

THE RELATIONSHIP BETWEEN PLANKTON AND WATER  
MASS PROPERTIES IN HIGH ARCTIC (SVALBARD)  
FJORDS

by

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## **An Abstract of the Thesis of**

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Four areas around the Svalbard archipelago were selected as sampling sites to study the relationship between plankton communities and water mass properties during the spring transitional period. At each station, we sampled physical water properties, phytoplankton, and zooplankton communities. The stations presented different plankton communities: fjords on the west side of the archipelago showed a higher presence of Atlantic water as well as Atlantic communities than the more Arctic site to the east. These differences were likely in part due to each station being at a different stage of the spring transition, which influences the presence or absence of some plankton species. The bloom stages varied from early stages at the most Arctic influenced area to late stages at the most Atlantic influenced area. Several zooplankton species, including the copepod *Calanus* spp., the krill *Thysanoessa* spp., and the two ctenophore species were particularly useful in relating plankton communities to the different water mass properties. This study presents plankton community data from little studied areas, as well as presenting many new questions and indicating areas for future research.

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## Introduction

Marine ecosystems in the Arctic are particularly sensitive to global climate change, and therefore are particularly important study sites (ACIA 2005). Decreasing amounts of sea ice and warmer sea water temperatures will impact Arctic organisms in numerous ways, as many organisms are dependent on certain temperatures and sea ice cover for reproduction and feeding. The extent to which the Arctic will be impacted is still unknown, due in part to relatively little research having been done in the area.

The waters around Spitsbergen, the largest island of the high Arctic Svalbard archipelago (74-80°N), are influenced by both Atlantic (AtW) and Arctic (ArW) waters, and in the past decades the influx of AtW to this area has increased (Pavlov et al. 2013). The AtW, originating in the Gulf Stream, flows along the west coast of Spitsbergen, creating the West Spitsbergen Current (WSC) (Aagaard et al. 1987, Foldvik et al. 1987). The WSC brings warmer, relatively higher salinity water into contact with ArW. The fjords on the west coast of Spitsbergen are therefore a mixture of AtW and ArW. The WSC brings warmer water northward, meaning that the west coast of Spitsbergen is considerably warmer than the east coast (Aagaard et al. 1987). Because of this, fjords on the west coast have warmer water masses and less sea ice cover over winter than those on the east coast, which has implications for the marine ecosystem. In recent years, an increase of AtW has been observed in the WSC (Svendsen et al. 2002a).

The abundance and composition of marine plankton has been related to these water masses (Hop et al. 2002, Daase and Eiane 2007, Blachowiak-Samolyk 2008). Communities of Arctic and Atlantic plankton have been defined, and both occur to differing degrees in the waters around Svalbard (Blachowiak-Samolyk et al. 2008,

Gluchowska et al. 2016). Additionally, the abundance of Arctic and Atlantic populations within certain areas have been shown to fluctuate in relation to the proportion of ArW and AtW present (Arnkværn et al. 2005, Dalpadado et al. 2016). With the increased flux of AtW towards the Arctic, it is expected that an increased abundance of Atlantic species will follow (Richardson and Schoeman 2004, Hop et al. 2006). However, most studies of plankton in the waters around Svalbard have taken place in the Fram Strait or the open water northwest of Spitsbergen (Hop et al. 2006, Daase and Eiane 2007, Blachowiak-Samolyk et al. 2008). Studies within fjords have primarily been limited to Kongsfjorden due to the presence of an international research station nearby (e.g. Hop et al. 2002, Blachowiak-Samolyk et al. 2008). In addition to the oceanic currents, Svalbard fjords are characterized by a variety of local factors including such as glacial influence, seasonal sea ice cover, and bathymetry (Skarðhamar and Svendsen 2010). In particular, all fjords in Svalbard have varying degrees of influence from glacial runoff, which can lower salinity and increase sedimentation in the fjord during summer melting (Svendsen et al. 2002a, Cottier et al. 2005). These local influences can limit the ability of some plankton species to thrive, which impacts the overall plankton communities, making fjords interesting study areas (Walkusz et al. 2003).

In the spring, the Arctic transitions from 24 hours of darkness to 24 hours of daylight. By the beginning of April, the sun is above the horizon for 24 hours a day in Svalbard. This increase in light allows for rapid growth of primary producers, referred to as the spring bloom. Around Svalbard the dominant group of phytoplankton is the class Bacillariophyta (diatoms) (Hop et al. 2002). This bloom of phytoplankton

begins and occurs to different extents in different areas depending on AtW influence, ice cover and glacial influence (Hasle and Heimdal 1998, Hegseth and Sundfjord 2007, Hegseth and Tverberg 2013, Piquet et al. 2014). This increase in primary production provides food for higher trophic levels, and many zooplankton species have their reproduction timed to match the spring bloom (Hop et al. 2002, Arnkværn et al. 2005, Hegseth and Sundfjord 2007). Since zooplankton are so dependent on the timing of the spring bloom, when the bloom occurs at different times due to differing amounts of AtW and ArW, there can be a mismatch between zooplankton reproduction and the phytoplankton peak (Hodal et al. 2012). This could lead to lower abundances of zooplankton in years where a mismatch occurs, highlighting the importance of the presence of the different water masses (Hodal et al. 2012).

There are several zooplankton species that are particularly useful in identifying Arctic versus Atlantic communities. Copepods are among the most numerically dominant species in the area, making up 60-90% of the biomass (Søreide et al. 2010). Three *Calanus* spp. are present in the Svalbard area: *C. finmarchicus*, *C. glacialis* and *C. hyperboreus*. *C. finmarchicus* has been associated with the higher temperature and salinity expected in AtW, whereas *C. glacialis* and *C. hyperboreus* are more commonly found in ArW (Arnkværn et al. 2005, Daase et al. 2007, Blachowiak-Samolyk et al. 2008). Additionally, *Calanus* spp. reproduction and growth is coupled with the phytoplankton peak, meaning that the presence of *Calanus* spp. stages can be an indicator of the timing of the phytoplankton peak (Arnkværn et al. 2005, Søreide et al. 2010). In addition to copepods, euphausiids (krill) and amphipods can be useful indicators of water mass. While overall krill abundance increases in AtW, the species

*Thysanoessa inermis* thrives in ArW (Buchholz et al. 2010, Orlova et al. 2015, Dalpadado et al. 2016). Similarly, the amphipod species *Themisto libellula* is typically described as an Arctic species, while *T. abyssorum* is in sub-Arctic and Atlantic dominated waters (Dalpadado et al. 2001).

This goal of this study was to characterize the physical water properties and plankton community at four different stations within the Svalbard archipelago. Hydrographic variables from CTD casts were used to determine the influence of different water masses – Arctic, Atlantic or local – at each station. Chlorophyll *a* and phytoplankton samples were taken to determine the community and abundance of primary producers. Zooplankton communities were determined by two different net samples to obtain a range of size classes. The plankton communities observed provide information about the stage of the spring bloom during sampling, as well as providing a useful comparison to older studies to observe how plankton communities may have changed over time. This study adds to a growing list of previous studies attempting to describe plankton at the Arctic and Atlantic interface and how the plankton may be affected by changing environmental conditions.

## **Materials and Methods**

### **Location of Sampling**

We collected data and samples for this project during a field cruise on the R/V Helmer Hanssen May 10<sup>th</sup>-16<sup>th</sup>, 2016 as part of the University Centre in Svalbard AB-202 course. Sampling took place around the high Arctic Svalbard archipelago. Four stations were sampled that had varying amounts of impact from the currents influencing the archipelago.

The stations were in Isfjorden (ISK), Kongsfjorden (KB3), Smeerenburgfjorden (SME), and the Hinlopen Strait (HIN) (Table 1, Fig. 1). ISK is a large, glaciated fjord, and sampling took place in the middle of the fjord, far from any land. KB3 is a much smaller fjord with strong glacial influence throughout. SME is a small, heavily glaciated fjord with large sills on all entrances. HIN was the only station where sea ice was present; at the time of sampling there was open, old drift ice, and earlier in the season there was much denser ice cover. HIN is surrounded by large glaciers, including the large ice caps on Nordaustlandet.

### **Phytoplankton**

#### *CTD and Niskin Bottles*

A Seabird 9/11 CTD was deployed at the four stations to measure conductivity, temperature and density of the water column. The CTD was deployed from the surface to several meters above the sea floor. Salinity was calculated from conductivity and temperature. Measurements were taken during the lowering of the CTD. The CTD

readings were used to identify the different water masses at the four stations based on the salinity and temperature limits defined in Cottier et al. 2005.

Twelve 10 L Niskin bottles were attached to the CTD. Niskin bottle samples were taken on the uplift at depths of 50 m and 5 m, as well as at the chlorophyll a (chl a) max of each station as determined by the fluorescence data from a sensor attached to the CTD. Two Niskin bottles were taken at each depth sampled and roughly a quarter of each were pooled together into 5 liter canisters using a funnel. These were stored at roughly 2° C for further analysis of chl a content as a proxy for phytoplankton abundance. The canisters were rinsed with water from the sample before the final collection to prevent contamination.

#### *Light Measurements*

Light penetration through the water column was measured using a Li-Cor sensor (2π LI – 192), measuring photosynthetically active radiation (PAR), which is the number of photosynthetically active photons ( $\mu\text{mol}$ ) per unit time ( $\text{s}^{-1}$ ) per unit area ( $\text{m}^{-2}$ ). Light was measured at each sampling station. Readings were taken at every meter from 0-10 m depths, and every 5 m beyond the 10 m threshold until readings were negative. At each depth the sensor was held for 5 seconds in order to allow the sensor time to adjust. Light intensity outside the CTD room was simultaneously measured as a reference and a single light measurement was taken from a clear spot on the ship (outside the bridge) as an additional control reference.

### *Phytoplankton Collection*

Phytoplankton net hauls were taken at each station using a handheld net with a mesh size of 20 $\mu$ m for qualitative analysis of phytoplankton composition. The depth of hauls ranged from 20-40m, well below the chl *a* max of each station. Two hauls were taken at each station with the exception of SME, where four hauls were taken due to low phytoplankton abundance in the water column. Phytoplankton sampled were analyzed the same day as collection. At least four subsamples of the algae from each station were viewed using Leica light microscopes and all identified species were recorded. No quantitative measures of phytoplankton were performed.

### *Chlorophyll *a* measurements*

Water samples from the Niskin bottles were filtrated for chl *a* analysis. Before filtration the canisters were shaken to suspend any settled phytoplankton. The water samples from each depth were filtrated with a vacuum pump filtration system through GFF-filters (maximum pore size = 0.7 $\mu$ m) and 10  $\mu$ m nucleopore filters. Three replicates of each sample were filtered through each of the filter sizes, resulting in 6 total filters for chl *a* analysis from each water sample. The volume of water filtered was dependent on the presumed phytoplankton content in the water at the depth as judged from the fluorescence measure from the CTD. Between each filtration the filtration system was rinsed with filtered sea water to prevent any cross contamination. After filtration, filters were placed in small, labeled glass containers with 10 mL 100% methanol for extraction of chl *a*. Samples that could not immediately be placed in methanol were frozen at -80° C and later placed in methanol. Filters were placed in

methanol and refrigerated in darkness for 24 hours for extraction before chl *a* measurements took place.

After 24 hours of extraction the content of the glass containers was placed into a 10 mL syringe with a 0.22 µm glass fiber filter attached and then filtered into a 13 mm cuvette. The cuvettes were wiped clean of any droplets on the outside before measuring chl *a* with a 10-AU Turner Design Fluorometer. Any error of the fluorometer was corrected for by measuring the reading of a cuvette containing only methanol. Two droplets of 10 % HCl were then added to the cuvette to extract all phaeophytin *a*. The cuvette was shaken and any droplets were wiped off before a phaeophytin measurement was taken. Chlorophyll *a* content in the water was calculated using the equations below.

$$\text{Uncorrectd raw Chl } a = \frac{\text{Chl } a \text{ read or Phaeo } \left[ \frac{\mu\text{g}}{\text{L}} \right] \times (\text{V(methanol)}[\text{mL}])}{\text{V (water filtered } [\text{mL}]) \times \text{dilution factor}}$$

[1]

$$\text{Acid corrected Chl } a = \frac{\text{Chl } a \text{ read} - \text{Phaeo } \left[ \frac{\mu\text{g}}{\text{L}} \right] \times 1.7 \times (\text{V(methanol)}[\text{mL}])}{\text{V(water filtered } [\text{mL}]) \times \text{dilution factor}}$$

[2]

## **Zooplankton**

### *Multi plankton sampler (MPS)*

A MPS (Hydro-Bios MultiNet) was equipped with five closing nets, each with 200 µm mesh size, 0.25 m<sup>2</sup> opening, and a 2500 mL non-filtering cod end with a fine meshed side for drainage of excess water. Each net was programmed to open and close

at five different pressure intervals, sampling zooplankton at five different depths, and a flow meter attached to the net recorded flow during the period each net was open. Samples from 0-20 m and 20-50 m were pooled, as well as the samples from 100-200 m and 200-260 m. Before sieving the sample, larger gelatinous and fragile plankton were sorted out with tweezers. The samples were mixed to ensure homogeneity of species distribution and subsamples were taken for each respective depth. The subsamples were immediately fixed with 4% formaldehyde in borax-buffered seawater and stored in a dark cooling room at 3° C until further analysis.

Leica stereo microscopes were used to identify the copepodite stages of *Calanus* spp.. Larger zooplankton (e.g. Chaetognaths and Amphipods) were identified, sorted, and counted. For smaller species, 5 mL subsamples were taken by stirring the sample to mix it using a syringe to collect the subsample. All *Oithona* spp. were counted and other copepod species were recorded as “other small copepods”. *Cirripedia*, Copepoda, krill nauplii, and *Calanus* spp. stages CI and CII were identified and counted. *Calanus* spp. were sorted to species level based on measured prosome length (Arnkvaern et al. 2005).

#### *Methot Issac Kidd (MIK) net*

A MIK net was fished from 30 m above the seafloor to the surface at each station to collect larger zooplankton. The net had an opening of 3.15 m<sup>2</sup> with a mesh size of 1.55 mm. A flowmeter was attached in the middle of the opening to measure the water flow. Volume of water filtered was calculated using data from the flowmeter.

Onboard the net was washed with seawater to collect all sample specimens left in the net. The total sample was filtered using a 1 mm sieve to separate smaller copepods from larger plankton and transferred into a container before being measured into 4 equal subsamples. Larger animals were sorted from all subsamples and put into a separate container. For one randomly picked subsample all larger animals were identified and counted. Early developmental stages, such as larvae and nauplii, were not taken into consideration for the analysis of the MIK sample as it is unlikely a representative sample was taken.

## Results

### Physical properties of water

The four stations showed distinct differences in temperature and salinity throughout the water column (Figure 2). HIN had cold, low salinity water with very little stratification throughout, whereas KB3 had warmer, more saline water below 50 m, but above 50 m had a layer of cold, low salinity water. ISK and SME both showed some stratification in the upper layers, particularly when looking at salinity.

Based on the temperature and salinity, HIN was the only station with Arctic water (Table 2, Fig. 2). The other stations were primarily composed of Transformed Atlantic Water (TAW). The surface layer in KB3 did not fit well with any classification, and it likely was a mixture of local influences and TAW. Both ISK and SME had slightly colder deeper water that fell outside of the classification of TAW, and may have been formed by the sinking of cold water during winter.

HIN had a much deeper euphotic zone than the other stations and ISK and KB3 had particularly shallow euphotic zones (Fig. 3).

### Standing Stock

KB3 and ISK both had a strong chl *a* max in the 15-18 m range, while SME and HIN had little change in the chl *a* concentration throughout depths (Fig. 3). The amount of chl *a* at the chl *a* maximum varied between stations (Fig.3,4). KB3 had a much larger concentration of chl *a* than the other stations, and SME had a very low concentration. KB3, HIN, and ISK had a larger proportion of large photosynthetic organisms, whereas SME was dominated by smaller organisms. In SME it was noted

that some of the nets used for zooplankton sampling were clogged with algae despite the low chl *a* concentrations presented here, so it is possible that there were patchy blooms occurring in the fjord.

KB3, SME and HIN had similar phytoplankton communities (Table 3). KB3, SME and HIN were dominated by diatoms, particularly the species *Fragilariopsis oceanica* and *Thalassiosira antarctica* var. *borealis*, which were abundant at all stations (Table 3). ISK had a bloom of the haptophyte *Phaeocystis pouchetii* occurring at the time of sampling, and was the only station that was not dominated by diatoms.

### **Meso and Microzooplankton**

KB3, SME and HIN had a similar abundance of meso- and microzooplankton, while ISK had a slightly higher biomass (Fig. 5). The most abundant organisms for HIN and SME were cirripedia nauplii, with abundances reaching 800 individuals per m<sup>3</sup> (Fig. 6). In ISK and KB3 copepod nauplii were the most abundant, reaching 580 individuals per m<sup>3</sup>. Cirripedia nauplii were still abundant at ISK and KB3, but concentrations were lower. Very few copepod nauplii were found at SME or HIN. Larval stages of krill, decapods, and polychaetes were found in low abundances at all stations. KB3 had a high abundance of eggs, which were not identified further. Small unidentified copepods were also fairly common at all stations.

Species diversity was higher for meso and microzooplankton than for macrozooplankton. The compositions throughout all the stations were relatively similar (Fig. 6). All stations were dominated by *Calanus* spp. and the copepod *Oithona similis*. There was a lack of *Metridia longa* at HIN, which was relatively common at the other stations. KB3 was the only station with no *Calanus hypoboreus* present.

### **Calanus spp. distribution**

*Calanus* species were common at all sampling stations. Throughout the stations the majority of *Calanus* were found in the upper 50 m, particularly at KB3 and ISK (Figure 7). At HIN, the *Calanus* were more dispersed throughout the depths. At ISK and HIN *C. glacialis* was found at a higher abundance than *C. finmarchicus*, opposite of what was found at KB3 and SME. Throughout all stations, *C. finmarchicus* was primarily adult females, with the exception of ISK where there was a high number of CIV individuals (Figure 8). *C. glacialis* was more commonly found in the CIV stage in all locations. KB3 had an exceptionally large amount of CI individuals.

### **Macrozooplankton**

HIN had large numbers of ctenophores and euphausiids compared to the other stations (Figure 9). All stations had large numbers of chaetognaths (*Parasagitta elegans* and *Eukrohnia hamata*), and in particular ISK had a high abundance of organisms that was primarily chaetognaths. *Parasagitta elegans* was the most common chaetognath species at ISK and HIN, whereas *Eukronia hamata* was more common at KB3 and SME. ISK also had a higher abundance of the pteropod *Limacina helicina* than the other stations, and pteropods were notably absent at HIN. Additionally, KB3 had the largest abundance of the euphausiid (krill), *Thysanoessa longicuadata*, which was fairly uncommon in the other stations. HIN was dominated by *Thysanoessa inermis*, which was present in all locations but at much lower abundances. ISK, KB3 and SME all had similar compositions of taxonomic groups, but the composition at HIN was unique to that area.

### **Overall plankton community**

A summary of the most common plankton species is presented in Table 4. While many of the same phytoplankton species were present at all stations, there was a bloom of *Phaeocystis pouchettii* occurring at ISK. ISK, KB3 and SME had similar zooplankton communities and were mainly different in terms of the abundances of the two main *Calanus* species. HIN differed from the other stations primarily by the macrozooplankton communities.

## **Discussion**

We observed clear distinctions in the water mass properties in the fjords sampled, ranging from primarily AtW (KB3) to primarily ArW (HIN), and varying plankton communities that appeared to be associated with the water masses. The four stations likely represented different stages of the spring bloom, as seen from the varying concentrations of phytoplankton and different abundances of certain zooplankton species. Despite this, there were still some clear differences in the fjord communities that relate to the varying water mass properties, and several key indicator species of Arctic and Atlantic communities became clear. When compared to past community studies in the same area, there are some indications of an increase of certain Atlantic krill species within the last decade.

### **Water Masses**

ISK, KB3 and SME all had influence from the WSC at the time of sampling, as seen by the presence of TAW in all areas (Table 2). The presence of local water at depth at ISK and SME is likely the result of winter cooled water sinking (Cottier et al. 2005, Nilsen et al. 2008). KB3, the only station with distinct stratification, appeared to have had a large local influence from glacier and snow melt, leading to the cooler, lower salinity surface layer (Fig. 2) (Nilsen et al. 2008). HIN was the only station with purely Arctic water, meaning that it has little to no influence from the WSC.

## Spring Bloom and Phytoplankton

The stations were all at different stages in the spring bloom, as is typical for Svalbard fjords in May (Hegseth and Tverberg 2013, Alou-Font et al. 2016). ISK and KB3 both had relatively high Chl *a* abundance compared to the other stations, indicating that there was a large amount of phytoplankton. ISK and KB3 also had shallower euphotic zones than SME and HIN, which may be an indicator of an abundance of phytoplankton cells blocking the light, though at KB3 this could also be due to sedimentation from the terrestrial runoff.

ISK had a high concentration of the phytoplankton species, *Phaeocystis pouchetii*, a late stage bloom species, and though there was a relatively high amount of Chl *a*, about half of the Chl *a* appeared to be from smaller cells, indicating a later stage in the bloom (Fig. 3) (Hodal et al. 2012). In addition, the *Calanus* spp. were almost entirely in the upper 50 m of the water column; there was a large presence of CII stage *Calanus*, and a large number of copepod nauplii, which are all indicators of a later stage of the bloom (Falk-Petersen et al. 2009, Søreide et al. 2010, Stübner et al. 2016). Due to all these factors, it appears that at the time of sampling ISK had passed the peak of phytoplankton abundance.

In contrast, KB3 appeared to be at or near peak bloom conditions. There was a high abundance of large cells, and the phytoplankton were primarily diatoms, indicating a peak in the bloom (Hasle and Heimdal 1998, Hodal et al. 2012). Interestingly, there was also a large number of CI *Calanus* spp., which generally would indicate a later stage in the bloom (Falk-Petersen et al. 2009, Søreide et al. 2010). There was a

phytoplankton peak observed at the end of April at KB3, and it is possible that there was a second peak due to mixing from late season storms (J. Søreide, pers. comm.).

At SME, it appears that there were patches representing bloom conditions: chl *a* and phytoplankton content were low in sampled water, but plankton nets taken near the same area were clogged with algae, primarily diatoms (pers. obs.). Several species of phytoplankton had resting spores, suggestive of the initial stages of a bloom, contrary to the low phytoplankton abundance. There were still *Calanus* spp. found at depths, and there were low abundances of CI *Calanus* spp., so it appears that a peak bloom had not yet been reached (Søreide et al. 2010). HIN had a low abundance of phytoplankton and was the only station where no resting spores were found. In addition, *Calanus* spp. were spread throughout the water column, indicating an early stage of the bloom (Søreide et al. 2010).

### **Zooplankton Communities**

ISK, KB3 and SME had similar species composition, with large amounts of *Calanus* spp. and the cosmopolitan copepod *Oithona similis*. In addition, chaetognaths were particularly abundant, with two species, the Arctic species *Parasagitta elegans* and the Atlantic species *Eukrohnia hamata*, present (Blachowiak-Samolyk 2008, Blachowiak-Samolyk et al. 2008, Gluchowska et al. 2016). While at KB3 and SME *E. hamata* was the dominant chaetognath, at ISK *P. elegans* was far more abundant, which could be an indicator of more Arctic influence. Additionally, at ISK *C. glacialis* was more abundant than *C. finmarchicus*, another indication of the presence of Arctic species. ISK is generally considered to be an Atlantic fjord, so it is particularly interesting that a mix of Arctic and Atlantic species was found there. There are two

likely possibilities for the mix of Arctic and Atlantic species found at ISK; either the local influences (glacial runoff) lead to lower salinity, colder water, or ISK is influenced by the Sørkapp current to a greater extent than expected. While the Sørkapp Current is known to influence more southern fjords, it has not been seen to have a large influence at ISK (Nilsen et al. 2008). ISK had similar temperature and salinity to SME and KB3 during sampling, but it is possible that there were Arctic influences at different points in the year.

The communities at KB3 and SME were primarily composed of Atlantic species, which would be expected due to the large influence of AtW. KB3 also had the highest abundance of *Thysanoessa longicudata*, an Atlantic krill species, out of all the stations (Dalpadado et al. 2001, Dalpadado et al. 2016). Both of these had larger abundances of *C. finmarchicus* than *C. glacialis*, which corresponds well to previous studies in the areas (Blachowiak-Samolyk et al. 2008, Walkusz et al. 2009, Gluchowska et al. 2016). Though Atlantic species dominated in these areas, the communities observed also had a strong Arctic presence, as would be expected at such high latitudes.

HIN was the only station with Arctic water, and there was a distinct difference in the larger size classes of zooplankton. In particular, HIN had a much greater abundance of the krill species *Thysanoessa inermis* and the two ctenophore species, *Beroe cucumis* and *Mertensia ovum*, than the other stations, all three of which have been classified as Arctic species in past studies (Blachowiak-Samolyk et al. 2008, Gluchowska et al. 2016). Interestingly, HIN had few of the pteropod *Limacina helicina*, which was fairly common at all the other stations. *L. helicina* is common throughout Arctic areas, and previously has been found to be associated with ArW around Svalbard

(Gluchowska et al. 2016). It is possible that the low number seen at HIN are due to species interactions between some of the other Arctic species, but this was not tested within this study. Additionally, HIN had a higher abundance of *Calanus glacialis*, the arctic copepod species, than *C. finmarchicus*, an Atlantic species (Arnkværn et al. 2005). Interestingly, though there was a slightly higher abundance of *C. glacialis*, *C. finmarchicus* was still common and made up a large portion of the zooplankton biomass.

Many past studies attempting to identify Arctic and Atlantic populations around Svalbard have been conducted outside of the fjords (Dalpadado et al. 2001, Blachowiak-Samolyk et al. 2008, Dvoretzky and Dvoretzky 2013, Dalpadado et al. 2016). Though the species composition found in past studies is similar to the composition presented here, the present data shows a lower presence of Atlantic species compared to studies outside of fjords (Daase and Eiane 2007, Blachowiak-Samolyk et al. 2008). The larvacean *Fritillaria borealis* and the copepod *Oithona atlantica* are two Atlantic species that have been reported as good AtW indicators that are relatively common near Svalbard, but neither were found in any abundance in this study (Blachowiak-Samolyk et al. 2008). Similar low numbers of Boreo-Arctic (Atlantic) species have been found within Svalbard's fjords (Gluchowska et al. 2016). It is possible that due to local influences, such as glacial runoff, the fjords have more of an Arctic environment than oceanic areas.

Historically, there has been limited and sporadic sampling of marine communities around Svalbard, making it difficult to determine community changes over time (Blachowiak-Samolyk et al. 2008, Gluchowska et al. 2016). Despite this, some

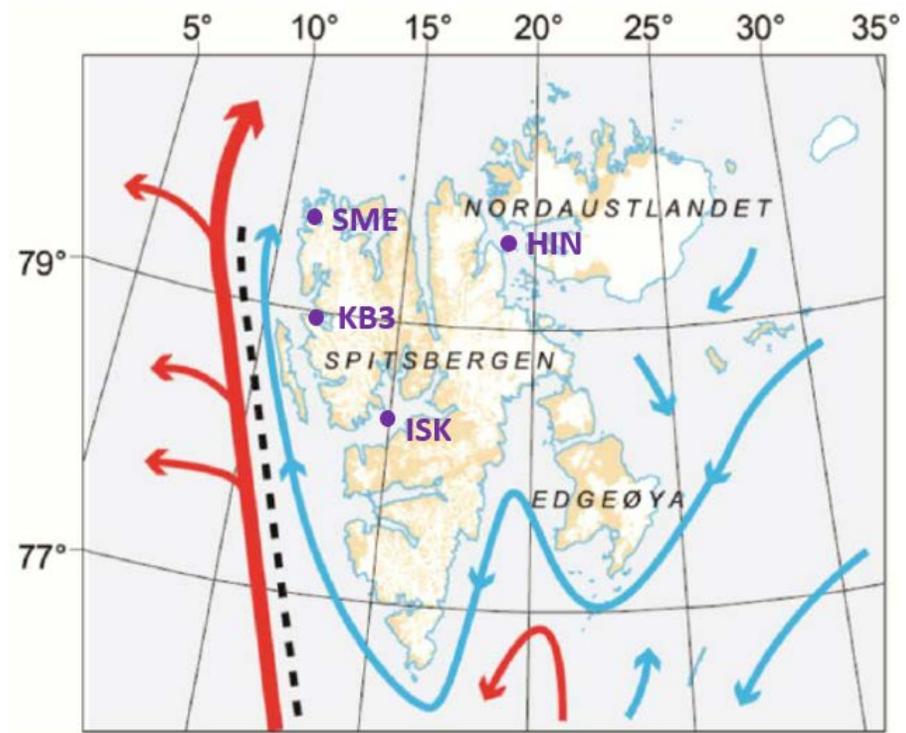
Atlantic zooplankton species have already been observed expanding their distributions northward and have an increased presence in Svalbard (Buchholz et al. 2010, Berge et al. 2015). Despite this, there is some indication found from this study that there may be more Atlantic species present in Svalbard fjords at times than previously reported. The presence of certain krill species has already been suggested to be an indicator of the northward movement of Atlantic species, namely the species *Thysanoessa longicuadata*, which was not previously found in Svalbard's waters (Węśławski et al. 2000, Buchholz et al. 2010, Buchholz et al. 2012). At KB3 there was a relatively high abundance of *T. longicuadata*, further indicating that KB3 may be increasingly influenced by Atlantic water. It is worth noting that there were few *T. longicuadata* at any of the other stations, once again indicating that the other stations have relatively less of an Atlantic influence. Compared to previous studies, besides the presence of an Atlantic krill species, there is little indication of any trend towards more Atlantic communities at any of the stations, though this is potentially due in part to limited sampling.

## **Conclusion**

From this study it is clear that plankton communities vary greatly between fjords in the Svalbard archipelago, and it seems likely that many of these differences are because of the presence of different water masses. As expected, the fjords on the west coast of Spitsbergen had Atlantic influence to varying extents, and at all stations some Atlantic species were found. HIN was the only station with ArW, which was reflected in the different species composition found. Several key species were particularly useful in identifying different communities. The *Calanus* spp. did not

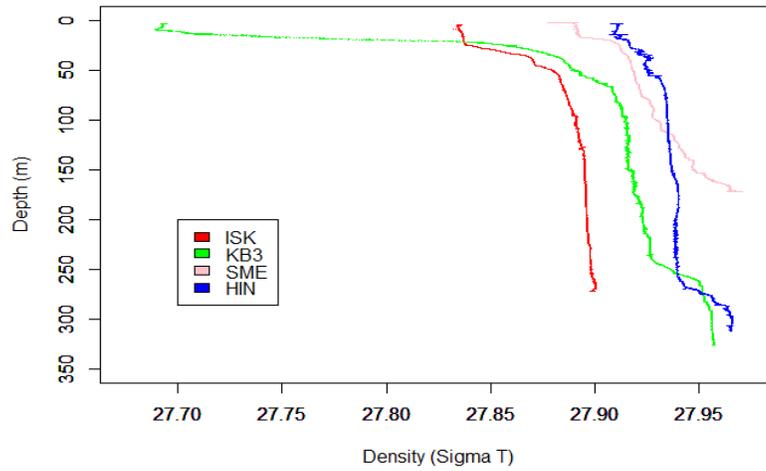
vary as much as expected between stations, indicating that within the temperatures sampled *C. finmarchicus* and *C. glacialis* are equally well adapted. Krill species showed much more variation, with *Thysanoessa inermis* dominating in ArW and *T. longicuadata* only being abundant in the most Atlantic station. Additionally, the two Arctic ctenophore species, *Beroe cucumis* and *Mertensia ovum*, were particularly abundant at HIN and rare in the Atlantic-influenced stations. The species found at KB3 confirm other observations of the presence of Atlantic species new to the area, but due to limited spring samples taken anywhere in Svalbard no further conclusions can be drawn. Regular sampling of these areas is necessary to truly understand to what extent a changing climate is influencing Arctic areas, both for physical and biological parameters, and to quantify if a shift to more Atlantic communities is occurring.

## Figures

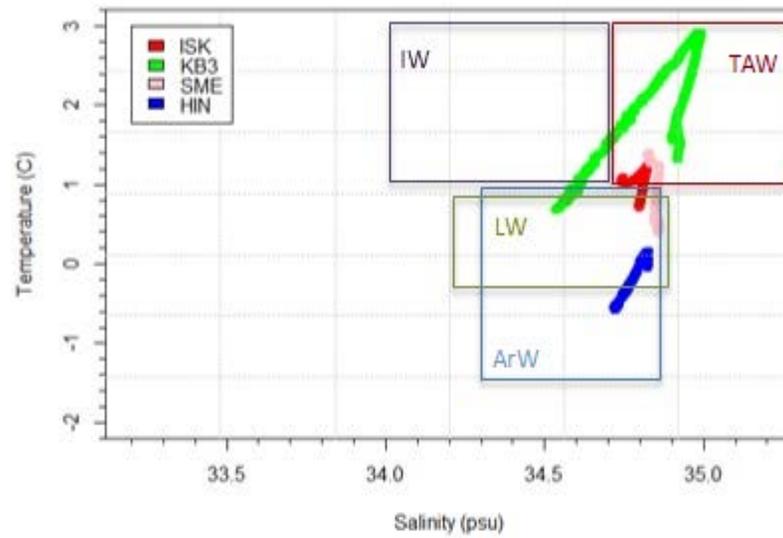


**Figure 1:** Map over Svalbard archipelago, showing Atlantic water in The West Spitsbergen Current (red arrows), and Arctic water forming an Arctic coastal current (blue arrows) Dotted line indicated mixing between the two currents. ISK = Isfjorden. KB3 = Kongsfjorden. SME = Smeerenburgfjorden. HIN = Hinlopen. (Svendsen et al. 2002b)

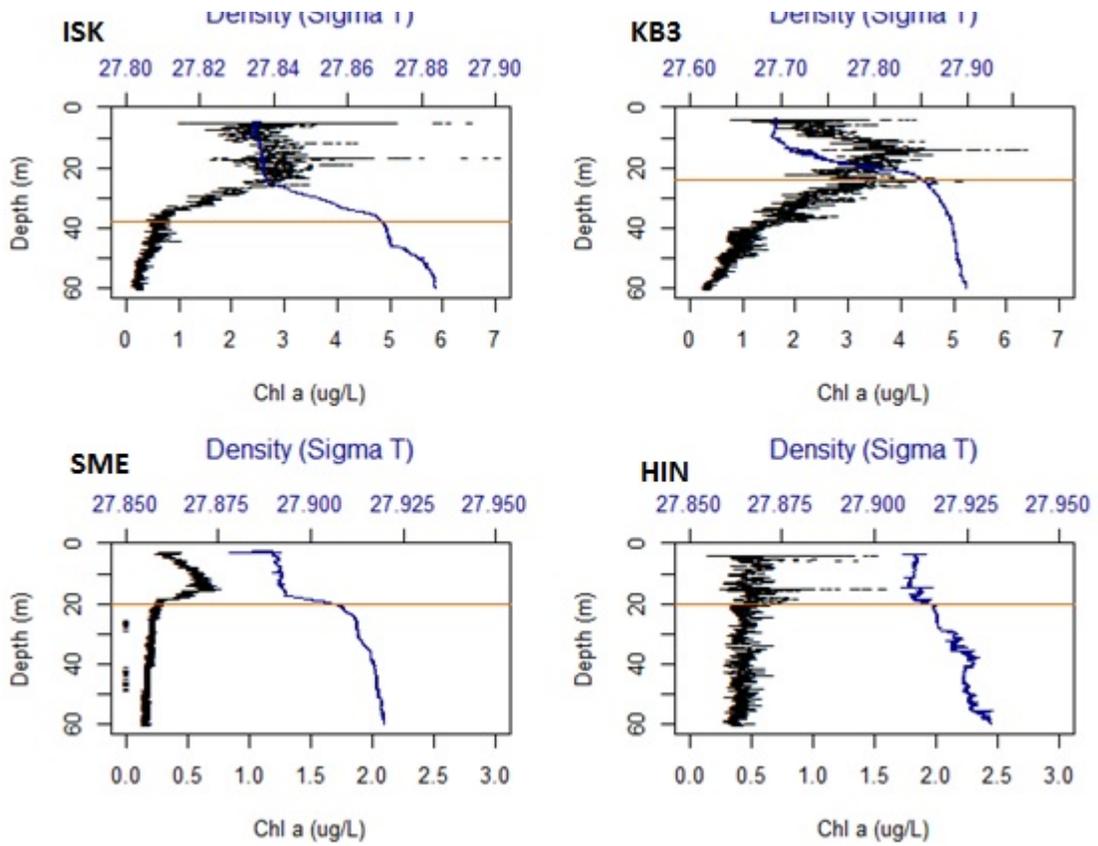
(A)



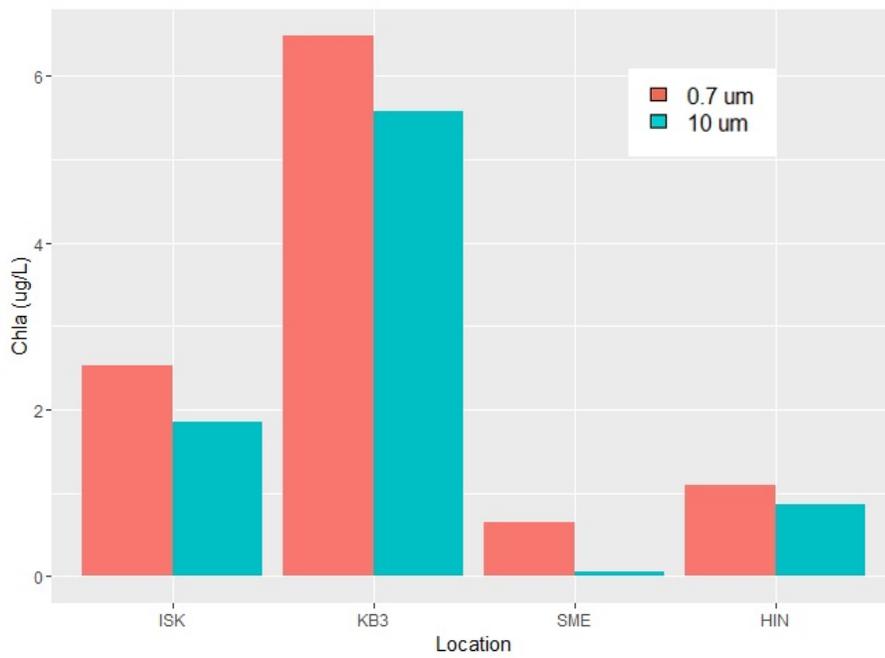
(B)



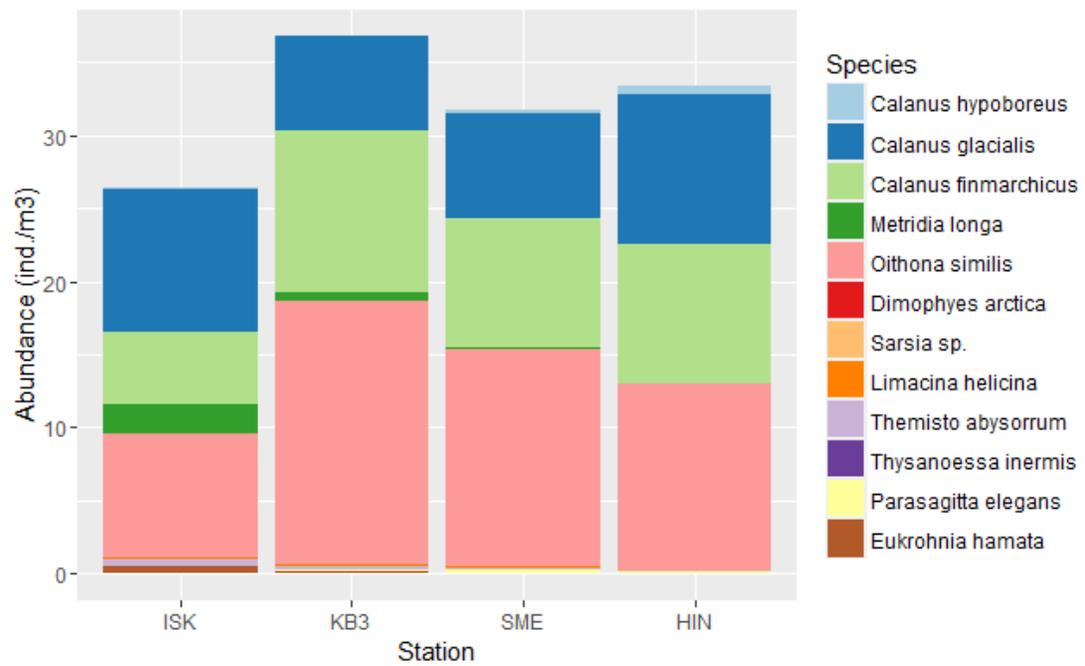
**Figure 2:** (A) Density throughout water column and (B) T-S plot indicating water masses. ArW -1.5 to 1.0 °C, 34.3 to 34.8 psu. Local water (LW) -0.5 to 1.0 °C, 34.2 to 34.85 psu. Intermediate water (IW) >1.0 °C, 34.00 to 34.65 psu. Transformed Atlantic water (TAW) 1.0 to 3.0 °C, >34.65 psu.



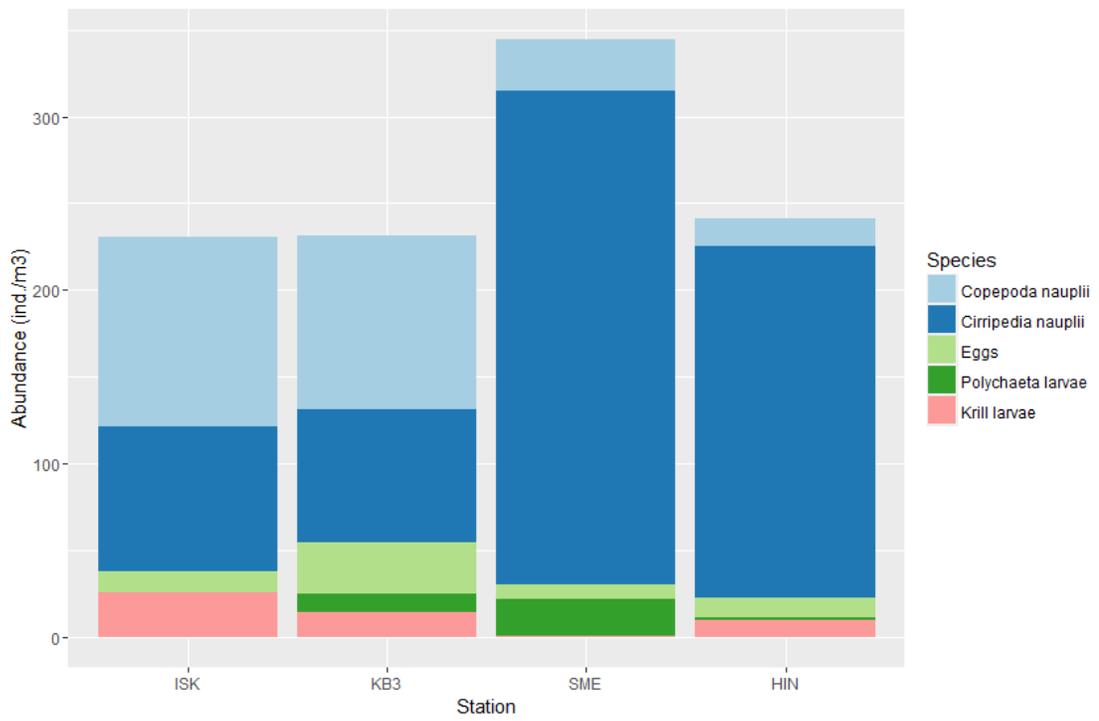
**Figure 3:** Chl a and density in the upper 60 m of the water column. The orange line indicates the lower end of the euphotic zone.



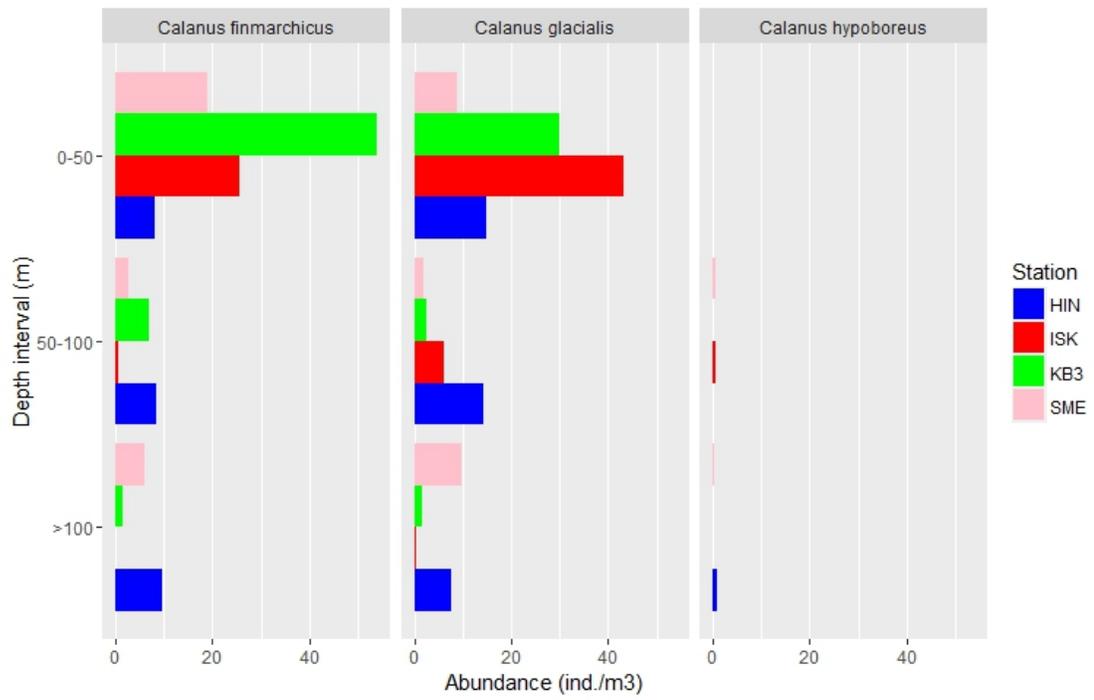
**Figure 4:** Chl a concentration (µg/L) at chl a maximum for two different cell sizes: >0.7 µm and >10 µm



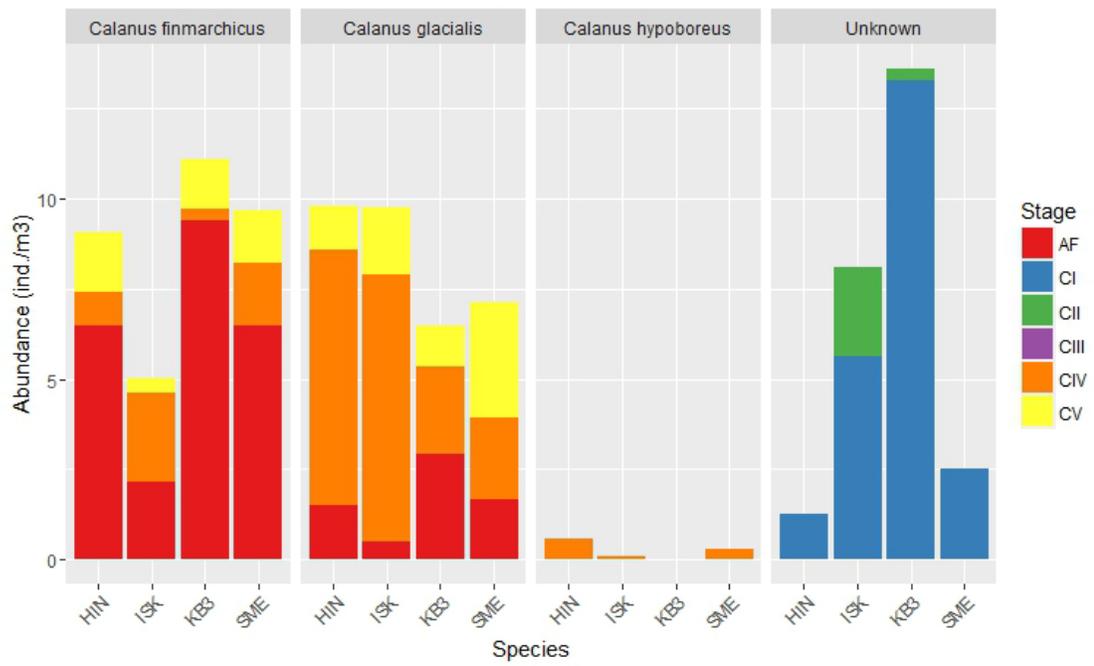
**Figure 5.** Abundance of most common species from Multinet (200 µm), excluding larval stages



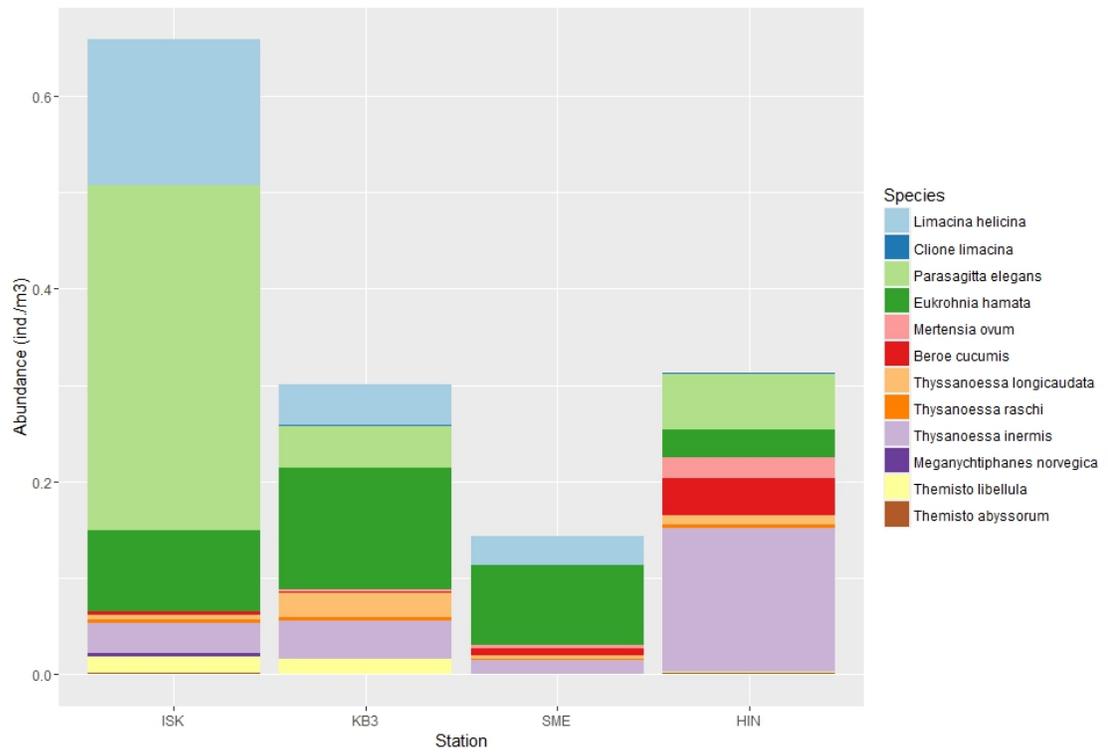
**Figure 6.** Abundance of larval stages and eggs from Multinet (200 μm)



**Figure 7:** *Calanus* spp. abundance through different sampling depths, including all identifiable CIV and CV stages as well as adults.



**Figure 8:** *Calanus* spp. abundance through entire water column at all stations.



**Figure 9:** Abundance of the most common species from the MIK net (1.55 mm).

## Tables

**Table 1.** Geographic and physical information on sampling stations

<b>Station</b>	<b>Date (UTC)</b>	<b>Time (UTC)</b>	<b>CTD Station number</b>	<b>Latitude (N)</b>	<b>Longitude (E)</b>	<b>Depth (m)</b>
ISK	15.05.2016	08:05:07	743	78° 18''91.2227'	015° 10''64.4063'	280
KB3	11.05.2016	07:10:54	689	78° 57''31.1532'	011° 57''64.1657'	341
SME	12.05.2016	07:09:55	703	79° 41''03.6843'	011° 09''64.7204'	180
HIN	13.05.2016	07:40:27	721	79° 36''36.9186'	019° 03''96.9158'	332

**Table 2.** Summary of the water masses at each sampling station as classified as per Cottier et al. 2005. ArW -1.5 to 1.0 °C, 34.3 to 34.8 psu. Local water (LW) -0.5 to 1.0 °C, 34.2 to 34.85 psu. Intermediate water (IW) >1.0 °C, 34.00 to 34.65 psu. Transformed Atlantic water (TAW) 1.0 to 3.0 °C, >34.65 psu.

<b>Station</b>	<b>Surface water</b>	<b>Stratification</b>	<b>Deeper water</b>	<b>Depth of chl a max.</b>
ISK	TAW down to ca. 120 m.	Halocline in the upper 25 - 50 m.	Local water	18 m.
KB3	Local and intermediate water	Both for temperature and salinity at the upper 15 - 20 m.	TAW	15 m.
SME	TAW down to 100 m.	Halocline at 20 m.	Local formed water with temperature below 1°C	15 m.
HIN	Arctic water down to ca. 270 m.	No clear stratifications in the upper part. A small stratification at 270 m.	Local water	15 m.

**Table 3:** Relative abundances of the most common phytoplankton species.

(P) = Present. (+) = common. (++) = abundant. (+++) = dominating. (\*) indicates that resting spores were found:

Class	Species	ISK	KB3	SME	HIN
<b>Bacillariophyceae</b>	<i>Bacteriosira bathyomphala</i>	P	+	P	P
	<i>Chaetoceros socialis</i>	P*	++*	+	++
	<i>Cylindrotheca closterium</i>	P	P	P	P
	<i>Entomoneis kjellmanii</i>	P	P	P	P
	<i>Fragilariopsis cylindrus</i>	P	+	+	P
	<i>Fragilariopsis oceanica</i>	++*	++	++*	+++
	<i>Navicula spp.</i>	P	+	++	P
	<i>Thalassiosira antarctica var. borealis</i>	++*	++	++*	+++
	<i>Thalassiosira hyalina</i>	P	+*	+*	++
	<i>Thalassiosira nordenskiöldii</i>	+	P	P	+
	<i>Odontella aurita</i>	P	P		P
	<i>Porosira glacialis</i>	P	P		P
	<i>Pseudo-nitzschia seratia</i>	+	P		P
<b>Dinophyceae</b>	<i>Protoperdinium bipes</i>	P	p	+	P
<b>Dictyochophyceae</b>	<i>Dictyocha speculum</i>	P		P	P
<b>Coccolithophyceae</b>	<i>Phaeocystis pouchetii</i>	+++		P	P

**Table 4.** Dominating plankton species from each station.

Station	Phytoplankton	MIK Net (macrozooplankton)	Multinet (mesozooplankton)	<i>Calanus finmarchicus</i> (ind/m <sup>3</sup> )	<i>Calanus glacialis</i> (ind/m <sup>3</sup> )
ISK	<i>Fragilariopsis oceanica</i> <i>Phaeocystis pouchetii</i> <i>Thalassiosira antarctica</i> var. <i>borealis</i>	<i>Eukronia hamata</i> <i>Limacina helicina</i> <i>Parasagitta elegans</i>	<i>Calanus glacialis</i> <i>Calanus</i> CI copepodites <i>Oithona similis</i>	5.02	9.75
KB3	<i>Chaetoceros socialis</i> <i>Fragilariopsis oceanica</i> <i>Thalassiosira antarctica</i> var. <i>borealis</i>	<i>Eukronia hamata</i> <i>Limacina helicina</i> <i>Parasagitta elegans</i>	<i>Calanus finmarchicus</i> <i>Calanus</i> CI copepodites <i>Oithona similis</i>	11.1	6.47
SME	<i>Fragilariopsis oceanica</i> <i>Navicula</i> spp. <i>Thalassiosira antarctica</i> var. <i>borealis</i>	<i>Eukronia hamata</i> <i>Limacina helicina</i> <i>Thysanoessa inermis</i>	<i>Calanus finmarchicus</i> <i>Calanus glacialis</i> <i>Oithona similis</i>	8.86	7.15
HIN	<i>Chaetoceros socialis</i> <i>Fragilariopsis oceanica</i> <i>Thalassiosira antarctica</i> var. <i>borealis</i> <i>Thalassiosira hyalina</i>	<i>Beroe cucumis</i> <i>Parasagitta elegans</i> <i>Thysanoessa inermis</i>	<i>Calanus finmarchicus</i> <i>Calanus glacialis</i> <i>Oithona similis</i>	9.53	10.3

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