How does climate change affect Arctic marine productivity? Abiotic Factors and the Arctic Phytoplankton Spring Bloom

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Abstract – Every year, during the Arctic spring, massive phytoplankton blooms develop at the ice edge, sometimes extending far under the pack ice. The complex links between sea ice dynamics and phytoplankton diversity and production are beginning to be unveiled. Climate-related changes have been reported to affect the process of the Arctic phytoplankton spring bloom (PSB) as well as the diversity of the algal community, yet little is known about the community composition and structure of the bloom. The Green Edge project (http://www.greenedgeproject.info) aimed at investigating the dynamics of the Arctic PSB at the ice edge during two consecutive years, 2015 and 2016. Samples for a suite of environmental and biological indicators were obtained at a fixed station on the ice pack in Baffin Bay (Ice Camp) before and during the PSB in 2015 and 2016. This location was chosen to have little influence from continental drainage. Here, data from the 2015 and 2016 GreenEdge project were analysed and patterns in shifting phytoplankton community structures were identified. The data included abiotic parameters over the first 60 m of the water column (temperature, salinity, nutrient concentration and light intensity), as well as biotic indicators of plankton (abundance of different size fractions by flow cytometry, photosynthetic pigments). Photosynthetic picoeukayotes showed a delayed but more intense bloom in 2016 compared to 2015. This could be linked to the fact that the melting starting earlier in 2016 suggesting that shifting abiotic conditions have drastic consequences on phytoplankton productivity and community structure in the Arctic Ocean.

Keywords – GreenEdge, Phytoplankton Spring Bloom, Arctic Ocean

1 INTRODUCTION

The Arctic Ocean is characterised by its highly productive ecosystem, in which many large communities rely on for sustenance (Highsmfth & Coyle, 1990; Grebmeier et al., 1995). This productivity stems from the annual **Phytoplankton Spring Bloom** (PSB), which begins as light in the region picks up after a long sunless winter (Sommer & Lengfellner, 2008). The bloom appears along the ice edge, sometimes extending far under the pack ice (Arrigo et al., 2012 & 2014). Although critical to the marine food web of the Arctic Ocean, the PSB phenomenon is poorly understood, due to limited studies on its dynamics and composition, stemming from the inaccessibility of the Arctic as a study site and the harsh conditions of sub-zero temperatures. This has limited studies to remote-sensing data and mathematical models as proxies, which are unable to account for the variation in many *in situ* physico-chemical parameters (Babin et al., 2015).

Phytoplankton are free-floating single-celled photosynthetic organisms at the base of the marine food web. For the bloom to occur, abiotic conditions supporting the growth of these organisms must be met. Firstly, “seeds” of algal cells must be present in the water column. These seeds require light, nutrients, and time to grow and reproduce (Anderson, 1989). Light is typically the limiting factor in the cold nutrient rich Arctic waters (Sommer & Lengfellner, 2008).

Rapid changes in abiotic conditions in the Arctic at rates far exceeding the rest of earth could have highly unpredictable effects on the PSB due to its high spatio-temporal variability (Kahru et al., 2011). Understanding how changing abiotic conditions affect the bloom can help us to determine future implications on the Arctic ecosystem and hence dependent human populations.

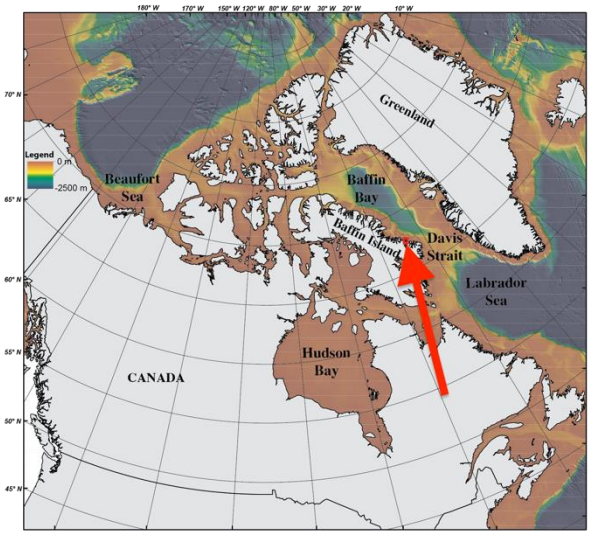

Fig.1 Location of GreenEdge Ice Camp

The GreenEdge Project was conducted to gather large amounts of quantified data on the PSB so as to study and analyse the bloom dynamics. An ice camp was established at 67°28.784N 063°47,372W near Nunavut, Greenland on the ice pack in Baffin Bay (Fig. 1). This location was chosen to have little influence from continental drainage. A host of parameters were recorded *in situ* as well as *ex situ* in labs across Canada and France. The data was further analysed to discover trends in changing bloom dynamics in response to inter-annual abiotic variation.

2 METHODS

During the Green Edge Project, an Ice Camp was set up to measure a total of 70 variables that characterised the physical, chemical, and biological conditions of the background winter and phytoplankton bloom. From these variables, we chose several key abiotic and biotic factors to explain the bloom dynamics.

2.1 ABIOTIC PARAMETERS

Using 8L and 20L Niskin flasks, the nutrient concentration of the water was measured by conducting a colorimetric analysis using an autoanalyzer. Nitrate (NO3) and Phosphate (PO4) concentrations were recorded.

A Compact Optical Profiling System (C-OPS) was employed to measure the Photosynthetically Active Radiation (PAR) through the water column.

Conditions such as temperature, salinity, density and conductivity could be measured from a seabird Pumped FastCat 49 CTD deployed to depths of up to 200m every few days.

Snow thickness was measured using a measuring stick placed perpendicular to the ice bed. Ice thickness was measured using an ice thickness gauge on ice cores.

2.2 BIOTIC PARAMETERS

Water samples from the Niskin flask were also analysed with a FACS Canto flow cytometer from Becton Dickinson at Station Biologique de Roscoff. From the flow cytometry, we recorded the abundance of photosynthetic nanoeukaryotes picoeukaryotes at 6 depths of 1.5m, 5m, 10m, 20m, 40m, and 60m every few days.

The CTD also took measurements of the chlorophyll-a fluorescence down the water column. This employed the Seabird Scientific / WETLabs ECO meters that recorded to a precision of 0.025µL.

Lastly, high-performance liquid chromatography (HPLC) was conducted using an Agilent 1200 HPLC at Université Laval on water samples at depths of 1.5m, 5m, 10m, 20m, 40m, and 60m every few days. Concentrations of a range of photosynthetic pigments were recorded.

2.3 VIZUALIZATION

The open-source programme R was used in conjunction with freely available libraries such as fields, ggplot2, and corrplot. The repository with supporting code and metadata for images and supplementary materials of this report can be found on GitHub and is available upon request, as it is still unpublished: https://github.com/vaulot/Cruise-Green-Edge

3 RESULTS AND DISCUSSION

3.1 COMPARING THE 2015 AND 2016 PHYTOPLANKTON SPRING BLOOM

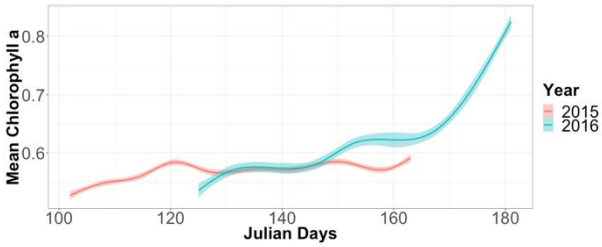

Fig. 2 Chlorophyll-a Concentration in 2015 & 2016

By plotting the chlorophyll-a measured from the CTD over time, we are able to construct a proxy for bloom appearance (Fig. 2). Comparisons between 2015 and 2016 blooms show the two chlorophyll-a levels oscillating around basal levels until julian day 146, where the 2016 bloom begins to pick up. In contrast, the 2015 bloom seems to occur later at day 158, almost 2 weeks after the 2016 bloom. Plotting the abundance of photosynthetic pico and nano eukaryotes down the water column allows us to visually compare the difference in bloom intensity, temporal distribution, and extent through depth between the two years. In terms of intensity, the 2015 photosynthetic picoeukaryote abundance was much less pronounced than in the 2016 bloom by a factor of 2, while the photosynthetic nanoeukaryote was slightly more pronounced – especially in the first 10m of water. Similar to Fig. 2, Fig. 3 shows the 2016 bloom preceding the 2015 bloom by about 2 weeks. Both blooms show similar extent in depth.

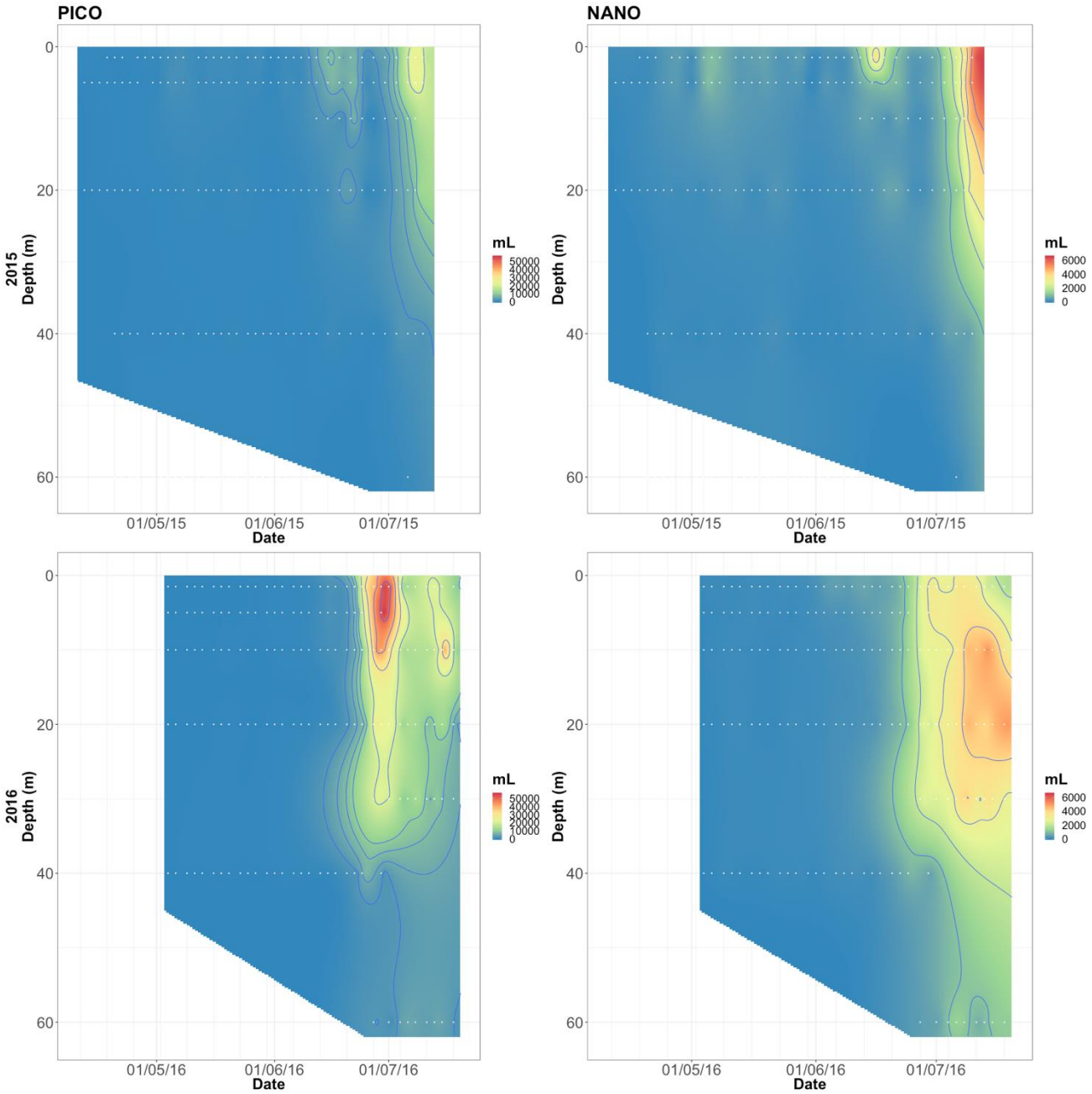

Fig. 3 Pico & Nano Phytoplankton abundance across Depth and Time in 2015 and 2016

Inter-annual variations in peak abundance and temporal distribution of phytoplankton blooms can result from a multitude of interacting factors such as availability of nutrients in the water column, presence of readily available algal seeds for starting the bloom, and the availability of sufficient daily PAR for periods long enough to compensate the respiratory energy expenditure (Anderson, 1989).

To further investigate these differences, we carefully examined the inter-annual variation in abiotic conditions. Using the temperature and salinity values from the CTD, we were able to plot Temperature-Salinity graphs to explore differences in water mass and stratification in the column between the two years.

By looking at the temperature-salinity plots of 2015 and 2016 (Fig. 4), we observe that they share a similar shapes and depth (colour) distribution, indicating their similarity across the two years. The presence of isopycnal lines of identical water mass in similar areas of the plots indicate that, there is little difference between 2015 and 2016 in terms of water column stratification that could account for the temporal difference in bloom timings.

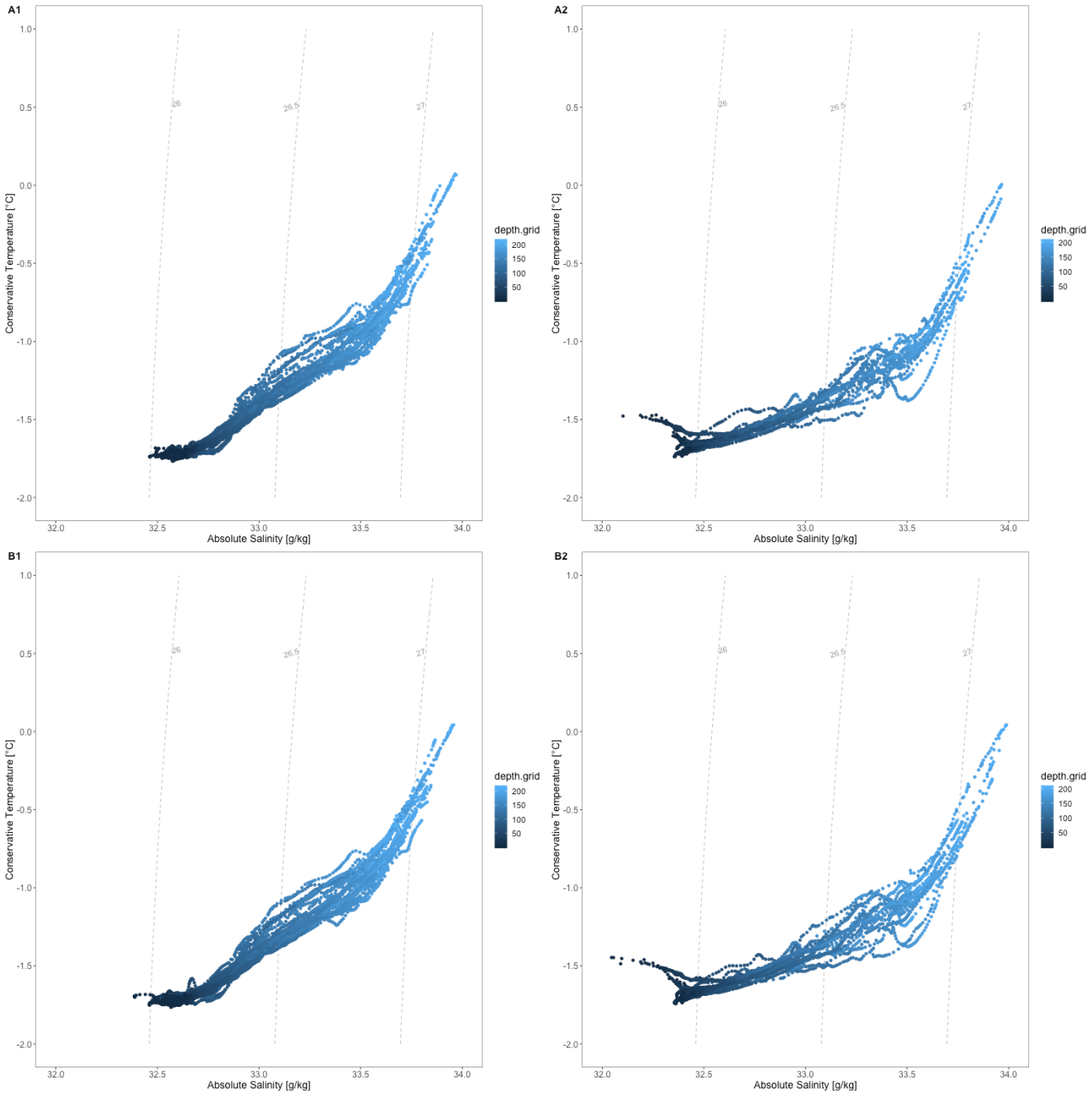

Fig. 4 Temperature – Salinity Graph for 2015 & 2016

The PAR value through the water column was measured using the C-OPS and plotted as a time-series for both years. The inter-annual variation in PAR intensity could be the cause for inter-annual temporal difference in the blooms. By looking at (Fig. 5), it is clear that light intensity in 2016 begins to increase significantly earlier than 2015. As light is often the limiting factor for blooms (Sommer & Lengfellner, 2008), it is likely that the bloom will follow the light intensity accordingly. Differences in PAR intensity is definitely a strong case for the reason behind the earlier onset of the 2016 bloom. An earlier and more intense PAR onset could also justify the larger intensity of pico eukaryotes in the water column. However, it does not explain the lower intensity of nano eukaryotes in 2016 as compared to 2015.

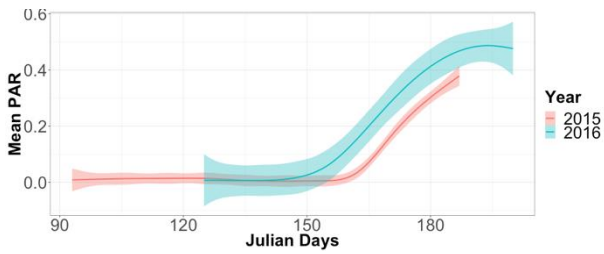

Fig. 5 Available PAR for 2015 & 2016

One explanation for the lower nano eukaryote intensity in 2016 as compared to 2015 could be the lack of nutrients in the water for continued growth of the bloom. As seen from Fig. 3, the nano eukaryote bloom appears after the pico eukaryotes begin to die down. This successional bloom transition suggests that the two groups are competing for resources. A likely limiting resource would be nutrients in the water as the bloom progresses. As the nutrient data for 2015 is not available, no comparison of water nutrient concentration can be made between 2015 and 2016. However, according to the scientific literature available, nutrient concentration is typically high in cold upwelling arctic waters throughout the winter and persists until the PSB consumes and strips the water of nutrients. A paper by Li et al. (2009) describes the tendencies for the bloom to shift towards smaller phytoplankton (pico as compared to nano) as the water receives more heat and freshens as is the case in 2016. The inter-annual variation in bloom intensity could be attributed to the intersecting influences of PAR availability and nutrient availability in the surface waters.

3.2 DETAILED ANALYSIS OF 2016 PSB

3.2.1 Nutrients

Due to the availability of a more comprehensive dataset for the 2016 bloom, a depth analysis of the bloom dynamics and composition was conducted. This included the nutrient data, pigment data, as well as some statistical analysis using correlation and principal component analysis.

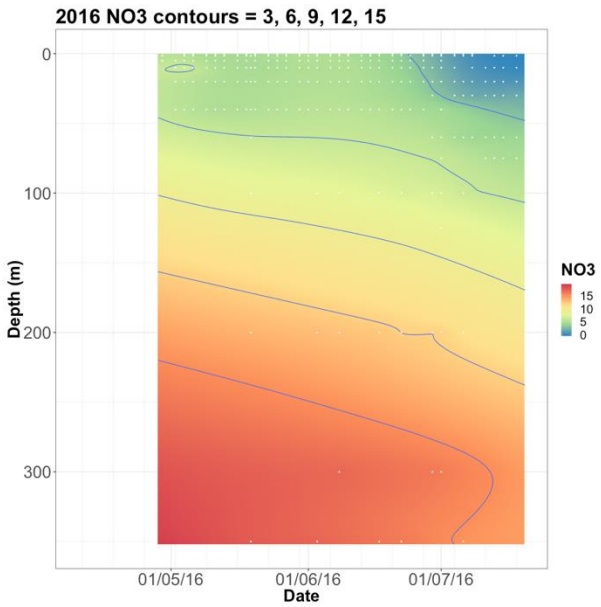

Fig. 6 NO_3 (Nitrates) availability over Depth & Time

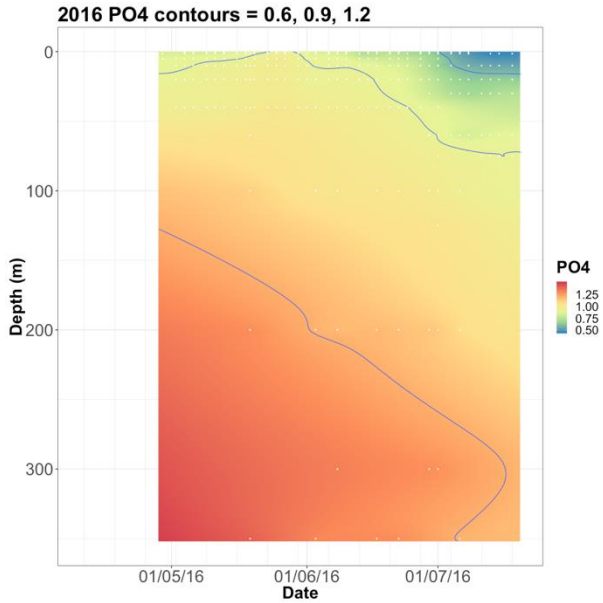

Fig. 7 PO_4 (Phosphates) availability over Depth & Time

Nutrient concentration in the water near the ice camp seems consistent with the hypothesised result. Both the NO3 (Fig. 6) and PO4 (Fig. 7) concentrations are high in the deeper part of the water as cold nutrient rich water blankets the basement. As we get higher up the water column near the surface, nutrient concentration starts to drop slightly. In both cases, as time progresses, nutrient concentration drops off slowly at first, followed by a steep drop around the end of June. This could be explained by the simultaneous appearance of the bloom as seen in Fig. 3. As the phytoplankton proliferated, the photosynthetic eukaryotes stripped the waters of nutrients in a swift exponential manner using it to reproduce. This caused the water in the upper column to be quickly depleted of nutrients, leaving the nutrients in the water at depth fairly consistent due to the limited light persisting through the water column to allow the growth of phytoplankton at depth. Nutrients at depth are seen to have decreased slightly, but nowhere as drastically as at the surface.

3.2.2 Ice & Snow Thickness

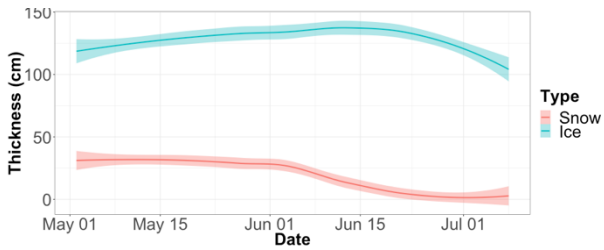

Fig. 8 Ice and Snow Thickness over Time in 2016

Another explanation for the decrease in nutrient concentration in the surface waters could be due to

the melting of the ice shelf leading to a dilution of the surface water. We have already seen in Fig. 5, how light intensity for 2016 starts to increase rapidly over time. It is therefore likely that there is a corresponding increase in heat in the environment as well, leading to increased melting of the ice pack. As can be seen from Fig. 8, there is a decrease in both snow and ice thickness, indicating an increasing rate of melting and hence freshening of surface waters. This influx of freshwater into the surface could account for some of the decrease in nutrient concentration, however the extent and speed of decreasing thickness of ice and snow does not track the exponential drop in nutrient availability in surface waters. More than likely, a combination of nutrient depletion by phytoplankton in the bloom and the addition of freshwater into the system caused the depletion of NO_3 and PO_4 in the surface waters.

3.2.3 Pigments

Pigment values from the HPLC conducted were plotted across depth and time to draw conclusions as to the type of phytoplankton that dominated in each stage of the bloom. Fig. 9 shows the absolute concentrations of the pigments: Chlorophyll-*b*, Prasinoxanthin, 19'-Butanoyloxyfucoxanthin, Fucoxanthin, and Chlorophyll-*c*.

Chlorophyll-*b* and Prasinoxanthin are pigments typically associated with Prasinophytes (Chlorophyta) – a group of unicellular green algae. These green algae are most prevalent at the surface of the water, however persist in quantity down to 20 m. They appear rapidly but also disappear just as rapidly, with only a basal level of these green algae persisting throughout the rest of the bloom. A likely large contributor to these pigment values is the very small green alga *Micromonas polaris* (1.5 µm), which is highly persistent in arctic waters. The small size of this alga, supports the hypothesis of picoeukaryotes being the bloom initiator and precursor to nanoeukaryotes (Fig. 3).

19'-Butanoyloxyfucoxanthin is often used as a proxy for Pelagophytes of the class Pelagophyceae. Pelagophytes are nanophytoplankton (typical size of 5 µm), which fit well the flow cytometry data (Fig. 3). It is present from the start of the bloom, and continues to persist in the later half as well, although at more moderate levels. There is also an indication that these pelagophytes could have been the algae to seed the bloom, as there is evidence of a fluctuating basal amount of 19'-Butanoyloxyfucoxanthin even before the start of the bloom.

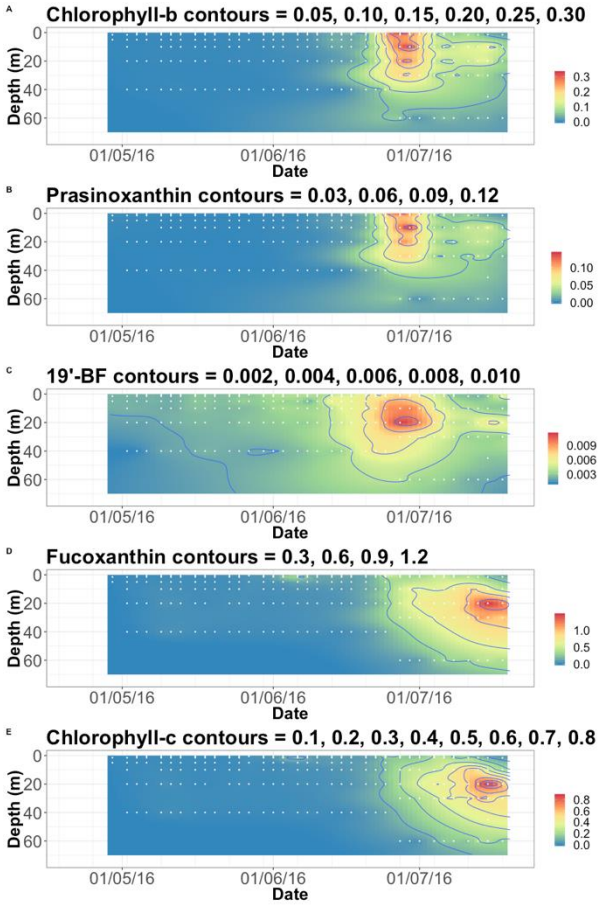

Fig. 9 Pigment Concentrations across depth & time in 2016

Fucoxanthin is often used as a proxy for diatoms, that belong to nano- and micro-plankton (typically size from 5-100µm and above). Fucoxanthin only appears in the later half of the bloom and only within a narrow depth range of 10-30m, being noticeably absent in the surface (Fig. 9).

Chlorophyll-c is also present in diatoms but also in other brown algae (Ochrophyta). Given the almost identical range and extent of spread over time and space for Fucoxanthin and Chlorophyll-c, it is likely that both pigments are associated with diatoms. Diatoms begin their bloom mid-bloom, and persist until the end of the bloom, effectively crowding out the competition and stripping the water of the remaining nutrients, corresponding to part of the nanoeukaryotes seen in Fig. 3.

3.2.4 Correlations and Principal Component Analysis

Correlation matrix of both abiotic and biotic parameters allows us to get a glimpse of the relationships between them (Fig. 10). As expected, Prasinoxanthin and Chlorophyll-b showed similar patterns in relation to abiotic conditions, while

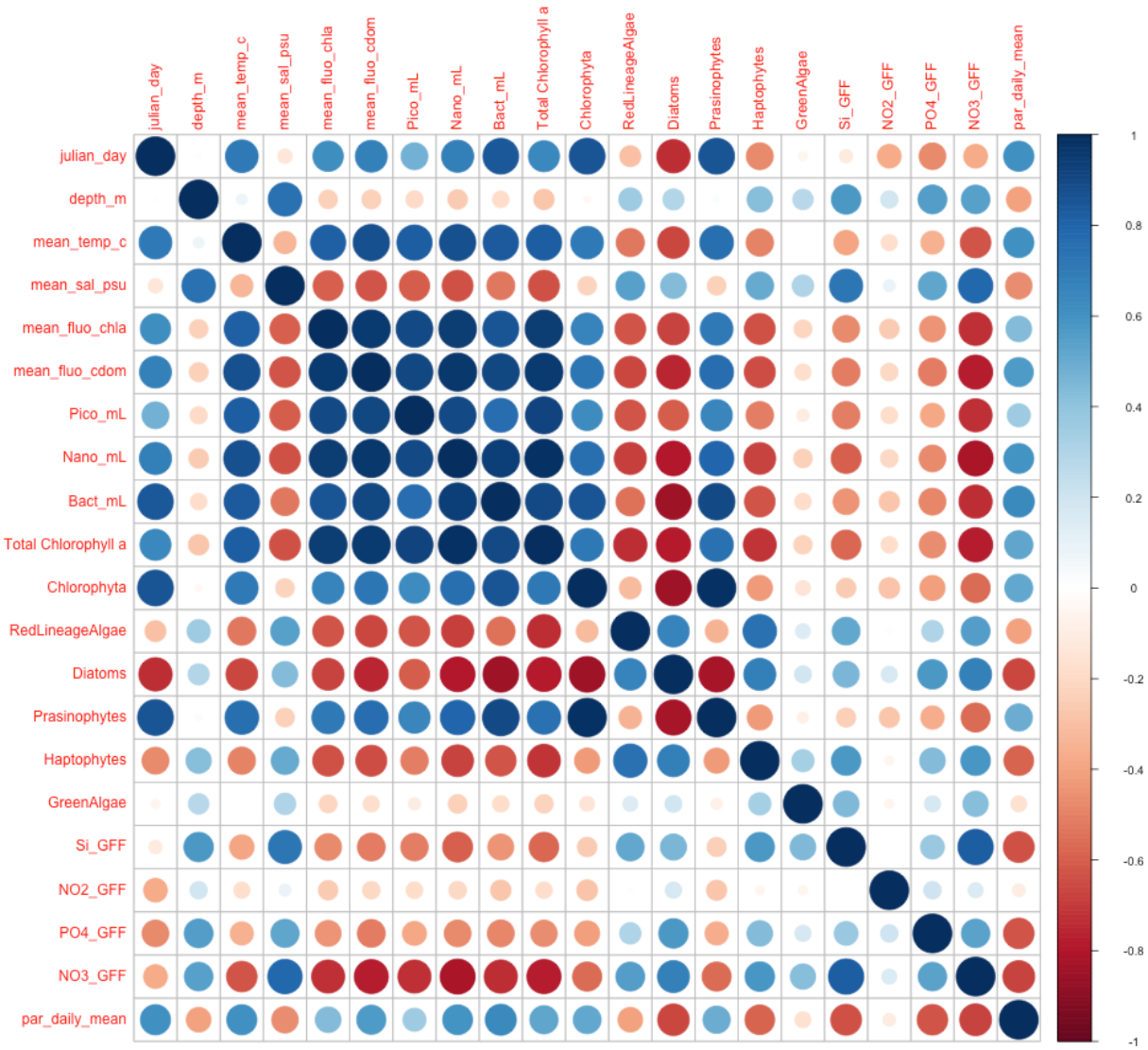

Fig. 10 Correlation Matrix of 2016 Parameters

Fucoxanthin and Chlorophyll-c showed similar patterns but opposite to the two former pigments. This grouping of responses is indicative of different stages of the bloom dynamics.

A better way to spot patterns is to use Principal Component Analysis (PCA). PCA was conducted on the parameters to determine their different loadings and clustering (Fig. 11). Again in this scenario, the 2 groups of pigments are clustered on opposing ends of the plot. One notable feature is how the 19'- Butanoyloxyfucoxanthin is clustered on the nanoeukaryote side of the PCA although its prevalence can be described as relatively abundant throughout the bloom in the earlier stages as well.

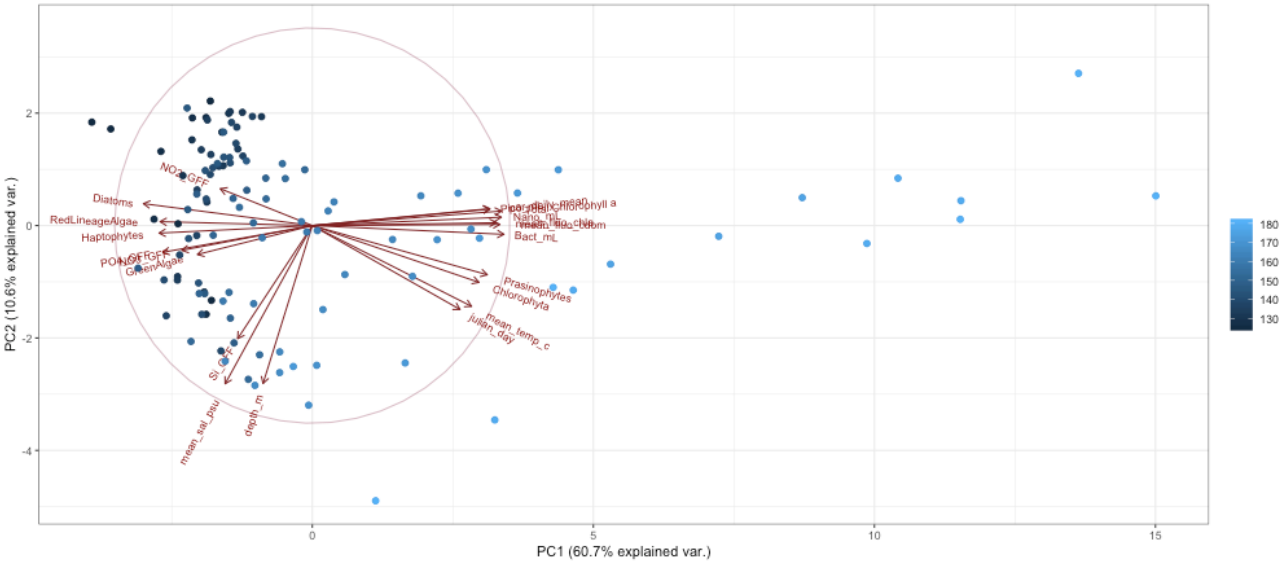

Fig. 11 PCA analysis of 2016 bloom. Arrows represents parameters and dots samples

4 CONCLUSION

The data collected from the Green Edge project can be woven into a single story of the phytoplankton bloom's changing dynamics and composition. Increased availability and intensity of PAR brought about higher abundance of photosynthetic picoeukaryotes such as the green alga *Micromonas polaris*. This bloom quickly developed as optimal conditions allowed their rapid proliferation. After some time, a larger photosynthetic nanoeukaryotes started to bloom as well. However the rapid depletion of nutrients in the water by the initial picoeukayote bloom reduced the capacity for these new contenders to proliferate. Changing abiotic conditions due to climate change could result in increased primary production in the Arctic Ocean due to longer growing seasons (Kahru et al., 2011). However, it could also reduce the biological production at higher trophic levels due to the favouring of smaller algae (Li et al., 2009).

ACKNOWLEDGMENT

I am grateful to Asst Prof Adriana Lopes dos Santos for taking me on for this URECA project. I am also grateful to Prof Daniel Vaulot from the Station Biologique of Roscoff for his immense help and guidance in the use of R. Lastly, I thank the GreenEdge team for sharing their raw data from their respective studies for this paper.

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