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Carbon to nitrogen (C:N) stoichiometry of the spring–summer phytoplankton bloom in the North Water Polynya (NOW)

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Abstract

The carbon to nitrogen (C:N) stoichiometry of phytoplankton production varied significantly during the spring–summer bloom in the North Water Polynya (NOW), from April through July 1998. The molar ratio of particulate organic carbon (POC) to nitrogen (PON) production by phytoplankton (ΔPOC:ΔPON) increased from 5.8 during April through early June to 8.9 in late June and July. The molar dissolved inorganic carbon (DIC) to nitrate + nitrite (NO_3) drawdown ratio (ΔDIC: ΔNO_3) increased from 6.7 in April and May, to 11.9 in June (no estimate for July because of ice melting). The discrepancy between ΔPOC:ΔPON and ΔDIC:ΔNO_3 was likely due to dissolved organic carbon (DOC) production. Increased ΔPOC:ΔPON of phytoplankton and surface water ΔDIC:ΔNO_3 throughout the phytoplankton blooms resulted from changes in physical properties of the upper water column, such as reduced thickness of the surface mixed layer that exposed phytoplankton to increased photosynthetically available radiation (PAR), accompanied by NO_3 depletion. This is expected to have significant effects on the cycling of carbon (C) and nitrogen (N) in pelagic ecosystems, as the increased C:N ratio of organic matter decreases its quality as substrate for grazers and microbial communities. Based on ΔPOC:ΔPON, the ratio of POC to chlorophyll *a* (Chl) production (ΔPOC:ΔChl) and the relationship between Chl yields and NO_3 depletion, we estimate that $71 \pm 17\%$ and $46 \pm 20\%$ of the depleted NO_3 went to PON production in the euphotic zone over the polynya from April to early June, and late June to July, respectively. The remaining NO_3 was likely channelled to dissolved organic nitrogen (DON) and heterotrophic bacteria, which were not returned to the dissolved inorganic nitrogen (DIN) pool through recycling during the course of the study. Hence, the autotrophic production of organic N and its recycling by the microbial food web were not coupled temporally.

Keywords: Phytoplankton bloom; Stoichiometry; C:N; DIC; NO_3; Biogeochemical cycling

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1. Introduction

Primary production in the North Water Polynya (NOW) is among the highest observed to date above the Arctic Circle (Lewis et al., 1996; Klein et al., 2002; Mei et al., 2002, 2003; Tremblay et al., 2002b). This high production is strongly associated with the dynamics of ice and the physical properties of the water column, which are forced by regional circulation and climate patterns (Barber et al., 2001; Mei et al., 2002; Melling et al., 2001; Tremblay et al., 2002b).

The photosynthetic fixation of carbon (C) by phytoplankton is accompanied by the uptake of major chemical elements such as nitrogen (N) and phosphorus (P), and for diatoms, silicon (Si). The long-term stoichiometry of nutrient consumption by marine phytoplankton is the same as the ratio of the principal elements in phytoplankton biomass, i.e. phytoplankton take up C, N and P at the approximate ratio of 106:16:1 (Redfield et al., 1963). Because this stoichiometry holds over large oceanic regions and long time scales, it is a critical parameter in global biogeochemical models that predict new and export production from nutrient drawdown (Fasham et al., 1990; Fennel and Neumann, 2004).

Short-term or local deviations of C:N drawdown from the Redfield ratio were discussed by Redfield et al. (1963), and have been reported frequently since then (Brzezinski, 1985; Brzezinski and Nelson, 1995; Codispoti et al., 1991; Daly et al., 1999; Sambrotto et al., 1993). Sambrotto et al. (1993) stressed that the elevated consumption of C relative to the Redfield C:N ratio causes underestimation of organic carbon export from the euphotic zone based on new production. The elevated consumption of C relative to N can result from the production of carbon-rich dissolved organic matter (DOM) (Banse, 1994; Williams, 1995), N limitation (Daly et al., 1999), N_2 fixation (Anderson and Pondaven, 2003; Lee et al., 2002), or growth limitation (Goldman et al., 1979; Goldman, 1986).

The first objective of this study is to investigate the seasonal changes in dissolved inorganic carbon (DIC) to nitrate + nitrite (NO_3) drawdown ratio (ΔDIC:ΔNO_3) and particulate organic carbon (POC) to particulate organic nitrogen (PON) production ratio (ΔPOC:ΔPON) in surface waters, and their relationships with physical, chemical and biological factors in the upper water column. Comparing ΔDIC:ΔNO_3 with ΔPOC:ΔPON would provide insights in the production of DOC and DON during phytoplankton blooms. Production and export from surface water of C-rich DOM makes carbon export more efficient than through POM, because DOM has much higher C:N ratio than POM (Hopkinson and Vallino, 2005).

It is generally assumed that the export of organic matter from the euphotic zone in a marine system is equal to the NO_3-based new production, when the system is in a long-term steady state (e.g. Eppley and Peterson, 1979). Recent studies have shown that NO_3 uptake by phytoplankton is accompanied by significant production of dissolved organic nitrogen (DON) (Bronk et al., 1994). Consistent with the steady-state assumption, the export of organic matter from the euphotic zone must be equal to total (gross) new production over the relevant space and time scales. Because most field estimates of new production (^{15}N uptake experiments, Dugdale and Goering, 1967) do not include the production of DON, the resulting values may underestimate total new production and thus the export of organic matter from the euphotic zone. The second objective of this study is to estimate the balance between NO_3 depletion and PON production, based on the stoichiometry of phytoplankton production, whereby exploring the fate of the N that is not accounted for by PON, and its implications for new and export production.

Data on the distributions of nutrients [NO_3, silicic acid ($Si(OH)_4$) and phosphate (PO_4)] (Tremblay et al., 2002a), DIC (Miller et al., 2002), new production (Tremblay et al., 2002b) and primary production (Klein et al., 2002; Mei et al., 2003) have been published elsewhere. Tremblay et al. (2002a) pointed out that during the spring–summer phytoplankton bloom, NO_3 was the limiting nutrient for primary production, and $Si(OH)_4$ and PO_4 were in extra supply in the NOW. The present paper is the first attempt to estimate ΔDIC:ΔNO_3 under complex hydrodynamic conditions and the seasonal variations in ΔPOC:ΔPON related to the physical properties of the upper water column, thus providing new insights in the response of the biogeochemical cycling of C and N in the NOW to future climate change.

2. Material and methods

2.1. Sampling

Samples were collected in the NOW (75–79°N, 66–80°W; located between Ellesmere Island, Canada,