CONTENT

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The effect of light and nutrient availability on the phytoplankton growth and composition in the Terra Nova Bay polynya (Ross Sea, Antarctica).

1. Introduction

The continent of Antarctica might seem as a lifeless and desolate place at first, affected by strong (katabatic) winds and covered with ice and snow. However, the Southern Ocean surrounding Antarctica has places that are teeming with life. The Ross Sea for instance has been shown to be one of the most productive areas when it comes to primary marine production, producing up to 28% of the annual production of the Southern Ocean, exceeding 200 mg Chl-a m^{-2} in Summer (Arrigo et al. 1998; Smith et al. 2006). This high amount of production is the result of phytoplankton blooms. These blooms usually originate in so-called 'polynyas', coastal areas of open water that are mainly conserved by strong katabatic winds (Mathiot et al. 2012). Polynyas are areas of increased productivity, due to the unique environmental conditions that are present. This high productivity rate influences the amount of grazers and detritus food webs, thereby affecting the whole ecosystem (Fonda Umani et al. 2002).

In the Western part of the Ross Sea, Terra Nova Bay is a site that contains one of such productive polynyas. This polynya has been studied in detail with regard to almost all of its environmental conditions, nutrient fluxes and phytoplankton blooms.

In the present paper, I intend to focus on reasons why the phytoplankton blooms in the Terra Nova Bay (TNB) polynya are more extensive than in other parts of the Southern ocean. The availability of sun light, water column stratification and nutrient availability are found to have significant influence on the development of phytoplankton blooms and on their species composition (Rivaro et al. 2012). These environmental conditions tend to be uniquely favorable in a polynya, thereby enhancing phytoplankton growth (Accornero et al. 2003). In order to establish what makes these polynyas so favorable for the phytoplankton, this paper shall discuss all three environmental conditions mentioned above and their influences on the phytoplankton blooms and the species composition.

2. The polynya phenomenon

2.1. Polynyas and high primary production

Polynyas are generally large and persistent areas of open water and/or thin ice within the sea-ice of the Arctic and Antarctic regions. Strong katabatic winds usually form and maintain the polynyas adjacent to the coastlines, while sea-ice drift and heat fluxes from the ocean water form polynyas in the open ocean (Ciappa & Budillon 2011; Mathiot et al. 2012). In case of coastal polynyas, the wind transports newly formed sea-ice away from the shore, keeping the area open. The exposed water and thin sea-ice are relatively warmer than the thicker layers of cold ice with which they are surrounded. The relatively warm water, with a temperature close to the freezing point of -1.8ºC for sea water (Morelli 2011), is exposed to the cold and dry katabatic winds, resulting in intense heat loss to the atmosphere. A consequence of this loss of heat is constant and rapid formation of new ice and brine rejection, leaving very salty and cold water which in turn descends into the Antarctic Bottom Water. This vertical convective process contributes to the ocean circulation (Buddilon et al. 2009).

Polynyas are often referred to as ‘hot spots’ of oceanic primary production, since they exhibit increased phytoplankton blooms (Mathiot et al. 2012; Fonda Umani et al. 2002; Rivaro et al. 2011). When compared to other regions of the Southern Ocean, it becomes clear that polynyas exhibit higher chlorophyll concentrations. The inlets and bays containing most of the polynyas in Antarctica, show an increased amount of chlorophyll with regard to the rest of the open ocean (fig.1).

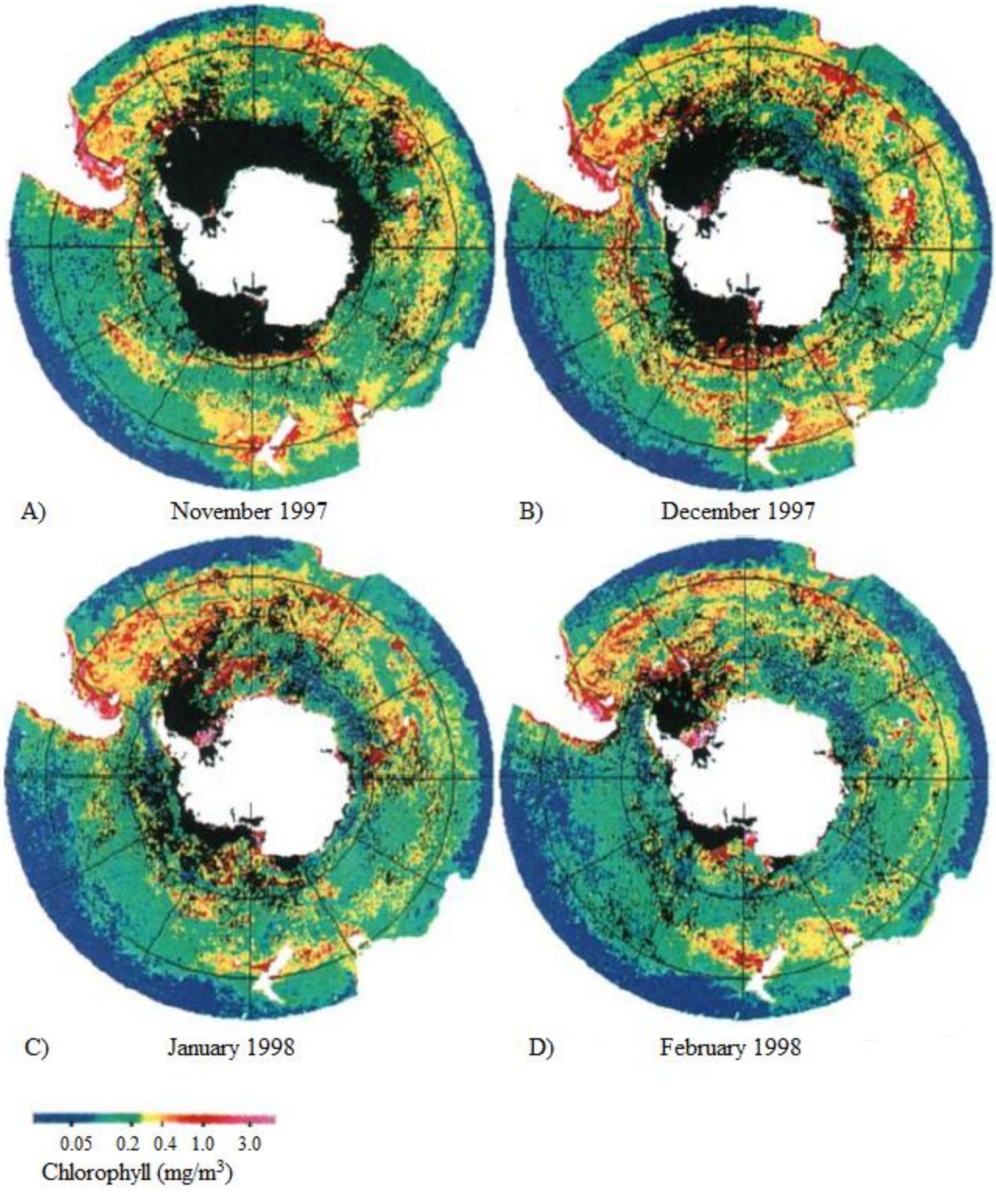


Figure 1. Monthly mean chlorophyll concentrations (mg/m^3) as reported by SeaWiFS in the Southern Ocean over the period of November 1997 to February 1998. (Original data from Moore & Abbott 2000).

Because polynyas are open water areas and/or covered with thin ice, sunlight can penetrate deep into the water column. Furthermore, vertical density stratification is common in polynyas, due to the influx of fresh melting water from glaciers (Van De Poll et al. 2011). In a stratified water column algae can grow closer to the water surface, thereby receiving a higher dose of solar radiation. This higher dose of solar radiation is also received by algae that grow in the upper layer of the sea ice. The difference in phytoplankton production between an upper ice layer in Terra Nova Bay and other areas of the Ross Sea was 32.4 mg C L^{-1} and 11.7 µg C L^{-1} (Baldi et al. 2011). These results support other findings of high phytoplankton concentrations in upper sea ice layers and platelet ice layers underlying pack-ice in the area bordering the Weddell Sea ice shelf. Blooms were found to reach up to 20,000 km^2, hereby showing a big contrast with the rest of the area between 74ºS and 58ºS (Smetacek et al. 1991). By the time that glaciers start to melt, the phytoplankton that is located in the ice-edges of the glaciers can attribute to the start of a phytoplankton bloom in a polynya.

2.2. Terra Nova Bay polynya

A well studied annually recurring polynya event is the polynya in the Terra Nova Bay, Antarctica (75ºS, 165º E) (Mathiot et al. 2012). This polynya develops in the Western Ross Sea and is bordered by the Drygalski Ice Tongue in the South and the peninsula of Cape Washington in the North. The polynya remains open due to the Drygalski Ice Tong, the floating extension of 65-75 km of the David Glacier (Frezzotti & Mabin 1994), which provides a blocking effect to ice drift from the rest of the bay (Bromwich 1989) (Fig.2).

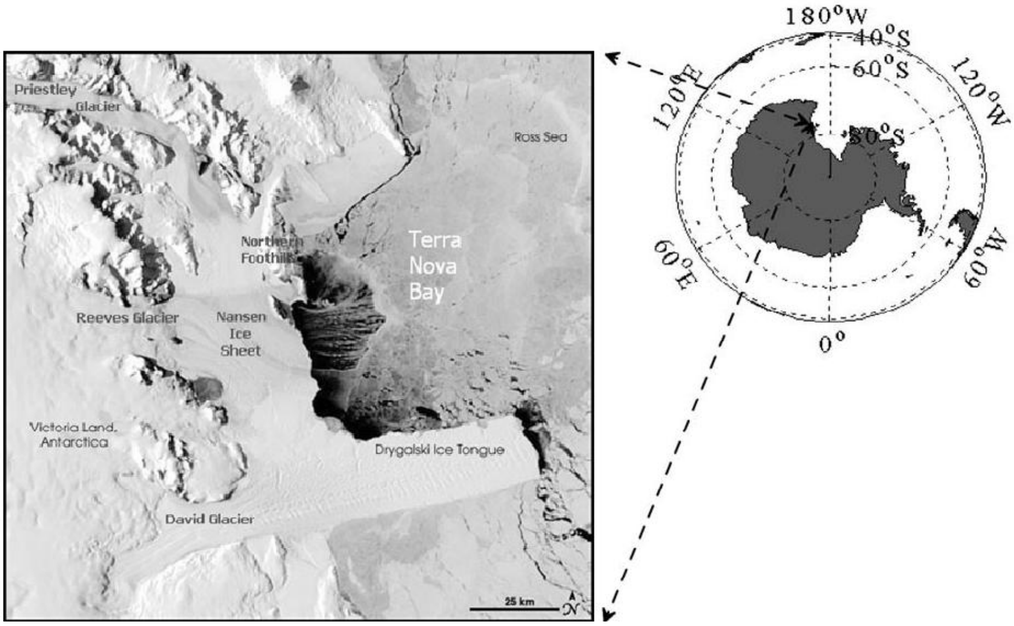


Figure 2. Satellite map showing the Terra Nova Bay polynya and the foremost geographical features (original photo from http://earthobservatory.nasa.gov/IOTD/view.php?id=8134) (Fonda Umani et al. 2002; Morelli 2011)

Also, katabatic winds surging down from the Antarctic continental plateau (Transantarctic Mountains) blow the newly formed ice eastwards away from the shoreline, thereby maintaining the polynya (Accornero et al. 2003).

The region in the Western Ross Sea that surrounds the polynya extends over 25,000 km^2 (including thin and loose pack ice), whereas the TNB polynya itself covers an average area of 1300 km^2 and in its completely ice-free periods extends up to an open surface of 5000 km^2 (Bromwich & Kurtz 1983). The polynya is ice-free from mid-October to the end of

February (Ciappa et al. 2012). In the months that the polynya is present, its area of open surface changes significantly between seasons. In Winter (June to September, respectively) the open area peaks at 3000 km^2 (Ciappa & Budillon 2012), while in Summer this area can double in size (Mathiot et al. 2012).

However, Summer months do not only increase the size of the polynya. In these months the stabilization of the water column increases, i.e. stratification, resulting in a clear pycnocline and more solar radiation that reaches the phototrophic zone. Together with the influx of nutrients by fresh melt water, the Terra Nova Bay polynya exhibits a favorable environment for the development of phytoplankton blooms (Fonda Umani et al. 2002), making it a true 'hot spot'.

3. Environmental conditions

Considering the fact that polynyas are zones with some of the highest rates of primary marine production (Fonda Umani et al. 2002), it can be stated that there are certain conditions that optimalize the conditions for the growth of phytoplankton in polynyas. It has actually been established that solar radiation and water column stratification are two of the most important environmental conditions that affect phytoplankton dynamics (Mitchell et al. 1991). Nutrient availability (and possible nutrient depletion) in this environment also has to be taken into account when considering optimal conditions for phytoplankton growth.

3.1.1 Light availability

The sun lit part of the water column (phototrophic zone), differs significantly between the open water surface of a polynya and water that is covered with ice and snow. Solar radiation that penetrates ice-covered waters has to pass though multiple ice layers (i.e. a surface layer, intermediate layer, bottom ice layer and platelet ice (Lazzara et al. 2007)) before reaching the water underneath. Due to strong attenuation/reflection of sunlight, the water underneath the ice is reached by only 0.15-5% of the surface PAR (photosynthetically active radiation, 400-700nm) in the Summer months and only by 0.1-1% of the surface PAR in the Winter months (Neale et al. 2012; reviewed by Lazzara et al. 2007). Apart from algae growing in the ice, light levels are too low for high phytoplankton growing rates underneath the ice. These low percentages of solar radiation compared to the full amount of solar radiation that hits the open water surface of a polynya, explain partly why polynyas are such productive areas.

Since the Terra Nova Bay polynya is located in the far South, it does not receive solar radiation throughout the entire year. In late April to the beginning of August, the sun does not crest the horizon and no direct sunlight reaches the polynya, i.e. polar night (Morelli 2011; Ciappa et al. 2012). In August, when the sun starts to rise above the horizon, the solar radiation is approximately 10 W/m^2 at the surface. Slowly this amount of solar radiation increases until it reaches its peak of 340 W/m^2 in December (Accornero et al. 2003). After this maximum the solar radiation starts to decrease again until it is completely absent in the polar night.

The amount of solar radiation in the photic zone in the Summer is thus not a limiting factor for phytoplankton blooms in polynyas. However, it is not the only environmental condition that determines the success of a phytoplankton bloom.

3.1.2 Effect of stratification on light availability

To fully exploit the available solar radiation, phytoplankton has to be able to stay in the phototrophic zone. Since phytoplankton tends to sink, it ends up on water layers with a higher density (saltier water). When a water column is more stratified and thus more stable, the phytoplankton can stay closer to the surface and receive more light for photosynthesis (Piquet et al. 2011). The stratification of the water column and the depth of the pycnocline is generated by the melting of the glaciers that border the polynya. The influx of fresh melt water causes a density drop in the surface layer, resulting in the stabilization of the mixed water column. In the Summer, the stronger solar radiation heats up glaciers and the surface water. At the TNB polynya, a rise in surface temperature from -1.03 to +2.82ºC has been detected (Rivaro et al. 2012). This temperature increase causes sea-ice to melt and, together with the glacial melt water, results in water column stratification in the TNB polynya.

The vertical structure of these water columns has been observed by Budillon & Spezie (2000). Their research concluded that the 'surface layer', extending to a depth of 50-150 m, is the most variable water layer in regard to different densities. Below the depth of 150 m the stability of the water column is preserved by the increasing salinity of the water throughout the year.

Budillon & Spezie (2000) also concluded that the pycnocline was not bound to a specific depth, but differed between months. At the beginning of the Summer (December), the pycnocline was not very prominent, whereas at the end of the Summer (February) a clear decrease in depth of the pycnocline could be seen, due to the influx of fresh water. These findings correspond with the results found by Fonda Umani et al. (2002), since a difference in the depth of the pycnocline was also detected between December and the beginning and end of February.

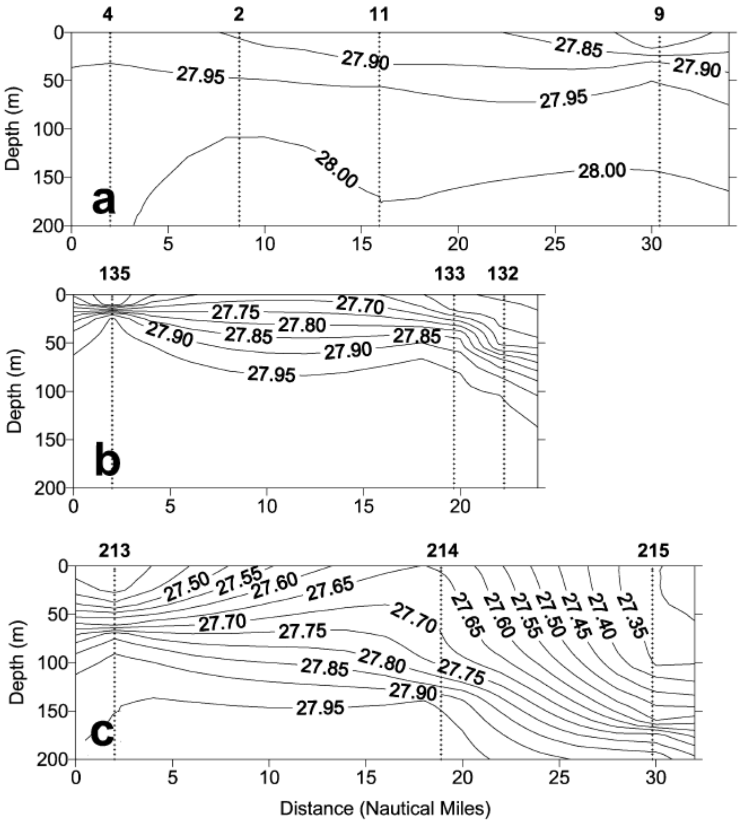


Figure 3. Potential density (kg/m^3) along a South to North transect in the Terra Nova Bay polynya, related to depth. (a) is data from December, (b) shows early February and (c) late February. A clear pycnocline is visible in (b) and (c). No prominent pycnocline was present in (a). (Original data from Fonda Umani et al. 2002).

In December no clear pycnocline was found (fig.3), as was also concluded by Budillon & Spezie (2000). Under these conditions there is no barrier for vertical mixing and vertical mixing due to wind or heat loss can transport algae out of the phototropic zone. This reduces the average dose of solar radiation that the algae receive (Budillon & Spezie 2000). At the beginning of February, the pycnocline was closest to the surface. This created a good environment for the development of a phytoplankton bloom, since they reside closer to the surface (Piquet et al. 2011). At the end of this month the prominent pycnocline was found deeper (fig.3). This deepening of the pycnocline results in a decrease of solar radiation availability, possibly contributing to the end of a phytoplankton bloom (Fonda Umani et al. 2002).

3.2

3.2.1 Availability of major nutrients

Beside light availability, the availability of nutrients in the water also plays a crucial role in the development of phytoplankton blooms in polynyas. Phytoplankton requires three major nutrients in order to grow: nitrate, phosphate and silicic acid (the latter is only required by diatoms) (Takeda 1998). These three major nutrients are found to be abundant in the waters of Antarctica (Rivaro et al. 2012).

The concentration of the three major nutrients are generally high in Terra Nova Bay, with the lower concentrations at the surface in Summer (Rivaro et al. 2012). In the upper 100 m concentrations of nitrate, phosphate and silicic acid were found to fluctuate between 5.6-30.7 µM nitrate, 0.29-2.18 µM phosphate and 31.8-98.1 µM silicic acid, respectively in the Summer. Rivaro et al. (2012) calculated the net utilization of nutrients in order to compare between Winter and Summer. By means of subtracting the Summer data from the data collected in the Winter months, assuming that these months represent the nutrient concentrations at the beginning of the phytoplankton growing season, net utilization was established. Nitrate, phosphate and silicic acid concentrations were 8.89-23.03 µM nitrate, 0.93-1.56 µM phosphate and 12.81-22.96 µM silicic acid. These values show that even after two phytoplankton blooms, nutrients in Terra Nova Bay polynya were not depleted.

However, these values are not representative for the polynya in general. The uptake of nutrients is not always consistent between years. For instance, as much as a 4-fold greater nitrate reduction has been found in the nutrient concentrations in the Ross Sea (Smith et al. 2006). Interannual changes like this can be the result of deep water mixing, the phytoplankton bloom size or other hydrographical influences (Smith et al. 2006).

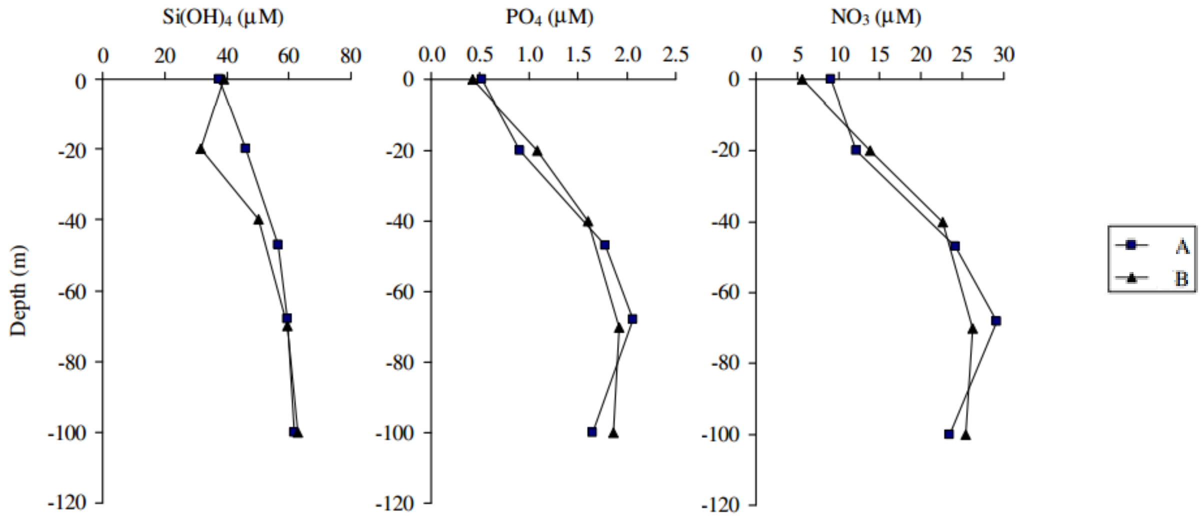


Figure 4. Concentrations of the three major nutrients in mid-January 2003; silicic acid ($Si(OH)_4$), phosphate (PO_4^{3-}) and nitrate (NO_3^-) concentrations along the vertical depth in the TNB polynya. Sampling location A was revisited after 5 days, i.e. B. (Original data from Rivaro et al. 2012).

At the end of a phytoplankton bloom there is depletion of nitrate and phosphate in the upper surface layer (<30m) (fig.4).The reduction of silicic acid is mediated by diatoms, whereas both diatoms and other phytoplankton reduce nitrate (Smith et al. 2006). However, the nutrients were never fully depleted, probably due to shortness of the productive season (Goeyens et al. 2000) or early iron-limitations.

3.2.2 Iron availability and sources

Since the three major nutrients are still present in high concentrations in the Antarctic waters when the phytoplankton blooms decrease, productivity in the polynya has to be limited by something else. A co-limitation of light and dissolved iron has been opted (Sedwick & DiTullio 1997), but since there is no apparent light shortage in the polynya during the productive season, light does not limit phytoplankton productivity. However, the trace metal iron is known for being present in limiting concentrations in the Southern Ocean (Rivaro et al.2012; De Jong et al. 2012).

Concentrations of dissolved iron have been rigorously studied in the open Southern Ocean in regard to its importance for phytoplankton blooms. It was proven that a shortage of this trace metal is responsible for the incomplete utilization of major nutrients by phytoplankton (Takeda 1998). Furthermore, strong interactions have been found between iron-limitation and photo-inhibition. Iron-limitation decreases the synthesis of photosynthetic proteins (Greene et al. 1992). Both these consequences of a dissolved iron shortage in the water can limit phytoplankton growth.

Sedwick & DiTullio (1997) investigated the role of dissolved iron at the center of the Ross Sea. Their findings fully support the hypothesis that fresh melt water contains dissolved iron and that, once added to the sea water, it increases the dissolved iron concentration. Iron concentrations in the upper water layer were 0.72-2.3 nM in water with sea ice and 0.16-0.17 nM without any sea-ice present (Sedwick & DiTullio 1997; Arrigo et al. 2003). Higher iron availability was accompanied by a decrease of the three major nutrients and a doubling of the phytoplankton abundance. Therefore, the release of iron into the sea water stimulated the phytoplankton bloom and primary production. Experimental research with iron limited laboratory cultures has also proven that the addition of dissolved iron increases the phytoplankton growth (Takeda 1998; Coale et al. 2003).

In a polynya, the iron availability is higher compared to that in the open Southern Ocean. There are multiple ways by which the amount of iron in the water can be replenished. The melting of sea-ice (contributing 0.7-2.9% of the necessary iron), upwelling of ‘iron rich’ water (contributing 0.4-1.7%), and atmospheric dust (contribution $< 1\%$) can all contribute to the enrichment of the iron concentration (Gerringa et al. 2012).

However, as mentioned above, the largest influx of dissolved iron comes from the glacial melt water. The TNB polynya is surrounded by three big glaciers (Priestley, Reeves and David Glacier, respectively). The amount of iron influx from the glacial melt water from these glaciers is high enough to satisfy the iron demand of the phytoplankton (Gerringa et al. 2012).

4. Phytoplankton blooms in the Terra Nova Bay polynya

When considering the uniquely favorable environmental conditions and nutrient availability in the TNB polynya, it comes as no surprise that phytoplankton blooms occur here. Two major blooms can be distinguished throughout the year. The first starts in early Spring (December) and is followed by a secondary bloom in Summer, i.e. February (fig.5) (Accornero et al. 2003; Rivaro et al. 2012; Smith et al. 2006). The species composition of these two phytoplankton blooms differs significantly due to the different environmental conditions that are present in December and February. The first bloom is dominated by prymnesiophyceae, most notably *Phaeocystis antarctica*, and can extend for more than 16,000 km^2 (Fonda Umani et al. 2002). The second bloom consists primarily of diatoms (Bacillariophyceae) (Goeyens et al. 2000; Smith et al. 2006; Fonda Umani et al. 2002& 2005). Diatoms and *P. antarctica* do not occur at the same time. By the time diatoms start to bloom, *P. antarctica* decreases in abundance (Fig.5).

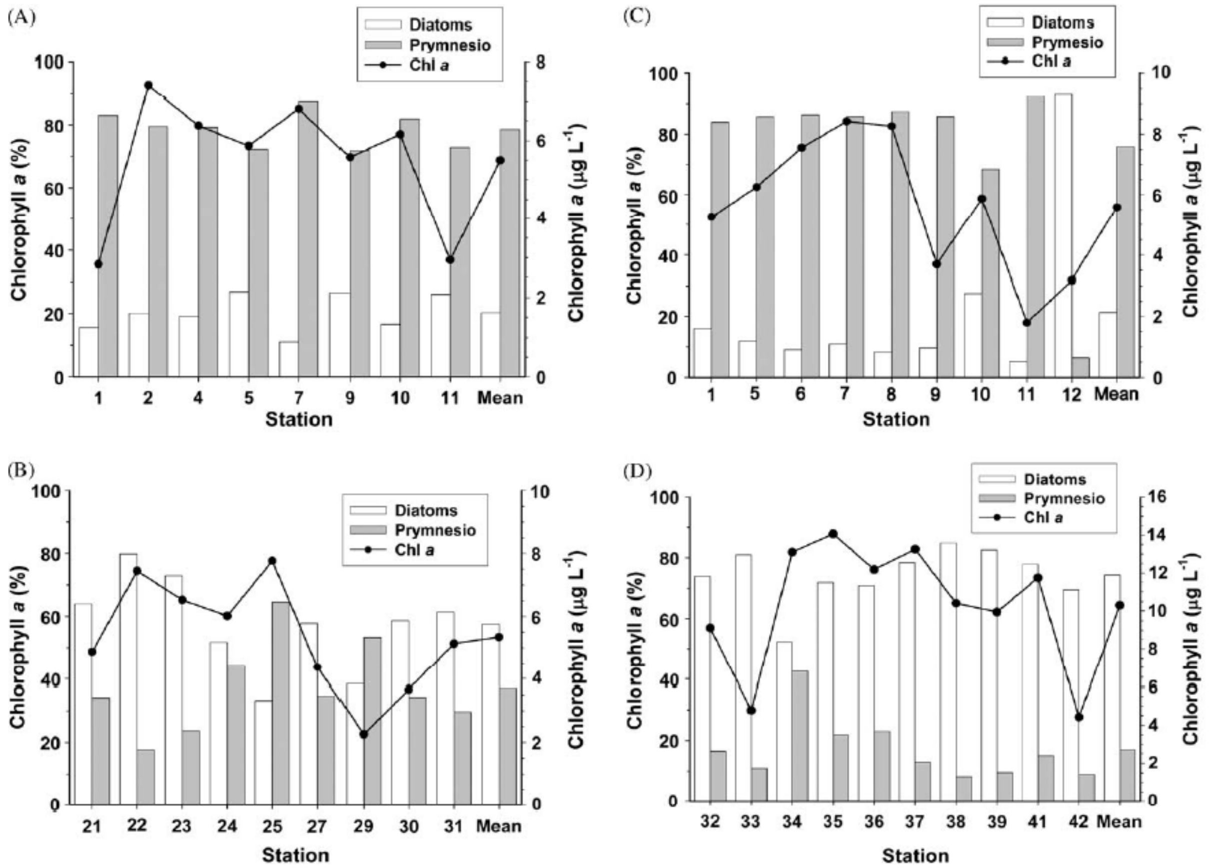


Figure 5. The percentages and mean concentrations of chlorophyll *a* concentrations contributed by diatoms and prymnesiophyceae along a Southern transect parallel to the Ross Ice Shelf, Ross Sea. Data was collected in December 2001/2002 (A), February 2001/2002 (B), December 2003/2004 (C) and February 2003/2004 (D) (Original data from Smith et al. 2006).

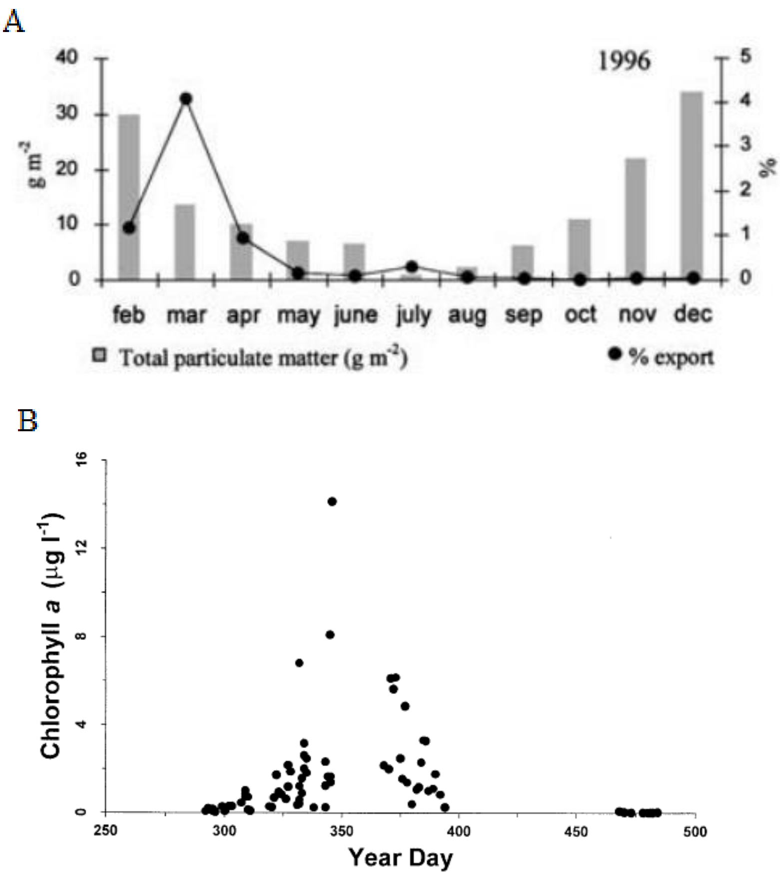


Figure 6. (A) The total particulate matter in the surface layer and percentage of export to 180 m depth throughout the year 1996 (Original data from Accornero et al. 2003). (B) shows the near surface (<30m) concentration of chlorophyll *a* in Terra Nova Bay in 1996/1997 (Original data from Smith et al. 1999).

Both blooms are being reflected in figure 6. The total particulate matter (TPM) starts to increase from the end of October/begin November and continues throughout the blooming season. In April the amount of TPM is considerably less than at the peak of the season. The percent of export of the TPM is continuous throughout the year, but has a major increase in March. This can be explained by the contribution of diatoms to the percentage of exported TPM. Since diatoms are bigger and heavier than the small *P. antarctica*, they have higher sinking rates. Since their bloom occurs in February, it is not surprising to see a percentage increase in March, when diatoms die and start to sink towards the bottom.

Increasing chlorophyll *a* concentrations correspond with the increase of TPM. The phytoplankton biomass peaks between November and early February, resulting in sinking TPM in March (Fig.6A&B).

4.1. Effects of light availability on the species composition

Due to the different physiological aspects of diatoms and *P. antarctica*, they react differently to specific environmental conditions. As already discussed, December exhibits less water column stratification than February (fig.3). The depth of the pycnocline increases from December to February, starting as a mixed water column and steadily progressing towards a stratified column.

The vertical mixing of the water layers determines how often phytoplankton gets transported through the phototrophic zone, hereby varying the exposure of phytoplankton to solar radiation (Neale et al. 2012). *P. Antarctica* is best acclimated to the dynamic solar radiation regime of the mixed water column and thus blooms in December (Alderkamp et al.

2012; Arrigo et al. 2003). *P. antarctica* cells are adapted to low-light intensities and possess the most efficient photosynthesis under dynamic light conditions, but have a limited photoprotective response to high radiation levels (Neale et al. 2012). Diatoms however prefer a more stable water column with more constant radiation exposure, thus dominating in January and early February. It is clear that diatoms fully dominate the upper layer, up to 30 m on average (fig.7) (Rivaro et al. 2012).

Due to their general immobility, the diatoms stay in the upper water layer (<20 m). Diatoms possess a higher photoprotective response than *P. antarctica*, making photosynthesis possible in near-surface water with constant high solar radiation (Neale et al. 2012, Rivaro et al. 2012). Once the solar radiation becomes less at the end of February and the pycnocline reaches a depth beneath the phototrophic zone, the diatom growth decreases (Fonda Umani et al. 2002).

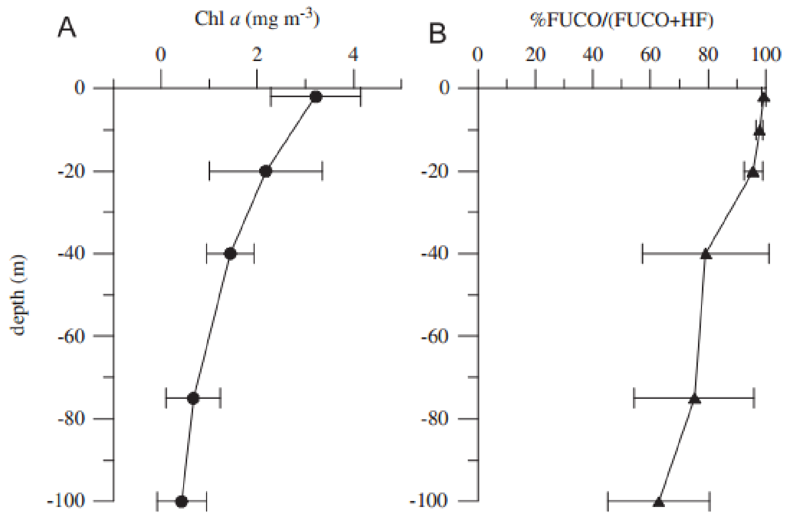
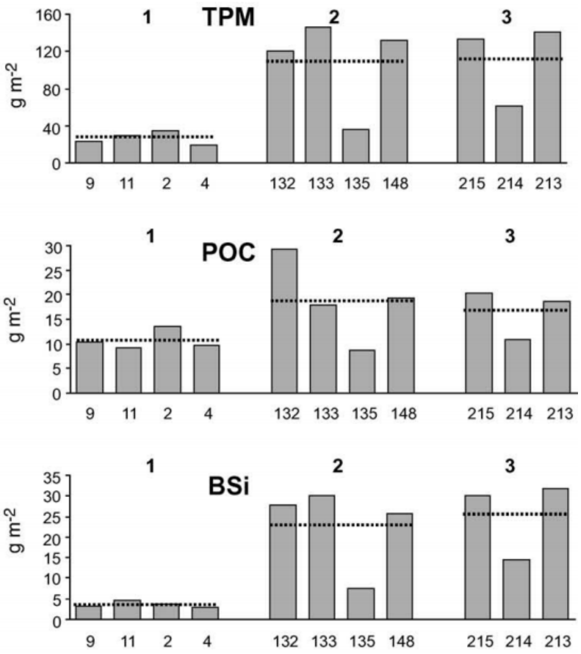


Figure 7. Vertical profiles of the average chlorophyll a concentration (A). (B) shows the fucoxanthin (FUCO)/fucoxanthin+19'hexanoyloxyfucoxanthine (FUCO+HF) percentage ratio in 8-12 January 2006 in Terra Nova Bay. Fucoxanthin concentrations are representative for the diatom abundance, whereas 19'hexanoyloxyfucoxanthine represents the prymnesiophytes. (Original data from Rivaro et al. 2012).

Due to the differences in photophysiology between the two species, their spatial variation can be explained in Terra Nova Bay. Diatomaceous growth occurs mostly on the ice edges of the TNB polynya, where the influx of fresh glacial melt water and stratification is highest. *P. antarctica* has been found to bloom in the more central part of the polynya, where the influence of stratification is less prominent (Smith et al. 2006; Fonda Umani et al. 2002&2005).

4.2. Nutrient concentrations in relation to the species composition
Silicic acid, nitrate, phosphate and dissolved iron are available in sufficient concentrations in order to sustain major phytoplankton blooms. By looking at the decrease of these nutrients



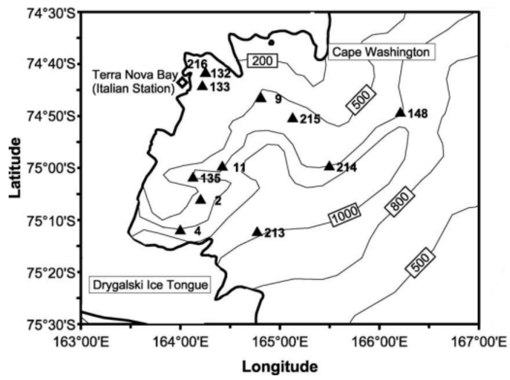


Figure 8. Amount of total particulate matter (TPM, particulate organic carbon (POC) and biogenic Silica (BSi) integrated in the upper 100 m. 1; early December, 2; early February, 3; late February. Dotted lines correspond to the averages of the stations. Samples were taken at the TNB polynya (Original data from Fonda Umani et al. 2002).

and/or the amount of particulate matter that gets deposited, the growth of the blooms can be followed. The temporal distribution of the two different blooms is reflected in the total particulate matter (TPM), particulate organic carbon (POC) and biogenic silica (BSi) (fig.8).

Fonda Umani et al. (2002) studied the dynamics of particulate matter in the TNB polynya. The conclusions regarding the spatial distribution of the two species being reflected by the TPM and POC, were clear. It was shown that in December the TPM and POC were more concentrated in the upper 100 m of the center of the polynya, whereas in February these concentrations were poorest in the center, hereby supporting the findings of the *P. antarctica* bloom in the middle of the polynya. From December throughout the beginning of February, the POC and BSi that was present in the upper 100 m showed a 7-fold and 10-fold increase, except in the central part (fig.8; stations 135 and 214). Considering the phytoplankton composition, diatoms are the dominant users of silicic acid. The 10-fold boost of the BSi in the upper 100 m is a result of the increase of diatoms. At the end of February, the BSi can even make up 23% of the TPM (Fonda Umani et al. 2002).

The shortage of dissolved iron that develops throughout the Summer also contributes to the spatial variation between the two blooms. Laboratory research done by Alderkamp et al. (2012) showed that both *P. antarctica* and diatoms (with *Fragilariopsis cyclindrus as* test organism) exhibit reduced growth rates when dealing with limiting iron concentrations (< 1µM). The growth rates of *P. antarctica* and *F. cyclindrus* were reduced by 51% and 67%, respectively. In this study, a small amount of iron had to added to the cultures containing the diatoms in order to maintain viability. This, along with the difference in decreased growth rates and the results from other field studies, suggests that diatoms have a higher iron requirement than *P. antarctica* (Alderkamp et al. 2012). As mentioned above, the *P. antarctica* bloom develops at the center of the TNB polynya where the effect of the fresh water influx is diminished, resulting in a reduced addition of iron. The diatom bloom develops at the ice-edge where influx of glacial melt water, containing iron, is higher.

5. Discussion and Conclusion

When considering the effects of solar radiation, water column stratification and nutrient availability on the growth success of phytoplankton, it can be concluded that the environmental conditions in the Terra Nova Bay polynya enhance phytoplankton growth.

In Summer the open water of the polynya allows deep penetration of sun light, thereby providing sufficient light for phytoplankton growth. Due to photophysiological properties, the solar radiation is partly responsible for the species composition of the phytoplankton blooms along with water column stratification. The prymnesiophyte *Phaeocystis antarctica* can dominate the phytoplankton composition under mixed water column conditions. When in a mixed water column, the exposure to solar radiation is reduced and will not cause photoinhibition. Since diatom cells contain photoprotective pigments, they are more resilient when it comes to exposure to strong solar radiation. Diatoms thrive when there is more stratification of the water column, i.e. a pycnocline closer to the surface.

Major nutrients (nitrate, phosphate and silicic acid) demanded by the phytoplankton are considered to always be abundant in a polynya. Nitrate, phosphate and silicic acid never get depleted, whereas the trace element iron is thought to be a limiting factor. However, due to fresh water influx from glaciers the dissolved iron concentration is elevated to a level that is sufficient for maintaining high phytoplankton biomass.

Data gathered throughout the years at the Terra Nova Bay polynya all represent consistent data and conclusions, with the exception of Fonda Umani et al. (2005). One of their conclusions with regard to the glacial melt water is not consistent with other researches. Fonda Umani et al. (2005) did not find any evidence of the influence that the influx of fresh water might have on the success of phytoplankton blooms. Since this influx is considered to be the major contributor of the dissolved iron present, it would be interesting for future research to focus on the influence of fresh melting water on dissolved iron concentrations. Iron concentrations are thought to be one of the most common constraining conditions for phytoplankton blooms, making research into this topic relevant for further understanding of the development of phytoplankton blooms.

Furthermore, the importance of phytoplankton blooms should not be underestimated. Due to the sinking of rather large diatoms and other phytoplankton faecal pellets, phytoplankton blooms can actively increase the efficiency of the drawdown of carbon dioxide. This process makes them serve as carbon sinks (Fonda Umani et al. 2002). Regarding the present day global environmental changes, more research into the role of phytoplankton blooms in carbon dioxide drawdown could lead to new alternative solutions for global climate change.

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