Entrapment of macroplankton in an Arctic fjord basin, Kongsfjorden, Svalbard*

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Abstract

This paper presents the results of 15 zooplankton tows collected with a Tucker Trawl (1 m^2 opening, net of 2 mm mesh size) in Kongsfjorden (79°N), Svalbard archipelago. The hydroacoustic survey revealed clear differences between the plankton concentrations in the outer and inner fjord basins. Plankton concentrations and fish were observed in the outer fjord, while uniformly scattered objects were detected in the inner basin. The macroplankton community was dominated by Euphausiacea (*Thysanoessa inermis*, *Thysanoessa rashii*), Amphipoda (*Themisto libellula*) and Pteropoda (*Limacina helicina*). Other taxa were of minor numerical importance. The macroplankton abundance reached 3300 indiv. 100^{-1} m^{-3} with a maximum biomass of 100 g wet weight 100^{-1} m^{-3} (over 440 kJ 100^{-1} m^{-3}). *L. helicina* was advected into the fjord with surface waters, and was found in large

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abundance (1000 indiv. 100^{-1} m^{-3}) in the subsurface layers of the inner basin. Euphausids were present in small numbers at the entrance to the fjord, but were found to be very abundant (600 indiv. 100^{-1} m^{-3}) at the innermost stations, especially in the surface water layer. The estuarine circulation driven by the glacial meltwater discharge is believed to cause the entrapment of zooplankton in the inner fjord basin.

1. Introduction

Arctic glaciated fjords are characterised by linear environmental gradients: the tidal glacier at the head of the fjord discharges freshwater and suspensions, thus conditions change from stable marine at fjord entrances to very unstable brackish in inner fjord basins (*cf* Freeland *et al.* 1980, Syvitsky *et al.* 1984). Following this axial gradient, mesozooplankton typically dominates the inner fjord basins with small, brackish water forms (mainly *Pseudocalanus* spp.) while the outer areas are dominated by *Calanus* spp. (Matthews & Heimdal 1980). Represented mainly by hyperid amphipods and euphausids, the macroplankton are difficult to sample quantitatively, so information on the occurrence of this ecological group in the study area is scarce. Indirect observations by Hartley & Fisher (1936), Dunbar (1951) and more recently by Mehlum (1984) have shown that the abundant macroplankton is used extensively by seabirds feeding close to the tidal glaciers in the Arctic. Within the BIODAFF (Biodiversity and Fluxes in Arctic Glaciated Fjords) project, we have clear evidence that environmental gradients exist along Svalbard's Kongsfjorden axis (Beszczyńska *et al.* 1997, Węsławski & Legeżyńska 1998, Keck *et al.* 1998). The aim of the present paper is to study how the macroplankton reacts to such gradients and how its distribution is affected by their existence.

2. Materials and methods

Sampling was carried out from r/v 'Oceania' during a BIODAFF cruise to Kongsfjorden from 12 to 17 July 1996. A Tucker Trawl with a 1 m^2 opening and a 2 mm mesh size net was hauled horizontally for 10 minutes at 2 knots. Hauls were performed in the surface (20 to 0 m) layer without net closure at the end of the haul. The bottom (200 to 20 m) layer was sampled with the net closed at 20 m, the end of the haul. Samples were preserved in 4% buffered formaldehyde and analysed in the laboratory four months later. Organisms from the whole sample were identified and counted. The total length was measured from a sub-sample of intact specimens (the diameter of *Limacina* shells, the rostrum-to-telson length of crustaceans). Mean individual weights of molluscs, crustaceans and fish were established after blotting formalin-preserved specimens on filter paper and weighing complete specimens to an accuracy of 1 mg. Comb jellies and medusae were counted, and their total volume in each sample was measured and divided by the number of specimens to obtain the 'mean individual biomass' (1 cm^3 = 1 g wet weight in gelatinous plankton). Separate macroplankton subsamples collected on board were frozen and analysed for energy and water content (microbomb calorimetry; samples analysed by Dr Monika Normant at the University of Gdańsk). For species missing from the 1996 subsamples, data on energy and water content were taken from samples collected in Kongsfjorden in 1995. Hydroacoustic measurements were collected with a Honeywell-Elac LAZ 4700 echosounder working at 30 kHz frequency with a pulse equal to 1 ms and a repetition rate of 1 s. Acoustic measurements were performed during two days, in calm weather, between 18.00 and 04.00 hours under full polar day conditions. Results were filtered to reduce the double signal and noise. Data on hydrography, phytoplankton and mesozooplankton were collected simultaneously and have been presented in other publications (Beszczyńska *et al.* 1997, Keck *et al.* 1998, Kwaśniewski unpublished data).

3. Study area

Kongsfjorden is a medium-size (30 x 12 km) Spitsbergen fjord, without a sill, at the entrance to the Greenland Sea (Fig. 1). The outer fjord is > 300 m deep and is separated from the inner basin by a sill at 30 m depth. The inner basin is expanding owing to the rapid retreat of

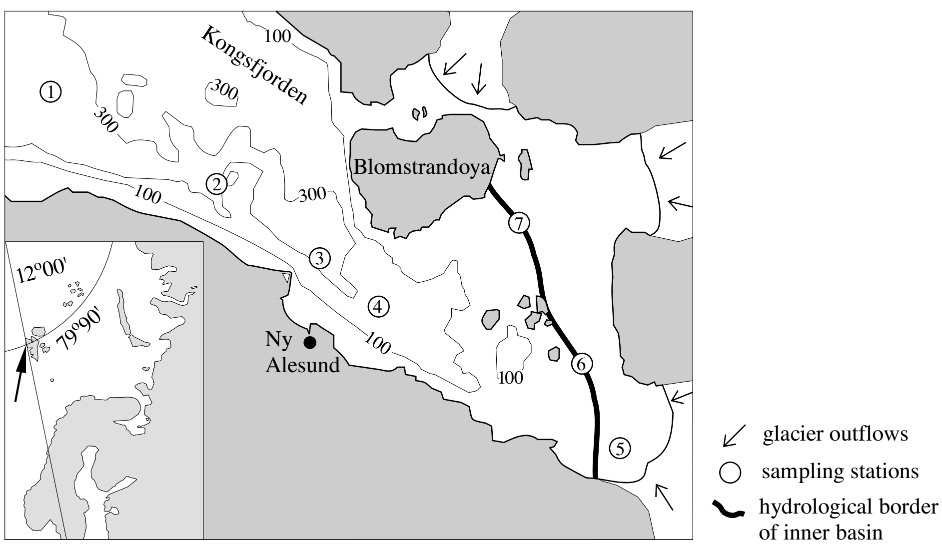

Fig. 1. Study area with sampling stations (1 to 7), July 1996

the glaciers (Elverhoi *et al.* 1983, Lefauconnier *et al.* 1994). Two large glaciers annually discharge some 0.5 km^3 of freshwater and sediment into the fjord (Lefauconnier *et al.* 1994, Beszczyńska *et al.* 1997). The hydrological regime is as follows: surface waters consist of freshened local waters, the intermediate layer of Coastal Spitsbergen Waters, while the near-bottom layer is dense water of winter origin (Węsławski *et al.* 1991, Beszczyńska *et al.* 1997). According to CTD-based calculations of geostrophic flows, marine waters enter Kongsfjorden along the southern coast at surface and intermediate depths, while local waters flow out at the surface along the northern shore. Summer chlorophyll *a* concentrations are relatively high in the outer fjord but low in the inner basin. Primary production is high is spring (2500 mg C m^{-2} day^{-1}), but much lower in the summer (700 mg C m^{-2} day^{-1}) (Wiktor unpublished data). The phytoplankton biomass may reach 50 mg m^{-3} at the peak of the bloom. Fecal pellets indicative of zooplankton grazing were found at concentrations of 140 mg C m^{-2} (high) in the outer fjord and 4 mg C m^{-2} in the inner basin (op. cit.). The mesozooplankton of Kongsfjorden is dominated by small forms, mainly *Pseudocalanus acuspes*, in the inner basin, while large *Calanus finmarchicus* and *Calanus glacialis* prevail in the outer fjord part (Węsławski *et al.* 1991, Kwaśniewski unpublished data).

4. Results

Data obtained from 15 Tucker Trawl hauls are presented in Table 1, which lists 19 taxa over 5 mm in size. The most numerous plankton species was the pteropod *Limacina helicina*, occasionally reaching abundances of 1000 individuals 100^{-1} m^{-3}, followed by the hyperid amphipod *Themisto libellula* (300 indiv. m^{-3}) and the euphausid *Thysanoessa inermis* (150 indiv. 100^{-1} m^{-3}). The abundances of other taxa lay below 50×100^{-1} m^{-3}, and five were found as single specimens only (Table 1). Macroplankton biomasses ranged from 2 to 100 g (mean 32) wet weight per 100 m^3. Because of their high individual energy content, euphausids contributed more to the caloric value of the sample than to the wet biomass, while *Thysanoessa* usually made up the bulk of the energy content in the sample (Table 1).

The distribution of major plankton taxa along the fjord in surface and subsurface waters is shown in Fig. 2. In the top 20 m, large numbers of *L. helicina* and *T. libellula* were found at the entrance to the fjord (station 1), while *T. inermis* was abundant only at the innermost stations (station 6 and 7). No macroplankton were present at station 5, as this is situated close to the glacier front (Fig. 2). The subsurface layer (from 20 m to the bottom) reveals a different pattern: *L. helicina* and *Themisto* are abundant

Table 1. Data on the mean individual wet weight, energy content and abundance of the macrozooplankton taxa examined, Kongsfjorden, July 1996

Taxon	Mean individual wet weight [mg]	Number of measurements	Wet weight standard deviation [SD]	Mean individual energy content [kJ g^{-1} d.w.]	Mean water content [%]	Mean density in all samples [indiv. 100^{-1} m^{-3}]	Mean biomass in all samples [g w.w. 100^{-1} m^{-3}]	Mean energy content in all samples [kJ 100^{-1} m^{-3}]
Ctenophora								
Beroe cucumis Fabricius	500	6	300	6.4	97	6.3	3.2	19.7
Mertensia ovum Fabricius		*						
Cnidaria								
Euphysa flammea (Linko)	30	3		6.4	97	0.2	0.0	0.0
Sarsia spp.		*						
Mollusca								
Clione limacina (Phillips)	167	15	93	14.6	93	1.0	0.2	2.3
Limacina helicina (Phillips)	56	20	19	15.0	88	318.0	17.8	235.3
Crustacea								
Calanus hyperboreus Kroyer	4.9	15	3.1	22.0	85	1.7	0.0	0.2
Eupagurus pubescens Kroyer zoea		*						
Gammarus wilkitzkii Birula		*						
Pandalus borealis Kroyer larvae	5.3	5	2.1	16.0	75	0.2	0.0	0.0
Sabinea septemcarinata (Sabine) larvae	9.9	4	10	16.0	75	0.7	0.0	0.1
Themisto abyssorum (Boeck)	12	10	14	19.8	80	0.5	0.0	0.1
Themisto libellula (Mandt)	16	95	20	19.8	80	292.0	4.7	74.1
Thysanoessa inermis (Kroyer)	113	60	16	25.0	75	50.0	5.7	106.3
Thysanoessa rashii (M. Sars)	62	30	8	23.0	80	1.3	0.1	1.4
Chaetognatha								
Sagitta elegans Aurvillius	56	10	27	17.0	85	0.1	0.0	0.1
Pisces								
Boreogadus saida (Lepechin)	40	15	34.5	20.0	80	0.3	0.0	0.2
Liparidae larvae		*						
Lumpenidae larvae	81	5	75	20.0	80	0.1	0.0	0.2

∗ – single specimens.

in the inner fjord basin but scarce at the entrance, while *Thysanoessa* remains dominant in the inner fjord area, as was the case in the surface layer. Ctenophores and other taxa do not display any particular distribution pattern. As in the surface layer, macroplankton was very scarce at the glacier front (station 5) (Fig. 2).

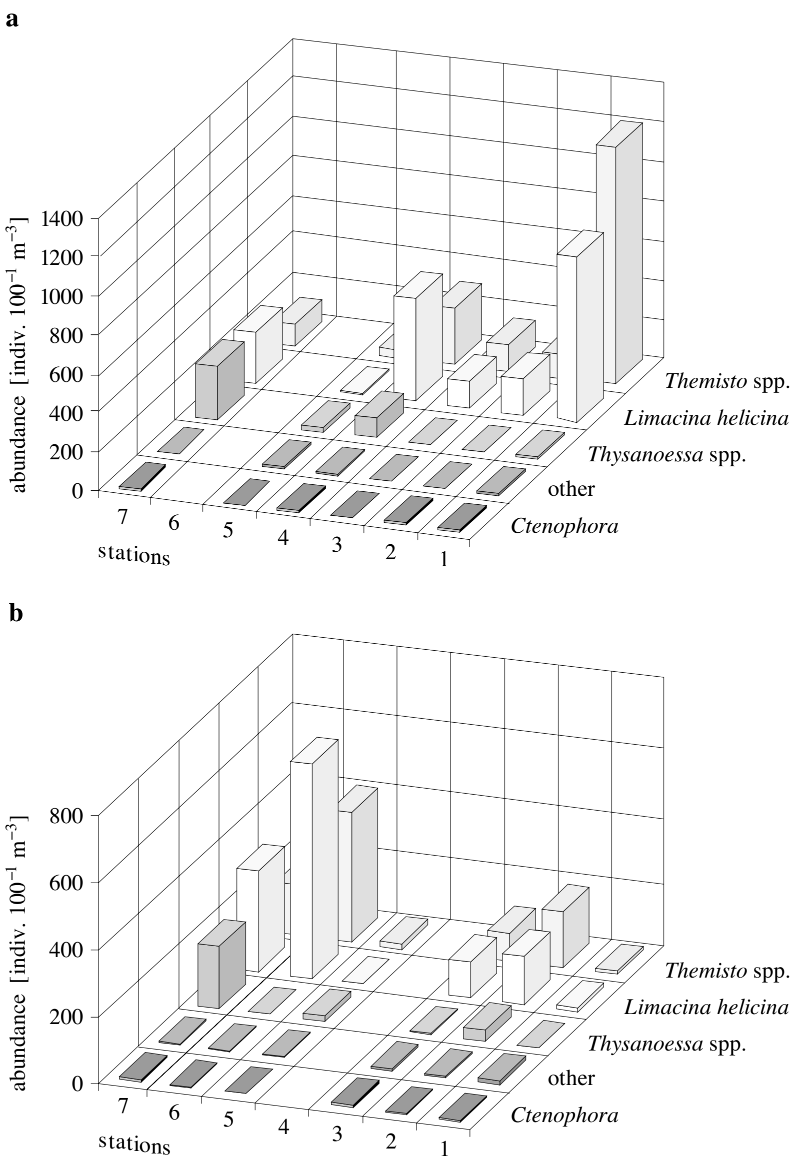

Fig. 2. Abundance of major macroplankton taxa in the 0–20 m water layer (a) and the 20 m-to-bottom water layer (b), from station 1 to 7, Kongsfjorden, July 1996

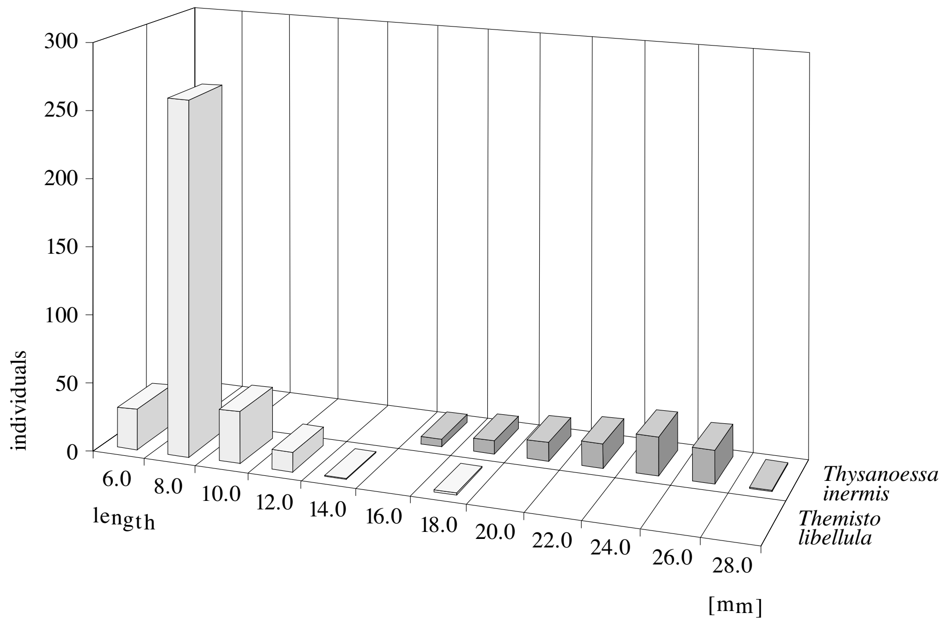

Fig. 3. Length frequency distribution for *Thysanoessa inermis* and *Themisto libellula*, data pooled from all samples

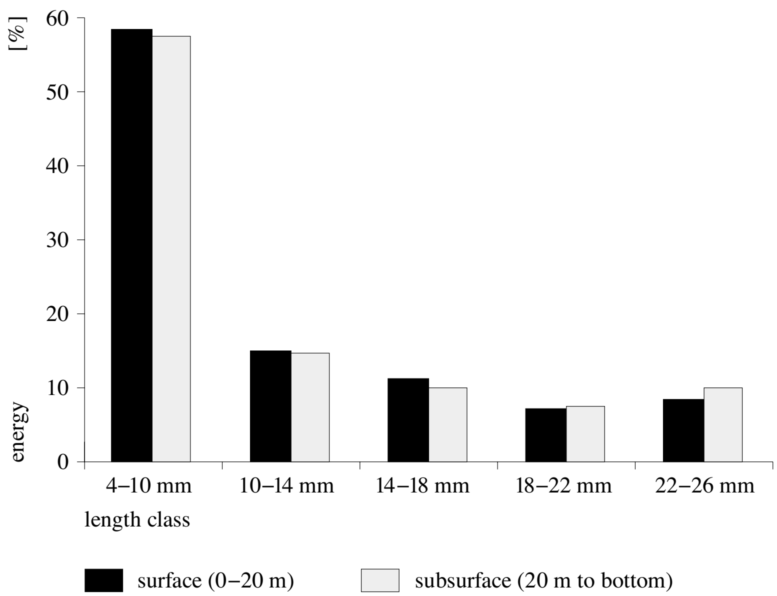

Fig. 4. Contribution of different size groups to the energy content of all samples examined in the 0–20 m and the 20 m to bottom water layers, Kongsfjorden, July 1996

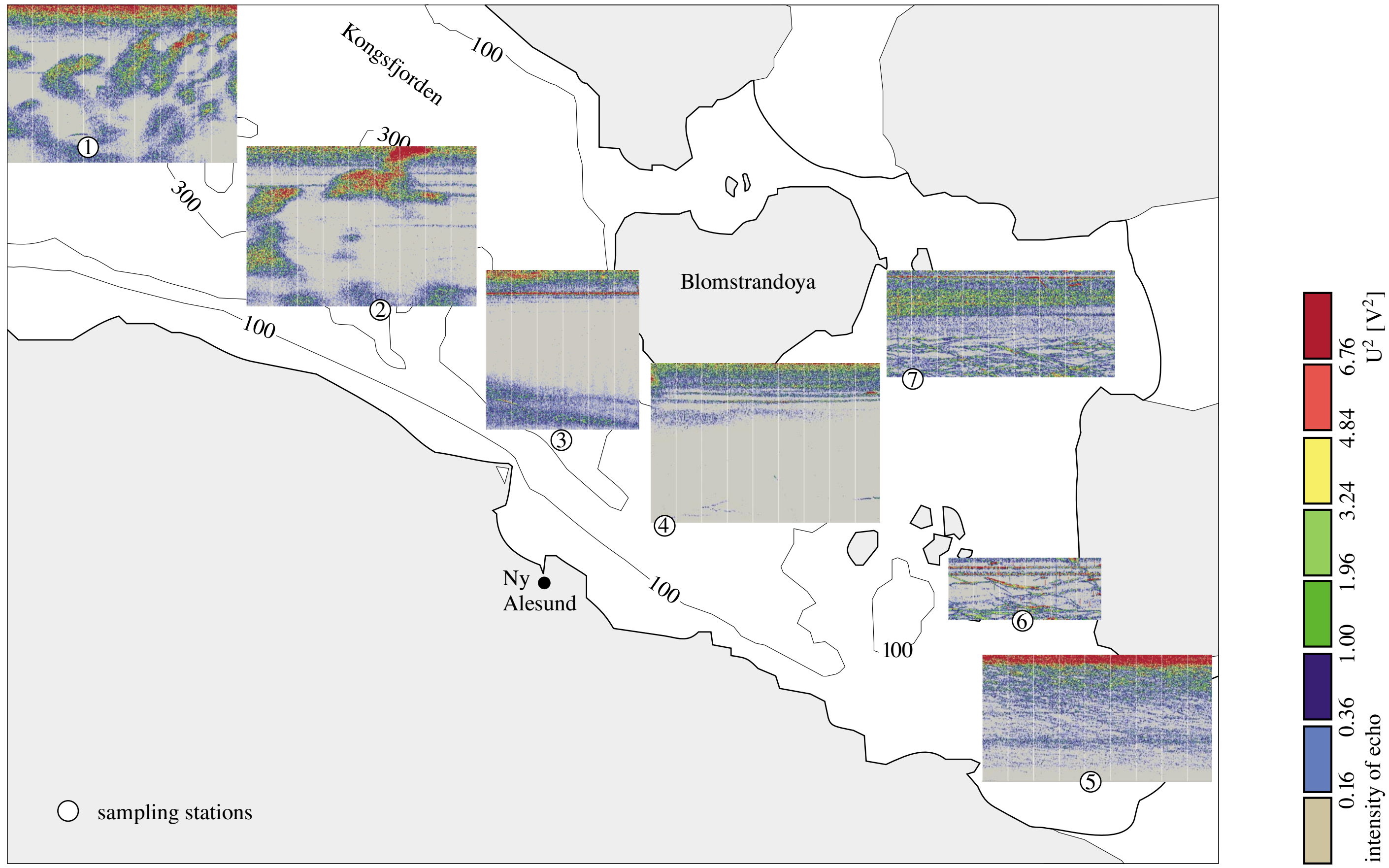

Fig. 5. Hydroacoustic cross-section in Kongsfjorden at stations (1 to 7) where Tucker Trawl samples were collected

The length frequency distribution of the major taxa examined shows that the samples from the surface and subsurface layers at the different stations consisted of individuals of similar size. Among *T. inermis*, nearly all specimens were fully grown individuals 22–26 mm in length. *T. libellula* consisted of two cohorts – a very numerous group of small, juvenile specimens of 6–8 mm and a less abundant group of sub-adult individuals 12–14 mm long (Fig. 3). All specimens of *L. helicina* fit into the 4–10 mm size class. Considering the macroplankton examined at all stations in terms of energy, almost 60% of this is due to animals from the 4–10 mm size group in both the surface and subsurface layers (Fig. 4).

This pattern of macrozooplankton distribution in the fjord was confirmed by echosoundings, which show two different types of plankton aggregations in the outer and inner fjord basin (Fig. 5). The outer area (stations 1 and 2) is characterised by large, dense patches of plankton, distributed more or less evenly from a depth of 15 m down to 300 m. Surface plankton concentrations in the central fjord are low (stations 3 and 4), with no aggregations below 100 m. The inner basin (stations 5, 6 and 7) contains evenly distributed, scattered objects. A number of fish echoes were detected at station 6 and 7 close to the bottom. However, fish do not appear to form any shoals here (Fig. 5).

5. Discussion

Species list

The list of taxa obtained in our samples is typical of the coastal Svalbard waters, containing as it does a mixture of Atlantic elements (*Themisto abyssorum*), Arctic (*T. libellula*, *L. helicina*, *Gammarus wilkitzkii*) and ubiquitous species (*Beroe cucumis*, *Mertensia ovum*, *Eupagurus larvae*, *Thysanoessa* spp.). All these species are common and abundant forms in the area (Węsławski & Kwaśniewski 1989, Gilmer & Harbison 1991, Węsławski *et al.* 1991, Loeng *et al.* 1995). The absence of appendicularians, commonly reported from West Spitsbergen waters in summer (Węsławski *et al.* 1991, Loeng *et al.* 1995), may suggest that tunicates tend to avoid the sediment-laden fjord waters.

Abundance and biomass

Comparison with other data is difficult owing to differences in the sampling gear used. However, the abundance of macroplankton in our samples is very high. In the Barents and Greenland Seas *Themisto* occurs in concentrations from 1 to 50 specimens per 100 m^3 (Koszteyn *et al.* 1995, Loeng *et al.* 1995). Euphausids rarely exceed 10 indiv. 100^{-1} m^{-3} on the

Svalbard shelf (Dalpadado & Skjoldal 1991, Drobysheva & Timofeev 1991, Loeng *et al.* 1995). According to Gilmer & Harbison (1991), concentrations of *L. helicina* in the Greenland Sea can reach 250 indiv. 100^{-1} m^{-3}. Ctenophores occur at an average abundance of 0.4 indiv. 100^{-1} m^{-3} (Swanberg & Bamsted 1991). The chaetognath concentrations in Kongsfjorden lay within the range of abundance reported for the open Norwegian and Barents Seas – 0.1 to 2 indiv. 100^{-1} m^{-3} (Falkenhaug 1996). The abundance of macroplankton reported in our study fits into the upper ranges of those reported in the cited literature. The biomass of macroplankton found in the inner basin of Kongsfjorden in our study (over 440 kJ 100^{-1} m^{-3} or about 32 g wet weight 100^{-1} m^{-3}) is similar to the macroplankton biomass previously reported from Svalbard fjords – 130 to 490 kJ 100^{-1} m^{-3} (Węsławski *et al.* 1991).

Size

The local population of *T. libellula* consisted of juveniles, probably hatched in April, which by midsummer reach a length of 8–9 mm (Koszteyn *et al.* 1995). Euphausids were represented by adult specimens close to the species-specific maximum size (Lomakina 1978, Loeng *et al.* 1995). The same applies to *Limacina*, no juvenile specimens of which were found in our samples.

Food

The summer distribution of phytoplankton in Kongsfjorden gives rise to two distinctly different feeding grounds for pelagic herbivores, namely, the marine area at stations 1, 2 and 3 dominated by Chrysophycae, Dinophycae and Diatomea, and the inner fjord basin (stations 4, 5, 6 and 7), where minute flagellates are the only phytoplankton present (Keck *et al.* 1998). Some of the observed plankters are opportunistic omnivores (*L. helicina*, *Thysanoessa rashii*), others are herbivores (*T. inermis*) or carnivores (*T. libellula*). A similar division obtains in the mesozooplankton distribution. At the outer stations the abundance of copepods is high and there is a large quantity of fecal pellets in the water column (pellets from 30 to 140 mg C m^{-2}). The inner fjord basin by comparison is poor in copepods with a very low fecal pellet count (4 mg C m^{-2}) (Kwaśniewski & Kotwicki unpublished matterials). With both phytoplankton and mesozooplankton scarce in the inner basin, this area appears to be an unpropitious feeding ground for macroplankton.

Light and suspensions

Macroplankton is exposed not only to salinity/temperature gradients, but also to abrupt changes in water transparency and the content of suspended fine mineral particles in Kongsfjorden. The water transparency falls from 14 metres (optical coefficent $C < 1$) at the fjord's entrance to less than 0.5 m (coeff. $C > 9$) at station 5 in the inner basin (Keck *et al.* 1998). The reduction of visibility is accompanied by the increased risk of the animals' filtering apparatus becoming clogged with fine suspended particles. The food is also dispersed in a large volume of discharge waters.

Fjord trap scenario

Advection has been reported as an important factor concentrating krill in Norwegian fjords (Matthews & Heimdal 1980, Falkenhaug *et al.* 1995). Dunbar (1951) reported local upwelling as the hydrological force concentrating plankton in fjords. Two papers, by Perkin & Lewis (1978) and Franks (1992), describe the mechanism of physical entrapment of plankton in fronts, Langmuir cells and similar dynamic phenomena. In our case, the reason for the unusually high concentration of macroplankton in the inner basin (stations 6 and 7) might be entrapment by an estuarine type of circulation. Macroplankton enters Kongsfjorden with the inflow of marine waters along the southern coast. On reaching the area around station 5, it evades the turbid and freshened glacial outflow waters, floating with the residual current to the northern branch of the fjord, where the water is less turbid and freshened (Beszczyńska *et al.* 1997). The return current flows along the surface carrying brackish and turbid water, hence macroplankton avoids this outflow and remains within the basin. In this scenario, the northern basin of Kongsfjorden acts as the marine plankton trap, which starts to operate in June during the early summer start of glacial discharge and ends in late September with the diminished freshwater outflow (Węsławski *et al.* 1995). Since it is not food that attracts macroplankton into the inner Kongsfjorden basin, hydrological forces are very likely responsible. A relatively high biomass of macroplankton is concentrated in a restricted, shallow area, which makes it interesting to top predators. The innermost basin of Kongsfjorden has often been reported as an important feeding ground for seabirds (Mehlum 1984) and for ringed seals, which in summer change their diet there from fish to euphausids (Węsławski *et al.* 1994). The mass mortality of zooplankton induced by the freshwater input in the vicinity of station 5 can be adduced in support of this particular scenario (Węsławski & Legeżyńska 1998).

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