

EFFECTS OF FRESH WATER INFLUX FROM MELTING SEA ICE AND GLACIERS IN POLAR REGIONS ON DIATOM OCCURRENCE WITH RESPECT TO SINKING RATES

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Different sized cells have similar sinking rates under growth conditions. However, sinking rates are different under nutrient deplete situations, sinking rate increases with increases in cell size. Indicating that sinking rate regulation requires energy. Water column characteristics, such as salinity, affect sinking rate. The salinity does not seem to be much different between ice-edge regions and coastal regions, and phytoplankton communities tend to be similar as well. Temperatures are rising, in the Western Antarctic Peninsula there has been an increase of 0.17 °C per decade for the last 50 years. In 2007 the sea ice cover in the Arctic reached a record minimum. With these increasing temperatures, there will be more meltwater input in the oceans surrounding Antarctica and in the Arctic. With increased melt water input, stratification will be stronger. Which will have an effect on sinking rate of a phytoplankton community. This can change the phytoplankton community, which will have an effect on higher trophic levels.

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1. Introduction

Temperatures on earth are rapidly rising. In the Western Antarctic Peninsula there has been an increase in mean air temperature of 0.17 °C per decade (reviewed by Moline et al., 2004, reviewed by Schloss et al., 2011). The mean temperature of the surrounding surface waters have increased by 1 °C and the upper water column by 0.7 °C over the last 50 years (reviewed by Annet et al., 2010). This warming is also evident in the Arctic region. The Arctic consists traditionally of a major ice sheet covering 16 x 10⁶ km² in March, and with a minimum extend of 7 x 10⁶ km² at the end of the summer melt season in September. However, the ice sheet is rapidly declining with a decline of $-8.6\% \pm 2.9\%$ per decade between 1979 and 2006 (Serreze et al., 2007). In 2007 the sea ice cover reached the record minimum extend (Zhang et al., 2008), indicating a temperature increase in this region as well.

The increasing temperatures will result in an increase in melt water, from sea ice and glaciers (reviewed by Schloss et al., 2011). The Palmer Long Term Ecological Research project documented a 40% decrease in mean duration of sea ice cover, and trends of later advance and earlier retreat of sea ice (reviewed by Annet et al., 2009) in the Southern Ocean. Melt water from ice and glaciers consists of fresh water, which will lower the salinity of the water column (Schloss et al., 2008). Glacial melt water does not only affect the salinity, but it also contains high amounts of particles which will affect the water column light properties (Schloss et al., 2008, reviewed by Schloss et al., 2011), the euphotic zone can be reduced to 0.3 m by high sediment concentrations in the water column (reviewed by Piquet et al., 2010). Both effects will have an effect on the phytoplankton community.

Phytoplankton communities in the polar regions are typically dominated by

diatoms (Moline et al., 2004, Annet et al., 2010, Degerlund and Eilertsen, 2010). Phytoplankton are denser than water, especially diatoms with their siliceous armor (reviewed by Waite et al., 1992, reviewed by Acuña et al., 2010, reviewed by Miklasz and Denny, 2010), which makes them susceptible to sinking. However, melt water promotes stratification of the water column (Schloss et al., 2011). In a stratified water column there is a more stable light environment, which light tolerant, bloom forming phytoplankton can utilize for increased growth rates (Bertolin and Schloss, 2009, Van de Poll et al., 2011, reviewed by Petrou et al., 2011). The upper waters of the Arctic Ocean are becoming warmer and fresher. Deep water density remains the same, which results to a stronger stratification (Li et al., 2009). Due to stratification the water column is stabilized. However, sinking phytoplankton need moderate levels of turbulence in order to remain near the surface (reviewed by Acuña et al., 2010). So the stabilizing has a greater effect than the decrease in salinity, due to melt water input.

There are two different regions of melting ice, the pack ice edge and coastal regions with glaciers and snow. Melt water from the ice edge will mostly contain freshwater with hardly any sediment, while glacial melt water and runoff from land will also contain sediment particles (Piquet et al., 2010). In the Kongsfjorden the salinity of the surface water can vary between 24 to the normal 34 PSU throughout summer (reviewed by Piquet et al., 2010). During the record ice melt of 2007 in the Arctic, the salinity averaged around 33.74 PSU, with a minimum of 31.52 PSU (Lasternas and Agustí, 2010). We can assume similar values are found at similar sites around the Arctic and Antarctic. This would mean that salinity would drop more near glaciers, which would have a greater impact on the phytoplankton community

compared to the salinity decreases near the ice edge. This raises the question, are there any differences in phytoplankton composition between sites with melt water from the ice edge and sites with glacial melt water.

Phytoplankton must remain near the surface in order to photosynthesize. Therefore, any tendency to sink should be negatively selected (reviewed by Acuña et al., 2010). However, most phytoplankton are denser than water (reviewed by Waite et al., 1992, reviewed by Acuña et al., 2010, reviewed by Miklasz and Denny, 2010) and thus tend to sink. Some factors reduce the sinking rate of phytoplankton, the mixing of water for example (reviewed by Acuña et al., 2010). Because of this turbulence denser species can remain near the surface. Due to the dominance of diatoms in most blooms (Mura et al., 1995, Moline et al., 2004, Acuña et al., 2010, Annet et al., 2010, , Degerlund and Eilertsen, 2010), one wonders if diatoms, and phytoplankton in general, have developed a sinking rate regulation mechanism and if there are other factors affecting the sinking rate of phytoplankton.

In this paper I will try to answer two questions:

1. Is there regulation of sinking rates in phytoplankton?
2. Are there changes in phytoplankton composition due to fresh meltwater influx?

2. Phytoplankton sinking rates

Maximum sinking rate can be measured during energy deplete situations, and this maximum sinking rate tends to be size related (Waite et al., 1992, Miklasz and Denny, 2010). Epply et al. (1967) suggested that sinking is influenced by the growth rate and physiological state of a cell. With increasing growth rate and physiological activity, the sinking rate should decrease. This would mean that sinking rate regulation requires energy. Studies have shown

(Bienfang et al., 1982, Waite et al., 1992, Acuña et al., 2010) that the sinking rate for different sized cells were different under energy deplete situations. However, under optimal conditions these cells had similar sinking rates. Indicating an energy requirement to remain near the surface. It has been suggested that diatoms maintain a low turgor pressure through a steady expenditure of energy (reviewed by Waite et al., 1997). In dark conditions respiratory energy is necessary to maintain low sinking rates (Waite et al., 1992), which is another indication for an energy requirement. On overcast days an increase in sinking rate was observed for several diatom species, indicating an influence of light. This negative effect of light on the sinking rate, suggests that energy is required for buoyancy regulation (Riebesell, 1989). This dependence on light is most likely due to a light-dependent ionic component, which affects sinking rates through changes in vacuolar ion densities, and that the respiratory energy expenditure which decreases sinking rates actually does so by maintaining the turgor of the whole protoplast, not the vacuole. The method by which turgor control is effected, are ATP-requiring ionic pumps.(reviewed by Waite et al., 1997).

Cell size has influence on the energetic requirements for sinking rate control. Waite et al. (1997) studied three different diatom species, *Ditylum brightwellii* (8000 μm^3), *Thalassiosira weissflogii* (600 μm^3) and *T. pseudonana* (60 μm^3). *D. brightwellii* had a high energetic requirement for sinking rate control, *T. weissflogii* had some energetic requirement, whereas *T. pseudonana* had minimal energetic sinking rate control. Waite et al. (1997) suggested that minimum cell volume necessary for active sinking rate control is ca. 200 μm^3 . Not only cell size has an influence, there is also a difference between pennate and centric diatoms. Centric

diatoms seem to have a more efficient buoyancy regulation than pennate diatoms (Acuña et al., 2010). Large pennate diatoms, *Gyrosigma* spp. and *Frustulia rhomboides*, sank rapidly during the non-growth phase. However, the giant diatom *D. brightwellii* had a neutral buoyancy. Indicating there might be a taxonomic differentiation between centrics and pennates that override the size effects on buoyancy regulation (Acuña et al., 2010).

Maximum sinking rate is related to particle volume (Eppley et al., 1967, Waite et al., 1992). The sinking rate at any given time depends on the physiological condition of the cell (Bienfang et al., 1982, Waite et al., 1992). Thus, mean sinking rate can be used as a measure of the physiological stress of a cell or culture. However, a more sensitive alternative is using the slope of the sinking rate versus volume relationship within a culture (Waite et al., 1997). Volume also has an effect on the sinking rate, as stated earlier

Not only available energy has an influence on sinking rate regulation, nutrients influence the sinking rate as well. Different diatom species react differently to different nutrient limitations (Bienfang et al., 1982). Si-depletion has the most profound effect on diatom sinking rates, sinking rates were 1,9 to 10 times greater than those measured under saturating silicate levels (Bienfang et al., 1982). Other nutrients studied were nitrate and phosphate. Both did not seem to have the same impact as silicate on the sinking rate.

Another important nutrient which has an effect on sinking rate is iron. A study done by Muggli et al. (1996) looked at sinking rates under iron stressed conditions for diatoms and the coccolithophore *Emiliana huxleyi*. The sinking rate for diatoms under these conditions were about five times greater than under iron replete conditions (figure 1), the effect on *E. huxleyi* was negligible. These findings were later also found during the Southern Ocean Iron Release Experiment

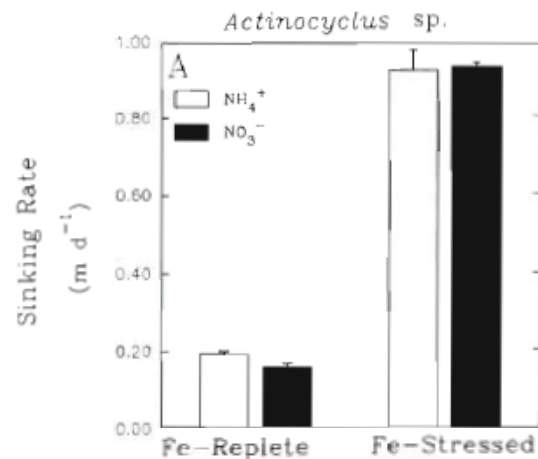


Figure 1. Sinking rate versus iron condition for *Actinocyclus* sp. Error bars represent SE (n = 3) (Muggli et al., 1996)

(SOIREE). During SOIREE iron was released in the Southern Ocean to study the impact of iron on phytoplankton blooms (Boyd and Law, 2001). During the SOIREE experiment sinking rate of diatoms was higher outside the patch (Waite et al., 2001). Sinking rates inside and outside the patch were initially quite high (1,8 m d⁻¹). The cells inside the patch lowered their sinking rate to 0,47 m d⁻¹, while the cells outside the patch increased to 2,0 m d⁻¹ during the experiment. After the time series cells inside the patch also had an increased sinking rate comparable to the cells outside the patch (2,4 m d⁻¹) (Waite and Nodder, 2001). Large cells (> 22 μm) had a decreased sinking rate within the patch over the 8 day period, indicating an iron-mediated physiological response to retain large cells near the surface (Waite and Nodder, 2001). The increased sinking rate under iron limitation is due to an increase in silicification. This is due to a co-limitation of iron and silicid acid uptake (Leynaert et al., 2004), which leads to an accumulation of thicker frustules (reviewed by Miklasz and Denny, 2010).

The sinking rate of diatoms is highly variable between species. Miklasz and Denny (2010) studied the sinking speed of five different diatom species and found sinking rates ranging from 0.3 to 7.9 meters per day for living cells. These cells were under near

nutrient-deprived conditions. However, Muggli et al. (1996) found much lower sinking rates for diatoms. The sinking rate was only 0.20 and 0.90 meters per day, for iron replete and iron deplete situations respectively. Riebesell (1989) used two different methods measuring the sinking rate of diatoms, SETCOL and traps. The sinking rate for traps were between 0.29 and 1.53 meters per day, whereas the SETCOL method gave sinking rates of 0 and 0.7 meters per day. Both methods yielded significantly different results (Riebesell, 1989). Data on the sinking rate of other phytoplankton species is rare. The sinking rate of *Phaeocystis* colonies lay between – 0.37 and 14 meters per day. Negative sinking rates demonstrate the ability to regulate their buoyancy (Schoemann et al., 2005). We can assume the sinking rate for single cells is most likely around 1 m d⁻¹. In the Southern Ocean, cryptophytes were found in low salinity water, most likely from the input of glacial melt water. The cryptophyte dominated blooms were confined to high temperature/low salinity waters characteristic of the melt water lens (Moline et al., 2004).

Assuming that this low salinity has an influence on the sinking rate of phytoplankton, we can assume cryptophytes have a lower sinking rate than diatoms.

3. Environmental data

3.1 Water column conditions near melting ice in the Arctic and Antarctic

When looking at the two different regions with melt water influence, one would expect to find different salinity values. Studies done at phytoplankton in these different regions, also look at the different environmental factors, such as temperature and salinity. Studies done near the ice edge (Mura et al., 1995, Bertolin and Schloss, 2009, Cefarelli et al., 2010, Lasternas and Agustí, 2010, Vernet et al., 2010) found salinity values averaging around 34 PSU. Bertolin and Schloss (2009) the effects of the collapse of the Larsen A ice shelf in Antarctica. They found salinity values ranging from 34.05 to 34.44, where the lowest values were found further away from the coast. During the record melt of Arctic ice, salinities were found ranging from 31.52 to

Table 1. Environmental data for the Krossfjorden and Kongsfjorden. Data with “~” are average values calculated for the 7 days preceding sampling; other values were measured on the actual sampling day. (Piquet et al., 2010)

	8.6.05	15.6.05	22.6.05	29.6.05	6.7.05	8.7.05
Salinity (psu)	27.3	33.3	30.5	29.2	20.9	22.7
Sediment index	0	0	0	2	2	1
~Sun hours (h d ⁻¹)	9.65	7.18	0.7	12.22	10.05	14.68
~Solar radiation (W m ⁻²)	236.98	222.68	154.53	265.11	230.56	273
UV radiation (W m ⁻²)	12.35	11.63	8.77	12.22	10.8	11.69
~Wind speed (m s ⁻¹)	1.04	2.64	3.37	2.65	2.41	3.11
~Wind direction (0.1°–360.0°)	241.57	220.86	193.14	184.31	172.54	249.76
Wind direction (0.1°–360.0°)	249.18	153.84	268.74	147.22	125.15	207.07

	Location									
	F1	F2	F3	F4	F5	F6	F7	F8	BF	DD
Salinity (psu)	17.8	16.3	22.6	21.6	25.1	28.1	23.3	19.6	23.3	17.5
Sediment index	0	0	0	0	0	1	2	2	2	1

35.12 PSU, averaging around 33.74 ± 0.14 PSU (Lasternas and Agustí, 2010).

In regions affected by glacial melt water, similar results were found (Annet et al., 2009, Piquet et al., 2010, Piquet et al., 2011, Schloss et al., 2011). Schloss et al. (2011) studied the dynamics in Potter Cove for 19 years (Kings George Island, Antarctica) with glacial melt input. They studied two sites in Potter Cove, one near the glacier (E1) and one closer to open water (E2). Salinities were measured at both stations for surface water and deeper water. The average salinity at E1 was 33.89 ± 0.37 PSU, at E2 this was 34.13 ± 0.10 PSU. Ryder Bay on Adelaide Island is another bay which is well-studied (Annet et al., 2010, Piquet et al., 2011). Both studies found salinities averaging around 32.5 PSU, while values ranged from 31.2 to 33.5 PSU. During periods of ice melt, the salinity dropped. Piquet et al. (2010) studied two fjords on Spitsbergen, the Krossfjorden and Kongsfjorden. Salinity varied between 16.3 and 28.1 PSU per station, lowest salinity values were found further up in the fjord, closer to the glacier (table 1).

Not just salinity is important for algal growth, nutrients are just as important. However, the Arctic and Antarctic differ in nutrient limitation. In the Arctic nitrogen is depleted during the season (Cota et al., 1996, Rysgaard et al., 1999, Carmack et al., 2004) which will limit the phytoplankton blooms. In the Antarctic iron is the limiting nutrient. Which have been shown by several iron fertilisation experiments (Boyd and Law, 2001). The reason for the nitrogen limitation and not an iron limitation in the Arctic is most likely the high input of fresh water from many large river systems (reviewed by Kaiser et al., 2005).

It seems that the input from glacial melt water has more effect on the salinity than the melting sea ice near the ice edge. Both the Arctic and Antarctic show similar

results. However, the regions differ in nutrient limitation. The Arctic experiences a nitrogen limitation and the Antarctic an iron limitation.

3.2 Phytoplankton composition near melting ice

In the Southern Ocean phytoplankton spring blooms are dominated by diatoms, both near the coast and in open water (Moline et al., 2004). Annet et al. (2010) studied the phytoplankton community in summer in Ryder Bay for 3 years. There was a seasonal succession in the diatom blooms. The early phytoplankton community was numerically dominated by *Phaeocystis antarctica*. During the season this shifted towards diatoms, especially *Chaetoceros* spp.. When looking at biomass diatoms consistently dominated the water column (Annet et al., 2010). Year 1 was initially dominated by *Minidiscus chilensis*, followed by *Odontella weissflogii*. The second year was initially dominated by *M. chilensis* and *Fragilariopsis curta*, these two then rapidly declined. After which the *Proboscia* group took over. In the third year the community was more diverse, biomass contributions rarely exceeded 30% for any one species (Annet et al., 2010).

The diatom dominated blooms near the coast were followed by a dominance of cryptophytes. This coincided with the occurrence of low salinity water from glacial meltwater input. (Moline et al., 2004). The presence of these cryptophyte dominated blooms was confined to the relatively high temperature/low salinity water, whereas diatoms and prymnesiophytes dominated in other physiochemical domains (Moline et al., 2004). In the Southern Ocean, phytoplankton community structure is closely associated with the physical conditions of the water column. Diatoms have the highest relative contribution to biomass in cold, saline, stratified waters (Mura et al., 1995, Annet et al., 2010), deep mixing of the water column will promote

P. antarctica (Annet et al., 2010), while picoplankton have the highest relative contribution to biomass in low salinity waters from ice melt (Mura et al., 1995).

In the Arctic phytoplankton blooms follow the same pattern. The most frequently occurring species found in the Arctic spring blooms are the prymnesiophytes *Phaeocystis pouchetii* (34%), followed by the diatoms *Thalassiosira gravida*/*T. antarctica* var. *borealis* (32%), *Skeletonema costatum sensu lato* (27%), *Chaetoceros socialis* (25%) *Fragilariopsis oceanica* (21%), *C. compressus* (19%), *T. norderskioldii* (16%), *C. furcellatus* (14%), *C. debilis* (12%), and *Bacterosira bathyomphala* (11%) (Degerlund and Eilertsen, 2010). During May the salinity slowly decreased, indicating an influence of melt water input. During May the most abundant species was *P. pouchetii* (Degerlund and Eilertsen, 2010). However, cryptophytes usually do not succeed the diatoms. A typical post spring bloom in sub polar regions consists mostly out of *Alveolata* and *Cercozoa* (Piquet et al., 2010). In the Barents Sea, the early part of the spring bloom is dominated by pennate diatoms, after which the centric diatoms take over. With one exception, *F. oceanica* was often abundant with centric diatoms (Degerlund and Eilertsen, 2010).

In phytoplankton studies the flagellates (except for *P. pouchetii*) are often overlooked, due to the destruction of cells in formaldehyde preserved samples (Degerlund and Eilertsen, 2010). However, they appear to play an important role in the early phase of the spring bloom in the Barents Sea, and may be equally important along the coast of northern Norway (Degerlund and Eilertsen, 2010).

During the record melting of sea ice in the Arctic sea of 2007, the phytoplankton community was dominated by the prymnesiophytes *P. pouchetti*, only in its colonial form (Lasternas and Agustí, 2010). In

the Southern Ocean, in weakly stratified waters *P. antarctica* formed large colonies and dominated the phytoplankton community. It is predicted that due to warming in the Southern Ocean, stratification will increase which will promote diatoms, which would replace *P. antarctica* (reviewed by Lasternas and Agustí, 2010). This is in contrast what Lasternas and Agustí (2010) found, during the massive ice-melt in 2007, *P. pouchetii* prevailed in the stratified waters.

The contribution of small flagellated species and dinoflagellates to Arctic phytoplankton communities consists usually between 30 and 40% (reviewed by Lasternas and Agustí, 2010). However, during the melt of 2007 the contribution to total phytoplankton biomass consisted only about 6%, the other 95% consisted for 82.1% out of *P. pouchetii*, 7.3% out of diatoms and 6.2% out of small flagellates. (Lasternas and Agustí, 2010).

4. Discussion

4.1 Different methods for calculating sinking rate

Most studies done on the sinking rate of phytoplankton, used the SETCOL technique for measuring the sinking rate (Bienfang et al., 1982, Riebesell, 1989, Waite et al., 1992, Muggli et al., 1996, Waite et al., 1997, Waite and Nodder, 2001). When compared to using sediment traps, there are some significant differences between the two techniques (Riebesell, 1989). Because of these differences the SETCOL technique underestimates the sinking rate of phytoplankton during the decline. While during the growth phase, both techniques give similar results (Riebesell, 1989). Another technique used was the tracking of individuals (Miklasz and Denny, 2010). Due to the differences between methods, some methods give an underestimation, and different nutrient conditions it is difficult to compare sinking rates between studies.

4.2 Iron stress/reduced sinking rate

Under iron stress phytoplankton will experience increased sinking rates, as pointed out earlier in this paper. However, cells have certain mechanisms to decrease the sinking rate under iron stress. Muggli et al. (1996) found that cells under iron stress reduced their cell volume. Sinking rates for the diatom *Actinocyclus* sp. were still 5 times higher than under iron replete situations, but without the cell size decrease sinking rate would have been higher. In contrast, the coccolithophore *Emiliana huxleyi* showed no decrease in sinking rate under iron stress. A possible explanation for this is the size difference between the two species, the larger diatom needs to energy in order to maintain its buoyancy, whereas the smaller coccolithophore does not (Bienfang et al., 1982, Waite et al., 1992, Muggli et al., 1996, Acuña et al., 2010). The reduction in cell size can be attributed to asexual cell division (Muggli et al., 1996). Iron enrichment may lead to a decrease in silicification, which would reduce the maximum sinking rates of diatoms due to a reduction in cell ballast (Waite and Nodder, 2001). However, this will take several cell divisions, doubling time is ca. 4 days (reviewed by Waite and Nodder, 2001). Increases in sinking rate can take place in a couple of days, which is more consistent with ionic changes in cell protoplast density. Thus, silicification does not seem to be the main method of sinking control (Waite and Nodder, 2001). Increases in stratification and nutrient limitation are often coupled in marine systems, both favour a decrease in cell size, which will act to increase nutrient diffusion, reduce nutrient requirements and reduce sinking rates (Finkel et al., 2009).

Iron is one of the limiting factors in the Southern Ocean that controls phytoplankton blooms. There are only a few main sources of iron, continental margins,

upwelling of Fe-rich deep water and the melting of sea ice and glaciers (reviewed by Gerringa et al., 2012). With increased melting of sea-ice and glaciers, this will increase the amount of iron available for phytoplankton. This can increase the amount and duration of phytoplankton blooms. The iron released from glacial melt water can reach distances of 100 – 150 km (Gerringa et al., 2012), and can have far reaching effects. Distances can even be further increased (over 300 km) by different currents surrounding Antarctica (reviewed by Gerringa et al., 2012).

4.3 Salinity and phytoplankton

Salinity did not seem to differ much between sites influenced by either melt water from the ice edge, or glacial melt water. Salinities in the studies found (see this paper) were averaging between 33 and 34 PSU. Although, sites affected by glacial melt water did seem to have salinity values that were a bit lower. One exception was found, the salinity in the Krossfjorden and Kongsfjorden (Piquet et al., 2010). Salinity was as low as 16.3 PSU in places closest to the fjords. No diatoms or *Phaeocystis* sp. was found in the surface waters (Piquet et al., 2010). This could indicate that the salinity was too low for diatoms to maintain themselves near the surface. However, the study was done in 2005 the same year the sea ice melt started earlier than usual. The phytoplankton community consisted mostly of *Alveolata* and *Cercozoa*, which are typical species found in the sub-polar post-spring bloom (Piquet et al., 2010). During the record melt of Arctic sea-ice in 2007, the dominating species was *P. pouchetti*. Diatoms were hardly found, whereas stratification promotes diatoms in the Antarctic (Lasternas and Agustí, 2010). During the record melt of 2007, waters were colder and less saline than usual. Diatoms were hardly found during the melt, indicating that diatoms were more affected by the

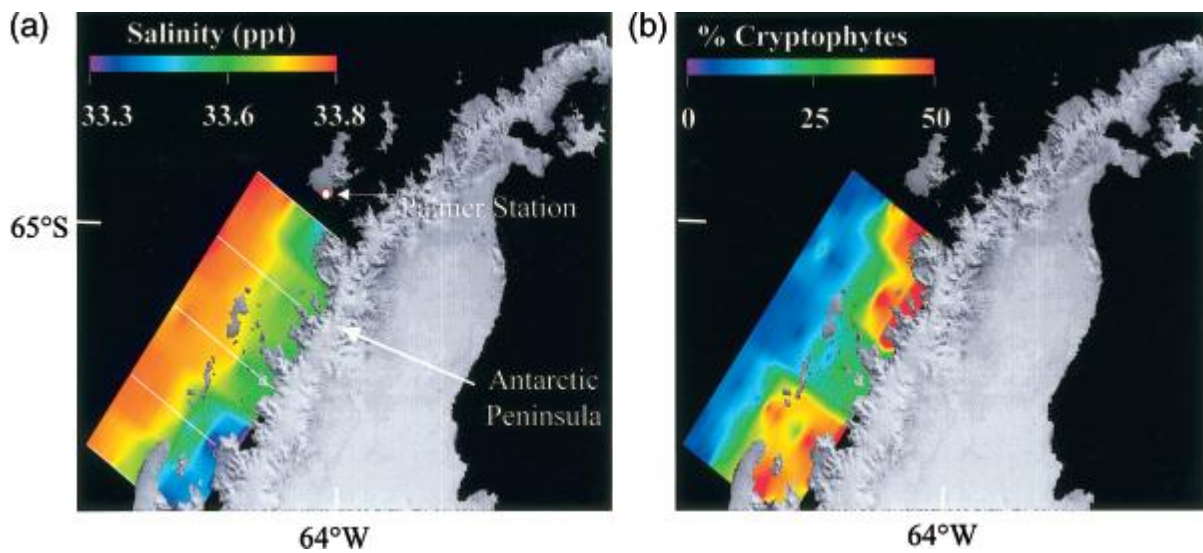


Figure 2. (a) Surface water salinity for a survey (December 1991 – January 1992) along the Antarctic Peninsula. Stations were occupied every 20 km along the historical LTER transect lines (white lines). (b) Concurrent integrated water column contribution of cryptophytes to total phytoplankton biomass (Moline et al., 2004)

melting ice than other species (Lasternas and Agustí, 2010).

4.4 Higher trophic levels

The dominance of cryptophytes in low salinity waters in the Southern Ocean is found in multiple studies (reviewed by Moline et al., 2004). This is not expected, as stratification promotes diatoms. An explanation for the lack of diatoms is a supposed limitation of iron input into the upper surface layer (reviewed by Mendes et al., 2012). Diatoms range in size from 15 to 270 μm , while Antarctic cryptophytes are around 8 μm . This represents a fundamental decrease in size, which will impact the grazing efficiencies of different zooplankton species (Moline et al., 2004). The two main planktonic grazers in the Southern Ocean are krill and *Salpa thompsoni*, both exhibit a broad-scale spatial and temporal variation in abundance and distribution (reviewed by Moline et al., 2004). The minimum particle size a salp can efficiently graze is 4 μm , whereas particles smaller than 20 μm will decrease the grazing efficiency of adult krill significantly (Moline et al., 2004). With the warming of the Antarctic Peninsula, more melt water will affect the phytoplankton community. Phytoplankton communities shifting from diatoms to cryptophytes would favour an increase in

salps and most likely decrease krill (Moline et al., 2004). An decrease in krill and an increase in salps has already been documented for the Southern Ocean (reviewed by Bertolin and Schloss, 2009). Krill is the central part in the Antarctic marine food web, changes in its distribution would affect higher trophic levels such as penguins, seals and whales (Moline et al., 2004). Recent reports are already suggesting that penguin ranges, foraging areas and migration rates appear to be changing (reviewed by Moline et al., 2004).

5. Conclusion

The sinking rate of phytoplankton depends on nutrient availability, cell size and volume, and abiotic factors such as turbulence, stratification. During nutrient deplete situations, the cell size has the biggest effect on sinking rate. The greater the cell, the faster it will sink. During nutrient replete situations, cell size does not have an effect on the sinking rate. Different sized cells have the same sinking rate, indicating a sinking rate regulation mechanism that requires energy. This suggestion is further supported by increased sinking rates during overcast days and dark conditions (Waite et al., 1992, Riebesell, 1989). Sinking rate is also increased under situations with reduced iron availability. However, cells under iron stress reduce their

cell volume in order to reduce the maximum sinking rate. While iron is one of the few limiting factors in the Southern Ocean, increased glacial melt water input might increase the iron availability for phytoplankton. Sinking rate is highly variable between species. It is difficult to compare between studies due to method differences. However, it seems that diatoms do not have higher sinking rates compared to other phytoplankton.

The differences in salinity between the ice edge and regions affected by glacial melt water seemed to be small, most were around 33 PSU. The only site where lower salinity values were measured was in the Krossfjorden and Kongsfjorden (Piquet et al., 2010). No diatoms or *Phaeocystis* sp. were found during the study, however this had most likely to do with the early sea-ice melt during 2005. In general the same salinity is found in regions affected by glacial melt and ice-edge melt water. However, salinities near glaciers seemed to be a bit lower. This could have an effect on the diatom species. However, the increased sediment input from glacial melt water will most likely have a greater impact than the slightly reduced salinity near glaciers.

A typical spring bloom consists of an early dominance by *Phaeocystis* sp., followed by diatoms. In the Antarctic the diatom bloom is followed by cryptophytes, in the Arctic diatoms are followed by *Alveolata* and *Cercozoa*. The cryptophyte bloom is induced by increased melt water, lowering the salinity of the water. With increasing melt water input due to warming, a shift could occur. Diatoms will still dominate the blooms, but the bloom might last shorter. The shift from diatoms to cryptophytes in the Antarctic poses a decrease in size in the phytoplankton. Diatoms are the preferred diet for krill, whereas cryptophytes are mainly predated by salps. Krill forms the basis in the Antarctic food web, and is prey for penguins, seals and whales. A decrease in krill

could be detrimental for the ecosystem, already a decrease in krill has been documented. Further research is needed in order to find out what the impact is of melting sea ice on the occurrence of diatoms in the Southern Ocean.

There does not seem to be a clear effect of (glacial) melt water input. In the Antarctic *Phaeocystis* dominates the early spring bloom, followed by diatoms. Most likely due to increased stratification, which promotes diatoms. However, with increased glacial melt water cryptophytes tend to take over. In the Arctic it is less clear, most sites studied were coastal regions. These coastal regions have increased sediment input which can block all algal growth.

There are other factors contributing to the phytoplankton community, such as nutrient limitation. The sinking of diatoms is important during nutrient limitation, although with iron enrichment from glacial meltwater this this might happen less in the Antarctic. The effects of salinity on phytoplankton communities is less clear. In the Arctic nitrogen limits algal growth, which leads to a selection of smaller species. The effects of meltwater input is less clear. It could lead to increased stratification, decreasing the time till nitrogen limitation. Assuming there is little sediment in the water column. With sediment there will be reduced light conditions, which will negatively affect algal growth.

6. References

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