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Sea ice algae – seeding the ice edge pelagic bloom?

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Abstract

Short-lived pelagic blooms are commonly observed near the sea ice edge in spring. Though the combination of light availability and stratification is commonly assumed to facilitate the bloom, seeding by sea ice algae may be of great importance. A seasonal study of the pelagic and sympagic algae in Kobbefjord, West Greenland was conducted to elucidate the role of sea ice algae. During the sea ice season, there were indications that some sea ice algae (prasinophytes, the diatom *Chaetoceros simplex*) remained suspended and viable when released from the sea ice, a prerequisite for an influence on the pelagic. The pelagic bloom at the sea ice edge consisted mainly of small flagellates, which were already present in both sea ice and seawater. Several species which had not previously been observed neither in sea ice nor in seawater – *Thalassiosira* spp. and *Chaetoceros* spp. - also contributed to the bloom. Statistical analysis showed that the sympagic and pelagic community were two separate entities, and indicated that the bloom community in Kobbefjord was influenced by pelagic species rather than being seeded by sea ice algae.

Keywords: sea ice, algae, pelagic, spring bloom, seeding

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Introduction

Sea ice is a principal feature of polar marine ecosystems, with great influence on e.g. element cycling and primary production, and alterations in sea ice extent are expected to have cascading influences on the Arctic marine food web. A stable sea ice cover, particularly with snow cover, attenuates and scatters irradiance with negligible pelagic primary production as a direct consequence (Mikkelsen et al. in press), and the annual primary production in the Arctic is correlated to the length of the ice-free period (Rysgaard et al. 1999).

The limited pelagic productivity and biomass under sea ice cover is frequently followed by a concentrated and short-lived pelagic bloom as sea ice melts. The bloom co-occurs with increased sunlight exposure following sea ice melt, combined with stable stratification created by the melt water (Heide-Jørgensen et al. 2007). Furthermore, sea ice algae may act as an inoculum with possible influence on both the species composition and magnitude of the pelagic spring bloom (e.g. Syvertsen 1991), an influence still subject to debate. Taxonomic analyses have been performed on several occasions; with some studies indicating a connection between ice algae and the pelagic spring bloom (e.g. Meguro et al. 1966, Schandelmeier & Alexander 1981, Michel et al. 1993) while other studies conclude that sea ice and pelagic algae are separate entities (e.g. Clasby et al. 1973, Alexander et al. 1974). The importance of sea ice algal seeding thus vary, and it is likely that their importance is greater in oceanic waters than coastal areas where benthic, brackish and freshwater algae influence (Syvertsen 1991). A prerequisite for seeding by sea ice algae is that they are viable, competitive and remain suspended when released to the pelagic environment.

The Arctic phytoplankton spring bloom can be considered the single most important event in the production cycle (Heide-Jørgensen et al. 2007), and the understanding of mechanisms behind this spring bloom is a prerequisite for predicting ecosystem changes with future changes in sea ice cover.

Methods

Kobbefjord/Kangerluarsunnguaq is a sill fjord near Nuuk, West Greenland (Fig. 1). The innermost part of the fjord (depths around 100 m) is usually sea ice covered, with extensive interannual variation in area and thickness. Data on irradiance were provided by Asiaq (Greenland Survey) and converted to PAR after calibration (R^2=0.99, P<<0.001, n=133) with a LiCor 1400 (Li-Cor, NE, USA).

Three positions in the fjord were visited throughout the sea ice season 2005-2006. A sympagic sampling station on the sea ice (64˚ 09,69N 51˚ 27,17W), a pelagic sampling station at the proceeding or receding sea ice edge and a pelagic sampling station with no sea ice cover (64˚ 09,54N 51˚ 35,93W).

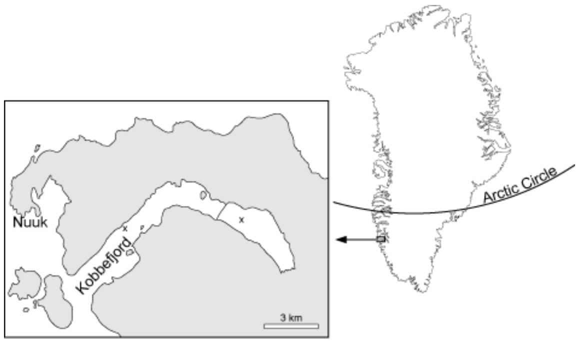

Figure 1. Kobbefjord. Line marks maximum sea ice extent. X marks two sampling stations, one on the sea ice and a reference. A further sampling station was the proceeding and receding sea ice edge.

At the sea ice station, sea ice cores were taken using an ice auger (Mark III, Kovacs Enterprises Ltd, NH, USA). The bottom ten centimeters were melted in polyethylene containers kept in darkness at 4˚C, a process that took 2-3 days. Seawater samples were collected at the two pelagic stations at up to six depths in the photic zone using a Niskin water sampler (KC Denmark, Silkeborg, Denmark). In addition, phytoplankton was sampled from 50 – 0 metres with a 20 µm plankton net. CTD-profiles (CTD plus SIS-1000, Sensoren Instrumente Systemen, Klausdorf, Germany) were obtained on all sampling dates at one or both stations.

For determination of the chlorophyll content, 0.5 – 2 l. seawater from each depth was filtered through GF/C glass fibre filters (<0.2 bar). Chlorophyll was extracted in 96% ethanol for 18 hours (Jespersen & Christoffersen 1987). Fluorescence was measured (TD-700 fluorometer, Turner Designs, California, USA) before and after addition of hydrochloric acid solution. Addition of hydrochloric acid degrades chlorophyll-like pigments (Aminot & Rey 2000), and the difference between the two measurements is thus total chlorophyll. The fluorometer measurements were calibrated against spectrophotometrically determined chlorophyll content in water samples (Dansk_Standardiseringsråd 1986) using a linear regression analysis (R^2=0.99, p<<0.01, n=13).

Melted sea ice and seawater samples were preserved in Lugol's solution (to a final concentration of 1%) for taxonomic analysis. The samples were allowed to settle for a minimum of 16 hours in 10 or 50 ml chambers before counting algae and protozoa at 200x magnification. Analyses were performed using an inverted microscope (Leica DM IL, Leica, Germany) and photo documentation was obtained using a digital microscope camera (Leica DFC280, Leica, Germany). Identification of species and morphological groups was primarily based on the work by Tomas (1997). The presence of fragile cells (e.g. flagellates) verified that direct melting at low temperature did not cause substantial cell lysis.

Results

Sea ice formed late November 2005, and grew steadily at 0.7 cm d^{-1} to a thickness of ~50 cm early February. The sea ice remained stable until May 2006, when it melted rapidly (3 cm d^{-1}).

The irradiance (PAR) from January to June fitted half a bell-shaped curve (Fig. 2a), with mean daily irradiance of 15 µmol photons m^{-2} s^{-1} in January and 600 µmol photons m^{-2} s^{-1} in mid June. Maximum irradiance was 1600 µmol photons m^{-2} s^{-1}.

Sea ice chlorophyll concentrations (Fig. 2b) were low throughout winter, and increased to 0.6 µg chl l^{-1} in March. Chlorophyll concentration decreased in April, and increased again in May, to a maximum of 0.9 µg chl l^{-1}. The pelagic chlorophyll levels at the sea ice edge were very low (<0.1 µg chl l^{-1}) during the sea ice season, until a bloom occurred at sea ice melt late May. Average chlorophyll concentration in the photic zone was 2.5 µg chl l^{-1} and the bloom was most pronounced at a depth of 15 meters (3.7 µg chl l^{-1}). In June, chlorophyll levels dropped again, to 0.6 µg chl l^{-1}. At the reference station, chlorophyll levels were also low in winter (<0.05 µg chl l^{-1}). The chlorophyll concentration began to increase in March, reaching a maximum integrated chlorophyll concentration of 2.2 µg chl l^{-1} early May.

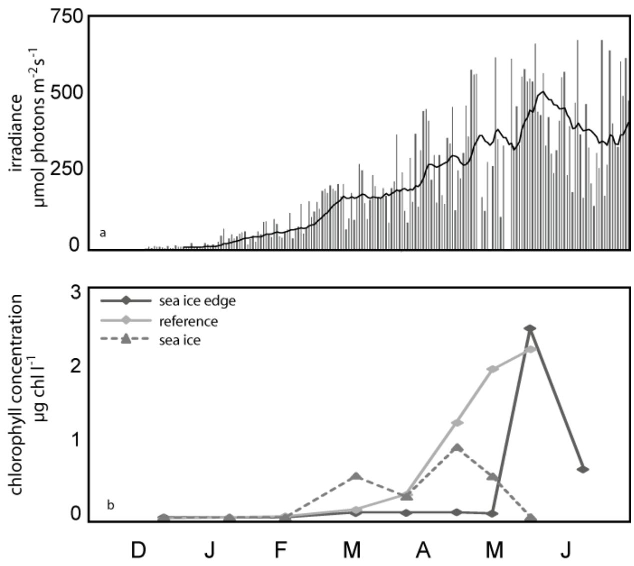

Figure 2. Irradiance (PAR, µmol photons m^{-2} s^{-1}) and chlorophyll concentration (µg chl l^{-1}) from December 2005 to June 2006. A) average daily irradiance (grey bars) with 14 days moving average shown (black line). B) chlorophyll concentration in sea ice, at the sea ice edge and at a reference station.

Most taxonomic groups were encountered in the sympagic algal community, with diatoms, dinoflagellates, cryptophytes and small unidentified flagellates constituting important groups. Two blooms were observed, one dominated by *Chaetoceros simplex* in March, and one dominated by pennate diatoms (*Navicula*, *Nitzschia*) in May. The pelagic algal community at the sea ice edge consisted mainly of dinoflagellates, cryptophytes and small unidentified flagellates throughout winter. At sea ice melt, a bloom dominated by small unidentified flagellates occurred. At this time diatoms (particularly the centric genera *Thalassiosira* and *Chaetoceros*) also appeared. At the reference station, the pelagic bloom late April was also dominated by small unidentified flagellates, with the appearance of the diatom genera *Thalassiosira* and *Chaetoceros*.

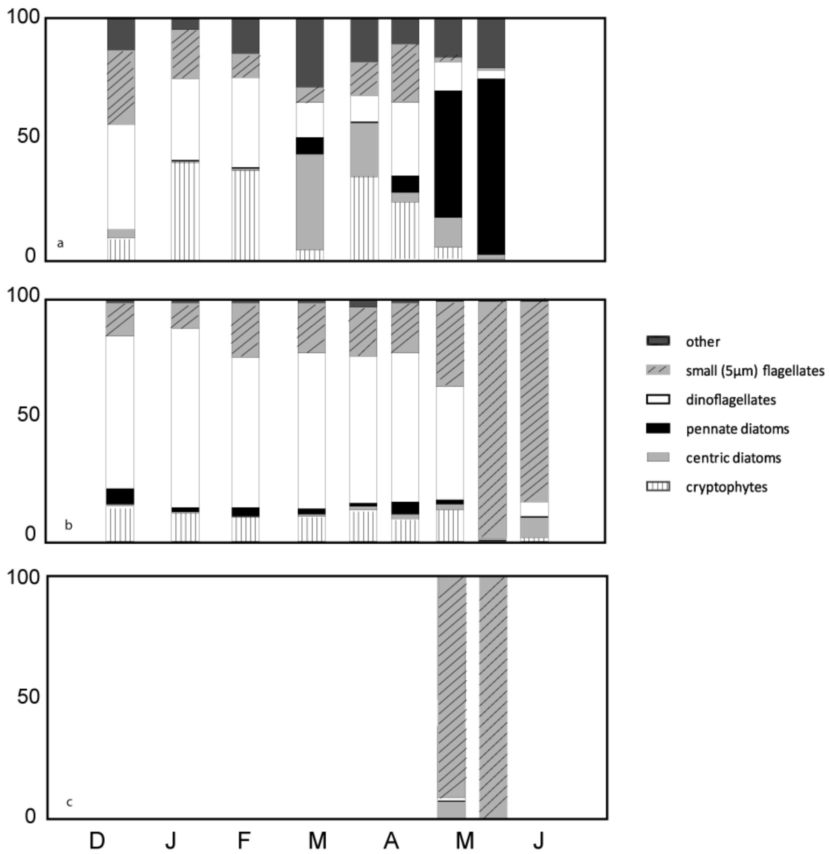

Figure 3. Composition of the algal community, percentage based on abundance. a) sympagic (bottom sea ice). b) pelagic at sea ice edge. c) pelagic at reference station.

Discussion

The chlorophyll concentration and algal abundance correlated well (R^2=0.94, p<<0.01) and showed the same pattern in both sympagic and pelagic samples. The biomass of sympagic algae increased in March, along with the increased irradiance. However, the sympagic biomass decreased again early April, most likely due to light impediment by increased snow cover. A second increase in biomass occurred late April, as snow cover melted. Overall, the sympagic biomass was low.

The pelagic algal biomass under the sea ice remained very low until sea ice melt mid May, due to irradiance limitation caused by attenuation and scattering by sea ice. At the reference station, the algal biomass increased as the season progressed, primarily regulated by irradiance (R^2=0,88, p<<0.01). Nutrient limitation and grazing presumably influence later in the season, as has been observed in other Greenlandic fjords (Rysgaard et al. 1999).

The pelagic algal biomass was significantly different on a temporal scale, both at the sea ice edge (ANOVA, p<<0.01) and the reference station (Kruskall Wallis, p=0.01). During winter, the development at the two pelagic stations was not significantly different. From March, as irradiance increased, there was a significant difference between the chlorophyll concentration at the two stations (Wilcoxon, p=0.1). The bloom at the sea ice edge is thus postponed in relation to the reference station.

During the sea ice season, there was some indication that sea ice algae remained suspended in the pelagic after their release. After the sympagic March bloom, *Chaetoceros simplex* was observed at the pelagic ice edge station. The increase in centric diatoms was small and short-lived, due to light limitation, sedimentation and/or advection. In May, the sympagic algal community consisted primarily of pennate diatoms (*Navicula*, *Nitzschia*). The sea ice edge bloom in Kobbefjord consisted mainly of small flagellates, which were already present in both sea ice and seawater. Several species, including *Thalassiosira* spp. and *Chaetoceros* spp. that had not previously been observed in or under the sea ice also contributed to the bloom. The pelagic bloom at the reference station also consisted of small (5µm) flagellates and centric diatoms. The two pelagic blooms thus had comparable maximal chlorophyll concentration and similar species composition. When comparing taxonomic groups, the sea ice edge bloom was well correlated to the pelagic bloom at the reference station (R^2=0.99, p<<0.01), while no correlation was apparent between the edge bloom and the sea ice algal community (R^2<0.1).

Encountering species in both sea ice and the spring bloom does unfortunately not always provide a clear answer on the origin of the species, as several species occur and grow simultaneously in both the sympagic and pelagic. However, the similarity of the pelagic communities coupled with the conspicuously different sympagic community show that seeding by sea ice algae was not of great importance in Kobbefjord.

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