# Climate change and Antarctic krill

*the effects on stocks and nutritional value*


Bachelor thesis by Marieke Krikke
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Marine Biology, RuG
Supervised by: Prof. A. Buma and Dr. P. Boelen

**ABSTRACT**

The effects of climate change are getting more and more visible. Temperatures have risen extremely the last 50 years, especially at high latitudes. The circumpolar Southern Ocean experienced a temperature rise larger than those of all oceans on earth together. The Southern Ocean is habitat of Antarctic krill, *Euphausia superba*, a key stone species in the Antarctic ecosystem. The main goal of this thesis is therefore to examine the effect of climate change on krill stocks and the nutritional value of krill.
Krill are under influence of climate change; krill stocks have declined severely the last 30 years. With global warming, sea ice extent, duration and timing are affected, which are important aspects in the different life history stages of krill. Ocean temperature also has an effect on krill. Phytoplankton communities are changing with negative effects on food availability for krill.
As krill is a key stone species and thus an important nutritious food source for higher trophic levels, it is also important to examine the nutritional value of their food source, the microalgae. Krill feed mainly on diatoms, which may contain less essential fatty acids when temperatures increases. This could have a great impact on krill and their nutritional value, important for higher trophic levels of the Antarctic ecosystem. This however, is not fully examined yet.
Overall, krill is affected by several processes which have changed due to climate change. The precise correlations are not clear and more research needs to be done on this important species and the whole ecosystem.

**CONTENTS**

# 1 INTRODUCTION

Marine ecosystems ensure many aspects critical to the functioning of the earth system. They provide long-term storage of $CO_2$, decomposition of organic matter, regeneration of nutrients and many more. Oceans need sunlight and nutrients, supplied via upwellings, for primary production. Recently, marine ecosystems are endangered by global climate change.
The existence of global warming has been well demonstrated. Global surface temperatures have risen extremely the last 100 years, with an average of 0.74°C ± 0.18°C (IPCC Fourth Assessment Rapport 2007). The last 30 years this rise has even increased more: the earth encountered a temperature rise of 0.2°C per decade. It seems a small increase, but many processes on earth are dependent on specific temperature ranges. A change that exceeds the limits of these ranges can thus have serious effects.

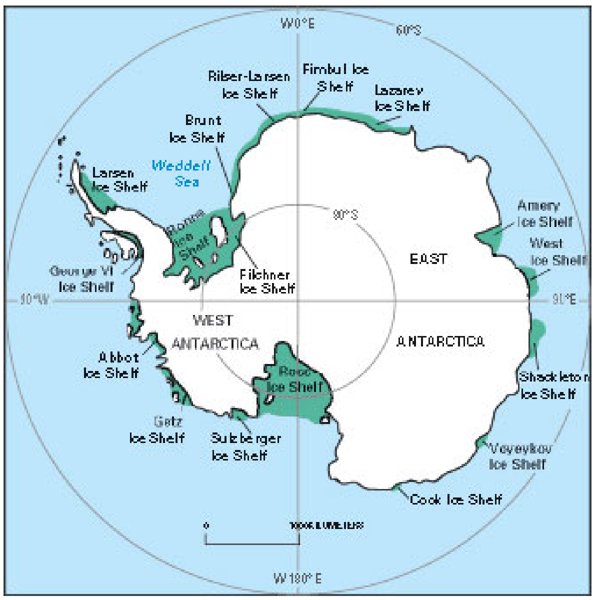


**Figure 1:** *Antarctica.*
(http://pubs.usgs.gov/fs/2005/3055/)

In the South Atlantic the largest concentration and highest densities of krill are found. Antarctic krill, *Euphausia superba,* are small marine animals and inhabiting the waters surrounding the Antarctic. This zooplankton plays an important role in the Antarctic ecosystem; it fills the midtrophic level at the centre of the food web. Krill feed on phytoplankton, mainly diatoms, and are prey of several larger animals, from birds to baleen whales. They make up an estimated biomass of 500 million tons, what makes them one of the most or maybe even the most successful animal species on earth (Nicol 2006). The phytoplankton krill feed on, contains many fatty acids, like the omega-3 polyunsaturated fatty acids (ω-3PUFA's). These ω-3PUFA's are said to be very nutritious and higher trophic levels will get these fatty acids through krill. Krill are also subject to commercial fisheries, because of the human demand on these healthy fatty acids.
The Southern Ocean has experienced temperatures rises the last 50 years, especially the Antarctic Peninsula region, it is one of the fastest warming areas on earth. According to the IPCC Fourth Assessment Report (2007) an increase in temperature will probably affect a marine ecosystem through loss of habitat, biodiversity and distribution. Thus with increasing temperatures this important animal species might endure many detrimental changes.

In this thesis a literature study was performed to answer this question:
*What are the effect of climate change on Antarctic krill, focusing on krill stocks and the nutritional value of krill?*

At first the ecology and life cycle of Antarctic krill are explained, thereafter evidence of the climate change is discussed. Subsequently the effects of climate change on krill stocks are shown as well as the effects of climate change on the nutritional value of krill. At the end a discussion is put out to draw and end conclusion.

# 2 KRILL

Krill look like small shrimps and belong to the taxonomic order Euphausiacea. They are crustaceans and have a stiff chitinous exoskeleton. Consequently they molt when they shrink or grow. Most krill species have a transparent exoskeleton. Krill occur in oceans all over the world and especially in the Southern Ocean they play a very important role by making up a large biomass. The last thirty years krill have also been target of commercial fisheries.

**Figure 2:** E. superba, *swimming under ice.* (http://www.awi.de/fileadmin/user_upload/News/Press_Releases/2008/1._Quartal/200801_Krill_JvFraneker_w.jpg)

Antarctic krill (*E. superba*), shown in figure 2, have a life span of 5 to 7 years (Quetin et al. 2007). They are schooling animals and densities up to 10.000-30.000 individuals per cubic meter can be reached in a swarm. Krill mostly occur at the Antarctic coastline and continental shelf break, inhabiting the (seasonal) sea ice zone (SIZ). Here they fulfill an important role in the Antarctic ecosystem as a grazer of phytoplankton, mainly diatoms, and as prey for larger animals that cannot feed on the small nutritious phytoplankton themselves. Krill are thus a significant intermediate step between several trophic levels, also called a keystone species.

Reproduction of Antarctic krill occurs in the four month summer period from December to March (Nicol 2006). Female krill are able to produce several batches of eggs (up to 3588 eggs per batch) with interbrood periods but only under optimal environmental conditions. Females may be capable of producing nine batches in one summer period. Gravid krill go to deeper water (offshore) to release the embryos. The embryos sink to a depth of 700-1000 meter and there they will hatch into larvae. These larvae will perform a "developmental ascent"; they will develop as they swim upward and in approximately 30 days the surface is reached. Within six days the larvae have to find food, or their chances for survival will decrease severely. The larvae drift with the movement of sea ice, formed during the winter, to inshore waters. The larvae metamorphose under the ice into juveniles and in spring a year later they will emerge as adults. These life stages are shown in figure 3. During these life stages krill are extra vulnerable to changes in their environment.

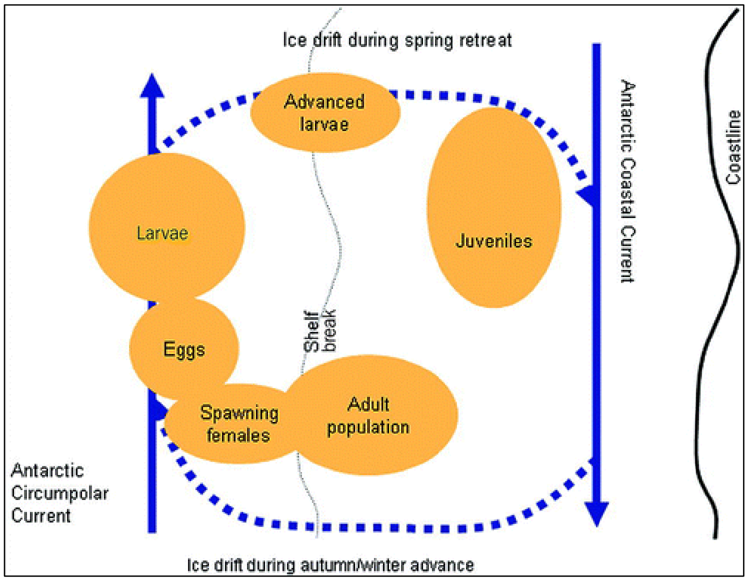


**Figure 3:** *Seasonal ontogenetic migration patterns of Antarctic krill, showing how the krill utilize the gyral circulation patterns that link the two major current systems.* (Nicol 2006)

Also shown in figure 3 are the Antarctic Circumpolar Current (ACC) and the Antarctic Coastal Current, two major currents surrounding the Antarctic. They have a great influence on many processes in the ocean. Krill utilizes these currents to migrate and reach the various sites of the SIZ (Nicol 2006).

## 3 CLIMATE CHANGE

The environment is always changing; it is an ongoing process. But when these changes are too large or happen too fast, it can cause difficulties for life on earth. Global warming is one of these large changes, most probably the result of anthropogenic processes. Temperatures have risen in such an unusual way that life may not be able to adapt. In the last 30 years the rate of warming is greater than in any other period in the last 1000 years (Walther et al. 2002). In mid-latitude regions, where data were available, an increase in the number of daily warm extremes was observed in 70-75% of the regions, as well as a reduction in the number of daily cold extremes and frost days (IPCC Fourth Assessment Rapport 2007).

The earth does not warm up equally because the heat capacity of oceans is much greater than the heat capacity of the atmosphere. Land temperatures also increase faster than ocean temperatures. Populations and communities will thus encounter different temperature rises. Especially the high latitude regions are affected by climate change; average temperature increase is almost twice as high as the average global temperature rise in the last 100 years (IPCC Fourth Assessment Rapport 2007).

The circumpolar Southern Ocean, habitat of Antarctic krill, has warmed up considerably the last 50 years. The rise in temperatures is larger than those of all the oceans on earth as a whole (Whitehouse et al. 2008). A study from M.J. Whitehouse et al. (2008) on rapid warming of the ocean around South Georgia, an island in the Southern Ocean, shows an increase in temperature of near-surface waters around South Georgia (figure 4).

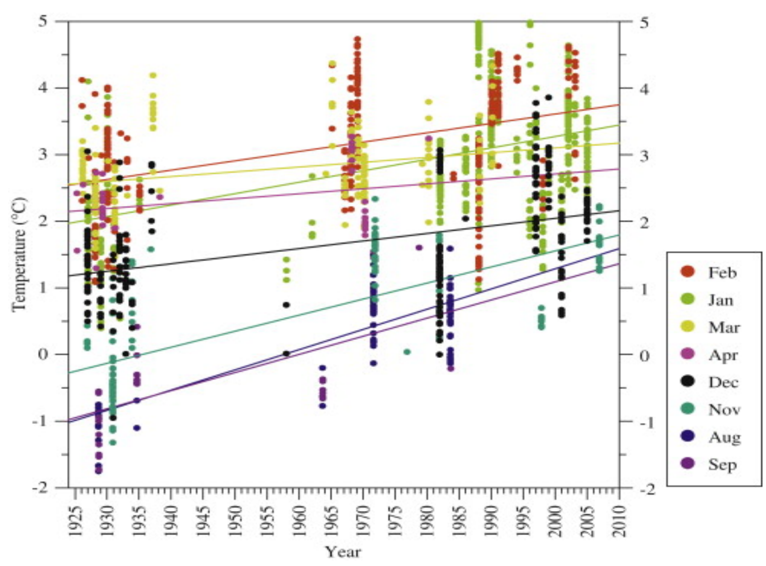


**Figure 4:** *Long-term monthly trend for mean 0-10m (near-surface waters) temperature (°C) around South Georgia, between April 1924 and November 2006.* (Whitehouse et al. 2008)

The region west of the Antarctic Peninsula (WAP) is also highly affected by the global climate change. Over the last fifty years surface air temperatures have increased with 5-6°C. Throughout the Antarctic Peninsula ice shelves and glaciers are retreating, sea ice duration has shortened and its concentration has decreased (Quetin et al. 2007). The ice shelves keep the Antarctic cool by reflecting light. Thus, a retreat of the ice shelves by an increase in temperature will subsequently contribute to the increase in temperature. In figure 5 the elevation of the Antarctic ice sheet is shown (IPCC Fourth Assessment Rapport 2007). Especially the southwestern part of the Antarctic shows a thinning of the ice sheet, demonstrated by the blue colors and purple triangles.

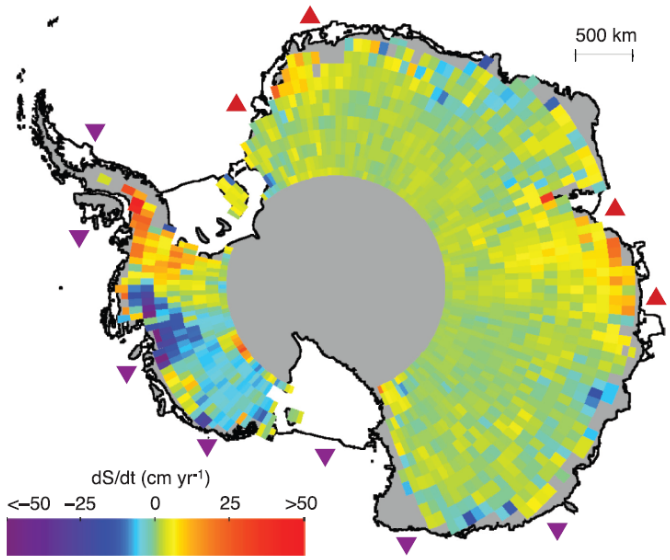


**Figure 5:** *Rates of surface elevation change (dS/dt) derived from ERS radar-altimeter measurements between 1992 and 2003 over the Antarctic Ice Sheet (Davis et al. 2005). Locations of ice shelves estimated to be thickening or thinning by more than 30 cm yr$^{-1}$ are shown by red triangles (thickening) and purple triangles (thinning).* (Zwally et al. 2005)

# 4 CLIMATE CHANGE AND KRILL STOCKS

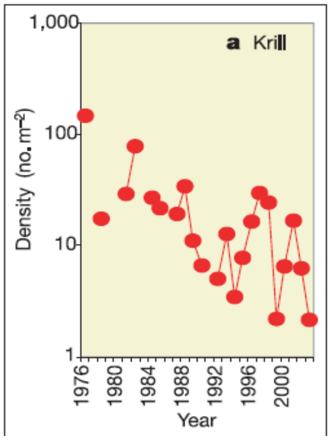


**Figure 6:** *Krill density in the southwest Atlantic sector measured between 1976 and 2004*. (Atkinson et al. 2004)

The fact that climate has changed, is already evident. But what are the effects of these changes on Antarctic krill? The southwest Atlantic contains more that 50% of the Southern Ocean krill stocks, but here their density has declined since 1970, as shown in figure 6 (Atkinson et al. 2004).

Atkinson et al. (2006) studied the effect of food, temperature and sex on growth rates of krill. They found a decrease in growth when temperatures rose above the optimal temperature of 0.5°C. With this they suggested that krill populations experience thermal stress at the upper limits of their temperature range.

Another study, done by Wiedenmann et al. (2008), also showed that temperature is important during the young life stages of krill. Research was conducted in the South Georgia region and the Antarctic Peninsula region. South Georgia lies at a lower latitude with higher temperatures. The biomass per recruit (BPR) was measured and plotted against the average temperature experienced in the first three years of life, shown in figure 7. Results are opposing; around the Antarctic Peninsula BPR increased significantly with an increase in temperature, while around South Georgia BPR decreased significantly with an increase in temperature. Thus a negative effect was measured when temperatures increased, but only for the warmer region. This might imply that krill biomass in the warmer regions of the Southern Ocean will be more affected.

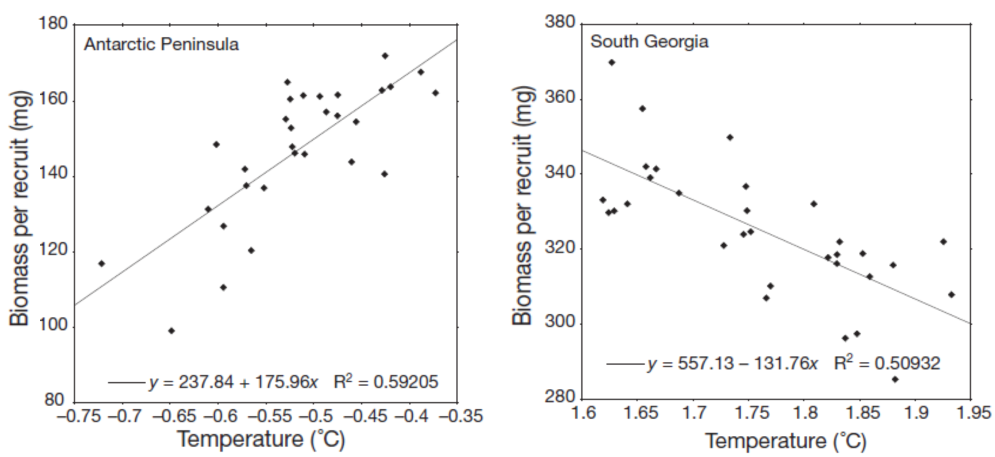


**Figure 7:** *BPR vs. average temperature that a cohort experiences in the first 3 yr of life for the Antarctic Peninsula and South Georgia.* (Wiedenmann et al. 2008)

Another factor influencing the habitat of Antarctic krill is the negative effect of climate change on seasonal sea ice. The SIZ is very important for krill and their reproduction. Figure 3 in chapter two shows the ontogenetic migration of krill and where at the SIZ this takes place. Changes in the SIZ can have various effects. A decrease in sea ice cover means a decrease in habitat for krill, especially for the juveniles, where they feed on the microorganisms growing on the underside of the ice and most likely also are protected from predation. An assumption has been made that regional krill abundance in summer is positively related to the extent of sea ice the previous winter (Nicol 2006).
Atkinson et al. (2004) has done research on the decline of krill stocks and salps in the Southern Ocean. A positive relation was found between krill density and winter ice latitude (a lower latitude means a larger extent of the ice), shown in figure 8. Also examined were krill density and winter ice duration, shown in figure 9. Here again a positive relation was found, altogether suggesting that krill density is indeed dependent on winter sea ice.

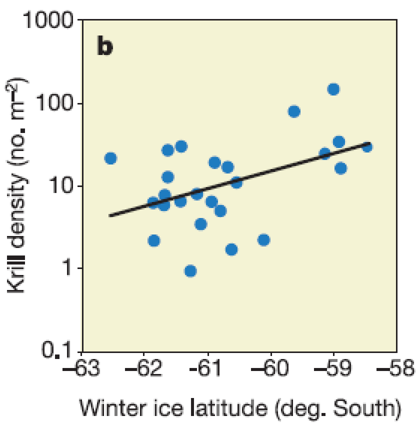


**Figure 8:** *Annual mean density of krill in summer across the Southwest Atlantic vs. the mean September(winter) latitude of 15% ice cover along a transect across the western Scotia Sea, measurements taken after 1976.* (Atkinson et al. 2004)

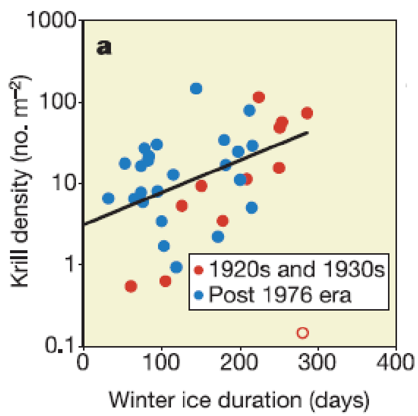


**Figure 9:** *Annual mean density of krill in summer across the Southwest Atlantic vs. sea ice duration (days of fast ice observed at the South Orkneys the previous winter).* (Atkinson et al. 2004)

When sea ice extent decreases, the distance between the deep waters (where spawning occurs) and the under-ice habitat (of which the larvae and juveniles are highly dependent) will become larger. This could result in a decrease in spawning regions due to inaccessibility and a highly reduced availability of food for the larvae, when the sea ice is not reached in time (Quetin et al. 2007). In addition, the timing of the sea ice advance is important. When ice forms late, less phytoplankton can be scavenged from the water column by the reduced rate of light in winter and thus the newly formed ice will contain less food for the larvae and juveniles (Quetin et al. 2007).

Like mentioned previously, sea ice ensures food for krill. When there is a high food availability, larval growth rates are also higher, indicating a higher survival during winter and probably also a higher recruitment success in summer. Immediate food supplies are important for ovarian development, instead of food reserves. The timing of the reproductive cycle appears to relate with the period of high primary production. In a study on krill responses to environmental variability by Quetin et al. (2007) the correlation between primary production and the reproductive intensity of krill is demonstrated (figure 10). When primary production was high, the reproductive intensity of krill was also higher. This shows the importance of enough available food for the maintenance of a krill population.

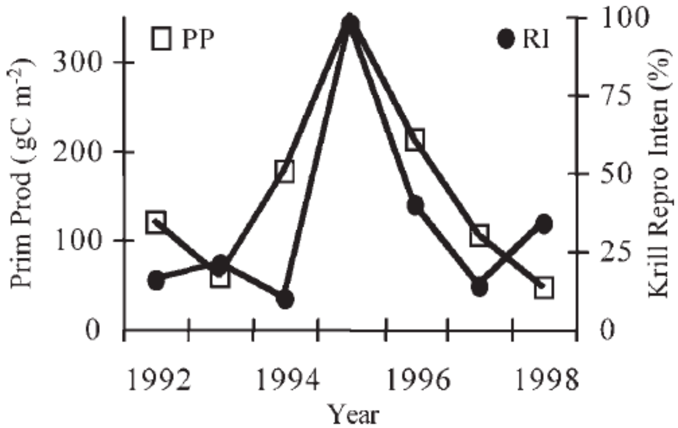


**Figure 10:** *Cycles of the intensity of Antarctic krill reproduction (RI) (% of mature females with red thelycums of the total immature and mature females) and seasonal integrated primary production (PP) (October–March as measured at stations near Palmer Station.)* (Quetin et al. 2007)

Usually krill feed mainly on diatom-dominated phytoplankton communities. These communities however, seem to change due to global warming. Moline et al. (2004) have studied the alteration of the food web along the Antarctic Peninsula in response to a regional warming trend. They found a shift in phytoplankton communities; from diatom-dominated to cryptophyte-dominated communities. This is correlated with a change in temperature and salinity. A low salinity is an outcome of glacial melt-water input when air temperatures were above freezing point. Cryptophytes function better in warmer and fresher water. This is shown in figure 11a and 11b.

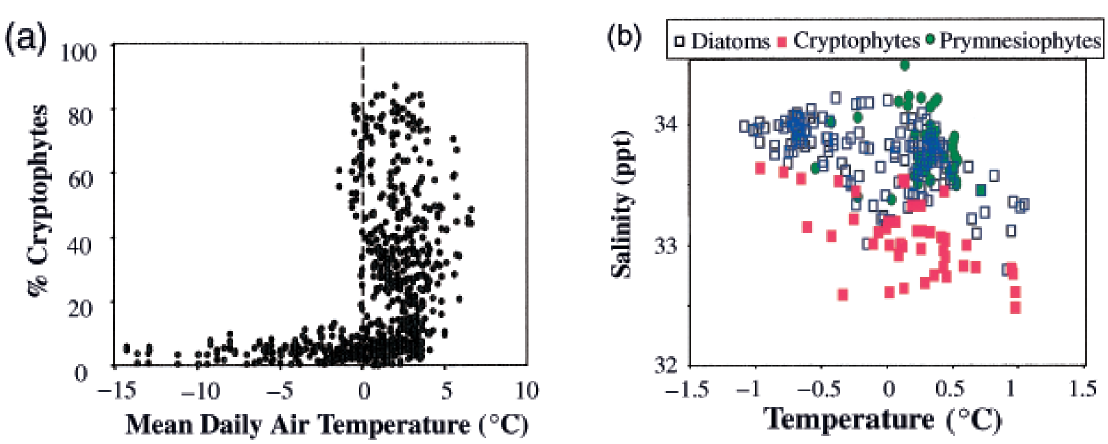


**Figure 11:** *(a) Percent cryptophytes shown as a function of mean daily air temperature at*

*Palmer Station for five sampling periods from 1991 to 1996. (b) Bivariate plot of temperature and salinity. Sample points indicate a >50% contribution to the total phytoplankton biomass by diatoms, cryptophytes and prymnesiophytes at Palmer Station from 1991 to 1994. When dominant, cryptophytes occupied significantly lower salinity water than either diatoms or prymnesiophytes*. (Moline et al. 2004)

Antarctic krill cannot feed as well on cryptophytes as on diatoms (Moline et al. 2004). Diatoms range in size from 15 to 270 µm and cryptophytes have an average size of 8 ± 2 µm. Cryptophytes are too small for krill as their grazing efficiency significantly decreases when particles are smaller than 20 µm. In the figures above it is clearly visible that with lower salinity and higher temperatures, cryptophytes dominate the phytoplankton community. This has a negative impact on food availability for krill. It is known however, that krill can adapt to locally available food in every life history stage (Nicol 2006). So krill may survive when food availability is not optimal, but there might be consequences for the predators.

The carbon transfer from phytoplankton to higher trophic levels could also be affected by this phytoplankton community-change. Biomass will be lost when the cryptophytes are not efficiently grazed, resulting in a possible decrease in carbon transfer of 40 to 65% (Moline et al. 2004).

# 5 CLIMATE CHANGE AND NUTRITIONAL VALUE OF KRILL

The nutritional value of krill is in this thesis seen as the amount of essential fatty acids. These fatty acids are essential for growth and survival because they provide energy, serve several biochemical reactions (especially immune reactions) and because they are an important structural component in cell membranes. In cells PUFA's regulate the degree of fluidity of the membranes (Thomas and Dieckmann 2002). In cold environments membranes are more oily-like, this is necessary for many cellular processes, correlated with a higher amount of PUFA's. Krill cannot biosynthesize these fatty acids themselves and are therefore dependent on phytoplankton (Saito et al. 2002). Higher trophic levels can also not biosynthesize the fatty acids themselves and are on their turn dependent on krill. To evaluate the nutritional value of krill it is important to examine the nutritional value of their prey, the microalgae.

The composition of the nutritious fatty acids and also their concentration differs in phytoplankton cells, dependent on growth conditions and physiological state (Ross et al., 2000). Changes in the environment can have a large impact on these growth conditions and physiological state of phytoplankton cells. Global warming may thus influence the amount of fatty acids or their composition.
Rousch et al. (2003) studied the changes in fatty acid profiles during temperature stress in thermo-intolerant and thermo-tolerant marine diatoms. These diatoms do not occur in the Antarctic, but their response to higher temperatures could be an indication of the response of Antarctic diatoms to higher temperatures. In figure 12 the fatty acid profiles are shown per temperature and per marine diatom.
When the temperature increased, the amount of PUFA's decreased. As mentioned before, the amount of PUFA's is higher in cold environments, which is important for membrane fluidity. This aspect could be the cause of the decrease in PUFA's in the two marine diatoms during temperature stress. If Antarctic diatoms show the same response to increased temperatures, it could mean that they will contain less PUFA's and will have a lower nutritional value. The reduced nutritional value may result in a reduced nutritional value of krill, with possible consequences for higher trophic levels of the Antarctic ecosystem. The results of this study are of course not conclusive evidence, but they do demonstrate the vulnerability of these microalgae.

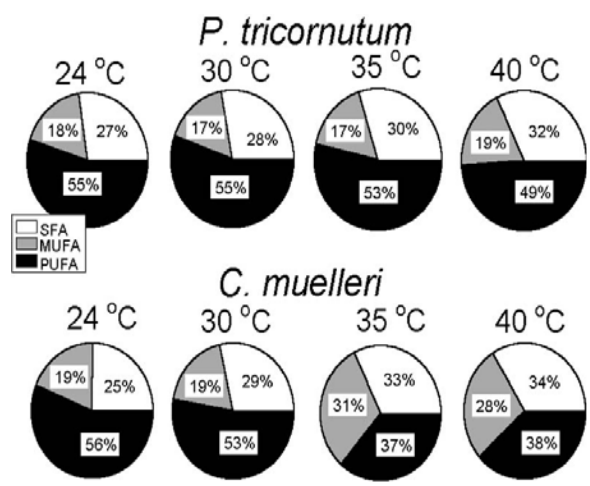


**Figure 12:** *Relative proportions of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) for P. tricornutum and C. muelleri heat-treated for 2 h at 24 (control), 30, 35 and 40 jC. Percentages represent the mean quantities of SFA, MUFA and PUFA in triplicate treatments.* (Rousch et al. 2003)

# 6 DISCUSSION

The effects on climate change on krill stocks were shown in chapter 4. The effect of temperature on biomass per recruit was measured and results showed a positive correlation in the colder region and a negative correlation in the warmer region. It is difficult to draw conclusions from these experiments, as it would be expected that the biomass per recruit was also affected by a higher temperature in the colder region. An explanation could be that the cold region experienced temperatures that laid well within the optimal temperature range for krill, meaning that the temperatures in the warm region balanced at the upper limit of their optimal temperature range, resulting in a negative impact on krill and the biomass per recruit.

There was also a correlation found between krill density and winter ice latitude and duration. But these aspects could also be correlated to another process for example to the ACC, instead of a correlation between them. However, according to Quetin & Ross (2003), recruitment of larvae is certainly affected by the winter ice duration, with high recruitment observed after at least five months with winter ice. Furthermore, a high recruitment results in a high population size. However, opposing to this study, krill abundance is highest in the region where sea ice extent is minimal. This is in the region of the Antarctic Peninsula. But in the region of South Georgia sea ice is even nonexistent, but does contain high krill abundance (Nicol 2006). These facts contradict the statement that krill density is correlated with winter ice latitude and duration. Krill density is probably affected by more environmental factors than sea ice alone.

The nutritional value of krill was difficult to examine, because of the lack of well suited studies. In many studies the importance of de phytoplankton community composition became clear, but little attention was paid to the components in these phytoplankton communities and the effect of climate change on these important components. The study by Rousch et al. (2003) did show lower nutritional value of two different diatoms during temperature stress, but this was not conclusive evidence for determining the nutritional value of Antarctic diatoms when temperatures increase.

For many experiments done around the Antarctic it was hard to make consequent observations and to take samples. The Southern Ocean is a harsh environment, with extreme temperatures, strong currents, storms and sea ice on the sites were samples and observations needed to be taken. Results are therefore not always completely reliable. Another problem with reliability is the difficulty of population dynamics. Krill have a complicated life cycle, with life stages occurring at different sites of the SIZ. The site of observations is sometimes remote from processes like recruitment and growth (Atkinson et al. 2004).

Overall the conclusion can be made that climate change has a negative impact on krill. The many aspects that influence krill stocks make it hard to draw conclusion on specific observations. The mechanisms underlying the different processes are still not clear. But as temperatures are rising, krill stocks are still decreasing and with the severe consequences for the whole ecosystem, more research needs to be done on important environmental factors and on the quality of prey for krill.

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