Community dynamics of bottom-ice algae in Dease Strait of the Canadian Arctic

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ABSTRACT

Sea ice algae are a characteristic feature in ice-covered seas, contributing a significant fraction of the total primary production in many areas and providing a concentrated food source of high nutritional value to grazers in the spring. Algae respond to physical changes in the sea ice environment by modifying their cellular carbon, nitrogen and pigment content, and by adjusting their photophysiological characteristics. In this study we examined how the ratios of particulate organic carbon (POC) to nitrogen (PON), and POC to chlorophyll *a* (chl *a*), responded to the evolving snow-covered sea ice environment near Cambridge Bay, Nunavut, during spring 2014. We also estimated photosynthesis-irradiance (PI) curves using oxygen-optodes *and* evaluated the resulting time-series of PI parameters under thin and thick snow-covered sites. There were no significant differences in PI parameters between samples from different overlying snow depths, and only the maximum photosynthetic rates in the absence of photoinhibition (P_s^B) and photoacclimation (I_S) parameters changed significantly over the spring bloom. Furthermore, we found that both these parameters increased over time in response to increasing percent transmission of photosynthetically active radiation (T_{PAR}) through the ice, indicating that light was a limiting factor of photosynthesis and was an important driver of temporal (over the spring) rather than spatial (between snow depths) variability in photophysiological response. However, we note that spatial variability in primary production was evident. Higher T_{PAR} over the spring and under thin snow affected the composition of algae over both time and space, causing greater POC:chl *a* estimates in late spring and under thin snow cover. Nitrogen limitation was pronounced in this study, likely reducing P_s^B and algal photosynthetic rates, and increasing POC:PON ratios to over six times the Redfield average. Our results highlight the influence of both light and nutrients on ice algal biomass composition and photophysiology, and suggest a limitation by both resources over a diel period.

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1. Introduction

Sea ice algae are important contributors to the base of the Arctic marine food web. Their abundance in the bottom of sea ice during the spring bloom provides concentrated nutrition for grazers at a time when resources are otherwise limited (Legendre et al., 1992). This food source is particularly significant because diatoms that are prevalent in sea ice algal communities contain large amounts of high-energy poly-unsaturated fatty acids (PUFAs) (Leu et al., 2010). Ice algal photosynthetic carbon uptake and oxygen release also significantly affect sea ice carbon dynamics

(Brown et al., 2015), thereby influencing air-sea gas exchanges (Else et al., 2012).

For most of the spring the spatial distribution of bottom ice algal biomass (e.g. Campbell et al., 2014; Mundy et al., 2007; Rysgaard et al., 2001) and production (e.g. Gosselin et al., 1985; Smith et al., 1988; Michel et al., 1988) varies in response to light availability that is largely controlled by snow depth. Ice algal chlorophyll *a* (chl *a*) biomass and production are also influenced by other factors that include nutrient availability (Lavoie et al., 2005), species composition (Gosselin et al., 1997) and stability of the ice matrix (Campbell et al., 2015). These factors contribute to the range of biomass and production measurements that are reported in the literature, although, the significance of each changes seasonally with the progression of spring melt and between different study regions (Leu et al., 2015).

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Ice algae can respond to changing environmental conditions by modifying their cellular carbon and nitrogen composition, as documented by shifts in particulate organic carbon (POC), nitrogen (PON) and chl *a* ratios. On average this results in a ratio of 106 mols carbon to 16 mols nitrogen, or 6.6 mols POC:PON, for marine phytoplankton (Miller and Wheeler, 2012). Although, recent studies have suggested a broader range for ice algae from 3 to 24 mol:mol (Niemi and Michel, 2015), where values may increase as a result of acclimation to high light intensities or nutrient limitation (Demers et al., 1989; Gosselin et al., 1990). Particulate carbon to chl *a* ratios typically increase with acclimation to high light and low nutrient conditions (Gosselin et al., 1990; Michel et al., 1996), resulting in a large range of estimates from 5 to 263 mg:mg for ice algae (Nozais et al., 2001).

Ice algae may also adjust the photosynthetic apparatus as seen by changing photosynthetic-irradiance (PI) parameters in response to environmental conditions. For example, PI parameters can vary considerably due to inorganic nutrient availability, the activity of photosynthetic enzymes (Michel et al., 1988), as well as light (Cota and Horne, 1989), salinity (Bates and Cota, 1986) and temperature conditions (Michel et al., 1989). The effects of these often competing or overlapping factors on parameter estimates can make their interpretation complex (Cota and Smith, 1991).

The goal of our study is to investigate the influence of inorganic nutrient availability and light intensity on sea ice algal composition and photosynthetic response over the spring bloom in Dease Strait, Nunavut. To meet this goal, we collected field observations in the region during the Ice Covered Ecosystem – CAMbridge bay Process Study (ICECAMPS) between April and June, 2014. Measurements of production from optode incubation methods are used to model PI relationships and derive associated photophysiological parameters for ice algae samples collected under thin and thick snow depths. Coincident measurements of environmental conditions were also recorded to assess potential controls of parameter response.

2. Materials and methods

2.1. Field site

Samples were collected in the vicinity of an ice camp established in Dease Strait, Nunavut, Canada (69.03°N, 105.33°W), that
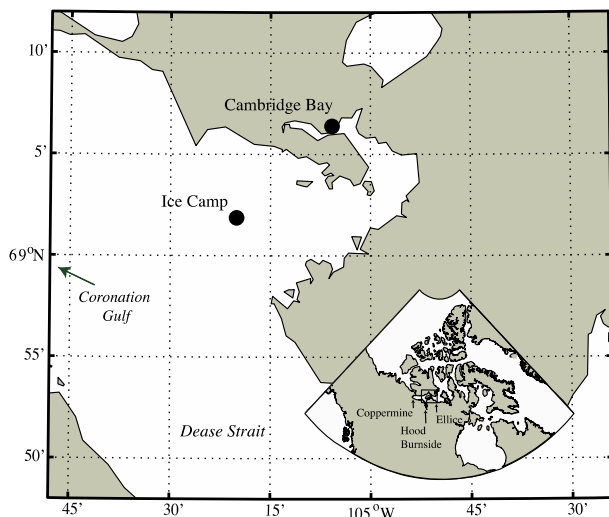

Fig. 1. Map of study location near Cambridge Bay, Nunavut. Inset includes approximate locations of the main rivers in the area.

was about 5 km offshore from the community of Cambridge Bay (Fig. 1). The general flow of surface waters in the Canadian Arctic Archipelago is from west to east; however, water in the nearby Coronation Gulf has been suggested to exit both to the Amundsen Gulf in the west and through Dease Strait to the east (McLaughlin et al., 2004). These suggested patterns of surface currents in the region, which are largely driven by the high level of riverine input, indicate that water at the study site may not readily exchange with neighboring water bodies. Freshwater inputs from nearby rivers include the Coppermine, Hood, Burnside and Ellice rivers (Fig. 1) that have historical average flow rates of 255 (above copper creek), 75.6, 134 and 83.4 $m^3\,s^{-1}$, respectively (Environment Canada).

Water depth at the station was 60 m and the landfast first-year sea ice in the region was covered by a drifted snowpack for the duration of sampling. Snow depth was categorized as 'thin' (<10 cm, between snow drifts) or 'thick' (15–25 cm, snow drifts). We sampled on 12 occasions between 21 April and 9 June, at approximately 4-day intervals.

2.2. Field sampling

Ice cores were collected at newly chosen thin and thick snow sites approximately every four days (one sampling cycle) using a 9 cm *Mark II Kovacs* core barrel. The bottom 05 cm of six to eight cores were pooled together for each site, while snow depth and ice thickness for each core were recorded and averaged. A separate core at each snow site was taken for analysis of bulk nutrients.

Average measurements ($n = 3$) of photosynthetically active radiation (PAR) for surface downwelling and upwelling, as well as under-ice downwelling were collected opportunistically between 9:00 and 12:30 local time throughout the sample period using 2π quantum sensors (LICOR) that were calibrated to air and water, respectively. The average of three values was calculated from readings to a *LI-1000* data logger, and albedo was calculated as the ratio of surface upwelling to downwelling. The under-ice sensor was deployed approximately 30 cm beneath the ice-ocean interface using a mechanical arm and the protocol described in Campbell et al. (2014). Transmittance was determined as the percent downwelling PAR transmitted to surface waters under the ice. Due to irregular collection of transmittance data and the need to perform paired statistical analyses (see Section 2.5), measurements ±2 days of core collection were averaged to estimate PAR transmittance at the ice core sampling interval of approximately 4 days. Estimates exceeding this 2-day threshold were not included in averaging, resulting in a total of 10 sampling events that are referred to hereafter as PAR transmittance (T_{PAR}). Finally, daily profiles of conductivity, temperature and depth (CTD) were made of the water column using an RBR XR-620 sensor.

Following transport to laboratory facilities in Cambridge Bay, pooled ice samples were melted in the dark for 24 h in 0.2 μm filtered seawater (FSW) with a mean ± standard deviation of 28 ± 0.3 salinity, that had been collected and filtered 24 h prior to use, which was added at a ratio of three parts FSW to one part ice. This melted sea iceFSW solution from the pooled cores was used for all incubations and measurements to follow, except for bulk nutrients that were melted separately in the dark without dilution. To account for FSW dilution when applicable, the volume of each pooled sample were multiplied by the ratio of total volume (FSW + ice melt) to ice melt.

A full core was also taken at the thin snow cover site to measure temperature (Testo 720 probe) and salinity (Orion Star A212 conductivity meter) for the bottom 0–5 cm, and 10 cm sections above. These values were used to calculate percent brine volume following the equations of Cox and Weeks (1983).