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AB-310  
**Marine zooplankton  
and sympagic fauna  
(=ice fauna) of  
Svalbard waters**

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Cruise reports





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## **Preface**

AB-310, Marine zooplankton and sympagic fauna (=ice fauna) of Svalbard waters, is a 9-credits course offered by the University Courses on Svalbard (UNIS). The course is intended for students at a M.Sc./ Ph.D. level and was given for the first time in 1998. The plan is to offer the course every second year. The overall objective of AB-310 is to acquaint the students with the marine invertebrates in pelagic and sympagic communities – faunal composition, faunal assemblages in different habitats and different relations. Training in practical skills such as, sampling methodology and identification of organisms, is also provided

An 11-day field cruise along the western and northern coasts of Svalbard, and the ice covered areas north of Svalbard with focus on the marine zooplankton and sympagic fauna, is an integral part of the course. The locations of the stations visited are selected in order to give the students an impression of the biodiversity found in these areas.

During the cruise the students were divided into four groups each responsible for carrying out and reporting on one of four assignments. The end result of each assignment is a report of which the final result is present in this volume.

Carrying out these tasks the students have been trained in designing a sampling programme, collecting the biological data and accompanying physical information. They have further been trained in working up the material and finally in report writing according scientific standards.

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# Distribution of the sympagic fauna at three different locations north of Svalbard

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## ABSTRACT

This project was a part of the AB 310 course “Marine zooplankton and sympagic fauna (= ice fauna) of Svalbard waters” at the University Courses on Svalbard (UNIS). The distribution of sympagic fauna, with main focus on the autochthonous amphipods *Gammarus wilkitzkii*, *Apherusa glacialis* and *Onisimus* spp., were investigated at three different locations in ice covered waters north of Svalbard in September 1998. The aim of the project was to determine the species diversity, the density (individuals/m<sup>2</sup>) and biomass (g/m<sup>2</sup>) at each locality as well as small-scale distribution along a transect at each locality. SCUBA divers using a hand-held dip net or a suction sampler carried out the sampling. All together, 7 taxa were found; The amphipods *A. glacialis*, *G. wilkitzkii*, *Onisimus* spp., *Gammaracanthus loricatus*, *Parathemisto libellula*, the copepod *Jaschnovia brevis* and a polychaet in the family *Polynoidae*. *A. glacialis* and *G. wilkitzkii* were the most numerous taxa at all stations. Generally *A. glacialis* was the most abundant taxon on the edge of the ice floe, while *G. wilkitzkii* dominated the habitats on the ice subsurface further in. In biomass, *G. wilkitzkii* is the all over dominating taxon at all localities. Between the three stations, the total biomass (the sum of *G. wilkitzkii*, *A. glacialis* and *Onisimus* spp.) ranged from 0.57 g/m<sup>2</sup> to 0.71 g/m<sup>2</sup>, whereas the total density ranged from 17 to 31 individuals/m<sup>2</sup>.

**Keywords:** sympagic (ice associated) fauna, small-scale distribution, large scale distribution, ice age, origin and history of the ice, species composition.

## INTRODUCTION

The Arctic Ocean is covered by ice in an area varying from 7 x 10<sup>6</sup> km<sup>2</sup> in the summer to 14 x 10<sup>6</sup> km<sup>2</sup> in the winter. The sea ice in the Arctic Ocean is in continuous motion, with main drift patterns across the Arctic ocean in the transpolar drift from the Siberian Coast towards the Fram Strait. Generally the drift of ice from the ice formation area along the Siberian Coast to the Fram Strait takes 3 to 5 years. The southward drift of ice through the Fram Strait into melting areas in the Greenland Sea, is the most important loss of sea ice in the Arctic. In the Canadian Basin, the sea ice can have a residence time of tens of years in the Beaufort Gyre (Maykut, 1985).

Associated with the sea ice in the Arctic, organisms represented by different taxonomic groups are found. These organisms are often called the sympagic biota, which means that they live in close association to the ice. The sympagic fauna is separated into allochthonous species which are considered as temporary occupants of the sea ice, and allochthonous species which have both sexes and all developmental stages in the ice (Gulliksen and Lønne, 1991a; Horner et al., 1992). Most of the sympagic taxa are allochthonous organisms, while few species are considered as autochthonous. The most conspicuous autochthonous taxa are amphipods, especially *Gammarus wilkitzkii*, *Apherusa glacialis*,

and two *Onisimus* species, *O. glacialis* and *O. nansenii* (Poltermann, 1998; Lønne and Gulliksen, 1991a,b; Melnikov, 1997). Polar cod (*Boreogadus saida*) is another common species living in close association with sea ice where it feeds on the other sympagic organisms (Lønne and Gulliksen, 1989; Bradstreet and Cross, 1982). The sympagic fauna in the Arctic is considered to play an important role both as trophic link between the sea ice and the water column, and between sea ice and organisms living partly on or above the upper surface of the ice (Bradstreet and Cross, 1982).

The composition of the sympagic fauna is determined by the age, structure and history of the ice as well as sea water temperature, salinity, currents and wave action (Horner et al., 1992). Earlier studies on the distribution of sympagic amphipods related to the age and structure of the ice show a large variation in species composition, density and biomass (Cross, 1982; Lønne and Gulliksen, 1989; Lønne and Gulliksen, 1991a,b; Poltermann, 1998). Biomass values from multiyear ice (MYI) were ten to hundred times higher than corresponding values from first year ice (FYI) (Lønne and Gulliksen, 1991a). First-year ice is defined as ice formed during the winter and not survived its first summer melt. After surviving the summer melt, the ice is classified as old ice, hereafter referred to as multiyear ice (Lønne and Gulliksen, 1991a). The overall mean of biomass from various studies in MYI ranges from 0.12 g/m<sup>2</sup> (Cross, 1982), 4.7 g/m<sup>2</sup> and 8.3 g/m<sup>2</sup> (Lønne and Gulliksen, 1991a) to 10.61 g/m<sup>2</sup> (Poltermann, 1998). Also on a smaller scale, the occurrence of sympagic amphipods varies (Poltermann, 1998). Due to higher light intensity and thus higher primary production at the ice floe edge in comparison to areas further in under the ice, a larger density and biomass is expected along the ice floe edge. In addition, the ice floe edge is a more dynamic and exposed habitat with wave actions and higher predation risk from seabirds and fish. All together this will influence the composition of amphipods and other sympagic fauna on a smaller scale distribution.

The object of the present study was to investigate the occurrence of sympagic fauna in terms of species composition, density and biomass in the perennial ice zone north of Svalbard. The occurrence of sympagic fauna was studied with respect to large-scale habitat characteristics such as age, origin of ice and hydrographical characteristics. The main focus of this study is on *G. wilkitzkii*, *A. glacialis* and *Onisimus* spp. *G. wilkitzkii* is considered as an omnivore species. It is believed to have a life span of about 6 years, with body length ranging from 5 to 45 mm with an adult mean dry weight of 12-50 mg (Gulliksen and Lønne, 1991; Sakshaug et al., 1992). *A. glacialis* is considered as a predominant herbivore (Werner, 1997; Scott et al., in press), with a lifespan of 1.5 years and an adult mean dry weight of 0.7 mg and length ranging from 3 to 17 mm (Sakshaug et al., 1992; Poltermann, 1998). *Onisimus* spp. is considered as omnivore/detrivore (Sakshaug et al., 1992; Scott et al., in press) with an adult mean length ranging from 10 to 23 mm, and an adult mean wet weight of 0.02-0.23 g (Poltermann, 1998).

According to previous studies higher biomass was expected to be found in areas dominated by MYI in comparison to FYI (Lønne and Gulliksen, 1991a). *A. glacialis* is known to have good swimming abilities, and might thereby colonise newly formed ice (Sakshaug et al., 1992). Thus a higher abundance of *A. glacialis* than *G. wilkitzkii* was expected to be found in FYI as compared to MYI. Due to succession, the taxa-diversity was expected to be higher in MYI in comparison to FYI. The occurrence of sympagic fauna was also investigated on a smaller scale beneath the ice floes. *A. glacialis* was expected to inhabit the areas of highest primary production (ice floe edge). As an species, *G. wilkitzkii* was expected to be found in the vicinity of its' prey (ice floe edge).

## **MATERIALS AND METHODS**

The samples were collected at three different locations in September 1998 during a two weeks cruise with the research vessel Jan Mayen. The cruise was financed by the University Courses on Svalbard and The Norwegian College of Fishery Science. Each of the ice stations was chosen after steaming into the ice as far north of Svalbard as possible (between 80° and 81° 30' north). The ice stations were located at about 0°, 15° and 30° east (Table 1).

Table 1. Date, station number and position of the three ice stations.

	<b>Date (1998)</b>	<b>Station number</b>	<b>Position</b>
<b>Ice station I</b>	14-15 September	902	N 81° 30', E 29° 12'
<b>Ice station II</b>	17-18 September	936	N 80° 42', E 15° 02'
<b>Ice station III</b>	20-21 September	963	N 80° 08', E 00° 18'

### **Quantitative material**

The material for the quantitative study was collected by SCUBA divers using an electric suction pump (Lønne, 1988). As many different localities as possible were investigated at each sampling station, in order to achieve representative data. The SCUBA divers collected organisms along a transect from the ice edge to ten meters in under the ice. The transect was divided into four zones; along the edge and around one, four and ten meters in under the ice floe. In each sample within the transect, organisms were collected in an area of three frames. The frame measured 0.5 x 0.5 m<sup>2</sup> each. The frame was placed under the ice haphazardly.

The animals in each sample (box from suction pump) were transferred into labelled bottles in the laboratory. The different species were separated and the numbers of individuals were counted. The samples were stored in 4% formaldehyde for further examination after the cruise. At the laboratory, the weights of each species of each sample were determined by using a Mettler AE 200, with 0,0001 g precision.

### **Qualitative material**

The material for the qualitative study was collected by SCUBA divers using hand-held dip nets (mesh size 180 µm) with a rectangular frame (Gulliksen, 1984). The samples were taken in as many different habitats as possible.

The material was separated into the different species and the numbers of individuals were counted. The samples were handled in three different ways. Some of the samples were stored in 4% formaldehyde, some of them were frozen in plastic bags, and the remaining samples were weighed in fresh condition on the ship. The weights of the frozen samples and the samples stored in formaldehyde were determined by using a Mettler AE 200 weight at the laboratory (0.0001 g precision). Due to disturbance aboard the research vessel, the precision of the samples weighed in fresh condition was only 0.1 g. The biomass was determined without any calibration for formaldehyde wet weight, frozen wet weight or fresh wet weight.

### **Description of the ice**

In order to describe the ice, the thickness was measured. The categories were classified as MYI or FYI. The size of the ice floe, melting condition, mixture and the presumed history of different icefloes was also taken into consideration. By the use of video camera and divers observations, the structure of the margin and the subsurface structure were described according to Poltermann (1998).

### **Hydrography**

At each location a CTD (Conductivity-Temperature-Density)-instrument was used to obtain some of the physical parameters (Appendix 2).

### **Statistical analysis**

The statistical analyses were carried out in Statistica 4.5 for Windows.

Due to a low sample size at each of the distances from the ice floe edge, non-parametric tests were used to analyse the data along the transects (Fowler & Cohen, 1992). At each

station, medians of the density and biomass within the transect were tested using a Kruskal-Wallis test. For the transect data showing statistically significant variation (the significance level was set to  $p < 0.05$ ) median differences between each of the distances were tested using a Mann-Whitney *U*-test.

The mean density data between the stations was analysed (both total density and species related) using ANOVA (Fowler & Cohen, 1992; Ims & Yoccoz, 1998). Since there were differences in the number of samples from each distances along the transect, this difference was adjusted within each stations to obtain similar weight of the distances along the transect. Prior to the analysis the data were transformed ( $\log(\text{density}+1)$ ) to obtain normality and homogeneity of the variance prior to the analysis. Data series with statistically significant main effects (the significance level was set to  $p < 0.05$ ) were further analysed by Least Significant Difference-test (Students' *t*-test between the means of each of the stations).

Due to a lack of normality and homogeneity of the variance after transformation of the data, the median biomass data between the ice stations were tested by the same analysis as the data along the transect.

## RESULTS

The material was collected at three ice stations with different geographical localities, ice composition and water properties (Table 2).

Table 2. Collected material at the three ice stations with respect to species found, total numbers of each species in quantitative (Quant.) and qualitative (Qual.) samples, sea water salinity (S) and temperature at surface in °C (T), age of the ice (multi-year ice = MYI, first year ice = FYI).

Station	Species	Quant.	Qual.	S	T (°C)	Ice age
I	<i>Gammarus wilkitzkii</i>	601	1763	30.8	-1.3	20% MYI
	<i>Apherusa glacialis</i>	471	1234			80% FYI
	<i>Onisimus</i> sp.	15	18			
	<i>Jaschnovia brevis</i>	6	43			
II	<i>Gammarus wilkitzkii</i>	544	1474	31.5	-0.5	70% MYI
	<i>Apherusa glacialis</i>	357	749			30% FYI
	<i>Onisimus</i> spp.	2	29			
	<i>Jaschnovia brevis</i>	0	68			
	<i>Parathemisto libellula</i>	0	3			
III	<i>Gammarus wilkitzkii</i>	255	784	31.2	-1.8	100% MYI
	<i>Apherusa glacialis</i>	285	333			
	<i>Onisimus</i> sp.	50	225			
	<i>Jaschnovia brevis</i>	155	271			
	<i>Gammaracanthus</i> <i>loricatus</i>	0	8			
	<i>Polynoidae</i> indet.	13	14			

### Description of the ice

Ice station I was dominated by FYI with elements of young MYI (2-3 years old). The ice floe diameter was on a kilometre scale. The floes had earlier been exposed to a long melting period, followed by freezing, resulting in patches of MYI connected to each other by FYI. The study site consisted of about fifty per cent FYI and fifty per cent MYI. The FYI was about one meter thick and the MYI was two to three meters thick. The MYI subsurface was smooth and compact due to earlier melting, followed by a freezing period. The ice edge was characterised by holes and depressions. Further into the MYI the subsurface structure was round with bumps, together with small and large brine channels. In contrast the FYI was rough and flat further into the ice, but resembled the MYI structures along the edge.

Ice station II was dominated by young MYI with elements of FYI, which was built up between narrow leads in the MYI. The study site consisted of MYI only. The ice floe diameter was on a kilometre scale and the ice thickness of about 2.5 metres. During the time of investigation the ice subsurface was melting. At exposed areas the subsurface of the ice was polished and hard while a porous subsurface was found at areas that were not very exposed. The floe edge was irregular with holes and depressions. Further into the ice the subsurface were characterised by bumps and a patchy distribution of wide and narrow brine channels.

At ice station III mainly four to five years old MYI with a thickness of about five metres was found. The ice also consisted of younger MYI of about two to three years old and two metres thick. The ice floe diameter was on a hundred-metre scale. The study site was characterised by small thick ice floes intermixed with thinner ice floes. The ice floes covered approximately fifty to sixty per cent of the water masses. Ice station III was situated in a peninsula of sea ice and not into the straight marginal ice zone. This may result in heavy movements of the ice and probably explains the mixture of different MYI and the small size of the floes. This may also explain the high degree of ridges and straight vertical ice edges. These straight vertical ice edges of the thick ice floes indicated that they have recently been broken and that there has not been any melting of importance. The ice subsurface showed a great variation in the structure. There were coarse surfaces, bumps, smooth and flat surfaces and often very wide brine channels (up to 0.5 m diameter) as a result from earlier melting periods.

### **Physical properties**

When studying the different CTD plots (Appendix 2) one can see that the stations differ in the shape of their salinity and temperature curves. The main water masses in the northern Barents Sea are surface waters, Arctic water, transformed Atlantic water and cold bottom water (Pfirman, 1994). The CTD-data showed that station I and II were influenced mainly of Atlantic water and ice station III mainly of Polar water. In addition, each station had a thin upper layer of melt water. According to the CTD-data ice stations I and II look more similar compared with ice station III.

#### **Ice station I**

The salinity of the upper surface layer was 30.8 and the temperature was  $-1.3^{\circ}\text{C}$ . The thermocline and halocline showed the same sharp pattern from the surface down to twenty meters depth. This pattern is probably due to a thin layer of melt water in the upper surface and Atlantic water in the deeper water mass.

#### **Ice station II**

The salinity of the upper surface layer was 31.5 and the temperature was  $-0.5^{\circ}\text{C}$ . Both the thermo- and halocline showed some irregularities, but they were generally sharp and reached a depth of approximately fifty meters. The irregularities were probably caused by the melt water. In general the pattern is due to a thin layer of melt water at the surface and warm Atlantic water below.

#### **Ice station III**

The salinity of the upper surface layer was 31.2 and the temperature was  $-1.8^{\circ}\text{C}$ . The thermocline reached very deep (approximately 200 m), while the halocline shows a large increase in salinity down to twenty-five meters and after that the salinity only gradually increase with increasing depth. The different pattern between the thermo- and halocline can be due to the upper surface layer containing melt water with low salinity causing a quick increase in salinity down to twenty-five meters depth. The melt water may have the same temperature as the deeper polar water, thus there are no changes in temperature down until two hundred meters.

## Occurrence of sympagic fauna

### Taxa composition and method comparison

All together, 7 taxa were found; the amphipods *A. glacialis*, *G. wilkitzkii*, *Onisimus* spp., *Gammaracanthus loricatus*, *Parathemisto libellula*, the copepod *Jaschnovia brevis* and a polychaet in the family Polynoidae. The highest taxa diversity was found at station III (Table 2). At station III, the frequency of *A. glacialis*, *G. wilkitzkii* and *Onisimus* spp. indicates a more even distribution between the taxa than at the other stations, whereas in taxa frequency based on weight this feature is not displayed (Fig. 1).

In order to compare different sampling methods, the frequencies of *A. glacialis*, *G. wilkitzkii* and *Onisimus* spp. in the qualitative and the quantitative samples at the three stations are presented (Fig. 1). Generally, the frequency data from net samples and suction pump samples were without considerable differences. *Onisimus* spp. was more abundant in the qualitative samples at station II and III than in the quantitative samples. *A. glacialis* tends to be more abundant in the quantitative samples at station III when compared to the qualitative samples. In general, *G. wilkitzkii* dominates the taxa frequency based on weight with more than 80% at all stations in both qualitative and quantitative samples.

### Distribution of amphipods along the transects

Each sample contained individuals collected from an area of 0.75 m<sup>2</sup>. At each ice station, 50 to 60 samples were taken, varying from 10 to 18 samples at each of the distances along the transect. The total area from which animals were collected was 37.5-45 m<sup>2</sup> at each station. Even if a large area was investigated the samples were all from one ice floe at each station.

#### *Apherusa glacialis*:

For all the ice stations the density of *A. glacialis* varied significantly along the transect (Kruskal-Wallis,  $p < 0.05$ , Appendix 3). Generally, the density of *A. glacialis* at all stations was significantly higher at the ice floe edges when compared to each of the distances further in under the ice (Fig. 2). The only exception was found at station II, at which the density of *A. glacialis* was significantly higher at the edge as compared to the density at 4 and 10 m distance under the floe. Further, the density of *A. glacialis* at 1 m distance was significantly higher than at 10 m distance from the edge, but there was no difference between the density at 1 m when compared to the edge and 4 m. Comparing the total density values on the edge, the highest density was found on station I with 33 ind/m<sup>2</sup>, followed by station III (25 ind/m<sup>2</sup>) and station II (15 ind./m<sup>2</sup>). The values at 1 m, 4 m and 10 m were not exceeding 10 ind/m<sup>2</sup>, with lowest values ranging from 1-3 ind./m<sup>2</sup> at 4m and 10m distance both at station II and III. Together this suggests a decrease in density for *A. glacialis* from the ice floe edge and further in under the ice floe.

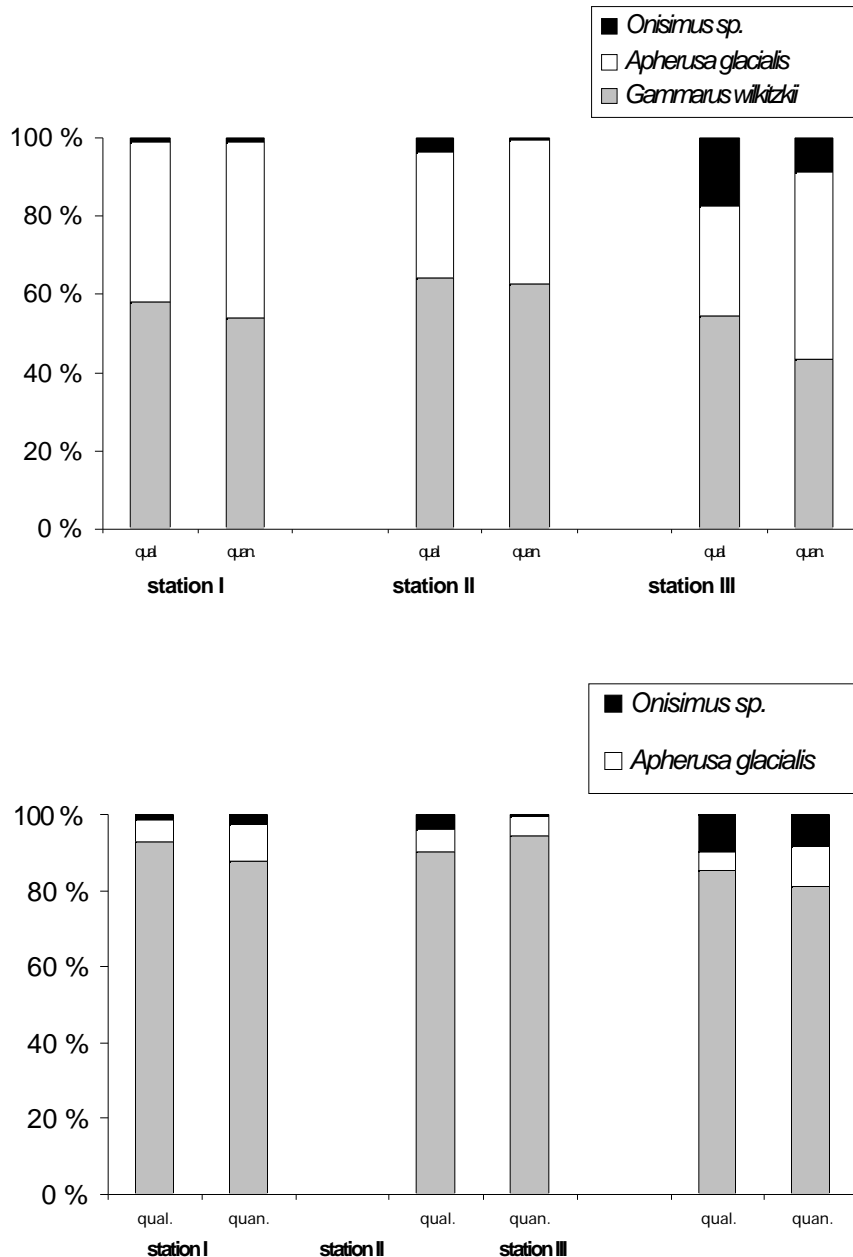


Figure 1. Frequency of taxa in density and biomass from qualitative and quantitative samples at each station. Upper panel a); Frequency of taxa based on numbers of individuals. Lower panel b); Frequency of taxa based on weight.

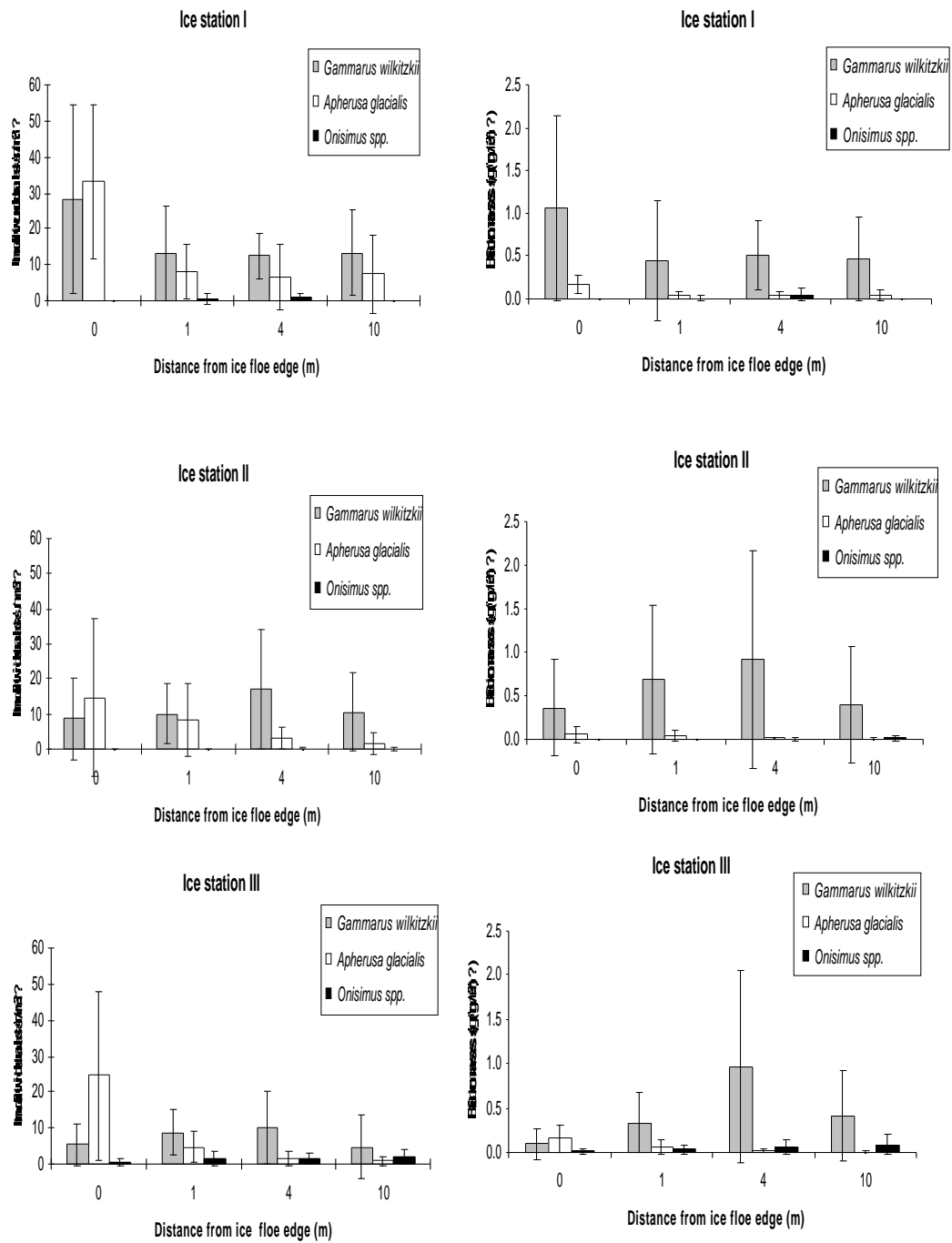
For station I and III, there was a significant variation in the biomass of *A. glacialis* along the transect (Kruskal-Wallis,  $p < 0.05$ ). At station I, the biomass of *A. glacialis* at the ice edge ( $0.16 \text{ g/m}^2$ ) was significantly higher than the biomass at 1 m, 4 m and 10 m distance from the edge, (Mann-Whitney,  $U$ -test,  $p < 0.05$ ). In biomass, there was no difference recorded between the distances further under the ice (1 m, 4 m and 10 m), all values were not exceeding  $0.05 \text{ g/m}^2$ . At station II, there was no significantly difference in the biomass of *A. glacialis* along the transect. However, it seems to be a trend of decreasing biomass of *A. glacialis* when comparing the values from the ice edge ( $0.05 \text{ g/m}^2$ ) along the transect to 10 m distance ( $0.01 \text{ g/m}^2$ ) (Fig. 2). At station III, the significant variation within the transect showed a trend of decreasing biomass from the floe edge ( $0.158 \text{ g/m}^2$ ) and further in under the ice ( $0.003 \text{ g/m}^2$ ). As the density data, the biomass in general show a decreasing trend going from the edge of the ice floe and in under the ice along the transect.

*Gammarus wilkitzkii*:

In general, *G. wilkitzkii* did not show any clear trend in density and biomass variation along the transect like *A. glacialis* (Fig. 2). However, the density at stations II varied significantly due to the higher density at 4 m (17 ind/m<sup>2</sup>) compared to the ice edge (9 ind/m<sup>2</sup>) (p<0.05, Appendix 3). Highest densities were measured on station I, were 28 individuals per m<sup>2</sup> were recorded on the edge. Further into the transect, lower values of 12 and 13 individuals/m<sup>2</sup> at each of the different distances were found. On station III, lowest density values were

a) Mean density (individuals/m<sup>2</sup>)

b) Mean biomass (g/m<sup>2</sup>)



**Figure 2.** a) Mean densities (individuals/m<sup>2</sup>) and b) mean biomass (g/m<sup>2</sup>) of the amphipods along the transects at each station. Error bars reflect the respective standard deviation of the samples from the mean values.

recorded, varying between 5 (at 10 m distance and on the edge) and 10 ind/m<sup>2</sup> (at 4 m distance from the edge).

In general, the biomass did not show significant variations within the transects. The only exception is station III, where significantly higher biomass was found at 4 m (0.96 g/m<sup>2</sup>) compared to the biomass at the floe edge (0.10 g/m<sup>2</sup>) and at 1 m distance (0.33 g/m<sup>2</sup>). Highest values on station I was recorded on the edge (1.05 g/m<sup>2</sup>), decreasing to approx. 0.5 g/m<sup>2</sup> at all different distances. All together *G. wilkitzkii* seems to be more evenly distributed than *A. glacialis*.

*Onisimus* spp.:

Due to few observations of *Onisimus* spp., statistical analysis on the distribution of this taxa along the transects were not carried out. However, at station III a higher density and biomass of *Onisimus* spp. was found in comparison to stations I and II (Fig. 2). At station III the biomass trend indicates an increase from the edge (0.01 g/m<sup>2</sup>) towards 10 m distance (0.09 g/m<sup>2</sup>), thus exceeding the corresponding biomass of *A. glacialis*. At station I, *Onisimus* spp. was found only at 1 and 4 m distance from the edge.

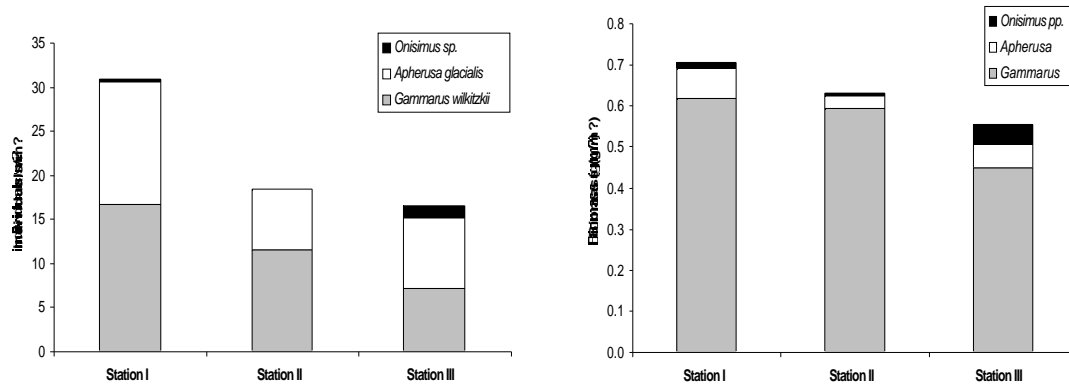
**Biological comparison between stations**

The total (*G. wilkitzkii* + *A. glacialis* + *Onisimus* spp.) mean densities ranged from 17 individuals/m<sup>2</sup> at ice station III to 31 individuals/m<sup>2</sup> at ice station I. The total (*G. wilkitzkii* + *A. glacialis* + *Onisimus* sp.) mean biomass ranged from 0.5656 g/m<sup>2</sup> at station III to 0.7059 g/m<sup>2</sup> at station I (Fig. 3).

A comparison of the mean density between the stations showed a significant difference with respect to both *G. wilkitzkii* and *A. glacialis* (ANOVA, p<0.05). The density of both *A. glacialis* and *G. wilkitzkii* at ice station I was significantly higher than at station II and III (p<0.05). For *G. wilkitzkii*, the density was also significantly higher at station II than III, whereas these stations did not show any significant difference for *A. glacialis*.

Within each station, the scarce material of *Onisimus* spp. did not allow statistical analysis. However, at station III *Onisimus* spp. was more numerous than at ice station I and II.

A comparison of the biomass between the stations showed no significant differences (p<0.05) with respect to *G. wilkitzkii*. For *A. glacialis*, a significant difference in the biomass between the three ice stations was found (p<0.05). When comparing each of the stations, there was only a significantly higher biomass of *A. glacialis* at ice station I compared to ice station II and III. There were no significant differences in the total biomass (*G. wilkitzkii* + *A. glacialis* + *Onisimus* spp.) of the three stations.



**Figure 3. a)** Mean density (individuals/m<sup>2</sup>) and **b)** biomass (g/m<sup>2</sup>) of *G. wilkitzkii* + *A. glacialis* + *Onisimus* spp. at each station.

## DISCUSSION

### Sampling methods

Two different methods were used while collecting the animals, a hand-held dip net (Gulliksen, 1984) and an electric suction sampler (Lønne, 1988). Since the suction sampler can be used to collect the animals within a well-defined sampling area of a frame, this method was chosen for the quantitative sampling. The hand-held dip net was used for qualitative sampling. By using both methods we increased the chances of finding as many species as possible. It also made it possible to compare the two methods with respect to species composition and the distribution of biomass between the species.

Collecting animals by SCUBA diving is demanding and the sampling areas are more or less chosen by the diver, which make the assumption of random sampling questionable. We therefore call it haphazard sampling. However, the samples were taken at different areas along a transect, which forced the diver to take the samples in a more random way. It is suggested that the distribution of samples along the transect contributes to give more representative data of the assemblage structure. However, a source of errors is the considerable amount of exhaled air from the divers regulator, which disturbs the organisms in the sampling area. The values obtained in the present report of biomass and abundance should not be considered as *in situ* reality. However the values are valuable in comparing different habitats. With respect to the ratio between the area of the ice edge and the area of the sub surface, samples were taken in a relatively higher proportion at the ice edge compared to the rest of the transect. The area of the ice edge constitutes a much less proportion compared to the total under surface area of the ice. In order to obtain a correct value of the biomass for the whole station it is necessary to calibrate for the relatively higher proportion of ice edge samples.

An advantage of SCUBA dive sampling is the possibility to study the behaviour of the animals in their natural environment and thus the efficiency of the methods in collecting the animals. This makes it easier to detect deficiencies of the methods.

### The representativity of the samples

Before one is able to compare different ice stations it is important to feel confident that the samples are representative for the stations. The samples within each station showed a large variance both with respect to mean density and biomass estimations. This suggests a patchy distribution of the organisms beneath the ice subsurface, and that the distribution of the sympagic fauna differ between ice floes in a relative short distance from each other. The large variation within each station must not be forgotten when the different stations are compared. The size of the frame is decisive to obtain a representative pattern over the patchy distribution. The area for each sample must be in proportion to how the animals are distributed. If the sample area is too large the small-scale distribution will not be detected. Small sample areas give a high resolution but as a result of that, it takes a higher number of samples to achieve a representative result. An examination of the mean values over biomass and abundance, shows that the variance increases with increasing mean values. This trend may indicate that there are a few samples with relatively high biomass and/or density. These samples contribute to increase the mean values as well as the variance and have a relatively high impact of the results. This again shows the importance of choosing a proper sample area. However, the lack of normality and homogeneity of the variance was considered during the statistical analysis.

### Ice drift pattern

The general pattern of ice drift in the Arctic suggests that the ice in station I and II is probably originated in the Kara sea and/or the Eurasian basin via the transpolar drift (Pfirman et al., 1997). Some of the ice may also have originated more locally, from the surrounding areas. This is mostly valid for the seasonal ice and some of the young MYI. The ice from station III was very old and thick. It is possible that this ice comes from the Beaufort gyre or from the transpolar drift stream according to the general drift patterns.

Since the ice at station III was a mixture of old and young MYI it is possible that the ice has different origin.

### **Taxa composition and comparison between methods**

Ice station III differed from station I and II due to the presence of Polynoidae indet. and *Gammaracanthus loricatus*. These organisms have previously been recorded in these ice covered areas north of Svalbard dominated by old MYI (Lønne and Gulliksen, 1991b). The presence of these taxa suggests a different origin of ice at station III compared to station I and II.

Comparing the fractions of taxa within each station, there are no striking differences between the two sampling methods used. So far, population parameters such as length or weight of single individuals are not part of this project. These measurements, which will be carried out later, may support a more detailed comparison between the methods.

### **Distribution within the transects**

The present small-scale distribution of sympagic amphipods under the ice may depend on different factors, such as food availability, predation as well as abiotic factors.

At all stations, *A. glacialis* showed a significant decrease when comparing data from the edge with data from different distances along the transect. Similar distribution pattern of *A. glacialis* has been reported earlier (Gulliksen and Lønne, 1991; Cross, 1982). These results are in accordance to the expectations of a preference to stay close to the ice floe edge due to higher primary production and thus food availability.

According to earlier physiology studies, *G. wilkitzkii* is considered to be more sensitive than *A. glacialis* to reduced salinity (Aarset and Aunaas 1990a,b; Aarset, 1991). Therefore, *G. wilkitzkii* was expected to be more abundant towards the ice edge as the salinity usually is higher there than beneath the ice floes (Aarset, 1991). In addition, we expected *G. wilkitzkii* to follow the distribution of its prey *A. glacialis* which was expected to be most abundant at the edge of the ice floes. Ice station I was the only locality at which *G. wilkitzkii* seems to have preferences to settle close to the ice edge. The comparatively even distribution of *G. wilkitzkii* along the transect at station II and III is in contrast to our expectations and to the results of Poltermann (1998). However, the present results suggest a more flexible life strategy of this amphipod.

Having long legs with spines *G. wilkitzkii* may be able to attach itself to the ice subsurface. Furthermore, *G. wilkitzkii* inhabits different structures under the ice such as brine channels and ridges, which may protect it from losing the habitat due to melting processes and/or wave actions. Organisms inhabiting preferably the open subsurface such as *A. glacialis* may first be subjected to these removal processes.

Although density as well as biomass of *Onisimus* spp. was scarce, the present results coincide with the result from the Franz Josef Land area (Poltermann, 1998). Compared to the other sympagic amphipods, *Onisimus* spp. seemed to avoid the ice edge, since *Onisimus* spp. was even more scarcely found in the samples close to the ice floe edges than further in under the ice.

### **Comparison between the ice stations**

Station I had a dominance of FYI, while the station II and III was dominated by MYI. It was expected that the stations dominated by MYI would have a higher density and biomass of sympagic fauna than the stations dominated by FYI. The mean density estimates were significantly different between the stations. There are almost twice as many animals at station I compared to station II and III. If we compare the density with the biomass we should expect a higher biomass at station I. However, there was no significant difference in the biomass estimations between the three ice stations. The proportion of *A. glacialis* to the total density was higher at station I compared to station II, but not when compared to station III. We suggest that the relatively lower (than expected) biomass at station I cannot

be explained by the higher fraction of *A. glacialis*, but by a higher proportion of small *G. wilkitzkii*. This is obvious when the relation between density and biomass of *G. wilkitzkii* at station I is compared with the other two stations.

The mean biomass estimations ( $\text{g/m}^2$ ) were within the lower range of earlier estimates from MYI (Lønne and Gulliksen, 1991b). Ice station III consisted of very thick ice floes in a mixture with thinner ice floes. According to the divers the thinner ice floes inhabited a higher density compared to the thick ice floes. However, the transects were placed mainly under thicker ice floes which might explain the lower biomass and density at station III. The light intensity might be too scarce to sustain a primary production under the thick ice floes, thus the organisms are expected to show a preference for a moderate thickness of the ice.

The Polar water (station III) is low in nutrients compared to Atlantic waters (station II). This also might contribute to the relatively low biomass found at stations III despite its dominance of old MYI.

Ice station III was a locality of ice floe movement, thus resulting in unstable habitats for the animals. Ice station I and II consisted of very large ice floes with less open water between. The animals that lived here probably experienced a more stable environment.

Station II differs from ice station I and III primarily due its high water surface temperature and its higher degree of subsurface melting of the ice (Appendix 2). However, a lower salinity was not observed at station II even though the ice melted. The change in the subsurface structure due to the melting may lead to unsuitable habitats for the organisms.

To sum up, the density of *A. glacialis* was higher at the edge of the ice floes compared to the rest of the transect. The observed preference of *A. glacialis* is suggested to be a result of a higher primary production at the ice edge. *G. wilkitzkii* had an even distribution of the density along the transect. *G. wilkitzkii* dominated in terms of biomass. A higher taxa diversity was observed at the most ice station III. All together, 7 taxa were found; *A. glacialis*, *G. wilkitzkii*, *Onisimus* spp., *G. loricatus*, *P. libellula*, *J. brevis* and Polynoidae indet.

This may a result of the suggested succession in older ice.

The two methods used did not result in any difference with respect to the taxa composition in the samples.

We believe the present study has contributed to the understanding of the presence of sympagic fauna in northern waters of Svalbard.

Further studies are needed concerning the interaction between physical and biological parameters in relation to the occurrence of sympagic organisms on a large scale (different watermasses and ice categories) and on a small scale (under ice floe structures).

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# Variation in the vertical distribution of zooplankton in high Arctic ecosystems

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## ABSTRACT

In the Arctic only a few studies have been done on the vertical migration of zooplankton and these have shown no distinct patterned in terms of diurnal variation. The aim of this study was to investigate vertical distribution of zooplankton and possible migratory behaviour. Sampling was done in Kongsfjorden, Svalbard, as well as at two ice stations, 81°30' N, 29°12' E and 80°55' N, 15°03' E respectively. Acoustic measurements were combined with biological sampling in the detected backscattering layers in order to verify their species composition. The results indicate that juvenile fish, mainly polar cod (*Boreogadus saida*) and *Lumpenus* sp., ascend to shallower depths to feed on copepods in Kongsfjorden. At the ice stations there was no evidence of pelagic fish. The results also show that *C. hyperboreus* and *C. finmarchicus/glacialis*, which were the dominant species in the net samples from Kongsfjorden exhibit seasonal rather than diurnal migration.

## INTRODUCTION

In order to shed light on the trophic relationships within the arctic marine food web, an understanding of the vertical distribution of zooplankton is essential with regard to the herbivore-primary production relationship. Zooplankton distribution, both horizontal and vertical, may be affected by biological factors as well as physical ones, such as the presence of pycnoclines and currents.

The presence of diel vertical migration among many zooplankton is a well-known fact (Ward *et al.*, 1995.) and krill and copepods have shown to be strong migrators in many areas (Mauchline, 1998; Mauchline & Fisher, 1969). The reasons behind this behaviour have been discussed widely and features like feeding and predation may play important roles. Avoidance of predators is the theory most often invoked to explain the diurnal migration patterns, in which the zooplankton migrate upwards to feed during the night (Bollens *et al.*, 1992). Light has been proposed to be a cue (Ringelberg, 1995) for vertical migration; herbivorous zooplankton follow an isolumen and stay in the surface layers feeding on phytoplankton during night, and descend to deeper layers during the day time to avoid visual predators. Previous investigations have revealed that the diel vertical migration patterns observed in lower latitudes is not as pronounced in the arctic (Longhurst *et al.*, 1984). Rather, a seasonal migration, connected to the life history strategies of the herbivorous species is what dominates the pattern in the Arctic (Schnack-Schiel & Hagen, 1995).

More omnivorous and carnivorous zooplankton tends to stay in depth layers reflecting their general ecology, that is, depths they assume in the ocean wherever they occur (Longhurst *et al.*, 1984; Buchanan & Sekarek, 1982).

The composition and distribution of different zooplankton species within an area will also be reflected by the origin of the water masses comprising the area studied. The waters on the west and north coast of Svalbard are characterised by two main currents. The West Spitsbergen Current runs north transporting warm Atlantic water along the West Coast and around the northern tip of Svalbard. The Sørkapp Current carries cold Arctic water around the southern tip of the island and up the west coast creating a wedge between the Spitsbergen Current and the coast line. The Arctic water, however, forms merely a surface current underneath which the current of Atlantic water dips down and reaches all the way to the coast line (Loeng, 1991). This water is characterised by a temperature of more than 3°C and salinity above 35 psu. The denser Atlantic water finds its way into the fjords over the thresholds and is covered by water of lower salinity originating mainly from melting glaciers. North of Svalbard the Atlantic water is more modified, becoming gradually colder and less saline as it is confronted with the Polar waters running south.

Studies concerning the vertical distribution of zooplankton in high Arctic ecosystems are few and several have been conducted during the summer (Smith, 1988; Kosbokova, 1978; Richter, 1994). The problem with studies of vertical migration in zooplankton at these latitudes is primarily that the areas of sampling are very dynamic in terms of currents and complexity of the water mass composition. Logistical problems, such as ice coverage are additional reasons why sampling in certain areas or at certain times of the year has not been done. In the present investigation, our aim was to describe and discuss the vertical distribution of different taxa in the zooplankton community in Svalbard waters and to compare possible migration behaviours of these taxonomic groups. This was carried out by biological sampling in combination with acoustical measurements.

## **MATERIAL AND METHODS**

### **Study area**

All samples were taken from "R/V Jan Mayen" at three different localities during a two week long cruise in September, 1998, in the waters west and north of Svalbard. The localities were Kongsfjorden (78°57 N, 011°50 E) with a depth of 350 m, and two separate ice stations at 81°30 N, 29°12 E and 80°55 N, 15°03 E, with 700-250 m and 1350 m depth respectively. At every locality, sampling was conducted over a 24-hour period with approximately six-hour intervals.

### **Environmental parameters**

Temperature and salinity were measured with a Neil-Brown Instruments Mark III CTD sond coupled to a PC with a 166 MHz processor. CTD profiles were taken 2-4 times at each sampling station.

### **Acoustic investigations**

The distribution of zooplankton sound scattering layers (SSLs) was recorded with a Simrad EK 500 echo sounder (120 kHz) while the recording of larger nekton as fish, was performed with the same echo sounder but 38 kHz was used. Integration of backscattering strength was made over discrete depths (every 50 m) at every sailed 0.1 nautical mile, and relative abundance was measured as decibel (dB) backscatter. The dB values are not comparable between the different frequencies.

### **Biological sampling**

Sampling of zooplankton in five consecutive depth layers was performed with a Multiplankton Sampler MPS 92 A at four occasions at every locality. Five nets were used and each net was mounted with a flow meter. A SCANMAR depth sensor was mounted on the net frame. The net opening measured 50 x 50 cm and the mesh size of all nets was 180 µm. The sampling depths for the MPS were determined at each locality by using data from CTD and echogram transects to identify possible zooplankton layers. The total volume of

the samples of each net was measured but the organisms were not sorted in taxonomic groups. The volume was measured by adding a known volume of water to the animal sample, measuring the total volume and then subtracting the known volume of water. As much as possible of the excess water was removed from the animal sample before measuring the volume.

Sampling for larger, fast swimming zooplankton was carried out with a Tucker trawl and/or a WP-3 net, mesh size 1000  $\mu\text{m}$  and net opening areas 1  $\text{m}^2$  and 1.13  $\text{m}^2$  respectively. The Tucker trawl was towed horizontally for about 20 minutes at 2 knots speed at two selected depths at the fjord station, and between the ice stations. The depths were selected in accordance with the echogram transects at 120 kHz showing the distribution of zooplankton. At the ice stations, towing of the Tucker trawl was impossible and thus only the WP-3 net was used. The net was hauled vertically with a speed of 0.5  $\text{m s}^{-1}$ , and by using a closing device (released by sending down a messenger weight), three depth intervals were sampled every six hours. The different taxonomic groups in each sample were separated, and the volume of each measured. Volume was measured as mentioned above.

In addition, a bottom and pelagic trawl were used to sample larger zooplankton, shrimps and fish. The opening of the bottom trawl was approximately 8 x 30 m and the mesh size in the cod end was 42 mm. Corresponding values for the pelagic trawl were approximately 11 x 40 m and 40 mm. The depths of the trawls were monitored with a SCANMAR depth sensor. The trawls were towed with a speed of 3 knots and a duration of 20 min. During the trawling, SSLs were recorded with a Simrad EK 500 (38 and 120 kHz). In Kongsfjorden, samplings were performed with both the bottom and the pelagic trawl (200 m depth) during daytime, and an additional pelagic haul was conducted during the night at 150 m. Between the Ice stations another pelagic sample was taken from 280 m at nighttime. The samples were sorted in species or taxonomic groups and the volumes were measured.

## **RESULTS**

### **Kongsfjorden**

In their article Ito and Kudoh (1997) refer to the water layers of Kongsfjorden as the surface layer, the top layer, the seasonal layer, the

winter layer and the bottom layer. The surface layer was likely not detected in our profile but the water existing below this down to a depth of 20 m is probably the top layer. This water is influenced by the addition of fresh water from the summer melting period as well as the higher incoming radiation during summer. Below this top layer, down to a depth of 220 m, follows a layer characterised by the surface conditions of last year. The temperature peak is likely the point at which the two layers converge. From 220 m and down ward we encountered the slightly warmer bottom water, which possibly originates from the Atlantic Deep Water.

The Multinet samples contained mostly copepods and chaetognaths, but a complete taxonomic analysis and calculations of the percentage of volume of each species will be done at a later date by the Institute of Oceanology, Polish Academy of Science. The sampling depths were 350-250 m, 250-150 m, 150-50 m, 50-20 m and 20-0 m (Fig. 1) Calculations of total zooplankton volume for sampling time 10:00 and 15:30 in Kongsfjorden revealed a concentration of volume between 250 and 20 meters depth. The results of the night sampling at Kongsfjorden at 23:47 and 03:40 showed an increase in volume in the upper layers of the water column (50-0 m), as well as at the deepest sampling layers (350-250 m). The volume of zooplankton at 250-50 m decreased in the night samples.

**Fig. 1:** Multinet samples from a) Kongsfjorden, 980910-980911 and b) Ice Station II 980917-980918. The samples show the vertical distribution of volume (ml/m<sup>3</sup>) at different times of the day/night.

Taxonomic groups represented in the Tucker trawl and the WP-3 net from Kongsfjorden were mainly copepods (*Calanus sp.*), chaetognaths and amphipods, and a few euphausiids and mysids. The Tucker trawl was towed at 150 m and 50 m depth (except at 16:10, when the deepest tow was at 175 m). The largest volumes were found in the deeper layers at all times (100-400 ml total), and the midnight tow had the overall largest catch. Chaetognaths and copepods dominated the WP-3 samples (ml), and they were distributed below 50 m at all times (Fig.2). *Calanus finmarchicus/glacialis* stage V and VI, and *C.hyperboreus* stage IV were the most abundant of the copepod species (100 – 1000 individuals/1000 m<sup>3</sup>), and their vertical distribution did not differ between times of sampling (Fig. 3).

**Fig. 2:** WP 3 net samples from Kongsfjorden, 980910-980911. The samples show a stable distribution of copepods and chaetognaths below 50 m depth.

**Fig. 3.** Abundance measurements from WP 3 samples in Kongsfjorden, 980910-980911. The graphs show copepod stage and species composition at three different sampling times and at three different depths.

In the bottom trawl large amounts of Polar cod (*Boreogadus saida*) were caught, mostly small ones (<15 cm), but also larger ones as well as Greenland Halibut (*Reinhardtius hippoglossoides*) and shrimps (primarily *Pandalus borealis*). In the pelagic trawl zooplankton was the dominant group (90 % krill), but small Polar cod was also present (Table 1).

**Table 1.** Volume (l) of species/taxonomic groups from hauls with bottom and pelagic trawl at four different occasions. “Other fish species” contained mainly Lumpenus spp., Liparis spp. and different species of flat fish, while “Shrimps” were constituted of *Pandalus borealis*. “Zooplankton” from Kongsfjorden was mainly comprised of krill while between the Ice Stations, the amphipod *Parathemisto libellula* dominated. “Gelatinous forms” were mainly comprised of *Cyanea capillata*.

The catch in the pelagic trawl at night was dominated by small Polar cod and *P. borealis* but contained also other juvenile fish species like *Lumpenus sp.* and *Liparis spp.* of which the former recently had been feeding on copepods. Zooplankton were also present, mainly euphausiids (Table 1).

**Fig.4.** Relative backscatter recordings at 38 kHz from Kongsfjorden/Kvadehuken during a) day and b) night. Decibel (dB) values are integrated every 50 m. Due to bottom contact no dB values are available for the deepest integration.

An acoustic transect from Kongsfjorden showed a sound scattering layer (SSL) from 200 m to the bottom at the 38 kHz echo sounder (Fig.4a), while at 120 kHz, the SSL began at 150 m and extended downwards. A corresponding echo transect during night time showed a separation into two SSLs at 38 kHz; one layer with a maximum around 150-200 m was observed as well as one close to the bottom (Fig.4b). The 120 kHz echogram revealed that there was no difference in relative backscatter between day and night (Fig.5). The same pattern was seen during the next night in the outer part of Kongsfjorden, where a pelagic sampling was conducted.

**Fig. 5.** Relative backscatter at all localities, during day and night, recorded by a 120 kHz echo sounder. Decibel (dB) values are integrated every 50 m. Due to bottom contact no dB values are available for the deepest integration.

### **Ice Station I**

CTD profiles at Ice Station I showed a consistent pattern with a surface layer of cold and relatively fresh water,  $-1.3^{\circ}\text{C}$  and ca 30.2 psu, down to 20 m. This cold and less saline water is a result of the melting of the sea ice. The measuring depth at this station was ca 275 m, except for the first sample which reached down to 675 m. From 25 m down to 375 m was a layer of warmer and more saline transformed Atlantic water ( $2\text{-}3^{\circ}\text{C}$  and approximately 35.0 psu). Below this depth was a layer of gradually colder water of 35.0 psu but the transition was rather diffuse and the layer may constitute a mix of transformed Atlantic water and cold bottom water (CBW) (Pfirman *et al.*, 1994). The only exception to the above mentioned pattern occurred on the first sampling profile and consisted of a lens of cold water (ca  $0.3^{\circ}\text{C}$ ) intercepting the warmer Atlantic water mass at 75 m to 120 m.

The sampling depths of the first multinet haul at Ice Station 1 were at 300-250 m, 250-120 m, 120-60 m, 60-20 m and 20-0 m. The remaining three hauls were taken at the depths of 250-120 m, 120-60 m, 60-20 m and 20-0 m as a result of drifting into more shallow waters. The sample at 10:00 showed a concentration of volume at 100-20 m and at 300-250 m. The samples taken at 15:14, 21:10 and 03:00 showed a similar distribution of biomass as the 10:00 sample except for the high values at 300-250 m since drifting did not allow sampling at this depth.

At this station the pteropods *Limacina helicina* and *Clione limacina* appeared in the upper 60 meters but copepods and chaetognaths were still the dominant species ( $0.1\text{-}0.2\text{ ml/m}^3$ ) in the WP-3 samples. They were distributed mainly below 60 meter during daytime, but with a slight shift upwards in the water column being noticed in the 22:30 sample.

When entering open waters after Ice station I, a Tucker trawl haul was made at 275 m, coinciding with the SSL (120 kHz), and an additional haul above this, at 50 m. The taxonomic groups dominating these hauls were appendicularians (*Oikopleura* sp.), copepods and chaetognaths. The highest volumes of appendicularians were found at 50 m (ml), whereas copepods dominated the deep haul.

The pelagic night sample between the two Ice stations contained small volumes of fish while the amount of zooplankton was almost the same as in the fjord, but instead of euphausiids, the amphipod *Parathemisto libellula* dominated (Table 1). The amount of *P. borealis* was the same as in the fjord environment, while the appearance of another species, *Cyanea capillata*, was recorded in relatively large amounts (3 l).

At the Ice stations and between them, the 120 kHz echogram showed almost the same pattern as in the fjord area i.e. a SSL from 150 m and downwards, and there were no discernible differences between day and night (Fig.5). Backscatter recordings from the 38 kHz echo sounder were almost absent (Fig.6)

**Fig. 6.** Relative backscatter at 38 kHz from the ice area during day and night.

### **Ice Station II**

The CTD profiles of Ice Station II were very similar to those of Ice Station I. An upper layer, at 0 m to 15 m, of cold, less saline water due to the melting of the sea ice. The pycnocline was located at 15 m and below it followed a layer of transformed Atlantic water, which decreased in temperature with increasing depth. The upper part of the CBW layer was encountered at ca 700 m.

Sampling depths for multinet at Ice Station II were at 300-200 m, 200-80 m, 80-20 m and 20-0 m (Fig.1). All samples taken at 80-20 m depth contained a substantial amount of algae. Algae were also found in the samples from 20-0 m taken at 11:00, 16:00 and 22:30. Some algae appeared in the sample from 120-80 m depth taken at 11:00. The high volume at 80-20 m depth at 16:00 is in part due to one large ctenophore.

The gelatinous forms (*Aglantha* sp., *Beroe* sp., *Mertensia* sp.) were more numerous at this station, and ostracods (*Conchoecia* sp.) were present in all depth intervals from the night samples with the WP-3 (Fig.7). Amphipods were distributed mainly below 80 meter during the day, but showed a bimodal distribution at night, when a small proportion of the animals stayed in the upper 80 meters. The highest volumes, about 0.1 ml/m<sup>3</sup> comprised of copepods, chaetognaths and gelatinous forms (mainly *Aglantha* sp.), were found in the 80-200 m layer at 17:30 and 04:30 hours. Copepod species commonly associated with deep water of Atlantic origin, like *Heterorhabdus norvegicus*, *Gaidius* spp. and *Scaphocalanus magnus* were also present at this station.

**Fig. 7.** WP 3 net samples from Ice station II. Samples show no clear pattern in the vertical distribution of volume ( $\text{ml}/\text{m}^3$ ). There is an increase in the  $\text{vol}/\text{m}^3$  of gelatinous forms as compared with the Kongsfjorden samples.

## **DISCUSSION**

### **Comments with regard to methodology**

In order to investigate the vertical distribution of zooplankton of different size and swimming ability, we had to sample using several types of nets, with varying mesh size and net opening, and which required different towing/hauling speeds. We chose to use wet volume as the entity of information for this study, giving a rough estimate of biomass that was comparable between the different sampling methods used. The acoustic back scatter is a measure of volume which is often used for assessment of fish abundance, but which gives no information on what actually is measured, in terms of taxonomic group or species. To reveal this, a direct sampling is required, in this case represented by the bottom and pelagic trawls to catch fish, and the Tucker trawl to catch large zooplankton such as euphausiids,

amphipods and chaetognaths. These are horizontal tows taken at a selected depth, and gives information about the species present within a distinct layer.

The acoustic back scatter from 38 kHz (at night-time) from Kongsfjorden showed a distinct layer at about 150 m, whereas the acoustic back scatter from the transect between the ice stations showed no layer at all. It turned out, as we saw from the pelagic trawl hauls, that the two locations actually differed only in the presence of small polar cod in Kongsfjorden. This emphasises the need to combine the acoustic measurements with biological sampling.

When collecting zooplankton with the Multinet or WP-3, which are vertical hauls, you get information about species present within an integrated depth interval. Comparing the results from horizontal and vertical samplings is not straightforward, since both the depth resolution and the accuracy with regard to volume of water sampled differs.

Due to the small mesh size of the Multinet, the device could only be hauled at a speed of ca 10 m/minute. Consequently amphipods, euphausiids and other fast-swimming animals were not caught during this sampling. In addition the samples contained a significant amount of algae and mucus which masks the actual volume of animals contained in the sample and is likely to change the appearance of the volume graph if excluded.

Presenting the vertical distribution of different taxonomical groups in terms of wet weight, gave a relatively good picture of the largest zooplankton, such as euphausiids, chaetognaths and amphipods, because these groups consisted mainly of 1 or 2 species. For the copepod group, however, which consisted of several species and stages, it was impossible to infer any explanations for the observed vertical distribution from the volume measures without knowing which species comprised the group. In Kongsfjorden the copepods were distributed mainly below 50 m at all times, and only knowledge of which species/stage that dominated the sample (in this case *Calanus finmarchicus/glacialis* stage V), can give an indication of the explanation for the observed distribution.

### **Total volumes of zooplankton**

Total volumes of zooplankton measured in Kongsfjorden show slightly higher values compared to the results from the ice stations, indicating a higher production in the fjord. Kongsfjorden's oceanography, as mentioned earlier, shows four main water layers according to its salinity and temperature regime. The freshwater run-off carries with it nutrients. As a result the waters of Kongsfjorden are known to be quite productive (Falk-Petersen *et al.*, 1990).

At the ice stations one can observe more "open-water" characteristics. Stability in the euphotic layer during summer results basically from the retreating ice edge forming a less saline water layer at the surface. Primary production will follow this process resulting in local phytoplankton blooms. During this time of a local phytoplankton bloom, herbivorous grazers will find themselves under extremely good feeding conditions for a rather short time. Nevertheless, the peak of zooplankton abundance will occur some time after the phytoplankton bloom. The low abundance of zooplankton at the ice stations could be due to the population not having reached the same stage in development as compared to the fjord population. Feeding conditions for herbivorous and hence carnivorous zooplankton in Kongsfjorden are possibly much more continuous and stable during the whole reproductive season, resulting in a bigger amount of zooplankton (volumes). In addition to different feeding conditions in the fjord and at the ice stations, it can be supposed that due to the wide mouth of Kongsfjorden many plankters (especially Atlantic forms) are introduced with the Atlantic deep water also known as more productive than Arctic water. All together, these might be possible reasons for the greater amount of zooplankton volumes in Kongsfjorden compared to the ice stations.

### **Vertical distribution of smaller zooplankton**

Fitness can be improved by increasing fecundity or decreasing mortality. As with any animal the behaviour of copepods and other zooplankton is adapted to achieve this. Diel vertical migration (DVM) and seasonal migrations are the dynamic responses to changes in

the availability of resources as well as predation pressure (Fiksen & Carlotti, 1998). Several studies (Kosobokova, 1978; Longhurst *et al.*, 1984 and Smith, 1988) have shown that DVM of various calanoid copepods is fairly slight or virtually non-existent in Arctic waters. The results from our investigation support these earlier findings.

Calculations of abundance as well as measurements of volume from WP 3 samplings in Kongsfjorden showed a consistently higher amount of copepods and chaetognaths at the two deepest sampling depths, and there was no sign of migration in the other taxonomic groups either. The abundance measurements revealed that the main part of the copepods sampled were *Calanus finmarchicus/glacialis* C V and C VI (f) as well as *C. hyperboreus* C IV. *C. finmarchicus/glacialis* are believed to have a one year life cycle in these latitudes, overwintering at depth as copepodite stage IV-V before moulting into adults and spawning the following spring (Hirche, 1983; Kosobokova, 1986, 1990). Both these species are primarily herbivores which means they have to survive the long and resource scarce winter. They do so by entering diapause and living off their stored up lipid reserves at lower depths (Kattner & Hagen, 1995; Hirche, 1996). The deep distribution of mainly *C. glacialis/finmarchicus* stage V observed in Kongsfjorden indicates that the productive season is over, and *C. glacialis/finmarchicus* have started their seasonal downward migration. The summer period in Kongsfjorden was over at the time of the sampling, and the 11<sup>th</sup> of September was the last day of the “no night” period. Solar radiation was thus rapidly decreasing causing a change in the relative light intensity. It has been suggested that a relative change in light intensity is the primary causal factor of DVM (Ringelberg, 1995). It seems logical then that the decreasing light in Kongsfjorden could also induce a seasonal migratory behaviour in these herbivorous copepods.

The vertical distribution at both ice stations was similar in the sense that neither one showed any detectable pattern with respect to the vertical movement of the different taxonomic groups. However, one point worth noting is that the volumes of chaetognaths follow quite closely the volumes of the copepods. Chaetognaths are known to prey on copepods (Falkenhaus, 1991), the most probable explanation for their distribution therefore is that they are following the distribution of their prey.

The main difference between the WP 3 samples of Kongsfjorden and, particularly, Ice Station II was that the overall volume of both copepods and chaetognaths was lower at the ice station. At the same time the volumes of gelatinous plankton were significantly larger as compared to the fjord. It is important also to take into account the fact that quite large amounts of algae were found in the Multinet samples at this station from ca 80 m and up wards. The absolute amount of algae was not measured, but a visual assessment sufficed to conclude that an algal bloom was occurring at this locality. A taxonomical study conducted at the same sampling location revealed that there was a significantly higher amount of younger copepodite stages at this second ice station (ref. group 3). No abundance measurements were done on the samples from Ice Stations I and II and hence nothing can be said about the relative composition of copepodite stages at Ice Station II from the WP-3 samples. If we however look to the results of the taxonomical study and take into account the knowledge of the algal bloom, it is possible that the lack of DVM of copepods at this site is due to intensive feeding. At these latitudes the ice retreats fairly late and an algal bloom represents a short and intense period of resource abundance. It is possible that the optimal strategy for these copepods is to feed as much as possible while resources are available. Studies have shown that *C. finmarchicus*, for example, exhibit no DVM during spring bloom (Tande & Båmstedt, 1985; Eilertsen *et al.*, 1989). Another explanation for the absence of DVM during blooms is the increased turbidity (self-shading), of the water which dims the water column enough to reduce predation from visual predators (Fiksen & Giske, 1995). In a model of optimal life history and diel vertical migration in *Calanus finmarchicus* developed by Fiksen & Carlotti (1998), absence of DVM during periods of high predation risk is shown to be a potentially optimal strategy if the physical condition of the individual is low.

The acoustic readings from Ice Station I and between Ice Stations I and II detected no presence of fish. As mentioned, there is, however, an increase in volume of gelatinous zooplankton, mainly the ctenophores *Mertensia ovum* and the trachymedusa *Aglanta*

*digitale*. The role of these ctenophores as potential predators and their possible impact on primarily the copepod population is not well known (pers.com. Norrbin, 1998) but we believe it is possible that their presence could play a role in the apparent lack of DVM in the copepods at the ice stations, as the gelatinous forms were distributed more or less throughout the whole water column at all times.

In Kongsfjorden the multinet day samples showed a fairly even distribution with slightly higher volume from 250-50 m. At night there was a clear bimodal distribution of volume, but which taxonomic groups of animals that caused this vertical change cannot be said since samples will be analysed at a later date. The abundance results of the night sampling with WP-3 showed no migration but a possible explanation for the bimodal distribution, however, could be the presence of fewer but larger chaetognaths in the upper and lower sampling layers. These would not have any effect on the abundance but could impact on the total volume of the Multinet sample. At Ice Station I and II there was no significant change in the vertical distribution of volume between day and night but it should be noted that all the samples from 80-20 m contained a considerable amount of algae.

### **Vertical distribution of large zooplankton and fish**

According to net sampling and acoustical measurements with both 38 kHz and 120 kHz echo sounders, no diel vertical migration seemed to take place among the larger zooplankton in the Kongsfjord area, while small fish and shrimps migrated upwards at night.

Earlier investigations reveal that the shrimp *Pandalus borealis* performs diel vertical migration (Bergstrøm, pers. com.) and this seems to be the case also in the Kongsfjord area. Together with *P. borealis*, juvenile Polar cod (*Boreogadus saida*) were found to migrate vertically in the fjord, and other juvenile fish were also represented in the mid water layers during night. Juvenile *Lumpenus* sp. caught at night time had stomachs full of recently ingested copepods which indicates that juvenile fish ascend to feed on the upper zooplankton layers during night; this behaviour may also be a way to escape competition and possible predation from larger fish. The feeding of *Lumpenus* on copepods is supported by the findings of Falk-Petersen *et al* (1986). *Liparis* spp., which was present in the daytime bottom trawl but not in the pelagic trawl, was found in both nighttime pelagic trawls. This is rather peculiar for a bottom dwelling species but may be explained by nighttime feeding. This could also be behaviour perhaps limited to juveniles.

In the ice area, backscatter from the 38 kHz echo sounder was almost entirely absent and together with small fish catches, this may point to a possible lower predation pressure in this area in comparison with the fjord environment.

Euphausiids, which are known to be a strong diel vertical migrator throughout the world (Mauchline & Fisher 1969), showed no tendencies towards this behaviour in the fjord area or at the Ice stations. The lack of migration may be surprising, but if light is a major cue for this behaviour (Ringelberg, 1995) it might be explained by the fact that at these high latitudes, the differences in light intensities between day and night are not pronounced enough. According to Han & Strakraba, 1998, the combination of light and predation pressure is necessary for zooplankton to perform diel vertical migration and during this investigation, these criteria were probably not fulfilled. *Thysanoessa* spp., which were the dominating euphausiids species, are primarily herbivores and if no algae are present in the upper water layers, there is no point for ascending to graze during night. The behaviour to reside at depth and feed on detritus instead and at the same time avoid visual predators, could be a better strategy.

In Kongsfjorden, euphausiids comprised a large amount of the zooplankton catch in both the pelagic day and night trawls, while they were not present in the bottom trawl. On the other hand, in the ice area euphausiids abundance was very low and only few specimens were caught. The observations of low euphausiids abundance at the Ice stations in this study agrees with earlier investigations which point out that *Thysanoessa* spp. are not true Arctic species and prefer more Atlantic water (Mauchline 1980, Dalpadado & Skjoldal 1996), which is found in the Kongsfjord area.

## CONCLUSION

In the Arctic the reproductive season for herbivorous copepods is very short and connected to the brief period of primary production (Conover & Siferd, 1993). The highly pulsed food input may force the zooplankters to focus on energy storage for over wintering rather than predator avoidance, thus resulting in an absence of DVM.

The relative difference in volume of zooplankton between Kongsfjorden and the ice stations can likely be attributed to the higher productivity of the fjordic waters.

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# Composition of Zooplankton in different pelagic habitats of Svalbard fjords and adjacent waters (with special reference to *Calanus* copepodite stages and *Metridia longa*).

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## ABSTRACT

Investigations of the zooplankton found in the upper water column were carried out in Svalbard fjords and adjacent waters, both quantitatively and qualitatively. A total of 35 species in 15 phyla were identified. Different geographical types: open and closed fjords; shelves and “deep water” were studied. Different hydrographic regimes: fjord water; polar water; continental shelf water and the Marginal Ice Zone (MIZ) were studied. Within these different geographic locations the composition was related to physical conditions and prevailing currents. The highest abundances of *Calanus* spp. were found in the open fjords, reflecting the role of advection in the high latitude pelagic ecosystem. Lowest abundances were found at the ice stations, but primary production was higher compared to the fjord stations. Composition and distribution of zooplankton are not simply limited to the physical conditions, but incident light and nutrients are important for growth and development of zooplankton.

**Keywords:** zooplankton, *Calanus* spp., Svalbard, fjord, Marginal Ice Zone, MIZ, Arctic

## INTRODUCTION

The distribution of zooplankton, in different pelagic habitats are inextricably linked to the origin of the components of the water mass itself. The waters of Svalbard and the adjacent waters are part of the larger complex system of the high latitude pelagic ecosystem. The Arctic Ocean is enclosed by land, with openings allowing exchange of water being limited to the Fram Strait, Bering Strait, Canadian Archipelago and through the continental shelf of the Barents Sea. The Fram Strait, with its width and plummeting opening is a key area of water mass exchange. Ice and polar water motion of the East Greenland Current, west of Svalbard, exports many organisms into the Atlantic Ocean (Aagaard, 1995).

In the east, transformed Atlantic water is carried north with the West Spitsbergen Current. The West Spitsbergen Current (WSC) is a multipath system showing a main coastal branch heading northwards to the Nansen basin, lesser branches move westward, directed by fracture zones, towards the East Greenland Current (Gascard *et al* 1995). The transformed Atlantic water in these currents is found, invariably, between 200 and 900m, and in the bottom water of the Arctic Ocean (Lewis, 1982). The inflowing north-eastward coastal branch of transformed Atlantic water is trapped in a boundary current running counterclockwise along the perimeter of the Nansen basin and is counter to the surface circulation.

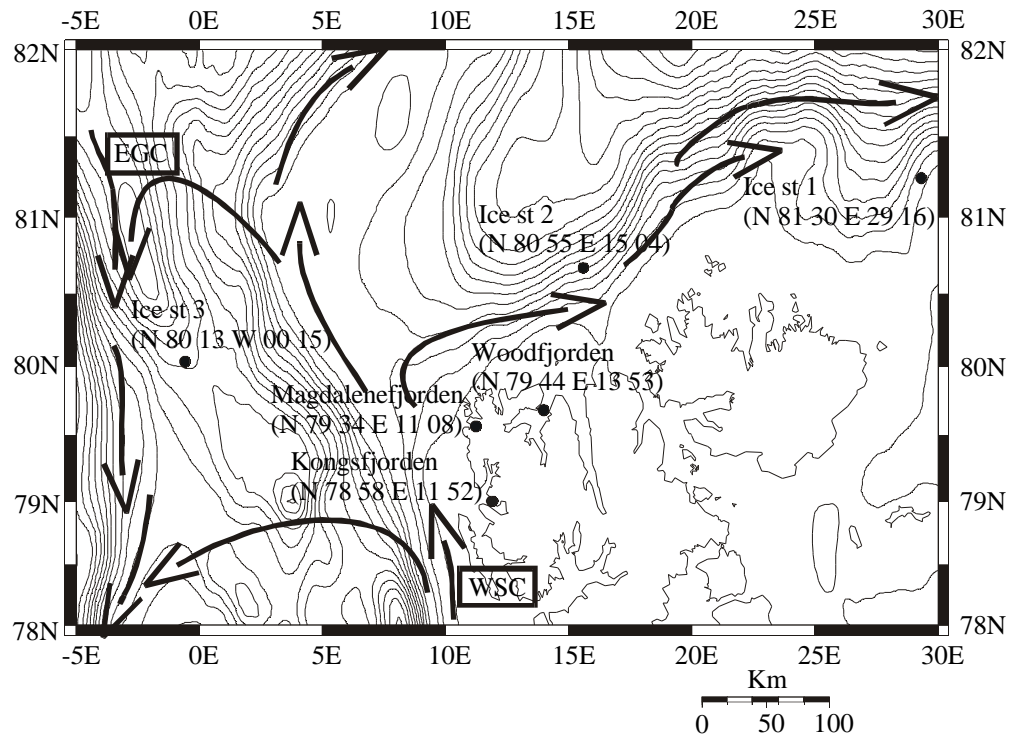
The western side of Svalbard is strongly influenced by Atlantic water that originates from the Norwegian Atlantic Current. Atlantic water, from the WSC, entering the fjords is transformed. Locally formed cold, saline water plus fresh water runoff from glaciers and rivers thus play an important role in the hydrography, and thus the biology, of the major fjords (Hornsund, Van Mijenfjorden, Isfjorden, Kongsfjorden and Magdalenefjorden) in Western Svalbard.

There is an import of species, of Atlantic origin, into the Arctic Ocean, in addition to the species within the indigenous water systems, i.e. the polar systems. The objective of the study was to document the composition of *Calanus* copepodite stages and *Metridia longa* quantitatively, and to assess the other zooplankton species qualitatively, at different geographic locations in selected fjords around Svalbard and associated waters, and to relate this to the physical conditions.

The three *Calanus* species studied belong to different geographical zones and their presence can be linked to different water masses. *Calanus hyperboreus* is a deep-water species, found, especially, in the Greenland Sea and the Central Arctic Ocean; *Calanus finmarchicus* is an boreal Atlantic water species and *Calanus glacialis* is a Arctic shelf species. The copepod *Metridia longa* is a cold water Arctic species usually found between 200–500m (Hirche, 1991).

## **MATERIALS AND METHODS**

Zooplankton material was collected during a cruise on the research vessel “Jan Mayen” organised by UNIS in connection to the UNIS course AB-310, “Zooplankton and sympagic fauna (=ice fauna) of Svalbard waters”, 9-22th. September 1998. The samples were collected by vertical hauls with a WP-2 plankton net (180 µm mesh size) at 6 stations. Three of the stations were situated at the northern coast of Spitsbergen, and three of the stations were located at the Marginal Ice Zone north of Svalbard (Figure 1). The zooplankton was, if possible, sampled at the same time of day at each station (Table 1).



**Figure 1:** Map containing the sampling localities and the main subsurface currents in the area. EGC is the East Greenland Current, who is transferring polar water through the Fram Strait. The West Spitsbergen Current (WSC) is a relatively warm current consisting of transformed Atlantic water.

Conductivity, temperature and density (CTD) measurements were performed using a Technical Mark EC&C Mark III CTD-sonde coupled to a computer. These measurements were performed as close to the time of zooplankton sampling as possible. The zooplankton samples were preserved in 4% unbuffered formaldehyde. The samples were split in two and one half was analysed for presence or absence for the different species, the other was retained for analysis at a later date. In addition, subsamples were taken with an automatic pipette from which the different *Calanus* species, *Metridia longa*, and chaetognaths were counted and enumerated. The subsamples usually comprised of 300 individuals. The mesozooplankton investigated was usually identified to species level. Larval stages, juvenile stages and chaetognaths were determined to higher taxa.

Table 1. Timing , position, weather and depth for the different sampling stations.

Station	Date	Time (GMT)	Position	Cloud (%)	Depth (m)	Wind (m/s)
Kongsfjorden	10.09	17.41	78°58'N 11°52' E	20	308	05
Magdalenefjorden	12.09	05.29	79°34'N 11°08' E	40	125	03
Woodfjorden	12.09	17.10	79°44'N 13°53' E	80	191	02
Ice station 1	14.09	09.29	81°30'N 29°16' E	80	278	12
Ice station 2	17.09	12.36	80°55'N 15°04' E	40	1354	00
Ice station 3	20.09	12.05	80°13'N 00°15' W	80	2738	05

The *Calanus* spp. were assigned to species by measuring the prosome length at the different copepodite stages (table 2). The different copepodite stages of the different *Calanus* spp. then were recalculated to give total abundances of the different copepodite stages.

Table 2. Identification key for *Calanus* sp. Prosome length of *Calanus* copepodite stages (mm). *C. hyperboreus* stages V and VI f were identified by their acute fifth prosomal segment.

Stage	Prosome length (mm)		
	<i>C. finmarchicus</i>	<i>C. glacialis</i>	<i>C. hyperboreus</i>
CI	<0.75	0.75-1.0	>1.0
CII	<1.1	1.1-1.4	>1.4
CIII	<=1.6	1.6-2.1	>2.1
CIV	<2.2	2.2-3.0	>3.0
CV	<2.9	>=2.9	
CVI f	3.2	>=3.2	

Phytoplankton samples were taken by Niskin water bottles (volume 5L) attached to the CTD. The samples were from 15 meters depth in the fjords and at ice station 2 and at the chlorophyll maximum at ice stations 1 and 3. Phytoplankton counts were conducted by using a haemocytometer, counting 10 subsamples at each station.

## RESULTS

### Phytoplankton counts

Table 3 presents the haemocytometer counts of 10 sub-samples of each of the six stations studied. Phytoplankton counts were uniformly low in the fjord systems whereas bloom proportions were found at ice station 1 and high numbers at ice station 3.

Table 3. Phytoplankton abundance from fjords and ice stations.

STATION	N	mean counts per ml	Bloom proportions*
Kongsfjorden	10	20	No
Magdelenefjorden	10	10	No
Woodfjorden	10	0	No
Ice Station 1	10	<100	Yes
Ice Station 2	10	20	No
Ice Station 3	10	90	Yes

\* bloom criteria supplied by Reigstad *pers. comm.*

### Faunal composition

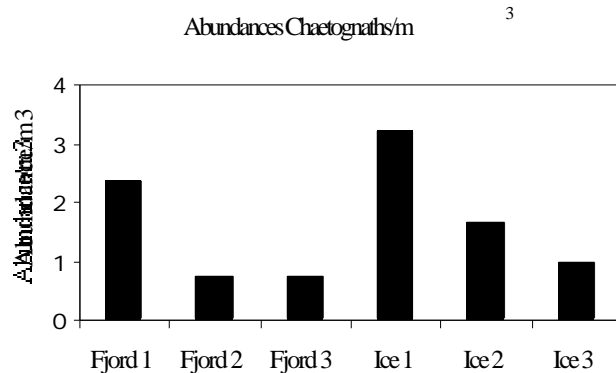
A total of 35 species and taxa in 15 phyla were identified at the sites investigated (Table 4). Many of the calanoid copepods were found throughout the fjords and ice stations e.g. *Calanus* spp. and *Metridia longa*. The poecilostomatoid *Oncaea borealis*, the cyclopoid copepods *Oithona atlantica* and *O. similis* were also found at all sites. Whereas the calanoid copepod *Acartia longrimes* and *Bradydus similis* were limited the fjord ecosystems; *Scaphocalanus magnus* was only found at the deep ice stations. *Gaidus brevispinus* and *G. tenuipinus*, warm water bathypelagic Atlantic species were only found in the Fram Strait site (Ice station 3), and were probably carried with the Return Atlantic Current water. Other zooplankton showed ranging distributions: the gastropod *Limacina*

*helicina* plus chaetognaths were found at all sites; both the ostracods and trachymedusae, *Aglantha digitalis*, occurred at the deep ice stations.

Table 4, species and taxa found at fjord and ice station sites.

Taxon		St. A	St. C	St. D	Ice st 1	Ice st 2	Ice st 3
Arthropoda	<i>Acartia longiremis</i>	X	X	X			
Copepoda	<i>Bradyidius similis</i>	X	X	X			
Calanoida	<i>Calanus finmarchicus</i>	X	X	X	X	X	X
	<i>C. glacialis</i>	X	X	X	X	X	X
	<i>C. hyperboreus</i>	X	X	X	X	X	X
	<i>Chirridius obtusifrons</i>						X
	<i>Gaidius brevispinus</i>						X
	<i>Gaidius tenuispinus</i>						X
	<i>Metridia longa</i>	X	X	X	X	X	X
	<i>Microcalanus</i> spp.	X	X	X	X	X	X
	<i>Pareuchaeta glacialis</i>						X
	<i>P. norvegica</i>	X			X	X	X
	<i>Pseudetideus armatus</i>					X	X
	<i>Pseudocalanus acuspes</i>	X	X	X	X	X	X
	<i>P. minutus</i>	X	X	X	X	X	X
	<i>Scaphocalanus magnus</i>					X	X
	Cyclopoida	<i>Oithona atlantica</i>	X	X	X	X	X
<i>O. similis</i>		X	X	X	X	X	X
Poecilostanatoidea	<i>Oncaea borealis</i>	X	X	X	X	X	X
Amphipoda	<i>Parathemisto libellula</i>			X			
	<i>Parathemisto abyssorum</i>	X		X	X	X	X
Monstrilloidea	<i>Monstrilla</i> sp.		X	X			
Chaetognatha		X	X	X	X	X	X
Polychaeta	<i>Polycapheatalarvae</i>	X	X				
Mollusca	<i>Bivalvia veliger</i>	X	X	X	X	X	X
Thecosomata	<i>Limacina helicina</i>	X	X	X	X	X	X
	<i>Limacina retroversa</i>				X	X	
Gymnosomata	<i>Clione limacina</i>	X			X		
Echinodermata	<i>Ophiuroidea pluteus</i>		X			X	
	<i>Ophiuroidea juvenale</i>		X				
Isopoda			X		X		
Ascidacea	<i>Ascidia</i> sp.	X	X				
Larvacea	<i>Oikopleura</i> spp.		X			X	
	<i>Fritillaria borealis</i>		X	X	X	X	X
Euphausiacea	<i>Thysanoessa longicaudata</i>				X		X
Trachylina	<i>Aglantha digitalis</i>					X	X

The presence of larval stages of isopods, polychaetes and echinoderms were restricted to Magdelenefjorden. Higher numbers of the predatory chaetognaths were found at the ice stations rather than at the fjord stations (figure 2). *Pareuchaeta norvegica* occurred at all the ice stations. While not quantified, mature, reproducing females of *Pareuchaeta norvegica* and *P. glacialis* were observed, potentially taking advantage of the wider range of species and copepodite stages at the ice stations.



**Figure 2.** Total abundances of Chaetognaths/m<sup>3</sup> in fjord 1 (Kongsfjorden), fjord 2 (Magdelenefjorden), fjord 3 (Woodfjorden), ice station 1, ice station 2 and ice station 3.

### Abundances of *Calanus* species and *Metridia longa* at the fjord and ice stations.

Abundances for the three species of *Calanus* spp. and *M. longa* at the three fjord sites and the three ice stations are presented in figure 3. *Calanus finmarchicus*, *C. glacialis*, *C. hyperboreus* and *M. longa* co-occurred at all stations although there were differences in both the geographic distribution patterns and their abundance.

In Kongsfjorden the abundances of the *Calanus* species and *Metridia* were higher than in the other fjords illustrating the advection from biologically rich Atlantic water of the WSC. The number of *M. longa* in Kongsfjorden was significantly higher than the other stations. Composition of *Calanus* spp. and *M. longa* in Woodfjorden is similar to Kongsfjorden in some ways. The CTD data (Figure 4c) indicates that, like Kongsfjorden, warm water of Atlantic origin was present.

In Magdelenefjorden abundances are less than Kongsfjorden and *C. glacialis* dominates. The unique structure of the fjord, with a sill at the entrance and a deep well at the base determines the species composition. The bathymetry of Magdelenefjorden is different to the other fjords. The CTD (figure 4b) shows the different hydrography in the fjord, indicating a stable water column with a high-density gradient. The sill at the entrance of the fjord prevents the advection of transformed Atlantic waters carrying *C. finmarchicus* and *C. hyperboreus* into the fjord.

At ice station 1, over the continental shelf of the Barents Sea, *C. glacialis* slightly dominated the *Calanus* population. The CTD profile (figure 5a) showed water, over a shallow shelf, that was predominantly of Barents Sea origin. *C. glacialis* is an Arctic shelf species unlike *C. finmarchicus* and *C. hyperboreus*. While *M. longa* prefers greater depths between 200 – 500 meters hence the low numbers at this site.









At ice station 2, the Arctic Ocean north of Svalbard, the CTD cast (figure 5b) showed that transformed Atlantic water was reaching this part of the Polar Ocean. A high number of *Calanus finmarchicus* were found, which indicates water of Atlantic origin. Despite this station being a deep water site *C. hyperboreus* was absent from the sample. The low number of *M. longa* resulted, most likely, from sampling the upper portion of the water column, while the species remained at a lower depth.

At ice station 3 abundances were significantly lower than the numbers of species found at all the other sites. The CTD profile (figure 5c) shows that polar water dominated the water column, with a possible small influx of Return Atlantic Water.

### **Abundances of *Calanus* copepodids at the fjord and ice stations.**

Noticeable trends were observed in the distribution of the copepodite stages in the individual *Calanus* species (figure 6). *C. finmarchicus* copepodite stages were more abundant at the majority of the sites except for Magdalenefjorden and ice station 1 where *C. glacialis* slightly dominated. At the fjord stations the older copepodite stages CVI, CV, CIV, of *C. finmarchicus* and *C. glacialis*, out-weighed the younger stages. A definite tendency towards the formation of overwintering stages (CV and CIV) was seen in the fjord sites in both *C. glacialis* and *C. finmarchicus*. The higher numbers of the smaller copepodite stages CIII, CII and CI were observed at the three ice stations. In general, the range of copepodite stages found was greater at the ice stations than at the fjord stations. This implies that the copepods were, unlike in the fjord systems, still in the process of growing and depositing reserves to fuel both metamorphosis to older stages and to optimise procreation in the following spring. The abundance of *C. hyperboreus* remained relatively constant at the stations studied, except for ice station 2 where they were absent.

The presence of males of the copepods studied was low, little or no representatives were found, throughout the whole study.

Naupilii of *Calanus* spp. were not collected quantitatively with the net size utilised, but they were found at all sites with the greatest numbers being observed at the ice stations 1 and 3.

## **DISCUSSION**

Zooplankton species composition and abundance reflect the water systems encountered during the cruise. Different water systems are characterised by different species. The species *Calanus hyperboreus* is considered a deep water species, found, especially, in the Greenland Sea and the Central Arctic Ocean; *Calanus finmarchicus* is a boreal Atlantic water species and *Calanus glacialis* is an Arctic shelf species (Mumm, 1993). The copepod *Metridia longa* is a cold water Arctic species usually found between 200–500m (Hirche, 1991). To a certain extent species are not strictly limited to a specific water mass, they may thrive at their optimum temperature but they are capable of surviving a range of temperatures and salinity, within reason (Rupert & Barnes, 1994). These generalisations act as a guide.

*Calanus finmarchicus*, *C. glacialis*, *C. hyperboreus* and *M. longa* co-occurred at all stations, except for ice station 2 where *C. hyperboreus* was absent. There were, however, differences both in the geographic distribution patterns and their abundance. The *Calanus* copepods are considered major biomass species (Unstad & Tande, 1991), hence both their importance in Arctic ecosystems and their importance in this study.

The relatively high abundances of *Calanus finmarchicus* at the majority of the sites links the flow of the West Spitsbergen Current (WSC) (figure 1). Transformed Atlantic water enters the Arctic Ocean via the WSC in two main paths. The Svalbard path flows north of Svalbard and then travels east; the Yermak path follows the western and northern ridge of the Yermak Plateau. Ice station 2 is in the path of the Yermak branch of the WSC and ice station 1 is south of the main path in an area influenced by Barents Sea continental shelf water.

The WSC passes the three fjords studied. Kongsfjorden, with its sill-less entrance, shows biotic indicators plus the water temperature and salinity that characterises water of Atlantic origin. Therefore we can assume that the water from the WSC is flowing freely into the fjord. The water system within Kongsfjorden is not solely limited to transformed Atlantic water. In the fjord, locally formed water is present along with glacial melt water and river run-off.

Woodfjorden is similar in some ways to Kongsfjorden – with an open structure and a mix of water of Atlantic origin and locally formed water. This pattern is not seen in Magdalenefjorden. The structure of Magdalenefjorden with a restrictive sill at the entrance of the fjord and a deep well at head forms a hydrographic environment quite different to the other fjords studied. The CTD cast (figure 4b) indicates that there is a drastic drop at 75m depth in temperature and an increase in salinity. The water within the well is formed locally during the freezing process that leads to the winter formation of ice. The denser, cold more saline water produced is retained within the well. Lighter, less saline water is restricted to the upper 75 meters. The presence of benthic larvae; including echinoderms, isopods and larvacea were in higher numbers than all the other stations. The fjord's water column is relatively stable, mainly due to the sill at the entrance. Coupled with the high-density gradient formed by the distinct water masses, larvae may remain in the column rather than descending. The sill also prevents the advection of transformed Atlantic water into the fjord. Thus the environment is quite different to Kongsfjorden and Woodfjorden – this is reflected by the low numbers of *C. finmarchicus* found and the, relatively, higher numbers of *C. glacialis* that are present. As stated previously *C. glacialis* is an Arctic shelf species, and it is adapted to colder temperatures and lower salinities than Atlantic species.

In addition to the imported open water species, species restricted to fjord environments are present e.g. *Acartia longiremis* and *Bradyidius similis* (Mumm, 1993).

One of the most intriguing facets of the study was the high number of *M. longa* found within the fjord habitats. Current knowledge (Hirche & Mumm, 1992) puts the calanoid copepod *M. longa* as an open water species that prefers depths between 200 and 500m meters, yet it was found in Kongsfjorden which is about 350m at its maximum depth but it is, in general, shallower. It is possible that the lack of a sill and the presence of deep wells can explain the presence of *M. longa* in the water column of Kongsfjorden. Exchange of water in Kongsfjorden is unrestricted at the mouth. Once within the fjord, apparently the species finds a niche in the bottom of the fjord and thrives.

At ice station 1, at the northern edge of the continental shelf of the Barents Sea, *C. glacialis* slightly dominated the sample. The CTD profiles (figure 5a) showed water that was predominantly of Barents Sea origin over a shallow shelf (Loeng, 1991). *C. glacialis* is an Arctic shelf species, unlike *C. finmarchicus* and *C. hyperboreus*, so it is understandable why it slightly dominates at the ice station. Transformed Atlantic water forms a small portion of the water column, however, as ice station 1 is south of the main path of the West Spitsbergen Current the abundance of *C. finmarchicus* is reduced. *M. longa* occurred, but as it prefers depths between 200 – 500 meters there were noticeably low numbers at this site.

The deep open water station, ice station 2, is on the direct path of the WSC. The high numbers of *C. finmarchicus* are characteristic of the transformed Atlantic water. The CTD cast (figure 5b) showed that transformed water of Atlantic origin was reaching this part of the Polar Ocean. The deep water evidently does not support high abundances of *C. glacialis* and *C. hyperboreus* was not found. The main distribution of the copepod *C. hyperboreus* seems to be the sub-arctic seas (Greenland Sea, Baffin Bay) where it spreads south into the Arctic Ocean (Hirche 1991). The copepod is imported through the Fram Strait and, evidently, is transported to ice station 1 via extant water currents. The numbers of *C. hyperboreus* are very low at ice station 1, evidently we were at the outskirts of the species' distribution. Its absence from ice station 2 can be best explained by zooplanktons' patchy distribution (Mauchline, 1998) or sampling error. The numbers of *M. longa* were low, possibly due to the fact that the sampling regime was between 350m to the surface, above their preferred depth. At ice station 3 abundances were significantly lower than the number of species found at all the other sites. The CTD profile (figure 5c) shows that polar water,

which is considered relatively unproductive when compared to Atlantic waters (Hirche *et al.*, 1991), dominated the water column. The widely occurring bathypelagic copepod *Scaphocalanus magnus* was only present at the two deep-water sites. Mumm (1993) notes that there is a general increase in the appearance of *S. magnus* towards the Nansen basin. *S. magnus*' presence at the ice station 3, during this study, was probably due to the advection of water through the Fram Strait carrying this species into the Arctic Ocean. The transformed Atlantic water in the West Spitsbergen Current splits, the majority of the water heading north; a smaller proportion becomes part of the Return Atlantic Current which bends back on itself and joins the East Greenland Current in the Fram Strait. The water in the Return Atlantic Current in the Fram Strait zone, while of Atlantic origin, is both diluted and has passed via a polar front where, possibly, aggregations of predators reduce the number of individuals in the water. Certainly there were high numbers of predators at ice station 3, e.g. *P. norvegica* and *P. glacialis* – some of which were reproducing. *Gaidius brevispinus* and *G. tenuispinus* are warm water bathypelagic Atlantic species (Mumm, 1993) that is closely affiliated with the Atlantic water. Their presence can also be linked to the Return Atlantic Current.

There were a higher numbers of nauplii and greater range of copepodite stages at ice stations when compared with the fjords; at the fjords the older copepodite stages dominated. *C. finmarchicus* overwinters mainly as CV (Conniver, 1988, Hirche 1991), and *C. glacialis* overwinters as a CIV (Hirche 1991) although Tande, 1985, states that *C. glacialis* overwinters as a CIII or CIV during its first year and as CV during its second year. It has been proposed that *C. glacialis* may have a shortened life cycle, to one year, in the productive fjords of west Svalbard (Scott *et al.*, in prep.). Additional sampling is required over a longer period of time to determine the specific stage of overwintering in such special situations. The numbers of males found was less than one percent, implying that reproduction was not high on the agenda. Regardless of the specific stage of overwintering the higher numbers of CV and CIV indicated that the fjord systems were gearing towards overwintering.

The most obvious difference between the fjord habitats and the open water ice habitats was the degree of primary production. Bloom levels of the diatom *Chaetoceros* spp. were observed at ice station 1 and, significantly high numbers of phytoplankton, again *Chaetoceros* spp., at ice station 3. At the fjord sites primary production was low (table 2). Level of primary production is dependent upon: light; available nutrients; water column stability and presence of cells (Eilertsen *et al.*, 1989). Light is the driving force in the Arctic ecosystems (Falk-Petersen *et al.*, 1990). At the coast of Norway there is a delay of about 3 weeks in the phytoplankton spring bloom at Vesterålen (69°N) relative to that of Møre (63°N) due to the time lag in the seasonal increase in total radiation (Eilertsen *et al.*, 1989). There may be such a delay effect at the higher latitude ice stations (compared to the more southerly fjords) or the late opening of the ice, allowing incident light through to the water column, may be a factor in the increased levels of primary production. Alternatively the very cold water at this site may delay or reduce the rate of reproductive development (Norrbin, *pers comm.*, Rupert & Barnes, 1994). Primary production was higher at the ice stations than compared with the fjord systems at that point in time. As food is available, indigenous *Calanus* species were taking advantage of the primary production and were still in the process of growing and depositing reserves to fuel both metamorphosis to older stages and to optimise procreation in the following spring. Predators that were present, e.g. *Pareuchatea* spp. and chaetognaths (figure 2), were taking advantage of the presence of such prey.

Sampling was restricted to a WP-2 net, other nets sample different taxa based on their size or speed. A WP-3 net generally selects larger species (personal observation) and using a multi-net allows sampling at different depths. We were unable to sample discrete water masses to determine whether species were retained within a specific water mass or if they were being expatriated into adjacent, distinct water masses.

Furthermore, Virborg, 1955, states that there is apparently a distribution of size ranges of *Calanus* copepodite stages, for example, large copepodids of the same stage can be found in the Barents Sea and the smaller individuals of the same copepodite stage can be found in

the WSC. Utilising a measuring technique looking at the range of lengths of organisms could, possibly, offer insight into the distribution and origin of *Calanus* spp. based on size. One has to be aware that, due to the normal distribution in sizes, there may be a degree of overlapping between size ranges of two different species of copepods. Unstad & Tande (1991) consider this to be a marginal effect when distinguishing two species when they occur in equal proportions of abundance. However if one species is under-represented there will be a substantial over-estimation. The larger stages of *C. hyperboreus* are distinctively different from *C. finmarchicus* and *C. glacialis*. However, it is possible that the *C. finmarchicus* and *C. glacialis* are mis-identified at ice station 2 where *C. finmarchicus* significantly outweighs *C. glacialis*.

In conclusion, physical conditions are not simply limited to the water masses carrying the organisms to specific sites. Incident light and nutrients also play a role in the composition of zooplankton in different pelagic habitats.

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## APPENDIX:

The sampling took place during a cruise with F/F Jan Mayen 9-22nd September 1998. Table number 5 summarises the sampling.

Table 5: Time, date, station number, weather conditions, and geographical position for each sample. The station numbers (St.nr.) refers to the following sampling locations: 848 and 853 – Kongsfjorden; 889 and 897- Magalenefjorden; 897- Woodfjorden; 905 and 909 - ice station 1; 941 and 942 - ice station 2; 964 and 979 were located at ice station 3.

St Nr	Position	Date	Time (GMT)	Clouds (%)	Temp (°C)	Depth (m)	Wind (m/s)	Ice (%)	Equipm.
848	78°58'N 11°54'E	10/9	10.57	20	-01.4	355	02	0	CTD
853	78°58'N 11°52'E	10/9	17.41	20	-00.6	308	04	0	WP2
893	79°34'N 11°08'E	12/9	07.09	80	01.0	137	03	0	CTD
889	79°34'N 11°08'E	12/9	05.29	40	01.2	106	05	0	WP2
897	79°44'N 13°53'E	12/9	17.10	80	00.8	191	02	0	WP2 CTD
905	81°30'N 29°16'E	14/9	09.29	80	-04.4	530	10	80	WP2
909	81°30'N 29°16'E	14/9	12.55	80	-03,6	276	13	80	CTD
941	80°55'N 15°04'E	17/9	12.36	50	-04.3	1236	00	50	WP2
942	80°55'N 15°04'E	17/9	13.07	40	-04.2	1354	00	50	CTD
964	80°13'N 00°15'W	20/9	12.05	80	-03.6	2984	04	80	WP2
979	80°03'N 00°26'W	21/9	06.20	80	-04.0	2649	12	80	CTD

## DAY BY DAY FIELD REPORT FOR THE CRUISE:

### Wednesday 9th September:

Equipment was loaded onto R/V Jan Mayen. Everything was checked to see if anything had been forgotten. The binoculars were calibrated and the tables for determination the different *Calanus* spp. were made.

### Thursday 10th September:

The first set of CTD data was collected using a Technical Mark EC&C Mark III CTD-sonde. Two WP-2 nets were hauled vertically from the bottom to the surface. The sample was preserved in 4% formaldehyde. The samples were split in two and one of these two halves was retained for further analysis at a later date. The remaining sample was analysed. When the samples were analysed, subsamples of 2 ml were extracted from the sample with an automatic pipette.

At the beginning of the analysis, all species were counted and enumerated. The goal for the project was re-evaluated when staging and identifying all species proved impossible within the proposed project time frame. Instead of counting and enumerating all the species our

new goal for the project was to enumerate all the different copepodite stages of *Calanus* spp.. In addition, the chaetognaths and *Metridia longa* were also counted and enumerated. The other taxa were analysed with respect to absence or presence. A list of the different taxa that were found in the sample was made.

**Friday 11th September:**

The analysis of the sample from Kongsfjorden was finished. To prevent inaccurate species and stage determinations, the individuals of the different copepodite stages of *Calanus* spp. were put aside so that they could be checked by the project teacher, Slawek Kwasniewski..

**Saturday 12th September:**

Two WP-2 nets were hauled in Magdalenefjorden and two WP-2 nets were hauled in Woodfjorden, both from the bottom to the surface (see table 5). CTD data, at both these stations, was also collected. The analysis of the sample from Magdalenefjorden was initiated.

**Sunday 13th September:**

The analysis of the sample from Magdalenefjorden was finished.

**Monday 14th September:**

Two WP-2 nets were hauled from bottom to surface on ice station 1. In addition, CTD data was collected. The analysis of the Woodfjord sample was started.

**Tuesday 15th September:**

The analysis of the sample from Woodfjorden continued.

**Wednesday 16th September:**

The sample from Woodfjorden was finished.

**Thursday 17th September:**

Two WP-2 nets were hauled from bottom to surface on ice station 2. In addition, CTD data was collected. The analysis of the sample from ice station 1 was started.

**Friday 16th September:**

The analysis of the sample from ice station 1 continued.

**Saturday 19th September:**

The analysis of the sample from ice station 1 was finished.

**Sunday 20th September:**

Two WP-2 nets were hauled from bottom to surface at ice station 3. The analysis on the sample from ice station 2 was initiated.

**Monday 21th September:**

There were collected CTD data at ice station 3. The analysis of the sample from ice station 2 was finished.

**Tuesday 22th September:**

The ship arrived at Longyearbyen and the samples were moved to the laboratory at UNIS.

**Friday 25th September:**

The sample from ice station 3 was analysed.

**Gelatinous zooplankton in high Arctic:**  
**I. General observations and evaluation of abundance measurement methods applied macrozooplankton.**  
**II. Feeding preferences, rate and different feeding modes of an arctic ctenophore, *Mertensia ovum* (Fabricius) from Svalbard waters.**

Lena Granhag, Jonas Henriksen, Jürgen Kolb and Hallvard Haanes

**Summary:**

The project was conducted as part of a course in sympagic and pelagic fauna in arctic waters, and all sampling and observations was done during a cruise with R/V JAN MAYEN to waters north of Svalbard. The project aim was to investigate the gelatinous zooplankton found during the cruise, both for abundance-measurements and for behaviour. Results from the project are divided in two reports. Part one emphasises general observations and evaluates different methods for abundance estimates of gelatinous zooplankton. Part one concludes that the different methods for abundance measurements that have been tried out all need refinements, and are often dependent on special conditions, to work the way they are supposed to. The second part focus on feeding preference experiments conducted on *Mertensia ovum* during the cruise. It concludes that smaller copepods as *Oithona sp.* can be regarded as an important food source to this ctenophore. *M. ovum* was also studied in situ, and it is suggested that different modes of feeding are used by *M. ovum* for capturing different sizes of prey.

The second part follows naturally after the first one, and they should therefore be read in the correct order.

**Part I:**  
**General observations and evaluation of abundance measurement methods applied to patchy distributed makrozooplankton.**

**INTRODUCTION**

One of the most conspicuous features of the ocean is the periodical occurrence of large gelatinous zooplankton. In fjords and estuaries, jellyfish can be so abundant that they overcrowd the sea. Still, gelatinous plankton are a group of which little is known. This is mainly due to methodical difficulties that appear when applying conventional sampling gear to collect these relatively large and fragile animals. Also they bloom in large numbers under favourable conditions, but since these conditions are not well known, planning of cruises and samplings is difficult. For obvious reasons neritic forms have been more frequently studied than open ocean forms, since they are easily reached with a small boat. Gelatinous carnivores are usually more abundant in neritic than in open waters (Alldredge 1984).

## **The physical properties of Northern Spitzbergen waters**

The physical properties of arctic waters are heterogeneous and dynamic when comparing Arctic areas. The heterogeneity is pronounced in all four dimensions, both when you go North-South, East-West, down in the deep or through the seasons. The main current systems around Svalbard are structured from the South by the tail of the Gulf Stream sending warm saline Atlantic water into the Barents Sea and along the west coast of Spitsbergen, as the West-Spitsbergen current (Pfirman et al. 1994). From the North, cold and less saline Arctic water meets the Atlantic water creating the polar front in the Barents Sea. Northeast of Spitsbergen the Atlantic water from the West-Spitsbergen current eventually meets the cold Arctic water from the North. The Atlantic water is then pushed down between the lighter, less saline Arctic surface water, and the heavier Arctic bottom water. Further to the west the East-Greenland current sends arctic water down along the East-Greenland coast.

The currents and ice-cover are strongly influenced by the seasons. The winter pushes the polar front, and with it the ice edge, far south in the Northern Barents Sea. In summer the front moves Northwards as the ice-edge pulls back. Surface waters in the marginal ice zone in summer are usually characterised by a pronounced layer of melt-water in the upper 20-30 m. This water has low, variable salinity, and temperatures generally below 0°C.

## **The high arctic species**

The term 'gelatinous zooplankton' is a grouping term covering a large and diverse group of zooplankters. The common definition on gelatinous zooplankton is a water content of at least 95% of the body, as compared to 70-90% water content for crustaceans, chaetognaths and fish (Alldredge 1984). They also usually lack hard parts, and are generally large compared to other zooplankton. The species considered in this study are *Euphysa flammea*, *Limacina helicina*, *Clione limacina*, *Mertensia ovum*, *Beroë cucumis* and *B. gracilis*. These are all Arctic or Subarctic species, found both in neritic and in open waters.

### *Euphysa flammea*

This is a carnivorous medusa belonging to phylum Cnidaria, class Hydrozoa. It is common in the upper water layers, where it feeds primarily on copepods.

### **Limacina helicina**

*Limacina helicina* is a common, and often abundant, thecosome pteropod. In stratified water masses it usually inhabits the upper 5-25 m of the water column, in a dense layer above the thermocline (Gilmer & Harbison 1991). For feeding it creates a large spherical external mucous web on which it collects food particles. This web is known to be very fragile and easily destroyed or withdrawn by the pteropod when disturbed. Pteropod feeding webs are known to contribute to production of marine snow in open waters (Alldredge & Silver 1988). *Limacina retroversa* feeding webs have been observed to produce mucous aggregates with sinking rates an order of magnitude larger than for *Calanus finmarchicus* faecal pellets (Noji 1991). Mucous derived marine snow is well known to make significant contribution to the vertical carbon flux.

### **Clione limacina**

*Clione limacina* is a gymnosome pteropod, thought to feed exclusively on *Limacina spp.* It is often found in low abundance in the same layers as *Limacina* (personal observations).

### **Mertensia ovum**

Among the ctenophores of the high Arctic waters, *Mertensia ovum* is definitely the most beautiful and conspicuous species, and probably also the most common. It is a carnivorous ambush predator (Matsumoto 1991), which catches its prey by using two long tentacles protruding from the lateral sides of the animal. *Mertensia ovum* has been found to feed mainly on copepods, depending on the prey types present (Swanberg & Båmstedt 1991).

### **Beroë cucumis**

This carnivorous species is considered to prey primarily on other ctenophores such as *Mertensia ovum* (Swanberg & Båmstedt 1991), and is in Arctic waters often found in association with these genera.

### **Beroë gracilis**

*B. gracilis* resembles *B. cucumis* morphologically, but is slimmer and the colour is more pale. It is believed to have a diet that is not depending on *Mertensia ovum* (Swanberg & Båmstedt 1991).

## **The sampling problem**

Sampling of gelatinous zooplankton is a commonly encountered problem. These fragile animals tend to be destroyed when sampled by conventional nets (Swanberg & Båmstedt 1991). At high abundance many species (for example larvaceans) are also known to clog the net, rendering the sample more or less worthless for quantitative studies. Another problem with net sampling is that it doesn't reveal many facts about the vertical and horizontal distribution of the animals sampled. Closing mechanisms used with nets for sampling only a part of the water column are useful, but their use is limited because dividing the water column in many parts is time-consuming work, and the resolution of the vertical distribution will still be poor. Lowering nets fastened to a wire for horizontal net hauls is also both difficult and time-consuming, and need special current conditions and a flow meter for quantitative sampling (Percy 1989). Some alternative methods for abundance measurements of large gelatinous zooplankton have been used:

### **Nearest Neighbour Measurements (NNM)**

Nearest Neighbour Measurements is a method of measuring abundance by measuring the distance between animals in a patch. By measuring the distance from a random point to the closest animal, and from the closest animal to the next closest, you get two measurements that when processed mathematically will give a measure of both the abundance of animals in a patch, and of how patchy the environment is. Hamner & Carleton (1979) used NNM to estimate copepod density in patches, by first using a camera to get pictures of the patches, and then measure the distance between animals. Gilmer & Harbison (1991) applied the same method on *Limacina helicina*, but measured the nearest neighbour distance manually while diving. The mathematical estimation of abundance from NNM data can be done in numerous ways.

### **Video-measurements**

The use of submersible video cameras for zooplankton abundance estimates has increased the latest decades. The principle is that the camera frames and focus depth defines the volume that is sampled. Paffenhöfer et al (1991) used such a camera with a defined volume of 10l to look at depth profiles of pelagic tunicates. The Video Plankton Recorder (VPR) is a more advanced form of underwater video designed specifically for plankton-abundance measurements. It samples much smaller volumes than a conventional video camera, and is therefore more useful to study small and abundant zooplankton. Norrbin et al (1996) used a VPR to look at distribution and fine scale structure of larvaceans and other zooplankton at Georges Bank.

## **The project aim**

The project aim had two main parts:

1. Estimate abundance of present gelatinous zooplankton applying variants of the methods sketched above.
2. Investigate behavioural features of the same species.

The outcome of the project was thus totally dependent of what species were actually present in high enough densities to make the investigations as planned. Of the species

mentioned above, *Limacina helicina* was thought to be the most common, ecologically important and best to work with.

## Materials and methods

All investigations in this study were done during a cruise with R/V JAN MAYEN north of Spitsbergen 9-22 Sept. 1998. The cruise went from the Isfjord, to Kongsfjord, on to Magdalenafjord and to Woodfjord, before going Northeast to Ice-station 1 (81°30' N and 29°13' E). From this station we went past Ross-island, and to Ice-station 2 (80°55' N and 15°03' E), and then Ice-station 3 (80°13' N and 00°13' E), before returning to Longyearbyen. Stations in the fjords and outside Ross-island were mainly short dive-stations, while ice-stations 1, 2 and 3 were about 48 hours long. The ice-stations were situated well within the marginal ice zone. All samplings and dives were restricted to the upper 30 m of the water column. CTD-profiles were taken at all stations, except at Ross-island. The weather conditions during the cruise were quite good, with temperatures ranging between 0 and -7°C, and wind velocity of maximum 20 m/s. Table 1.1 sums up some physical observations of water properties from the cruise. There was virtually no pitch or roll-movement in the boat at the ice-stations, thus yielding good experimental conditions on board.

Table 1.1: Distribution of water masses and the depth of the surface pycnocline at the different stations of the cruise. All data derived from CTD-profiles.

Station	Surface pycnocline depth / temp	Upper water masses	Deep water masses
Kongsfjord	~10m / ~2°C	Atlantic water	-
Woodfjord	~10-20m / 3°C	Atlantic water	-
Ice station 1	~15m / -1°C	Atlantic water	-
Ice station 2	~15m / -0.5°C	>700m: Atlantic water	<700m: deep arctic water
Ice station 3	~15-20m / -1,8°C	>150 m: Arctic water	180m<Atlantic water <700m <700m: Deep arctic water

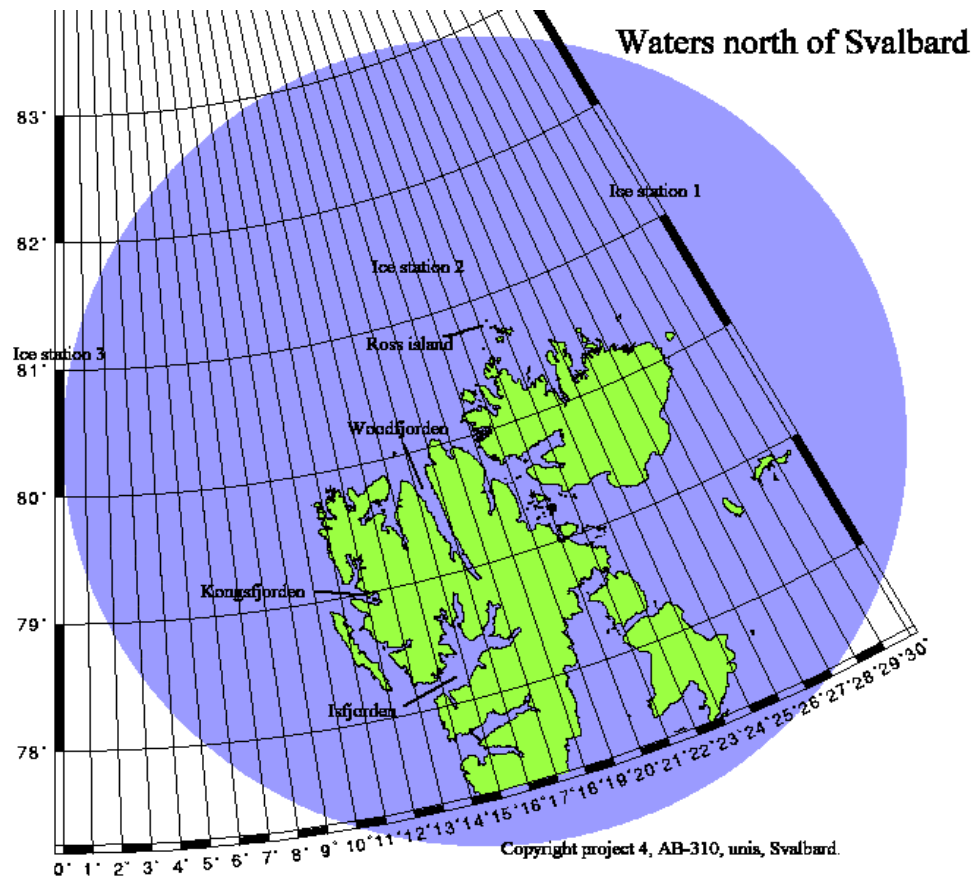


Fig 1.1: Map of Spitsbergen, with the sampling stations at Kongsfjord, Wood-fjord, and ice-stations 1, 2 and 3.

### Diving as a method.

Diving may be used to observe patches. Methods for measuring patch density will be described later. In the Arctic full-face mask and care for freezing is required, protection cap of glycerol and no use of octopus may prevent freezing of air distributor. A line should be used between the diver and the surface. Usually a “pilot dive” gives a good basis for planning.

Diving allows observation and collection of undisturbed gelatinous plankton. In experimental biology it is very important to use undamaged and unaffected animals to obtain results that actually reflects natural behaviour. We used water containers of 0.5 l and 1 l with a lid for collection. The lid was fastened to the container. Transparent containers were used so inspection after collection was possible, to check if the animal is hurt. We found it easiest to catch one animal per container to avoid injuries of the catch. To get the animal into the container one should twist it a little bit, and generate a current into it, and then gently slide the lid across the opening without making any current. The transparent container was inspected and put back in the diving net. Handling of animals after a dive was as quick as possible to avoid temperature fluctuations. We let containers stand on deck until transference because air temperature was similar to sea temperature.

## Measuring abundance

### Net sampling.

We used net hauls on one station only, ice station 2. We made 7 hauls from 30 meter with a WP-3 net with a mesh size of 1000 microns and an opening of 1,13 m. The gelatinous forms were counted immediately while live and identifiable.

### Nearest neighbour measurements (NNM).

We wanted to use the nearest neighbour model to estimate patch density from distances between animals measured diving. Measurements were tried from a random point to the closest individual and to the next individual closest. The closest individual was defined as the nearest one in a half sphere in front of the diving. The diver reported distances and actual depth via communication to the surface where they were recorded. The NNM would be applied on board. In Kongsfjord distances was tried measured between *Limacina helicina* with a rope, and at ice station 1 distances between *Mertensia ovum* was tried to measured with a rod. Both rope and rod was divided in centimetres.

### Video measuring

To estimate the density of patches or layers, we tried to video record a known volume of 8 litres “in situ”. This was tried on ice station 2 with a Panasonic video-8 camera with 20 x zoom. The zoom was set (10 x) to give passing animals appropriate sizes and the focus was adjusted to a 8-litre volume. A cross with a depth meter was mounted to the camera to view the back limit of the volume (fig.1.2), which was measured with a ruler recording the volume. The criterion for focus was the ability to read the numbers on the ruler clearly. All passing objects in focus would then be a part of the 8 litres volume, and density could be estimated. Two strong lights were pointed through the volume from two different angles, and the camera was lowered through the water column to a depth of 30 m. We kept it still for 30 seconds each fifth meter marked on the rope, so the densities at different depths or layers could be recorded and estimated. Total recording time was 10 minutes after which the battery was flat. The video recordings were analysed on board.

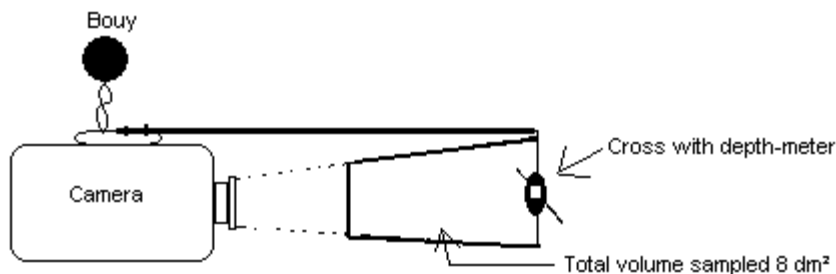


Fig 1.2: Sketch of the video camera used for the abundance measurements.

### Measuring abundance by use of a frame

In ecology density is estimated counting through a frame, giving a square density. We wanted to measure volume densities, and used a square frame measuring a water volume passing through it. From the square of the frame and the water velocity the volume could be calculated. The number of passing individuals in this known volume of water would give the volume density. A diver lying behind the frame in the current direction counted the animals. We measured current by timing the drift of an animal. On ice station 2 counting of *Limacina helicina* was performed for 10 minutes through a frame of 1,5 m and at ice station 3 counting of *Mertensia ovum* were tried for 15 minutes through the same frame. Counting was tried in the densest layers (tab. 1.2).

## **Pilot experiments.**

### **Setting up the design.**

R/V JAN MAYEN has a pump designed for keeping live fish, which is designed to pump a large volume of seawater. This keeps a large water flow with a constant temperature, and from this a small volume can be tapped at a constant flow. This enables scientists on board to get fresh seawater with natural temperature and salinity for experiments and keeping animals.

Keeping animals on deck can give temperature fluctuations, and animals were therefore put in aquariums standing in trays with circulating seawater. The trays functioned as a water bath, keeping the temperature constant at a natural level. 4 aquariums of 6 litre volume were used, two in each water bath. The aquariums were filled with 4 to 5 litres of filtered seawater, which was circulated with two aquarium air pumps. Air flowing through plastic tubes from the bottom to the surface dragged water along between ascending air bubbles. A very modest and fine circulation was obtained without turbulence. This was set up the first day of the cruise and animals were obtained for testing it during the first station in Kongsfjorden. All collected animals were kept in these aquariums.

### **Observations and recordings**

Observations were made and evaluated during all under water activity and during the time we kept animals alive on board. The observations were written down, and some observations were recorded with video camera. Video recordings were made through an aquarium with a black backside, made with black plastic or black clothing. This gave the best contrast and minimum reflection. A Panasonic video-8 camera with 20-x zoom was used, mostly from 5 to 15 x zoom for maximum enlargement of animals. 2 cold light spots were used in addition to sealing lights. The aquarium where animals were recorded was put on sea ice to keep the temperature down during the long observation watches. All animals caught by diving were filmed for later presentations and morphological descriptions. Observations made will just be reported in writing as no editing equipment were available on board or on UNIS after the cruise.

### **Limacina helicina and Clione limacina**

In Kongsfjorden (fig.1.1) we performed 2 dives. We caught several *Limacina helicina* and a few *Clione limacina*. They were caught in the same layer at a depth of approximately 10 to 5 meters. They were easy to catch unharmed and were transferred to the 6 litre aquariums directly after acclimating. *L. helicina* went into a bad shape from the beginning of its captivity, and it is earlier reported to not feed in captivity (Gilmer & Harbison, 1991). Circulation did not seem to help suspend *L. helicina*, which mostly lay on the bottom of the aquariums only swimming periodically. Swimming appendages were increasingly damaged as it spent time on the bottom. Larger volumes were not tried. *L. helicina* was therefore used only as a non-optimal food for *Clione limacina*, but swimming mode was recorded once. *C. limacina* survived for several days in good shape under all the different experimental conditions, with or without circulation and in all volumes. It fed in a collection container on *Limacina helicina* and was concluded to be easy to keep. One pilot experiment was made and recorded with one *C. limacina* and three *L. helicina*. The *C. limacina* caught its prey before recordings could start, and an additional *C. limacina* was added. The handling and consumption of prey was recorded and observed. The second *C. limacina* did not feed for several hours and the experiment was terminated. In a second pilot experiment *C. limacina* were put together with 50 calanoid copepods in 4 litres volume of filtered uncirculated water for 48 hours, but ate neither of them.

### **Beroë sp. and Mertensia ovum**

In Kongsfjorden we caught one *Beroë cucumis* and several *Mertensia ovum*, both species Ctenophores. They were collected in the same layer at about 5 meters depth. The catching in one-litre collection containers often resulted in damage to *M. ovum*'s tentacles as they were torn off against the entrance of the container. On the fjord stations most *M. ovum* therefor had injured tentacles, and pilot experiments were possible only with a few individuals which were not injured. On the later stations special collection methods were

developed to avoid injuries of *M. ovum*'s tentacles and these are described in part 2. The capture of *Beroë cucumis* was easier, the animal did not seem to get hurt being caught. Even so, it fell lifeless to the bottom of the aquariums after transference. *Beroë cucumis* was concluded to be extremely fragile and not to fit our experiments. All other medusa kept in collection containers seemed to stay in good shape for several days as *Euphysa flammea* which was caught in Woodfjord (fig.1.1), and kept successfully for almost a week.

Turbulence was observed to damage both *M. ovum* and *Beroë sp.*, especially during transferring between containers. Lobes and tentacles were torn off, especially when *M. ovum* not had withdrawn its tentacles. *Beroë sp.* should probably be transferred in larger volume, and the development of transferring *M. ovum* is described in part 2.

*Mertensia ovum* was kept successfully in all volume sizes both with and without tentacles in circulated and non-circulated water. During the fjord stations *M. ovum* was kept in a small volumes with calanoid copepods to check food preferences. These pilot feeding experiments will be described in the second part as they turned out very successful.

## RESULTS AND DISCUSSION.

### General observations

Table 1.2: Species observed diving on a Cruise along West Spitsbergen to 81° N and along this latitude, two fjord stations, one coastal and three ice stations. Subjective observed abundance presented as three orders of density and absent. Symbol explanation: -- = not observed + = observed ++ = few specimens seen +++ = high abundance.

	Kongs- fjord	Wood- fjord	Rossøya	Ice Station 1	Ice Station 2	Ice Station 3
<b>CTENOPHORA</b>						
<i>Beroë gracilis</i>	--	--	+	--	--	--
<i>Beroë cucumis</i>	+	--	++	+	--	--
<i>Mertensia ovum</i>	+++	++	++	++	++	++
<b>CNIDARIA</b>						
<i>Aglantha digitalis</i>	--	--	+	--	--	--
<i>Euphysa flammea</i>	--	--	--	--	--	--
<i>Halitholus cirratus</i>	--	--	--	--	--	--
<b>MOLLUSCA</b>						
<i>Limacina helicina</i>	+++	++	+++	+++	+++	--
<i>Clione limacina</i>	++	--	++	++	+	--
<b>APPENDICULARIA</b>						
<i>Oikopleura vanhoeffeni</i>	--	--	+	--	--	--

In general all diving observations seem to fit well with the physical properties of the water column, measured with the CTD (tab.1.1). The layers with a high abundance of species often fell together with the surface pycnocline. *Mertensia ovum* was the most common species and seen at all stations in the upper 20 m (tab.1.2). In Kongsfjorden the two pteropods *Limacina helicina* and *Clione limacina* were found in a dense layer in the upper

5-10 m with *Mertensia ovum* less dense above. *Beroë cucumis* was observed individually among *M. ovum*. In Woodfjord the *L. helicina* was found at the same depth as in Kongsfjorden but the *M. ovum* occurred below in a layer at approximately 15 m depth. On Rossøya a similar depth distribution was found with *M. ovum*, *Beroë cucumis* and *Beroë gracilis* observed from the surface to 10 m in low densities. Rossøya was the only location where *Aglantha digitalis* and *Oikopleura vanhoeffeni* were observed diving. At ice station 1 the *L. helicina* layer was very distinct and found at approximately 5 m and a few *C. limacina* were observed in it. Large numbers of *M. ovum* and a few *B. cucumis* were observed below down to 10 m. At ice station 2 the *L. helicina* layer was observed deeper, at 10-15 m depth, still with individual *Clione limacina*. *B. cucumis* was observed at all depths and *M. ovum* was observed from 5-20 m in high abundance, but with highest densities above the *L. helicina* layer. Two different arrangements of the tentacles were observed and we called them the *-mode* of feeding (fig. 2.5) and the *-mode* (fig. 2.4). This will be more thoroughly described in part 2. At ice station 1 and 2 *M. ovum* was found in all size classes from small (0.9 cm) to large (4.0 cm). The two species *Euphysa flammea* and *Halitulus cirratus* were caught in net hauls from 300 m. At ice-station 3 *M. ovum* was the only animal observed diving, observed above 5 m as two distinct size groups. Especially large ones (>4 cm) and small white ones (<1 cm) which may be juveniles.

During experiments we made several general observations of the behaviour of the species.

*Clione limacina* was observed to eat a *Limacina helicina*, both in a collection container and during an experiment. The experiment was set up to be videorecorded, but the *C. limacina* caught the *L. helicina* before recordings could start, but the handling of the prey was recorded. The *C. limacina* held its prey while consuming it, and spent several minutes dragging the prey out of its shell. According to the optimal foraging theory a specialist has a long handling time but is specialised to its particular prey species. The colour of the stomach changed from orange to black as the prey entered, and this was both observed and recorded. Looking in a binocular it appeared *C. limacina* captured *L. helicina* by means of creating a mucous thread from the anterior part. Then bending its body it brought the *L. helicina* forward to the mouth.

Table 1.3: Summary of evaluation on different abundance measuring methods of Gelatinous plankton. Problems and the concluding result are presented in the same chronological order as tested on the cruise.

<b>Type.</b>	<b>Problem.</b>	<b>Result.</b>
<b>Net hauls.</b>	Animals lost and Patches neglected.	Abandoned as useless for gelatinous forms.
<b>Acoustic backscatter.</b>	Needs verification by diving.	Needs investigation.
<b>Diving observations.</b>	Not accurate and quite subjective.	Not scientific, can just say present or not.
<b>Distance measurement.</b>	Difficult to perform between animals.	Useless at low densities.
<b>Video recordings.</b>	Too low density recorded or too little volume recorded.	Need trials at higher densities and larger volumes.
<b>Frame counting.</b>	Too low density or too low water current.	Should be carried out at high water currents.

#### **Evaluation of measuring abundance.**

Most gelatinous plankton are difficult to sample, and net sampling is discussed in the literature. Hamner et al (1975) reported losses of gelatinous plankters through the mesh of nets which was observed diving, after not getting any specimens in nets even though they

were observed diving. Some animals as Pteropod Gymnostomates were reported to escape net hauls as well. Therefore abundance data from net hauls may give a wrong picture of the gelatinous plankton distribution. Swanberg and Båmstedt (1991) reported few ctenophores caught per thousand copepods in net hauls, and said it to be rare that a net haul will sample a large enough volume of water to collect a statistically significant number of gelatinous predators. A net will have a relatively small probability of transecting a patch as a vertical haul through a layer or a horizontal haul through a patch and will only sample a small fraction of its total volume. We observed totally damaged ctenophores as well as less damaged ones, and concluded as Hamner et al (1975) that losses through net meshes may obscure abundance data of gelatinous plankton. Too few hauls not giving statistically significance and losses lead us to conclude that other ways of measuring the abundance of gelatinous plankton should be used. To determine the predatory impact of any patchy distributed animal we think that patch abundance's and number of patches are the most important. An evaluation of the different abundance measuring methods we have tried is presented in table 1.2, and described in the previous chapter. As Hamner et al (1975) we saw patch densities of gelatinous forms

(*M. ovum*) during diving which was not collected in net hauls. In Kongsfjorden the high abundance of *Clione limacina* did not appear in net hauls and we conclude it has similar escape responses as the Gymnostomates (Pteropoda) reported in Hamner et al (1975). The only species recorded in net samples at same frequencies as observed diving was *Limacina helicina*. *L. helicina* is also the only species, which does not fit the definition of gelatinous plankton presented in the introduction as it has a hard collectable shell.

Dive observations and the pilot studies made the basis for which animals we decided to work with. As a method for deciding abundance, dive observations are very inaccurate. It can just be used to conclude that when an animal is observed it has to be present. We observed *Limacina helicina* and *Mertensia ovum* at most stations, but other species may actually be present as individuals too small to be observed diving. Other species may also be present in densities too low to be observed on a dive or in locally abundant patches. On ice station 3 we did not observe any *L. helicina*, but recorded small specimens in net hauls.

On ice station 3 we observed a dense layer of *Limacina helicina* on the 38 MHz backscatter just after seeing it diving. A similar layer was observed at all ice stations and from ice station 3 to open waters. It may have occurred in the fjords but were not recorded as we were not aware of it. This is a type of zooplankton abundance measurement that needs further development.

Measuring distances between animals dispersed in water is very difficult. Animals are often spread and measuring gear limits measurements. Turbulence made by the diver complicates the matter. Using a rope turned out difficult as it limits measuring distance to the arm width of the diver, and two divers will make too much turbulence. Using a rod did not work due to too low densities. It may have worked at higher densities as it can be pointed at next animal without making turbulence. Our workgroup decided these measurements to be too complicated and to take too long, even though a rod at high densities and no water current might work.

The video recordings of a known volume were made at too low densities using a 8 litre volume. Only two single animals passed through the focus width of the video camera. A higher volume made by less zooming might work at such low densities, but fast passing animals might be a problem in water currents. At higher densities volumes of 8 litres might be appropriate for video recordings. We conclude as others that this is a promising field, which needs more investigation and especially development of an apparatus with a defined volume to record in.

We did not achieve abundance data from counting through a frame either. This was done on ice station 2, but high density of a layer of *Limacina helicina* was too dense to be counted. The diver was not able to count the amount of 50 to 100 animals passing through the frame at the same time with the water current. The full-face mask also turned out as a problem because the angle of view did not allow observation of the whole frame at the same time. On ice station 3 the method failed due to a too low density and due to no water current. The

spread animals did not pass the frame during the 15 minutes of measuring. Frames of all sizes are needed for different water currents and densities. Low densities demand a large frame and high densities demands smaller frames. The frame size should also become smaller as water current increases. With no water current recordings of a known volume with a video camera might be more appropriate, at least at low densities. The conclusion was that a combination of video recordings of known volumes and frame counting with a frame sizes depending on density and currents should be used for measuring abundance of gelatinous zooplankton.

### **Conclusions on abundance measurements and the pilot experiments.**

The diving observations told us that *Limacina helicina* and *Mertensia ovum* were the most abundant species. *Limacina helicina* is reported to be common in the Arctic and Antarctic (Gilmer & Harbison, 1991). Ctenophores *Mertensia ovum* and *Beroë sp.* are reported from 70° to 80° N in the Greenland Sea (Swanberg & Båmstedt, 1991). Pteropods of observable size were common at all stations except the last ice station, which consisted of Arctic water above 50 meters depth. Surprisingly *Beroë sp.* was just found at some stations, but this might just be a reflection of a low abundance due to the low densities of its prey, *Mertensia ovum*. Species observed diving were *Limacina helicina*, *Clione limacina*, *Mertensia ovum*, *Beroë sp.* and *Euphysa flammea* (tab.1.2.). *Mertensia ovum* was the only species observed on all stations, but this may be due to its size.

The conclusion from pilot experiments with *Clione limacina* was that experiments might not be successful because its prey, *Limacina helicina*, was in such a bad shape that it could affect the experiments too much. *Clione limacina* was therefore excluded as research animal even though diving observations showed high enough numbers for catching, and both pteropods were easy to catch. Improvement of keeping *L. helicina* on board ships should give a basis for further and successful behavioural experiments with the two species, as *C. limacina* was easy to keep. The pteropods are neither so easily damaged in net hauls and abundance data would come more easily to hand.

From the pilot experiments it was clear that *Mertensia ovum* was the natural choice as research animal as it was the only successful one. Advantages on determining predatory impact from behavioural feeding experiments were describes in the previous chapter, as abundance measurements are uncertain with methods available. Methods to measure abundance was tried to develop, but failed on all trials, and we concluded that experiments were easier to perform than getting good numbers of patch densities of gelatinous plankton. To estimate total impact as predators the number of patches also would have to be measured in some way, and this offered further difficulties. We therefore chose to focus on behavioural studies of *Mertensia ovum*, as this would give us a better measure of gelatinous plankton predatory impact. *Mertensia ovum* had turned out to be possible to sample, was abundant at all stations and fed in captivity. The pilot experiments made a basis for further development of experiments, called pilot experiments and later feeding experiments described in part 2.

## **Part 2: Feeding preference, clearance rate and different feeding modes of an Arctic Ctenophore, *Mertensia ovum* (Fabricius) from Svalbard waters**

### **INTRODUCTION**

The ctenophore *Mertensia ovum* (Tentaculata; Cydippida) is an Arctic species with a circumpolar distribution. Abundance records from Canada, Frobisher Bay, indicate that it

may occur as a key organism in Arctic planktonic ecosystems throughout the year (Percy 1989). It is a carnivore feeding on zooplankton. *M. ovum* feed on prey adhering to its tentacles. The tentacles are filamentous but strong and sticky. Thus the ctenophore is able to capture prey of different sizes from small copepods to large amphipods and krill, although large copepods are regarded as the main food source (Swanberg & Båmstedt 1991).

*Mertensia ovum* covers a large volume when its tentacles are spread out. An individual with the size of 4 cm was measured to have a total tentacular length of 161 m, and covers a sphere with a radius of 30 cm (Madin 1988). This enables the ctenophore to feed within a large volume. The predatory impact of *Mertensia ovum* on copepods is estimated to reach an average of 0.7% per day (Swanberg & Båmstedt 1991). *Mertensia ovum* is able to move fast and can swim with a velocity up to 13,4 cm/s (Matsumoto 1990).

Since *Mertensia ovum* has a major role in the Arctic ecosystem the aim of our study was to find out if it has any feeding preference, calculate the clearance rate and also study the feeding behaviour. This was performed as follows:

#### **A) Experiment with calanoid copepods**

A possible feeding preference was to be tested with two different size classes of *Calanus* sp. and clearance rate calculated.

#### **B) Experiments with the natural fauna of Arctic waters**

The feeding preference of *Mertensia ovum* in its natural habitat was investigated. Comparison of prey composition in the guts of experimental *Mertensia ovum* with the fauna of natural water used for the experiment.

#### **C) Gut content analysis of free-living *M. ovum* compared with zooplankton composition of natural water**

Comparison of gut content of free living *Mertensia ovum* with the fauna composition in water samples from depth of maximum *Mertensia* abundance.

#### **D) Study of feeding behaviour**

Diving for in situ observation of feeding.

## **MATERIALS AND METHODS**

### **Pilot experiment**

Aquaria with different volumes (1 l and 4 l) were used to get information about the size of aquaria needed for successful feeding experiments. Concerning volumes that have been used before, see Swanberg & Båmstedt 1991 and Chandy & Greene 1995.

Calanoid copepods were used as prey to see if the *Mertensia* feeds under laboratory conditions. The copepods were caught with a WP 2 net (mesh size of 180 µm) and held in a stock bottle of 0.5 l. A net with a mesh size of 1 mm and a diameter of 5 cm was fixed into the lid. This allowed a circulation of fresh seawater into it and achieved a sufficient food supply for the copepods.

The pilot experiments revealed that *M. ovum* was able to feed in captivity, with a feeding rate of approximately 1 copepod per hour and that a larger volume should be used in further experiments

### **Sampling and handling of live *Mertensia ovum***

The sampling of *Mertensia ovum* was done by scuba diving as described in part 1. It was found to be difficult to get the individuals through the narrow opening of the bottles without any damages of the tentacles. The sampling was therefore improved on ice stations 1,2 and 3. The scuba divers used 10 l buckets with lids as sampling containers. The ctenophore was slightly touched on its upper mouthpart before collection. This mechanical

disturbance made the animal withdraw its tentacles and the sampling could be done without any damages. (Hamner et al. 1975)

The experimental predators were transferred to acclimate into containers of 10 l and 25 l as soon as possible. The containers had been pre-cooled in the laboratory to a constant temperature of 1°C in a circulation water bath.

The experiments with calanoid copepods were done on ice station 1 and experiments with natural fauna on ice station 2 and 3. The gut content analysis of free sampled *Mertensia ovum* was done with specimens caught on ice station 2. Studies of feeding modes during diving at all ice stations

#### **A) Experiments with calanoid copepods**

Two *Mertensia ovum* were collected by scuba divers in 10 l buckets, transferred with a 0.5 l bucket into 25 l aquarium filled with filtered (45 µm) sea water and a circulation water bath. 50 calanoid copepods (collection and treatment described above) were used for each experiment. 25 *Calanus sp.* CIV-V (ca. 2mm) and 25 *Calanus sp.* adults (ca. 4mm) were picked out with a net spoon (mesh size 90 µm) by visual inspection from the stock bottle. The duration for the first four experiments was 6.5 h and for the two last experiments 4.5 h. After termination the water was filtered (45 µm) and remaining copepods counted.

The prey instantaneous mortality rates (m) and the predator clearance rate (F) were calculated from these experiments as follows (from Chandy & Greene 1995).

$$m = (-1/t) * \ln(C0/Cf)$$

t = experimental time(h)

C0 = number of prey at start of exp.

Cf = number of prey left after end of exp.

$$F = (V*m)/P$$

V = experimental volume (l)

P = number of prey in experiment

#### **B) Experiments with the natural fauna of Arctic waters**

Water samples from the natural environment of *Mertensia ovum* were collected with seven Niskin water bottles (5 l) connected to a CTD. The set-up was used twice and 25 l from each time was carefully transferred to one of the experimental container. The remaining water from both collections was filtered through a 90 µm sieve for later estimation of the natural copepod composition of this habitat and time. The depth of highest abundance of *M. ovum* had been determined during its collection to be at 15m on ice station 2 and 5 m on ice station 3.

The seawater in the aquaria was equilibrated to a temperature of 1°C with a circulation water bath. The ctenophores were starved for 12 h in filtered water (90 µm) in advance to make sure that all prey found in their guts came originally from the experiments and the time was set to 3 h as done by Chandy & Greene 1995.

The transfer of *M. ovum* to the starving container was done via two washing steps to avoid an import of copepods.

After termination of the experiments the water was filtered (90 µm) and the guts were cut out, preserved in 4% formaldehyde and frozen for later analysis at the laboratory at UNIS.

#### **Analysis of the water samples**

The estimation of copepod species and their abundance in the samples were done on board R/V JAN MAYEN and at laboratory at UNIS. There were taken sub-samples of 2 ml with an automatic pipette out of a 100 ml solution containing the filtered copepods for their identification and counting. To ensure an error margin of less than 20% a minimum of 100

*Oithona sp.* was counted. The whole sample was scanned for *Calanus sp.* A Leica-Wild stereoscopic microscope with the magnification of 16 and 40 was used.

### Analysis of the gut contents

The content of the guts of six free-living *Mertensia ovum* were analysed in the laboratory at UNIS. The digestion parts were cut out generously to avoid any methodical loose of material. The sample was taken on a slide and scanned in a Leitz compound microscope and a magnification of 40 and 100. The copepods found were identified and the prosome length and width was measured

C) Gut content analysis of free-living *M. ovum* compared with zooplankton composition of natural water

The depth of highest abundance of *M. ovum* was determined by scuba diving during collection with a hand held net. The oral-aboral length was measured, the specimens were preserved in 4% formaldehyde and stored cool until dissection.

The natural fauna composition was collected with three different methods.

One vertical net from 20 m depth was taken from the ice edge. A horizontal net was taken at 20 m by scuba divers over a distance of 24 m. Water was also collected with Niskin water bottles from 15 m depth. The water was filtered through a 90 µm sieve.

The analysis of water and gut samples were performed as described above.

## RESULTS

A) Experiments with calanoid copepods

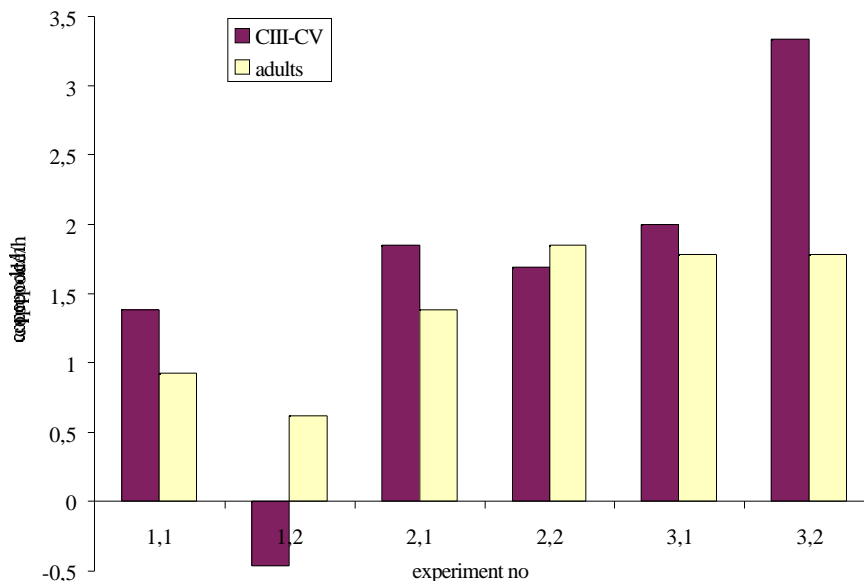


Fig. 2.1. Number of small (CIII-V) and large (adults) copepods eaten by six *Mertensia ovum*

Figure 2.1. shows the eaten amount of copepods for the different individuals of *M. ovum*. There is no significant difference in the feeding between the size classes of *Calanus sp.* at  $\alpha = 0.05$  (pair comparison t-test  $P = 0.52$ ;  $n = 6$ ). No significant correlation can be seen between the size of *Mertensia ovum* and the size class of *Calanus sp.* either ( $R^2(2mm) = 0.04$ ;  $R^2(4mm) = 0.52$ ).

Table 2.1. Estimated clearance rate ( $\pm$  95% KI) of *Mertensia ovum* feeding on *Calanus sp.* (CIII-adults)

	<b>Clearance rate (l/ind/h)</b>	<b><math>\pm</math> 95% KI</b>	<b>n</b>
From exp. water	1,9	0,9	6
From gut+tent.	0,58	0,11	6

The size of *M. ovum* seems not to be correlated with the clearance rate ( $R^2(\text{aquaria}) = 0.34$ ;  $R^2(\text{stomach}) = 0.02$ ). The number of copepods in stomach also includes copepods at tentacles.

**B) Experiments with the natural fauna of Arctic waters**

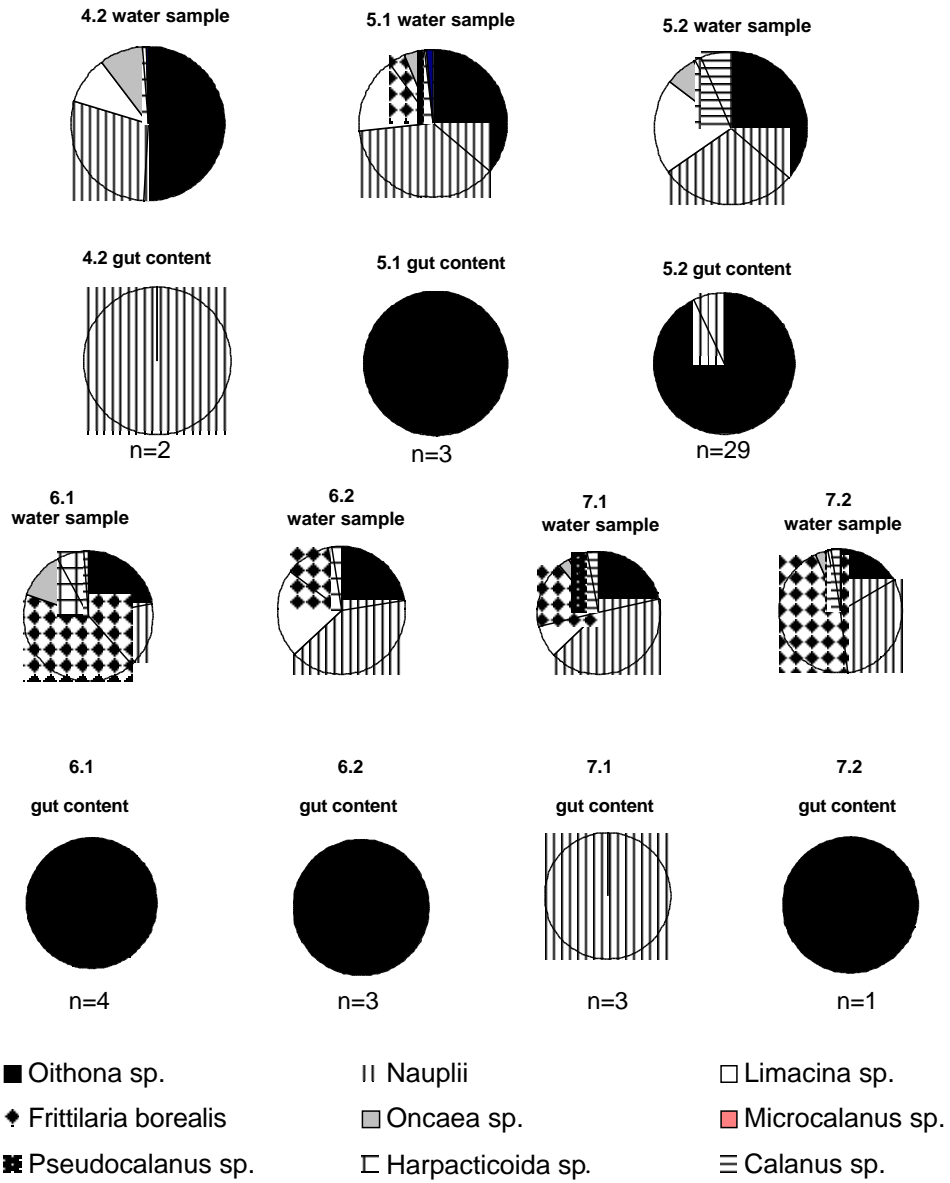


Fig.2.2 Zooplankton composition in experiment water and gut content of *Mertensia ovum*

Experiment 4 and 5 was done at ice station 2 and experiment 6 and 7 at ice station 3. The gut of *M. ovum* in experiment 4.1 was empty. 60-70% of the species found in the guts after the experiments was *Oithona* sp., while the remaining part was naupliar larvae. In addition to *Oithona* sp. and naupliar larva, the experimental water was comprised of young

*Limacina helicina* and *Fritillaria borealis*, sometimes in high abundance. Non of these species were present in the guts. Also *Calanus sp.*, *Pseudocalanus sp.*, *Microcalanus sp.*, *Oncaea sp.*, and the order *Harpacticoida* was present in water but always in low abundance.

C) Gut content analysis of free-living *M. ovum* compared with zooplankton composition of natural water

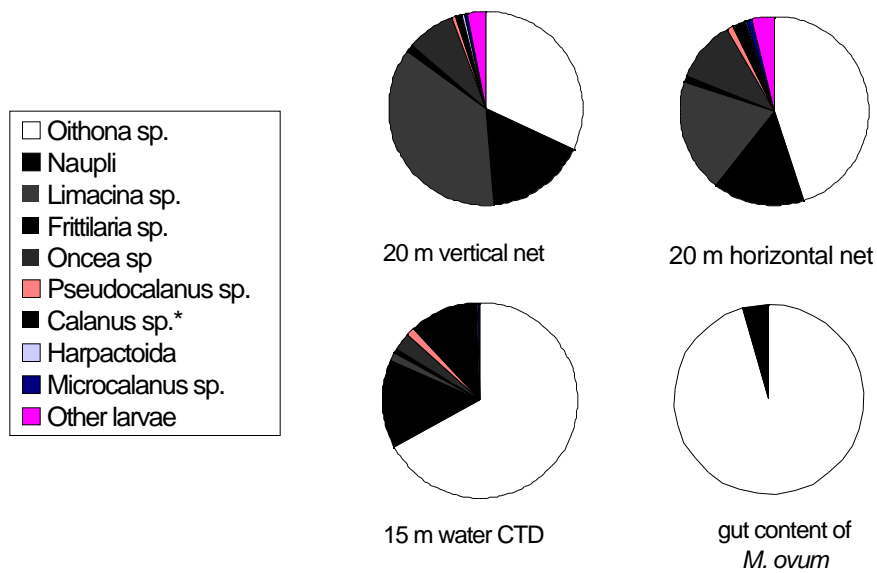


Fig. 2. 3. Faunal composition of natural water sampled with three different methods compared to the gut content of free-living *Mertensia ovum* based on four individuals

Four individuals of six analysed *M. ovum* contained either Nauplii or *Oithona sp.* No other species were found in the guts of the free-living *Mertensia ovum*. In two of the ctenophores no structures of food items were found.

#### D) Feeding modes

There were two different manners of tentacle arrangements observed during scuba diving.

##### $\Omega$ mode

The tentacles are spread out widely to both sides of the body. This makes a row of tentillae spread out in all directions so that the distance between the tentillae becomes as large as possible (see fig 2.4).

Fig 2.4: Description of  $\Omega$  mode: *Mertensia ovum* with tentacles spread out widely.

##### mode

Here the tentacles hang downwards, and tentillae are spread towards each other. This minimises the distance between each tentillae (see fig 2.5).

Fig 2.5: Description of mode: *Mertensia ovum* with tentacles downwards.

## DISCUSSION

*M. ovum* was found to cope with disturbances like ship vibrations or movements in long-term experiments (Swanberg & Båmstedt 1991). Therefore we assume our results not to be affected by these parameters.

#### A) Experiments with calanoid copepods

We found that *M. ovum* did not have a feeding preference for large or small copepods in these experiments. This can be due to lack of feeding preference, but it can also be explained by our method of picking out calanoid copepods. The sizes in the two size classes were not properly measured just roughly checked by visual inspection. The negative

amount in the group of the CIII-CV in the experiment 1.2 is likely to be due to this sorting method.

The fact that more copepods were found in the gut content of animals in exp. no. 3 can be due to our improvement to dissect

Since we are not sure that the division of copepods into different size classes worked out, those results are not reliable. The correlation between the size of *M. ovum* and the size group of its prey is strongly dependent on an accurate division of copepods into size classes. Our experimental data does therefore not exclude that there might be such a correlation.

The clearance rate was calculated from the total amount of calanoid copepods since we realised the problem to distinguish the size classes.

The clearance rate of  $1.9 \text{ liter} \cdot \text{predator}^{-1} \cdot \text{h}^{-1}$  calculated from the amount of copepods remaining in the aquaria was higher than the clearance rate from the gut content estimated to  $0.58 \text{ liter} \cdot \text{predator}^{-1} \cdot \text{h}^{-1}$ . This is probably due to that the experimental time exceeded the digestion time. Sullivan & Reeve (1982) calculated mean digestion times for ctenophores in general to be  $1.7 \pm 0.6 \text{ h}$  (mean  $\pm$  SD, one food item) and  $2.2 \pm 0.7 \text{ h}$  (mean  $\pm$  SD, several food items). The mean clearance rate of  $1.9 \text{ liter} \cdot \text{predator}^{-1} \cdot \text{h}^{-1}$  can be compared to clearance rates for the ctenophore *Pleurobrachia bachei* of 0.2 and  $0.5 \text{ liter} \cdot \text{predator}^{-1} \cdot \text{h}^{-1}$  depending on type of prey (Chandy & Greene 1995). The higher clearance rate of *M. ovum* is probably due to larger size compared with *P. bachei*. That size of *M. ovum* did not correlate with clearance rate can be due to the size of the experimental containers. They were probably too small at least for the large *M. ovum*. In nature one would definitely expect a strong correlation between size of *M. ovum*, and clearance rate.

Copepods in stomach also include copepods at tentacles because observations during experiment showed that *M. ovum* not always feed directly after catching the prey. It was observed that *M. ovum* sometimes could catch 3 large calanoid copepods before it fed.

B) Experiments with the natural fauna of Arctic waters

and

C) Gut content analysis of free-living *M. ovum* compared with zooplankton composition of natural water

In case of no preference for size or species the gut content of free-living ctenophores would contain the same or similar composition of species as found in the water samples. Only *Oithona sp.* and Nauplii were found in the gut. Table 2.2 shows the fractions of *Oithona sp.* and nauplii in the guts and in the water at different ice stations.

Table 2.2: Fractions of *Oithona sp.* and Nauplii larvae in experiment water and in guts of *Mertensia ovum* at ice station 2 and 3 and free living *M. ovum*, water sample and net samples from Ice station 2 (derived from figure 2.2 and 2.3)

	Ice station 2 - experiments		Ice station 3 - experiments		Ice station 2 - free sampled	
	water	gut, n=3	water	gut, n=4	water	gut, n=4
<i>Oithona sp.</i>	41%	65%	20%	75%	30-60%	95%
Nauplii	31%	35%	32%	25%	15-20%	5%

## Probable explanations for species not represented in the guts of *Mertensia*

*Limacina helicina* could possibly escape from the tentacles of *M. ovum* even though its feeding net (see part 1 of the report) is caught. The shell of *L. helicina* might also be hard to digest.

Members of *Fritillaria borealis* are known to leave its house as reaction to disturbances. This can explain why *Fritillaria borealis* were not found in the guts. *Fritillaria borealis* also contains no hard body parts, and might not be recognised in the *Mertensia* guts.

The remaining species might have been present in too low abundance to be caught.

## Comparison of the two species represented in the gut of *Mertensia*

Nauplii-larvae were represented by similar fractions in guts as in the water. *Oithona* sp., is on the other hand highly over represented. Morphological, biochemical or behavioural features of *Oithona* compared with nauplii can give possible explanations for this.

We believe that size and swimming behaviour is important. Even though the fine tentillae of *Mertensia* has shown to be able to catch nauplii, it might be too small to be caught regularly. This can explain why *Oithona* usually was caught in much higher numbers than nauplii.

We conclude here that *M. ovum* seem to have a preference for *Oithona* sp. compared with *Limacina helicina* and *Fritillaria borealis*. A preference is also seen for *Oithona* sp. compared with Nauplii but this preference is less pronounced.

### D) Feeding modes

It seems reasonable to relate the different organisation of the *M. ovum* tentacles and tentillae, to differences in access and types of prey present. A feeding net organisation that brings the tentillae close together will be more efficient to catching small and abundant prey. On the other hand will widely spread tentillae search a larger volume, and thus catch larger and scarcely distributed prey. On Ice station 2, the -feeding mode was observed. This coincided with high abundance of small copepods (mostly *Oithona* sp.), and only *Oithona* sp. and nauplii was found in the *M. ovum* guts. On Ice station 3, -feeding was observed. Unfortunately no gut content analysis was done at this station, but zooplankton counts revealed that total zooplankton abundance was an order of magnitude lower than at Ice station 2, and with a slightly larger fraction of *Calanus* sp.

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**APPENDIX:  
CRUISEACTIVITIES AND PHYSICAL PROPERTIES OF STATIONS.**

Date	Place	Activity outbaord	Activity on board	Depth (m)	% ice	wind velocity	Ice drift
10/9 -98	Kongs- fjorden	None	Planning	380	0	0,4 m/s	None
11/9 -98	K.fjord: Kvade- hukun	Diving collect Measure	Planning & Exp. Design	30	0	0 m/s	None
12/9 -98	Wood Fjorden	Diving Collect	Pilot experim.	30	0	2 m/s	None
13/9 -98	Sailing	None	Planning				
14/9 -98	Ice station 1 0900	Diving Collect measure	M. ovum & Calanus	692	80	10 m/s	High
15/9 -98	Ice station 1 0900	Diving Collect measure	M.ovum & Calanus	274	80	3 m/s	High
16/9 -98	Rossøya	Diving collect	Filming				
17/9 -98	Ice station 2 0900	Diving collect measure	M.ovum & nat. fauna	1387	80	1 m/s	Low
18/9 -98	Ice station 2 0900	Diving measure	Treating data, planing	1698	80	0 m/s	None
19/9 -98	Sailing	None	Treating data			5 m/s	
20/9 -98	Ice station 2 0900	Diving collect	M.ovum & nat. fauna	2977	80	5 m/s	Medium
21/9 -98	Ice station 2 0900	None	Treating of data	2463	50	20 m/s	High
22/9 -98	Sailing	None	Washing				