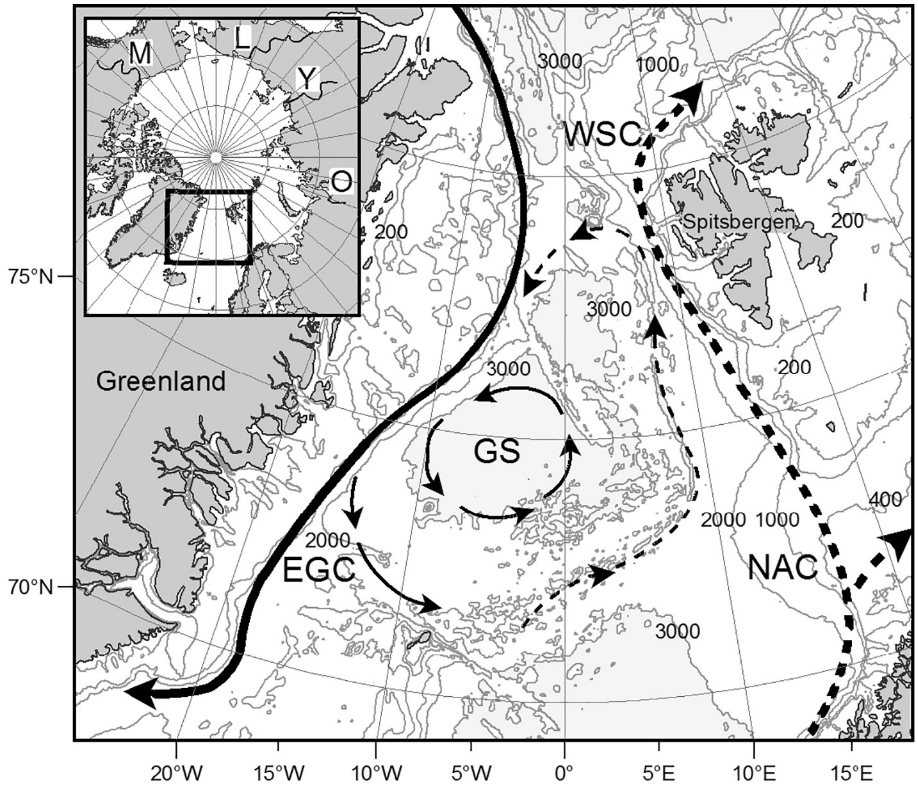

Fig. 1. Topography and major currents in the region discussed. EGC: east Greenland Current. GS: The Greenland Sea. NAC: North Atlantic Current. WSC: West Spitsbergen Current. Inserted figure shows the Polar Ocean and the location of major rivers. O: Ob. Y: Yenitsej. L: Lena. M: Mackensie.

current come from the Arctic Ocean, which is surrounded by land containing vast reservoirs of organic material (Tarnocai et al., 2009).

Contributions of allochtonous organic carbon do not only influence the bacterial production, but will also have consequences for primary production because bacteria compete with phytoplankton for inorganic nutrients (Rivkin and Anderson, 1997). In most oceanic ecosystems, photosynthesis is the main source of carbon. When carbon is supplied from other sources, such as the vast drainage from land into the Arctic Ocean, bacteria need a larger fraction of mineral nutrients such as nitrogen and phosphorus compared to ocean areas with small or no input of allochtonous organic carbon. Because bacteria are efficient competitors for inorganic nutrients, input of organic material may lead to decreased total production (Thingstad et al., 2008). In the Greenland Sea, outcome of competition between bacteria and phytoplankton, and consequently the total production, may change in the future if the load of allochtonous organic carbon changes, for example if higher temperatures accelerate melting of the tundra landscape surrounding the Arctic Ocean. Only scattered observations of net primary production rates are available for the region, therefore satellite sensed data were used to estimate regional and seasonal distribution of net primary production.

2. Material and methods

Samples were collected on two cruises in the Greenland Sea area (Fig. 2). Bacterial production rates were measured by the ^{3}H-[methyl]-thymidine method (Fuhrman and Azam, 1980, 1982). Tritiated thymidine with a specific activity 3.1TBq mmol^{-1} (Du Pont New England Nuclear, USA) was added to a final concentration of 12 nM in 10 ml Nunc minisorb tubes and incubated in the dark for 50 to 60 min. Care was taken to incubate the thymidine incorporation experiments close to the in situ temperature, using a thermostated gradient (Børsheim et al., 2014; Børsheim, 2000). The incubations were stopped by filtering using 0.2 µm pore size Nuclepore filters, followed by washing the filter 3 times with 3 ml ice cold TCA (Børsheim, 1990). Radioactivity was quantified using Ultima Gold XR (Perkin Elmer) and a Packard Tri Carb

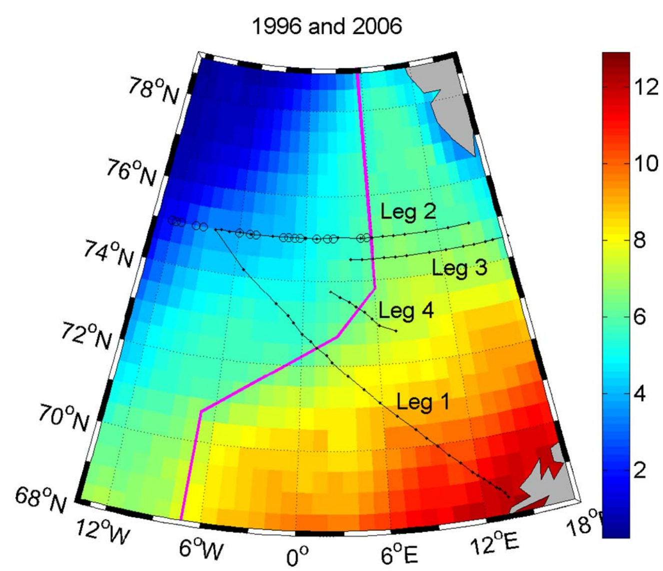

Fig. 2. Stations visited in 1996 (July 22–August 3), and stations sampled for bacterial production rate measurements in 2006 (July 24–August 2). Dots: 1996, circles: 2006. The color map represents average SST from MODIS data in the period 2003–2012 for the last week in July and first week in August (°C). The magenta line indicates the position of the Arctic Front deduced from bottom topography.

scintillation counter. Bacterial production was calculated assuming a yield of 0.023 µg C (pmol thymidine)$^{-1}$, corresponding to a thymidine to cell production conversion factor of $2.0 * 10^{18}$ bacterial cells (mole of incorporated thymidine)$^{-1}$ and an average cell biomass of 11.5 fg C cell^{-1} (Ducklow and Carlson, 1992). These conversion factors are open ocean averages and have previously been used in Nordic Seas work (Børsheim et al., 2014; Børsheim, 2000).

Subsamples for total counts of bacteria were fixed with glutaraldehyde in 100 ml bottles, and stained with SYBR Green I within few hours after sampling (Noble and Fuhrman, 1998). The mounted

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