The effects of Global warming on the Arctic organisms of the Kongsfjorden ecosystem

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Abstract

The Kongsfjorden is a fjord ecosystem on the west coast of Spitsbergen. Because of its unique location the fjord is seen as a model system for the effects of global warming in the Arctic. For this reason a lot of scientific research takes place in the Kongsfjorden. The influence of warm Atlantic water masses entering the Kongsfjorden from the West Spitsbergen Current may cause the warming of the Arctic to occur faster in the Kongsfjorden than in the rest of the Arctic region. These unique oceanographical circumstances have an effect on the community composition making it a mix between boreal and Arctic species. Because of the increasing warming of the climate and the increasing inflow of Atlantic Water the Arctic community members are threatened. Organisms constituting the base of the food web like the phyto- and zooplankton are strongly linked to their original water masses. Other primary producers like benthic macroalgae experience additional negative effects of the warming climate by changing hydrographical condition in the fjord caused by an increasing runoff of melt water from the adjacent glaciers. These effects cascade through the entire ecosystem threatening to change the community composition in the Kongsfjorden from a mixed to a more Atlantic composition.

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Introduction

Warming of the global climate system is unequivocal, as is now evident from observations of increases in average air and ocean temperatures. At continental, regional and ocean basin scales numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ocean salinity. Average Arctic temperatures increased almost twice the global average rate in the past 100 years (IPCC 2007).

There are a number of physical processes that are expected to have a strong impact on the climate and the biology of the Arctic. A key issue is the inflow of Atlantic water (AW) to the Arctic. These relatively warm waters from the Atlantic flow through the Nordic seas into the Arctic Ocean via the Barents seas and through Fram Strait (ACIA 2005). Between these two the Fram Strait, between Greenland and Svalbard represents the only deep connection between the Atlantic and the Arctic Ocean. The exchange of water masses between the North Atlantic and the Arctic Ocean takes place in two opposing current systems, the West Spitsbergen Current (WSC) heading north along the shelf slope on the eastern part of the region and the East Greenland Current (EGC) heading southward along Greenland (figure 1). This makes the Fram Strait very important with regard to heat and mass exchange in the Arctic Ocean (Hop et al., 2006).

There is general agreement that the Arctic Ocean at present is in a transition towards a new, warmer state (Polyakov et al., 2005). The cause of these variations are not well understood, but variations in the inflow of AW and the outflow of Polar Water (PW) masses are shown to be related to the Arctic Oscillation and the North Atlantic Oscillation. These pressure systems are strongly linked to the atmospheric heat balance. Climate changes may thus alter the strength of the large-scale ocean circulation in the region. This would result in modification of the water masses created on the shelf of West-Spitsbergen. The mixing of AW with the coastal Arctic Water (ArW) from the South Cape Current results in Transformed Atlantic Water (TAW). This water mass is advected towards the coast and into the fjords on West-Spitsbergen (Svalbard)(Svendsen et al., 2002), carrying both Arctic and Atlantic plankton into the fjords (Hop et al., 2006).

The Kongsfjorden fjord is one of these fjords receiving the advected water. This makes the Kongsfjorden very suitable for studying the effects of global warming on the Arctic ecosystem since it receives both Atlantic and Arctic water masses. Because of these two different biogeographic zones that meet in the fjord, the biodiversity is strongly structured by the different physical factors influencing the Kongsfjorden. An increased influx of AW into the system would alter the species composition towards boreal species whereas Arctic input and distance from the coast would tend to make the inner part of the fjord more Arctic. In addition to this, glacial input of fresh water and sediments create strong environmental gradients, these gradients induce large changes in community composition and abundance from the inner to the outer fjord. Primary production in Kongsfjorden is dependent on these physical factors like light and stratification. For example the euphotic layer varies between 30 m at the fjord entrance and 0,3 m in the turbid waters close to the glaciers (Hop et al., 2002).

The aim of the present thesis was first of all to describe how the predicted increasing temperatures and AW inflow affect the current species composition. Secondly it will describe what the effects for Arctic community in Kongsfjorden will be. In this paper I will try to answer these questions. First I will look at the current oceanographic situation in the Kongsfjorden and the causes of changes in this situation. Then I will look at the pelagic phytoplankton and the primary production in both Arctic and Atlantic water in the Kongsfjorden followed by the zooplankton in both water masses. Then I will describe the current situation of the benthic macro algae and the threats they face because of global warming. Finally I will describe the future if there would be no arctic algae and plankton for the entire Kongsfjorden ecosystem including the higher trophic levels.

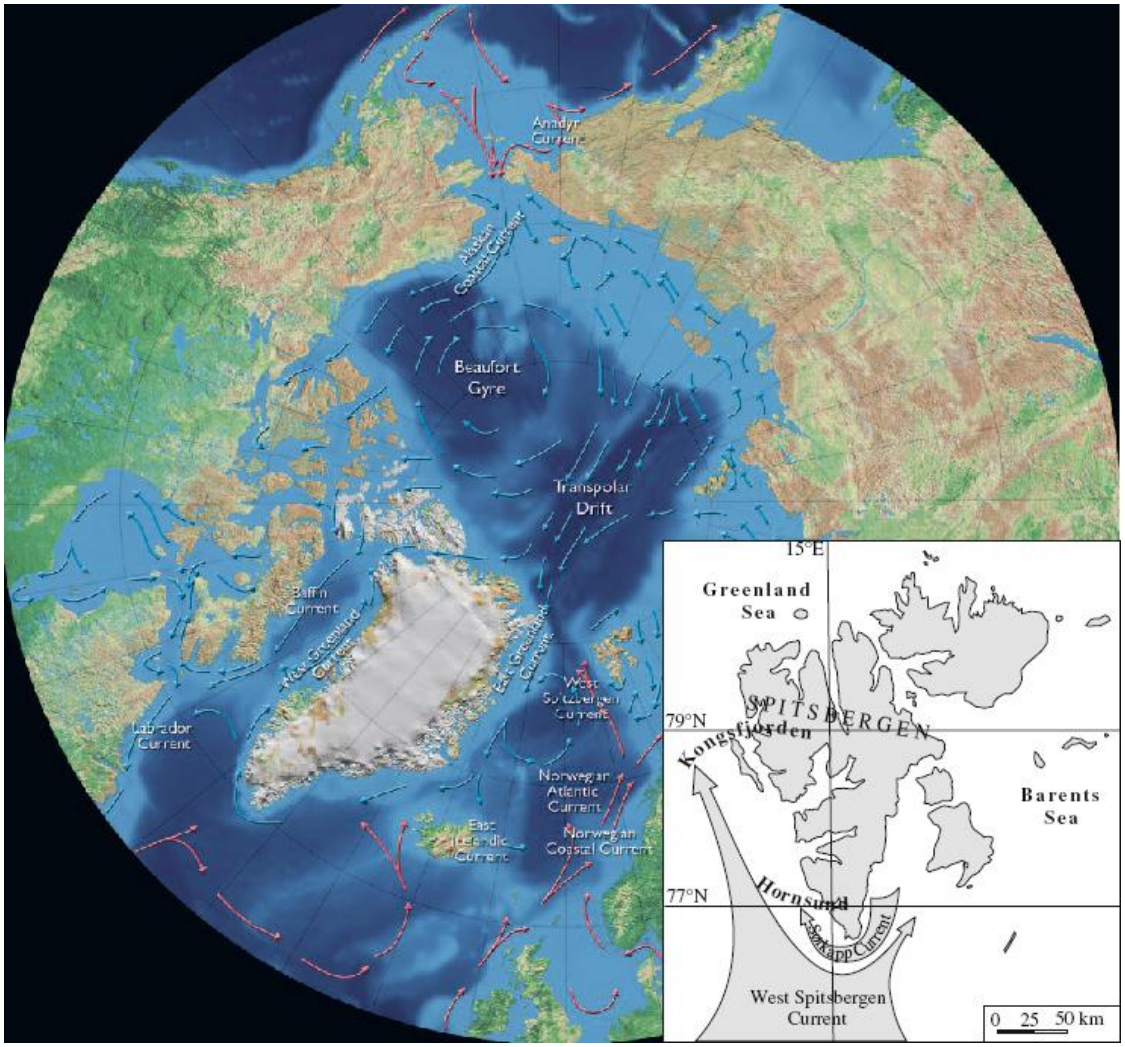

Figure 1. Map of the Arctic Ocean with the cold currents in blue and the warm currents in blue. Taken from ACIA 2005. Detail; Map of the Svalbard archipelago showing the WSC and the South Cape (Sørkapp) Current and the Kongsfjorden. Taken from Piwosz et al., 2002)

Chapter 1: The Kongsfjorden; Geographical and Oceanographical influences.

The Kongsfjorden is a glacial fjord in the Arctic, located on the west coast of Spitsbergen, Svalbard at 79°N, 12°E. Because it is an open fjord with no sill at the entrance, there is a large exchange along the shelf-fjord boundary (Hop et al., 2002). The large influence of the Atlantic makes the Kongsfjorden sub-Arctic rather than Arctic as might be expected at this latitude. More southern fjords like the Hornsund fjord are more influenced by cold Arctic waters from the Barents Sea, flowing around the Archipelago in the South Cape Current causing Arctic conditions in this fjord (Piwos et al., 2008).

The cause of the large Atlantic influence on the Kongsfjorden is the inflow of warm Atlantic water into the Arctic by means of the West Spitsbergen Current. This Atlantic inflow is driven by thermohaline circulation. This thermohaline circulation is the main source for the generation of North Atlantic Deep Water, the main driver of the global ocean “Great Conveyor Belt” (ACIA, 2005). This North Atlantic Deep Water is generated by the upper layer inflow of warm, saline Atlantic water (O.A. by means of the West Spitsbergen Current) into the Arctic Ocean. When this water is cooled it

becomes denser causing a vertical transfer from near surface waters to deeper layers. These deep waters then flow over the Greenland-Scotland Ridge and return to the Atlantic (ACIA 2005) (figure 2).

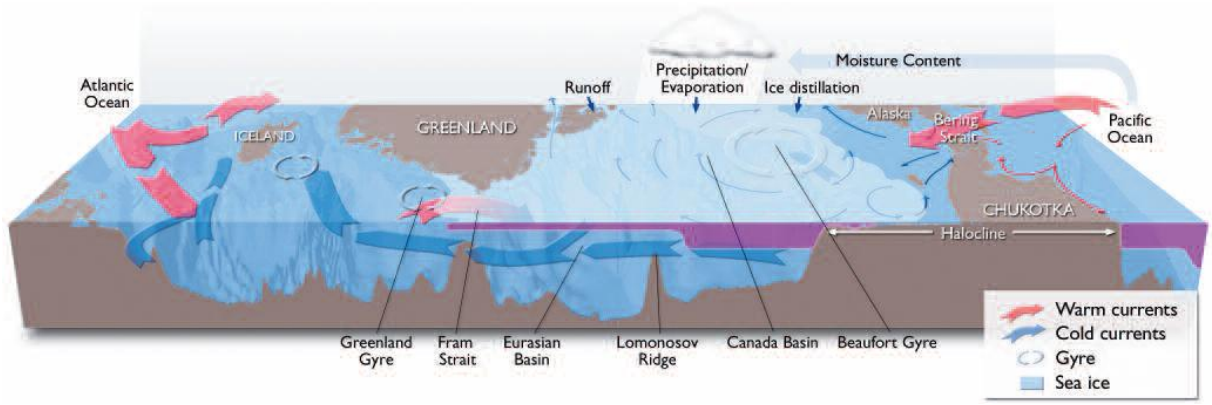

Figure 2. The inflow of Atlantic water into the Arctic Ocean through Fram Strait (WSC) and the formation of North Atlantic Deep Water in the Arctic. Taken from ACIA 2005

While the inflow of Atlantic water into the Arctic is caused by thermohaline circulation, the variation in the amount of Atlantic water and thus the amount of heat transported into the Arctic is linked to variations in large scale atmospheric patterns. In particular, correlations with the winter North Atlantic Oscillation (NAO) index were estimated (Schlichtholz & Goszczko 2006). The NAO is an alteration in the pressure difference between the sub-tropic atmospheric high-pressure zone centered over the Azores and the atmospheric low-pressure zone over Iceland. It is the dominant mode of atmospheric behaviour in the North Atlantic throughout the year, but it is most pronounced during winter and accounts for more than one-third of the total variance in sea level pressure (Ottersen et al., 2001). The NAO is known to have large ecological effects. For example the increase in temperature and alteration in the winter circulation pattern observed during the last decades of predominantly positive NAO index values have resulted in unfavourable conditions for the population of the copepod *Calanus finmarchicus,* leading to a significant decrease in the abundance of the species in the northeast Atlantic. Conversely, these hydro climatic shifts have proved beneficial to *Calanus helgolandicus*, the abundance of which has increased during these years. This is caused by variation in the direction and strength of oceanic surface currents under influence of the NAO causing changes in food availability and the volume of Norwegian Sea Deep Water where the overwintering *C. finmarchicus* population resides. (Ottersen et al., 2001).

The mechanisms causing the link between the NAO and the evolution of the AW water layer are multiple. For instance, an increase of the NAO index enhances the water exchange across the Arctic Front. Another mechanism contributing to the correlation between the heat content anomalies in the WSC and the NAO is the heat exchange with the atmosphere during the northward flow of Atlantic water through the Nordic Seas. During periods with a positive NAO index more warm air is advected by the stronger westerlies into the Nordic seas area which reduces the local winter heat loss to the atmosphere. Temperature anomalies created in this way are advected by the Norwegian Atlantic Current towards Fram strait (Schlichtholz & Goszczko 2006) .

These processes connect the inflow of warm Atlantic water into the Arctic to the atmosphere and thus to global warming. Because of its geographical location and the fact that it receives both Atlantic water and Arctic water the Kongsfjorden ecosystem represents a unique border area between

Atlantic and Arctic zones (Hop et al., 2002). This makes it an ideal system to investigate the effects of global change on Arctic organisms like phytoplankton, zooplankton and benthic algae.

Chapter 2: Effects of Global warming on the Phytoplankton in the Kongsfjorden

A total of 148 phytoplankton taxa have been recorded from Kongsfjorden; 67 of the taxa belong to the Bacillariophyta and 46 to the Dinophyta. Most of the species are either of Atlantic or cosmopolitan origin. Only 31 (21%) of the phytoplankton species in Kongsfjorden are considered to be Arctic or boreal-Arctic species based on the classification by Hasle & von Quillfeldt (1996) (Hop et al., 2002). There is a pronounced seasonal signal in phytoplankton growth and distribution. The long polar night (116 days) stops production by autotrophic organisms. In spring more than 60 phytoplankton taxa have been identified, most of which are diatoms. The summer season in Kongsfjorden is characterized by very diverse phytoplankton communities, with > 130 taxa recorded. In the inner fjord dinoflagellates and small unidentified flagellates dominate. In the middle part of the fjord the chrysophyte *Dinobryon balticum*, in addition to dinoflagellates are numerous. Diatoms occasionally occur in the middle and outer part of the fjord, together with *Phaeocystis pouchetii, Dinobryon balticum* and dinoflagellates. Occasional observations of coccolitophorids, sometimes in high amounts indicate that the inflow of Atlantic Water takes place in the fjord at irregular intervals(Hop et al., 2002).

Heterotrohic nanoflagellates and bacteria(picoplankton) are also relatively important in the Kongsfjorden microbial community. Wang et al. 2009 investigated the effect of the rapid transformation from an Arctic Water to an Atlantic Water dominated system and the input of large quantities of fresh water from glacial melting on the local communities. They found that the distribution of pico- and nanoplankton is co insisting with the four types of water masses; Transformed Atlantic Water in the outer basins of the fjord, intermediate layer water, deep layer water and the glacial melt surface water in the inner fjord (Svendsen, 2002). This suggests that the structure of plankton communities integrated with environmental variables can act as indicator for, and thus is effected by, Atlantic Water inflow (Wang et al., 2009).

Another study by Keck et al. 1999 investigated the effects of glacial meltwater on composition, abundance and distribution of the phytoplankton summer community in Kongsfjorden. They sampled during the mid-summer period when glacial meltwater discharges are maximal. This caused a stratification of the water column near the glacier. The phytoplankton community encountered in the glacier-influenced environment was rich in dinoflagellates and other flagellate species. The highest abundances were attained by the colonial chrysophyte *Dinobryon balticum*(figure 3), an oceaninc species that is advected into the fjord with the incoming Atlantic Water. This species was particularly dominant in the outer reaches of the fjord and much less so in the inner basin. An explanation for this might be that because of their colonial life form they are more susceptible to particle collisions in high turbid environments like the inner Kongsfjorden. In contrast, other flagellates seem to be much less affected by effects of glacial discharge.

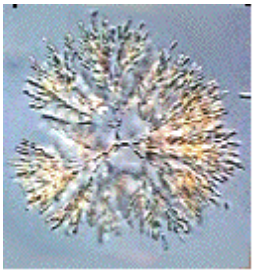

Figure 3. Colony of *Dinobryon balticum.* Test.b-neat.org

Because the presence of high motility in many solitary flagellates, they may tolerate the increasing particle concentrations better. This may also explain why the species richness was found to be higher in the inner fjord compared to the outer fjord (Keck et al., 1999).

To investigate the effect of increasing Atlantic influence in the Kongsfjorden it might be useful to compare the phytoplankton community and primary production of the Kongsfjorden to a fjord system that is much like the Kongsfjorden but is less influenced by Atlantic Water. This was done by Piwosz et al. in 2008. They compared the Kongsfjorden system to the Hornsund fjord system during mid-summer 2002. The latter fjord lies south of the Kongsfjorden but more influenced by Arctic water from the cold South Cape Current and thus more Arctic in. Hornsund (77°N) is geologically similar to the Kongsfjorden but earlier research showed that phytoplankton communities and primary production might differ significantly from Kongsfjorden. For both fjords major contributors of total phytoplankton biomass at the mouth of the fjords were diatoms(>40%). Dinoflagellates and cryptophytes were also quite important in terms of biomass in Kongsfjorden (~20%), whereas cryptophytes and unidentified nanoflagellates contributed importantly in Hornsund. The vertical and horizontal distribution of total phytoplankton biomass also varied between the two fjords. The highest phytoplankton biomass in Kongsfjorden was in the deeper layers at the mouth of the fjord. In contrast, phytoplankton biomass was concentrated in the surface layers (>15 m) of Hornsund. The most important species were *Pseudonitzschia seriata* in Kongsfjorden and *Chaetoceros socialis* in Hornsund. The second most important contributor to total phytoplankton biomass in Kongsfjorden, were autotrophic dinoflagellates, e.g. *Scrippsiella trochoidea, Ceratium arcticum*. They contributed >60% of the biomass in subsurface layers (10-15m). They were of lesser importance in terms of total phytoplankton biomass in Hornsund, their biomass contribution did not exceed 22%(Piwosz et al., 2008). Primary production rates in the water column were much higher in Hornsund than in Kongsfjorden. At all stations, maximum primary production was found in subsurface layers (3-7 m), while at the surface (0 m) it was usually approximately three times lower. The vertical distribution of chlorophyll-*a* was highly variable in both fjords, but in Hornsund chlorophyll-*a* concentrations were approximately an order of magnitude higher than in Kongsfjorden (figure 4). The most obvious explanation seems to be the difference in light regime. When you compare the thickness of productive layers at the innermost sampling stations you see that the productive layer in Hornsund was ~15 m (PAR <1% of surface intensity) and only ~5 m in Kongsfjorden.

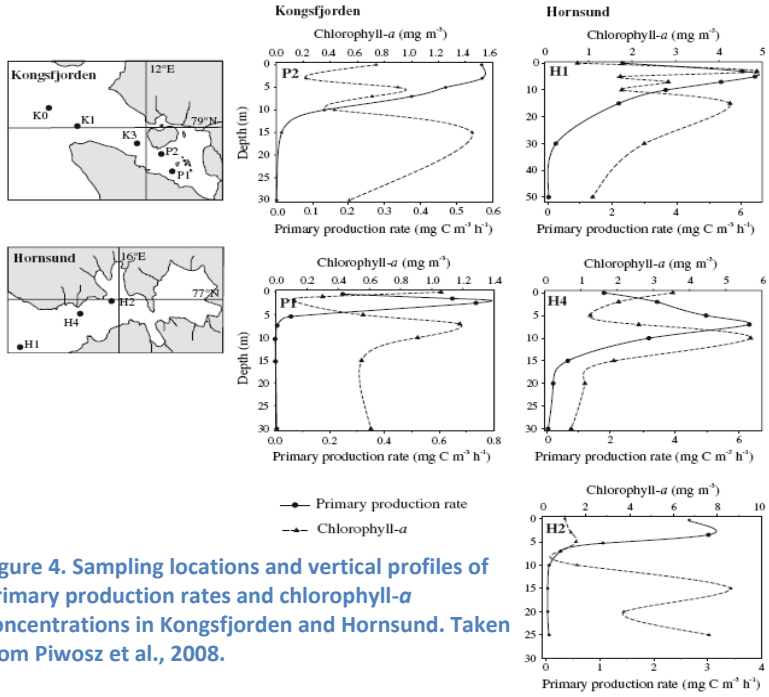

Figure 4. Sampling locations and vertical profiles of primary production rates and chlorophyll-*a* concentrations in Kongsfjorden and Hornsund. Taken from Piwosz et al., 2008.

Chapter 3: Effects of global warming on the Zooplankton community in the Kongsfjorden

Typical for polar latitudes, zooplankton in Fram Strait and Kongsfjorden is predominated by calanoid copepods. Other crustaceans relatively rich in species are Amphipoda and Euphausiacea. Of 103 taxa recorded in both regions there are 64 that are in common and 19 and 20 found exclusively in Fram Strait or Kongsfjorden respectively. The key zooplankton components of both areas are, first of all, Copepoda such as three *Calanus* species(*C. finmarchicus, C. glacialis* and, *C.hyperboreus*), *Metrida longa, Pseudocalanus* (*P. minutes* and *P. acuspes*), *Microcalanus* (*M.pusillu*s and *M.pygmaeus*)and *Oithona similis*. The Fram Strait zooplankton fauna differs by the presence of meso- and bathypelagic copepods such as *Augaptilus glacialis, Heterorhabdus compactus, Scaphocalanus brevicornis,* or ostracods *Boroecia borealis* and *B.maxima*. The Kongsfjorden zooplankton fauna includes, for example, hyperbenthic copepods *Bradyidius similis, Masaiokeras spitsbergensis, Xantharus siedleckii, Noescolecithrix faranni* and neritic eupasiid *Thysaniessa raschii* (Hop et al.,2006).

The majority of information in zooplankton abundance and biomass in Fram strait regards the large herbivorous calanoid copepod species *C. finmarchicus, C.glacialis* and, *C.hyperboreus*. All studies indicate close association of individual species with their original water masses. The boreal *C.finmachicus* is associated with Atlantic Water of the WSC. The two other species are associated with cold Arctic water masses, although *C.glacialis* is regarded a shelf species whereas *C.hyperboreus* is an oceanic one inhabiting primarily deep water sea basins. In Kongsfjorden during summer (July), where the zooplankton was sampled during 1996-2002, the mean water column abundance of *C.finmarchicus* varied from 50 to 600 ind. m^{-3}, *C.glacialis* varied from 20 to 330 ind. m^{-3} and *C.hyperboreus* varied from 2 to 110 ind. m^{-3} (Hop et al., 2006).

A study by Blachwiak-Samolyk et al. in 2008 in north-eastern Svalbard waters revealed that Atlantic-associated species of zooplankton such as *C.finmarchicus* increased in biomass with increasing temperature and salinity. The Arctic species such as *C.glacialis* were found to be inversely correlated with the temperature-salinity gradient. They found three distinct assemblages of zooplankton related to the water masses. The first group is the 'Atlantic shallow' group was related to higher temperatures in accordance with their Atlantic Water or boreal preferences. This group consisted among others of *C.finmarchicus, Fritillaria borealis* and *Oithona atlantica.* The second group constituted and "Arctic shallow" shallow community with among others *C.glacialis, Pseudocalanus* spp. and *Mertensia ovum.* This community structure was similar to the post-spring community in western Greenland waters. The third 'Deep' group included many cosmopolitan species that are also commonly found in the Atlantic Ocean. This group consists among others of *Paraeuchaeta* spp. and *Tricornica borealis* (Blachwiak-Samolyk et al., 2008).

Global warming may change the migration patterns of the "warmer water" species from the North Atlantic, causing them to arrive earlier en depart later from the Arctic regions. This may cause a general northward movement of Atlantic/boreal zooplankton species (Blachwiak-Samolyk et al., 2003). The most important feature of the zooplankton in Kongsfjorden is the co-occurrence of boreal and Arctic taxa. *C.finmarchicus* belongs to the Atlantic biogeographical province whereas *C.glacialis* is an inhabitant of the Arctic biogeographic province. Generally the proportion of *C.finmarchicus* was found to decrease while *C.glacialis* increased with distance from the fjord entrance. This can most likely be contributed to the amount of cold water present, cold water providing a refugium for the Arctic *C.glacialis* (Hop et al., 2002).

The Atlantic influence is expected to become stronger and the climate to become warmer and this will most likely be reflected by changes in the zooplankton community of Kongsfjorden. The pelagic community is probably the most sensitive to interannual variability, as is indicated by a shift in community composition of species between 'cold' and 'warm' years. *C.glacialis* was abundant in the cold year of 1996, whereas *C.finmarchicus* dominated in the warmer year of 1997 (figure 5). An increased influx of Atlantic Water will probably result in the establishment of other boreal species in Kongsfjorden (Hop et al., 2002).

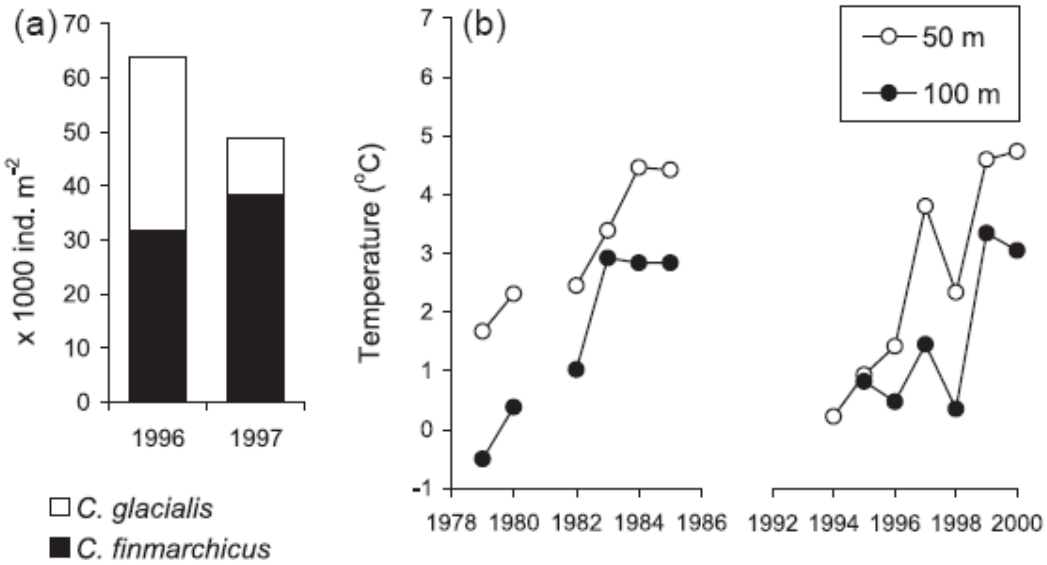

Figure 5. (a) Abundance of Arctic *C.Glacialis* and boreal *C.finmarchicus* in a "cold"(1996) and "warm" (1997) year. (b) Historical variability in ocean climate (summer sea temperatures) in Kongsfjorden. Taken from Hop et al., 2002

Chapter 4: Effects of Global warming on benthic macro algae in the Kongsfjorden

The underwater flora of the Kongsfjorden is composed of at least 50 different macroalgal species. These kelp forests are structurally complex and highly productive components of coldwater rocky coastlines like the Kongsfjorden. The growth of these marine macroalgae is controlled by light, temperaturenutrients, water movement and salinity. Climate change has caused measurable effects on kelps near their thermal limit. The high scenario of the IPCC report (2007) predicts that the annual Arctic surface temperatures north of 60°N will increase in the range of 2.4-6.4 °C by 2100. Furthermore the increased temperature of the Arctic Ocean, including Spitsbergen, will lead to earlier ice melt and later freeze-up within the yearly cycle, increases in precipitation a decrease in sea-ice cover with a decrease of ocean salinity in the upper 500 m (Fredersdorf et al., 2009).

In 1996 and 1998 Wiencke et al. studied the species composition and zonation of benthic macroalgae in the middle region of the Kongsfjorden. They selected a steep, hard bottom location on a rocky island close to Hansneset on the western shore of Blomstrandhalvøya and sampled the macroalgae by means of SCUBA diving. They found that the marine flora of Kongsfjorden occupies in intermediate position between the marine floras of East Greenland and northern Norway. They found 17 species that occur in the Arctic to cold temperate region and 7 species that extend from Arctic to warm temperate region. So the composition of marcoalgae in Kongsfjorden reflects the fact that West-Spitsbergen is influenced by both Arctic and Atlantic water masses. The zonation of the

macroalgal community shows four algal belts: the littoral, the upper sublittoral down to about 3 to 5 m depth, the mid sublittoral between 3 and 8 to 15 m depth, and the lower sublittoral down to about 30 m depth. The upper sublittoral is characterized by the brown algae *Fucus distichus,* and the green alga *Urospora penicilliformis*. The most important red alga in this belt is the endemic Arctic species *Devalereae ramentacea.* The key species in the mid subittoral are the brown algae *Alaria esculenta, Laminaria digitata* and *L. saccharina*. The red alga *Callophyllis cristata* and the brown alga *Desmarestia viridis, Sphacelaria plumosa* and *D.aculeata* occur as undergrowth species in this belt. The lower sublittoral is characterized, besides crustose red algae, by the red algae *Phycodrys rubens* and *Ptilota gunneri.* This zonation pattern is comparable to that described for other Arctic locations and is principally determined by the physical conditions and the radiation regime (Wiencke et al., 2004)

Alaria esculenta, a large brown alga, populates the sublittoral zones of Arctic and cold temperate coastal ecosystems. The regional distribution of *A.esculenta* is temperature controlled and it is present in the North Pacific as well as in the North Atlantic. In Kongsfjorden *A.esculenta* can be found between 3 and 10m depth. Fredersdorf et al. 2009 researched the effects of abiotic environmental factors on the kelp *A.esculenta*. They indentified the effects and interactions of temperature, radiation and salinity and tested two potential physiological tolerance limits on two different life history stages of *A.esculenta* from Spitsbergen. They found that the predominant and most influential environmental factor for *A.esculenta* is temperature. Temperature is not only responsible for regulation of metabolism and reproduction but also for the geographical distribution of kelp species. In both investigated life stages of *A.esculenta,* an upper temperature limit close to 16-20 °C was determined, which is considerably higher than in the Kongsfjorden. Temperature dominated as an individual effect and interacted synergistically with radiation and salinity. In regard to environmental changes in the Arctic, *A.esculenta* proved to be tolerant and adaptable to increased temperature, UV radiation and decreased salinity, which are occurring due to global warming (Fredersdorf et al., 2009).

Figure 6. ***Alaria esculenta.*** **Picture from:** ***static.panoramio.com***

Another effect of global warming in the Kongsfjorden can be an increased inflow of melting water from the adjacent glaciers. Next to causing a decreasing salinity this may also cause an increased inflow of nutrients. The predicted increase in the inflow of Atlantic Water may also cause in increase in the nutrient availability in the Kongsfjorden. Gordillo et al. 2006 investigated the effects of a nutrient input in summer on the marcoalgal community in the Kongsfjorden. They found that acclimation to summer nutrient input seems to involve mechanisms that allow for the maintenance of a stable biomass composition, rather than a rapid assimilation of newly available resource. This indicates a high degree of resilience of the algal community to a disruption in the natural nutrient availability pattern. At the moment eutrophication does not seem to be a problem but eventually biodiversity could be compromised since fast-growing nitrophillic species are likely to show enhanced growth and outcompete resilient slow-growing species (Gordillo et al., 2006).

Discussion

All the areas investigated in this study are expected to face changes due do global warming. This applies to the oceanological circumstances the zoo- and phytoplankton and the marcoalgae. The reason I chose these three groups to study is that they form the basis of the food web of the Kongsfjorden ecosystem (figure 7). Changes in these groups will have large effects on the higher levels in the food web like the fishes, the birds, the marine mammals and the polar bears, especially when you take into account that on average in an ecosystem only 10% of the energy is transferred to the next trophic level.

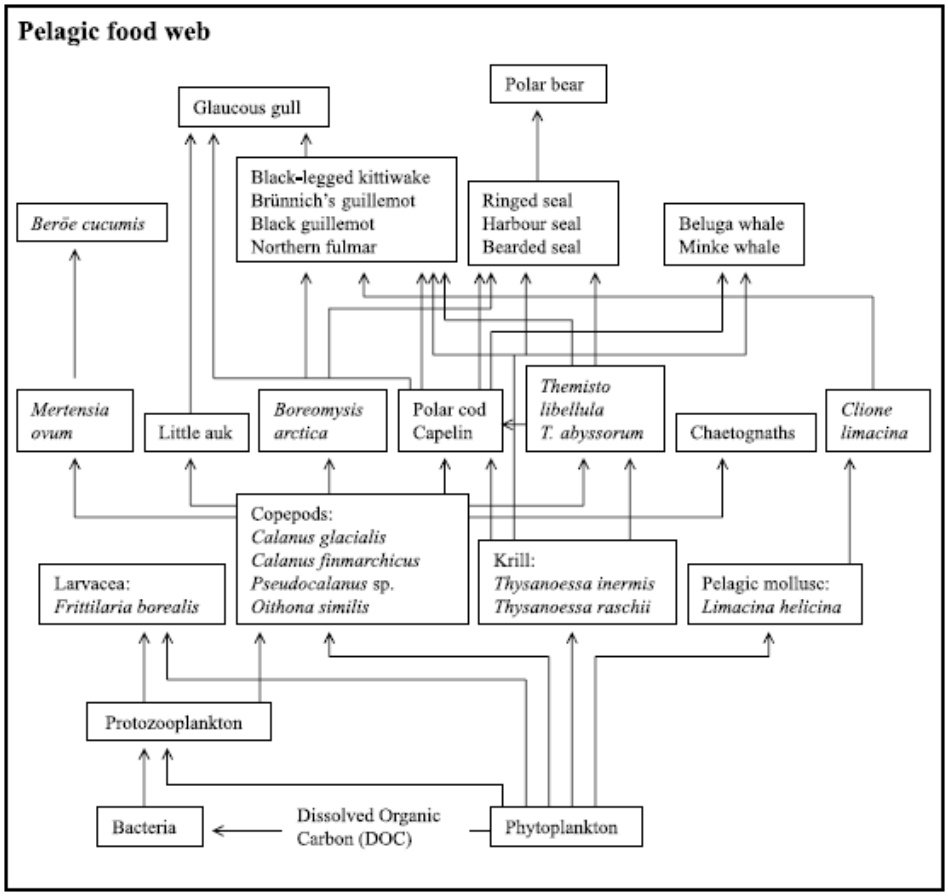

Figure 7. Model of the pelagic food web in the Kongsfjorden. Taken from Hop et al., 2002.

The paper by Piwosz et al. in 2009 is especially worrying in this regard because it was found that the primary production in the Kongsfjorden was much lower than in the more Arctic influenced Hornsund fjord system. This suggests that the increasing Atlantic influence in the Kongsfjorden can cause a dramatic decrease of primary production influencing the rest of the ecosystem. One factor that might have influenced the observations of the primary production was the timing of the phytoplankton bloom in both fjords. Even though sampling was conducted at about the same time in July in both fjords, the phyptoplankton bloom, and thus plankton communities, may have been more advanced in Kongsfjorden than in Hornsund. Typically, the spring bloom starts with diatoms and progresses into flagellates and smaller algae during summer, and the original surface blooms will sink down to become the deep chlorophyll maximum (DCM). The fact that the diatoms at DCM were in rather poor conditions, with bleached chloroplastst and plasmolysed cytoplasm, is consistent with a senescent and sinking bloom (Piwosz et al., 2008).

To conclude, I think the predicted influence of global warming will be felt greatly in the Arctic regions what all reports and studies confirm. West-Spitsbergen with is big Atlantic influence from the West Spitsbergen Current will be one of the places where the changes will be the biggest and the first noticeable. The Kongsfjorden system will be faced with these changes and they will definitely be affected. Possible effects can be a shift from a blended Arctic/Atlantic community to a more Atlantic dominated system. Some of the Arctic organisms may be able to adapt to the changing circumstances but on a whole the changes will be too quick. Further research should focus on the effects of the changes in the lower trophic levels on the rest of the ecosystem. It is also important that long term monitoring series are continued to be able to quantify the effects of the changing climate on the oceanographical situation and the plankton communities.

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