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Summer hydrology and zooplankton in two Svalbard fiords

ABSTRACT: Two West Spitsbergen fiords, Hornsund (77°N) and Kongsfjorden (79°N) were compared with respect to their hydrology and zooplankton occurrence on the base of two summer surveys made in 1987 and 1988. Both fiords were found to be influenced by four types of masses: Atlantic Waters, Intermediate Atlantic Waters, Local Waters and Brackish Surface Waters, Intermediate Atlantic Waters, Local Waters and Brackish Surface Waters. The amount of fresh water in both fiords reached up to 10% of water volume of the uppermost water layers. Hornsund in August 1987 was richer in mesozooplankton biomass than Kongsfjorden in 1988. Estimated energic value of pelagic prey of marine birds was 180–500 KJ/100 m^3 in Hornsund, and 130–200 in Kongsfjorden. Two major plankton communities were found in both fiords: *Pseudocalanus* community in the inner fiord basins and *Calanus* dominated community in the outer areas of the fiords. Plankton occurrence in fiords was not linked directly with the temperature — salinity patterns but rather with dynamic phenomena like upwellings and wind drift of surface waters.

K e y   w o r d s: Arctic, fiords hydrology, zooplankton, pelagic food base.

Introduction

Fiord oceanography is still in the centre of marine biologists interests (Brattegard 1980) although extensive multidisciplinary studies like those by Eilersten, Schei and Taasen (1981) carried out on Balsfjorden in Northern Norway are rare. A comprehensive review of this subject is given in Freeland *et al.* (1980).

The fiords of Svalbard have not been investigated as extensively as the ice covered waters around the archipelago, where large international projects have been caried out in recent yerars. The Norwegian PRO MARE, the international FRAM, MIZEX and the Greenland Sea Project were oriented towards shelf and open waters of the European Arctic. Gulliksen and Jakola (1980), Gulliksen and Haug (1987) were dealing with coastal fishes of West Spitsbergen, including Kongsfjorden. From that last area data on primary production were given by P. Halldal and K. Halldal (1974). Gulliksen and Jakola (1986), Eilersten, Schei and Taasen (1975) studied the hydrology, planktonic and benthic species in the Van Mijen fiord. Isfjorden was studied in the beginning of this century by the Swedish expedition (Burggen 1909, Hofstein 1917). Hornsund, the southernmost of Spitsbergen fjords where Polish research Station is located, was extensively studies by Polish expeditions (review in Swerpel and Węsłowski 1988). The influence od sedimentation upon the benthos distribution in Hornsund was presented in earlier paper (Görlich *et al.* 1987). Present work aims at the description of the role of fiord waters for the pelagic biota occurrence as well as the distribution of pelagic food base for seabirds within two Spitsbergen fiords.

Materials and methods

The Polish reserach vessel *Oceania* was sampling Hornsund in August 1987 and Kongsfjorden in August 1988. Temperature, salinity and depth were measured with the use of Plessey Environmental sampling gear, zooplankton with the use of WP-2 net with 200 μm size. Caloric measurements were performed by A. Szaniawska (*unpubl.*) and partly will be published elsewhere. Both investigated areas were sampled once in each of three parts of the fiord (innermost basins, central and outer part; Fig. 1). For statistical treatment zooplankton data were subjected to cluster analysis (Florczyk 1989).

As pelagic food items we understood species found by Lydersen, Gjertz and Węsławski (1988), Węsławski and Kwaśniewski (1990), to be the prey for Little auks, Guillemots, Kittiwakes, Fulmars and Ringed seals in Svalbard waters.

The amount of freshwater was calculated according to methods described by Ketchum (1950), Nutt and Coachman (1956). Exchange of water in a fjord or an estuary with a deep basin and sill may be divided into two parts: one taking place above the sill and driven by wind and tidal action as well as fresh water transport; the second below the sill in deep part of the fiord related to the vertical processes of convestion and supercooling of water. On the basis of the field observation of salinity one can estimate actual quantities of freshwater volume (FWV) in warious layers of the fiord at the time of observation. The volume of the water in the layers used in calculations was determined by planimetry and the average salinity was calculated from the STD data applied to appropriate segments

within these layers. The freshwater fraction (FWF) of each segment can be calculated by the formula:

$$FWF = (So - S)/S \quad or \quad FI = FWF \times 100\%$$

where S equals the base salinity of the source water and So equals the average observed salinity of the water outside the fiord. In the calculations the highest value of salinity recorded during observation was used. By multiplying FWF by the volume of each segment the actual quantity of the fresh water volume (FWV) in the segment was determined and the total value within each layer was obtained by the summing up the freshwater amount in each segment.

Results

Hydrology

The average percentage share of freshwater in two fiords was similar: from 2.9 to 3.2% (Tab. 1). Obviously the highest amount of freshwater occurred in uppermost 0–10 m water layer. The highest value found was 12% of freshwater

Table 1

Calculation of fresh water volume in both fiords

FWV — Fresh water volume; FI — Fresh water fraction in %

Layer	Outer part		Middle part		Inner part		Total	
	FWV 10^6 m^3	FI %	FWV 10^6 m^3	FI %	FWV 10^6 m^3	FI %	FWV 10^6 m^3	FI %
Hornsund 1987 calculated for $S_o = 35.23\%$								
1	2	3	4	5	6	7	8	9
0–10 m	66.9	5.8	58.5	9.8	91.0	12.3	216.4	8.7
10–20 m	61.9	5.7	39.0	6.7	35.9	5.6	136.7	5.9
20–30 m	53.6	5.3	25.8	5.0	27.1	4.7	106.5	5.1
30–50 m	106.0	3.8	48.7	1.7	53.1	3.4	207.9	3.6
below 50 m	81.7	1.0	28.6	0.2	14.7	0.9	125.0	1.0
Total	370.0	2.6	200.6	3.6	221.8	4.2	792.4	3.2
Kongsfjorden 1988 calculated for $S_o = 34.56\%$								
1	2	3	4	5	6	7	8	9
0–10 m	36.0	8.0	38.0	10.3	45.6	10.1	119.6	9.4
10–20 m	24.0	6.4	21.9	7.8	28.1	7.4	74.2	7.1
20–30 m	15.9	4.4	12.1	4.8	16.4	5.0	44.4	4.7
30–50 m	23.3	2.1	17.0	2.5	22.0	2.8	62.3	2.4
below 50 m	23.2	0.5	5.6	0.5	–	–	28.9	0.5
Total	122.8	1.9	94.7	3.4	112.0	5.8	329.5	2.9

in the central part of Hornsund, an area supplied with the discharge from the large Samarinvagen and Burgerbukta glaciers (Fig. 1).

Hydrological profiles in three main areas of the compared fiords are shown on Fig. 2. Note from Fig. 1 than Kongsfjorden station K7 lies at the border between central basin and mouth of the fiord, but it was outermost station during our investigations in 1988. So the differences between Hornsund's outermost H6 and K7 are clearly seen on Fig. 2.
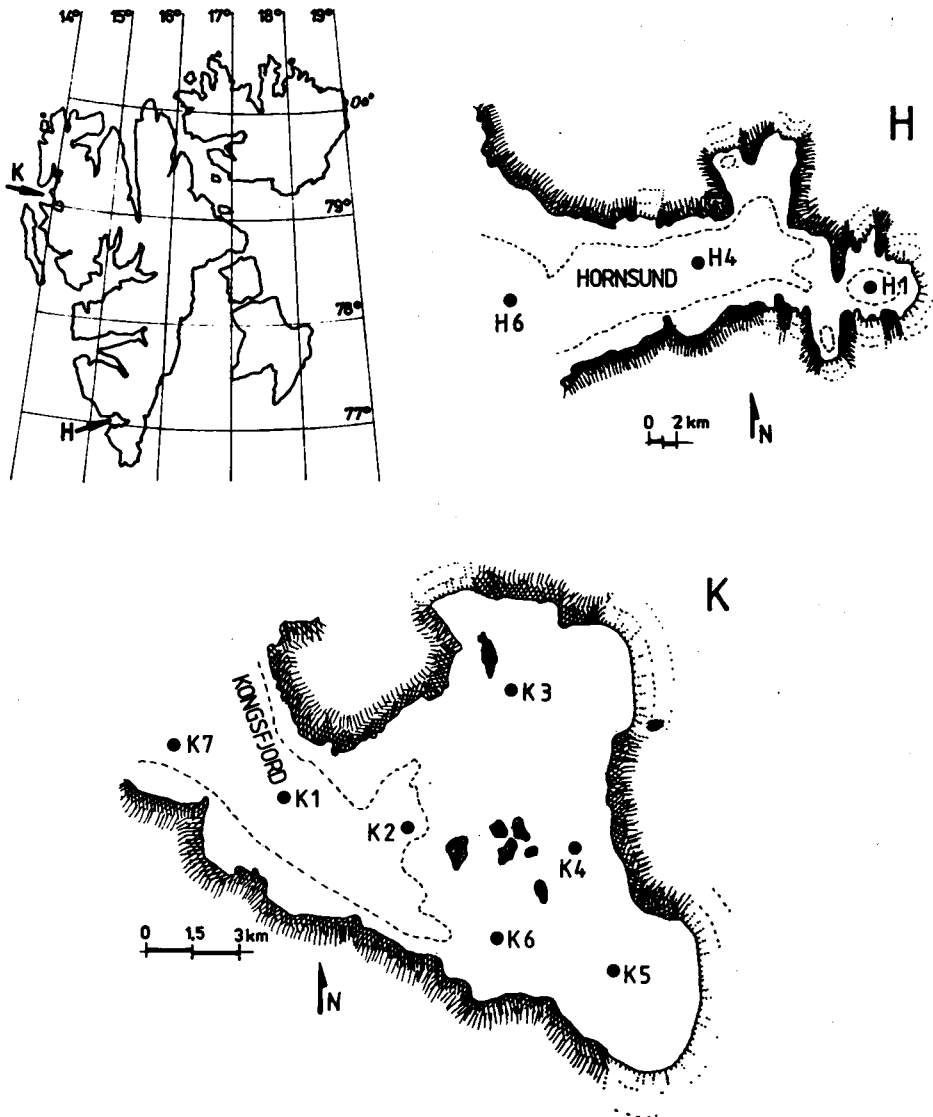

Fig. 1. Svalbard and sampling stations in Hornsund (H) and Kongsfjorden (K); dotted line indicates 100 m izobath
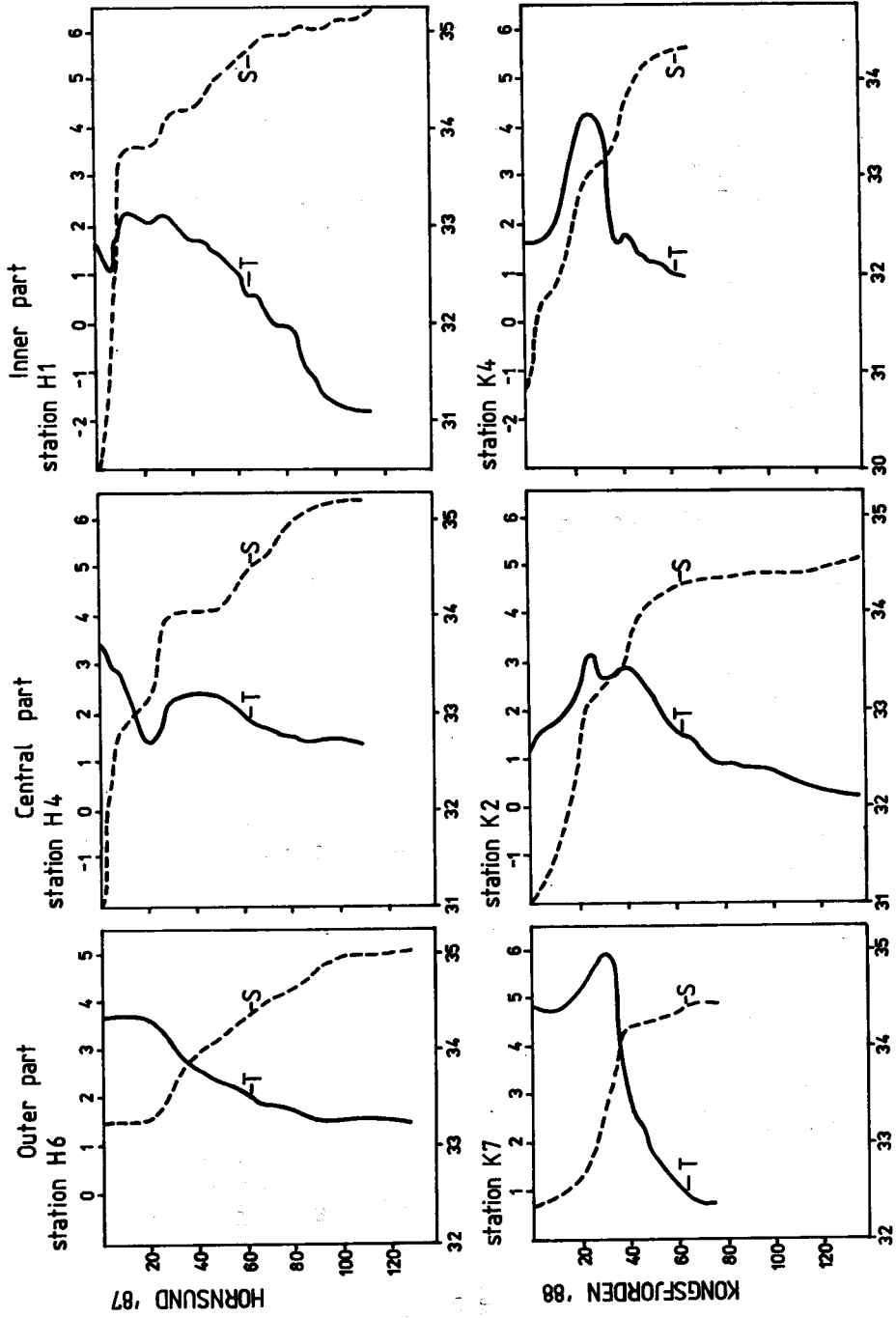
Fig. 2. Temperature (T) and salinity (S) profiles in chosen stations

Table 2

Characteristics of physical and biological parameters in Hornsund (**H**) and Kongsfjorden (**K**)

		outer		central		inner	
		H	**K**	**H**	**K**	**H**	**K**
surface temp.	°C	3.7	4.8	3.4	1.4	1.6	1.6
surface salinity	ppt	33.20	32.34	30.92	31.00	30.48	30.83
first subsurf.	m	—	9	8	15	5	—
temp. minimum	°C	—	4.6	2.7	1.5	1.2	—
subsurf. temp.	m	—	31	33	26	14	26
maximum	°C	—	5.9	2.4	3.2	3.2	4.7
subsurf. salinity	m	—	—	33	—	17	—
minimum	ppt	—	—	33.95	—	33.8	—
salinity maximum	m	130	77	111	146	113	65
	ppt	35.01	34.41	35.16	34.55	35.18	34.3
temp. minimum	m	130	77	19	146	113	65
	°C	1.5	0.7	1.4	0.2	-1.8	1.0
mesozooplankton density (ind/m³ in 0–100 m water column)		2316	2612	4543	1766	246	3007
prey species biomass (KJ/100 m³)		343	175	490	195	184	132
prey species density (ind/100 m³)		4640	4282	10472	5771	7067	3765

In Hornsund the T/S profiles at the outer station are not disturbed by run-off, as it can be seen in K7. The influence of the fiord surface waters is very strong in central basins. Salinity profiles were very similar in both fiords. Sharp gradients in surface layer reached at 60–80 m almost their maxima. The temperature profile was more complicated. The warm layer existing at the depth of 30–40 m is connected with the Atlantic water presence.

The T/S distributions for the innermost basin in Kongsfjorden were very similar to those in the central part of this fiord. However the innermost part of Hornsund had completely different T-S structure comapred to the central basin. Salinity gradients at the Hornsund's surface were much steeper and temperature values were lower than in Kongsfjorden. Near the bottom water of very high salinity and temperature of ca. −1.79°C occurred in Hornsud (Fig. 2). Table 2 presents some hydrological parameters typical for both fiords. The differences are noted especially in the intermediate layer. In Hornsund very clear subsurface salinity minimum occurred. Salinity minima (at the depth between 10–40 m) were connected with inflow of fiord basin waters to the central part of the fiord. Frequently it occurred simultaneously with temperature minimum. Frequently it occurred simultaneously with temperature minimu. Thus sea ice cover generated such types of T-S profiles in the intermediate layer (Fig. 2).

The classification of water masses is put together in Tab. 3. Limiting values are not the same for Hornsund and Kongsfjorden. The geographical position of the fiords is the main reason for these differences. More northern position of Kongsfjorden, compared to Hornsund makes parameters of the respective water masses different.

The T/S diagram for all observations is presented in Fig. 3. Surface waters points are scattered at the left part of the diagram. For the intermediate waters there is a concentration of points in Hornsund (see A position in Fig. 3). Atlantic water points are concentrated in different places (B1 and B2) for each fiord. Position C in Fig. 3 shows a peculiar type of waters connected with the process of surface waters supercooling in autumn-winter period.

Table 3

Water masses characteristics

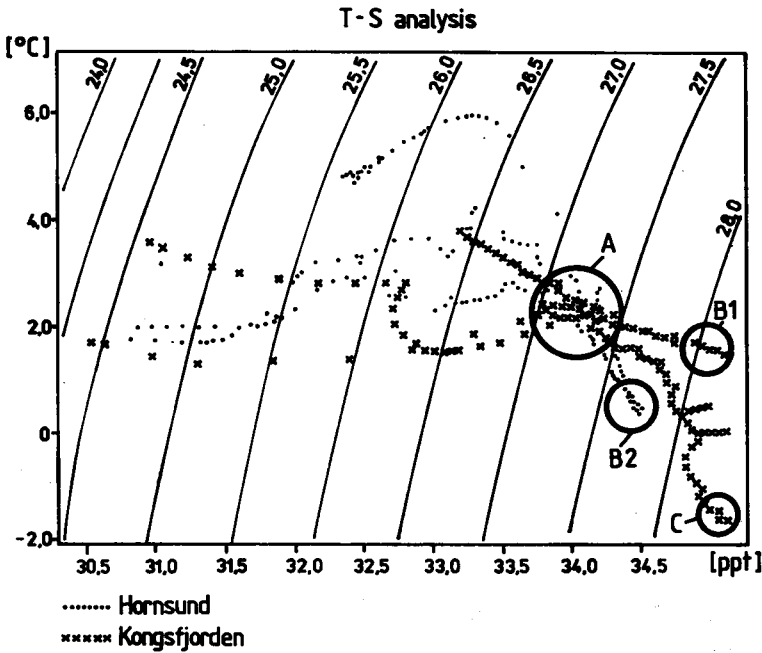| Water masses	Hornsund 1987		Kongsfjorden 1988	
	S	T	S	T
Surface waters	33.25		32.50	
Intermediate waters	33.25 to 34.5		32.5 to 34.0	
Transformed Atlantic waters	over 34.7	over 1.0	over 34.2	over 0.5
Local waters	over 34.7	below 1.0	over 34.2	below 0.5
Winter cooled waters	over 35.0	below −1.7	–	–

Fig. 3. Temperature and salinity diagram for all the collected data

Zooplankton

In both observed fiords the species compositon of zooplankton was highly similar, with *Calanus finmarchicus* and *Pseudocalanus acuspes* constituting more than 90% of all specimens collected (Tab. 4). Decapod larvae were more abundant in Hornsund while Euphausiidae in Kongsfjorden. The set of dominant species was in both fiords the same, namely *C. finmarchicus, P. acuspes, Oithona similis, Microcalanus pygmaeus* and *Acartia longiremis*. Percentage share of *C. finmarchicus* was similar in both areas (about 20%). *P. acuspes* was more abundant in Hornsund than in Kongsfjorden (70% versus 40%). *Metridia longa* was abundant in Hornsund while only common in Kongsfjorden (Tab. 4).

Analysis of the similarity of the samples was carried out and the result reflects the vertical distribution of communities within the fiords (Fig. 4a). It is worthy to emphasise that the dominant community of *C. finmarchicus + P. acuspes + O. similis* is divided into the zone of *P. acuspes* dominance (inner fiord basins) and *C. finmarchicus* zone (outher fiord parts; Fig. 4b).

Density of zooplankton in vertical cross-sections for both fiords was higher in Hornsund. Upper water layers in this fiord contained more than 2000 ind./m^3 all over the fiord. In Kongsfjorden areas of low plankton density at the surface were observed (Fig. 4c).

From the list presented in Tab. 4 the species known to be food items for planktonivorous birds and seals were selected for the following treatment. Their average length and weight as well as the energy content is presented in Tab. 5. Multiplying the energy value by the density of proper size class, we have got the figure presenting the distribution of the pelagic food base for planktonivorous vertebrates (Fig. 5a). The richest layers are those at the surface and in the outer fiord part in Hornsund. In Kongsfjorden concentrations of food items were found in the central fiord part as well as at the outermost point. Hornsund was apparently richer in food organisms than Kongsfjorden (mean value 350 KJ/m^3). The density of food items did not correspond with the general distribution of mesozooplankton density (Figs. 4c, 5a).

Discussion

Hydrology

The method used in calculations of fresh water amount is rather crude, because of assumptions and simplifications of the exchange processes (stationary and horizontal ones only). In the absence of tidal recordings, time series of salinity, time series of rivers and glaciers outflow, this method gives only the global figures of fresh water volume needed to reduce the salinity of the open sea water entering fiords. The calculated amount of fresh water in the present study is comparable to those in the Canadian Arctic and East Greenland (Thorson 1936, Nutt and Coachman 1956).

The division of water masses was made especially for the hydrometeorological conditions existing in 1987 and 1988. The hydrological regime in the Spitsbergen area is rather complicated. Several currents carrying Atlantic, Transformed Atlantic, Arctic, Intermediate and Local Brackish Waters occur (Rudels 1986, 1987, Rudels and Andersson 1982, Swerpel 1985). Application of water masses terminology recommended by Swift and Aagaard (1981), and by Swift (1986) is misleading. Atlantic water found in present study at the mouth of fiords are not the same characteristics as the core Atlantic Waters from the West Spitsbergen Current measured in profiles at the shelf break (Rudels 1987, Jankowski and Swerpel 1990). Atlantic water observed during present survey at the fiords mouth was colder and less saline than the above mentioned core of Atlantic waters.

Local waters in Hornsund are of special interest since they remain all the year round velow 0°C (Swerpel 1985, Segan and Moskal 1987). Out of West Spitsbergen fiords only Van Mijen fiord is known to have similar type of waters (Schei 1979). In the case of Hornsund those highly saline and cold waters were also well aerated (Węsławski, *unpubl.*). As it was shown by Freeland *et. al.* (1980) and by Swerpel (1985) that type of water originated during autumn/winter cooling, fast ice formation and the descending of cold, highly saline waters to the bottom.

Table 4

Density of species observed during surveys

|	Hornsund			Kongsfjorden		
	H6	H4	H1	K7.1.2	K6.5	K3.4
Mesozooplankton (n/m³)						
Calanus finmarchicus (Gunnert)	749	600	274	510	368	276
C. hyperboreus Krøyer	6	42	24	16	37	64
Pseudocalanus acuspes (Giesbrecht)	1499	2866	1761	686	1046	929
Microcalanus pygmaeus (Sars)	14	42	18	19	36	24
Acartia longiremis (Lilljeborg)	60	187	59	61	28	18
Metridia longa (Lubbock)	10	40	16	4	4	13
Neoscolecithrix farrani Smirnov	0	0	0	0	2	0
Scolecithrix minor Brady	0	0	+	0	0	0
Pareuchaeta norvegica (Boeck)	0	0	0	0	+	0
Rhincalanus nasutus Giesbrecht	1	0	0	+	+	0
Oithona similis Claus	387	548	250	674	884	685
Oithona atlantica Farran	3	1	1	4	3	6
Oncaea borealis Sars	1	26	10	25	101	72
Copepod nauplii	90	131	56	67	49	23
Echinodermata — larvae	7	0	2	15	15	0
Cirripedia — larvae	26	0	5	+	+	+
Bivalvia — larvae	3	18	5	13	5	+
Polychaeta — larvae	12	0	2	+	16	0
Ostracoda	+	0	0	0	0	+
Nematoda	+	0	0	0	0	+
Macrozooplankton (n/100 m³)						
Hydromedusae	4	28	26	440	+	0
Oikopleura sp.	4	0	6	0	0	0
Fritillaria borealis Lohmann	85	26	25	28	1	+
Clione limacina Phipps	117	171	23	7	+	0
Mysis oculata (Loven)	0	0	0	0	2	2
Thysanoessa inermis (Krøyer)	8	44	101	7	82	61
Pisces — larvae	0	9	0	0	0	0
Themisto libellula Lichtenstein	145	186	70	64	158	129
Decapoda — larvae	34	389	439	2	19	3
Sagitta arctica Aurivillius	2463	3356	894	1063	292	233
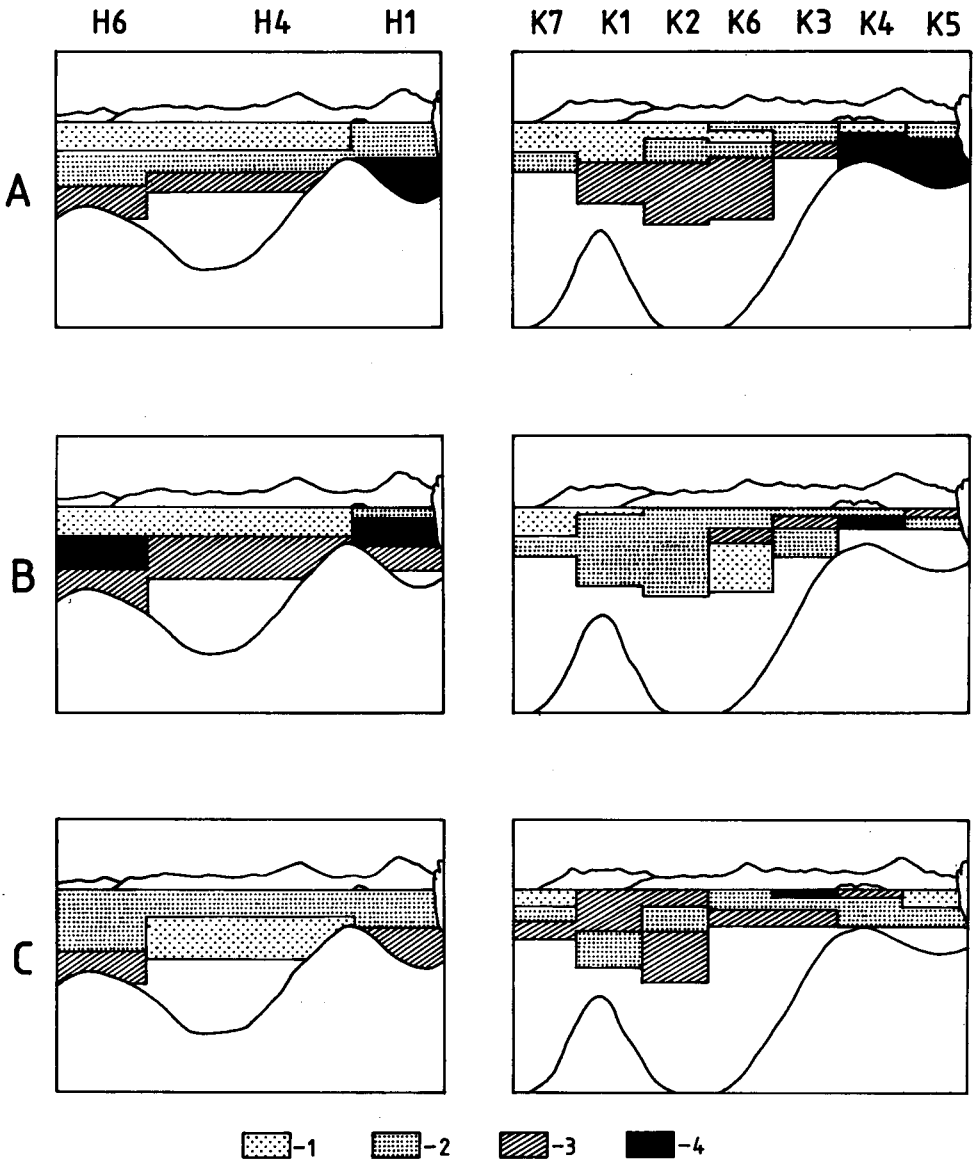
Fig. 4. Comparison of zooplankton distribution in both fiords:

A — Plankton communities: 1 — *Calanus* community, 2–3 — intermediate community, 4 — *Pseudo-calanus* community;

B — Share of *Calanus* in fjords plankton: 1 — over 50% of all specimens, 2 — 25 to 50%, 3 — 10 to 25%, 4 — below 10% of *Calanus* in zooplankton;

C — Density of zooplankton: 1 — over 4000 ind./m^3, 2 — 2000 to 4000, 3 — 1000 to 2000, 4 — below 1000 ind./m^3

Pelagic prey organisms; values used for calculations

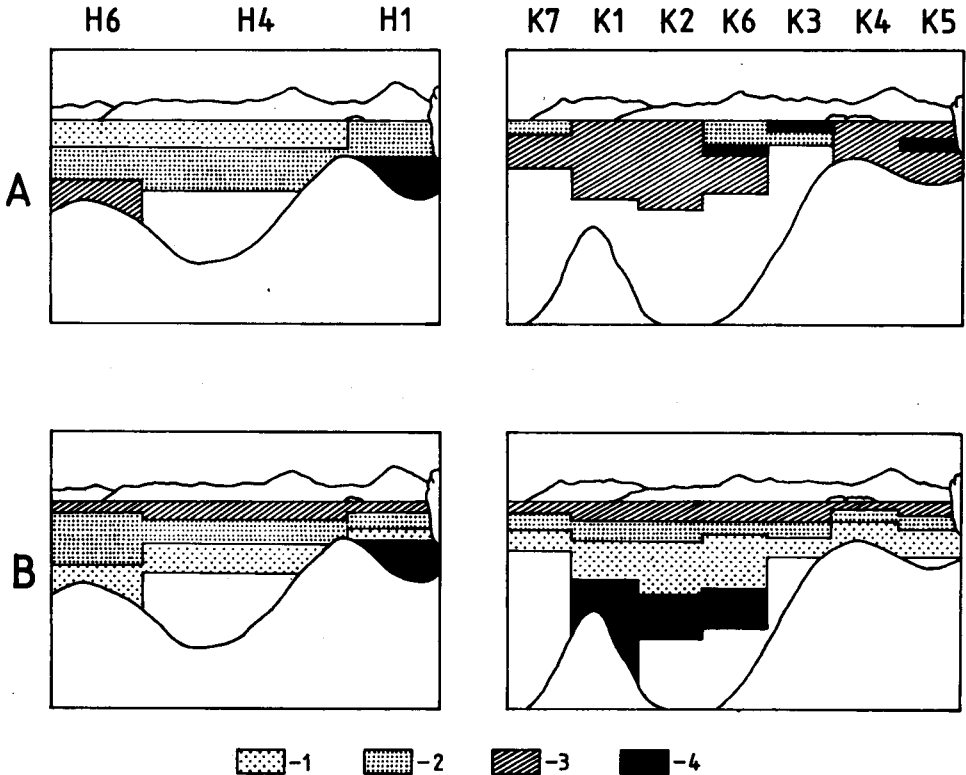| Taxon	mean wet weight in g	mean dry weight in g	kcal/g dry weight	KJ/individ. mean
Calanus sp. *adultus* and Vth copepodit	0.006	0.0009	6.2	0.02
Sagitta arctica	0.041	0.0041	4.93	0.085
Themisto libellula	0.03	0.006	4.7	0.12
Thysanoessa inermis	0.05	0.016	6.0	0.4
Mysis oculata	0.027	0.008	4.6	0.15
Pisces — larvae	0.023	0.0046	5.25	0.10
Decapoda — larvae	0.006	0.0012	4.6	0.023
Pteropoda	0.20	0.02	3.7	0.31

Fig. 5. Comparison of water masses distribution and pelagic prey items occurrence in both fiords:
A — prey species biomass in KJ/100 m^3: 1 — over 400, 2 — 200 to 400, 3 — 100 to 200, 4 — below 100 KJ/100 m^3;
B — water masses distribution: 1 — Atlantic waters, 2 — intermediate waters, 3 — brackish waters, 4 — local waters

Zooplankton

The set of species and their vertical and horizontal distribution presented above were similar to those found in other studies carried out in Svalbard coastal waters (Koszteyn and Kwaśniewski 1988). Our point of interest were Atlantic and Arctic water species in the study areas. Our classification of cold and warm water forms follows Dunbar and Harding (1968) and Koszteyn and Kwaśniewski (1988). In these papers *Calanus hyperboreus, Microcalanus pygmaeus, Metridia longa* and *Pareuchaeta norvegica* were usually regarded as cold water species and *Calanus finmarchicus, Oithona similis* and *Oncaea borealis* as relatively warm water species. According to this classification both fiords were characterized by the dominance of warm water species (75 to 90% of density) and in both areas the share of cold water species in the pelagic community was equally low (6 to 8%). Similar proportions were given for the neritic and fiords plankton of Southern Spitsbergen by Koszteyn and Kwaśniewski (1988).

Good indicators of water masses are some macroplanktonic species, like *Gammarus wilkitzkii, Apherusa glacialis* for Arctic and *Eukrohnia hamata, Themisto abyssorum* for Atlantic waters (Gurjanova 1951, Dunbar 1968, Kwaśniewski and Węsławski 1986). Both groups of indicators were found in earlier studies of Hornsund plankton (Węsławski and Kwaśniewski 1983), but were absent in present collections. That reflects the importance of year to year changes and their influence on the single set of data (Węsławski and Adamski 1987).

Communities found in the present study (the neritic one dominated by *C. finmarchicus* and fiord one with *P. acuspes;* Fig. 4) were not directly dependent on the hydrological situation. The neritic community apparently enters the fiord with surface waters although shelf Atlantic waters flow below the uppermost brackish layers (Fig. 5b).

The decreasing density of *C. finmarchicus* towards the inner fiord part is known from Norwegian fiords (Fosshagen 1980, Matthews and Heimdal 1980). *P. acuspes* was reported in the literature as an inhabitant of innermost fiord basins and brackish water pools (Landry 1977, Fosshagen 1980, Matthews and Heimdal 1980). Apparently the main biotope for *P. acuspes* found in present study is the near bottom, highly saline and cold waters of local origin. There were no direct correlations between dominant plankton occurrence and temperature/salinity values. Atlantic waters were entering both fiords in the intermediate layers (Fig. 6), whereas Atlantic plankton was present at the surface. Oceanic species were found all over the fiord, however in the inner fiord basin the mass mortality of plankton was observed. *Calanus* and chaetognaths were found on the beach at low tide in great amounts in the vicinity of stations with more than 10% of fresh water (Fig. 5b).

Important physical factors governing the plankton distribution in both fiords are the dynamic phenomena like tidal and wind currents, local upwellings and downwellings, Langmuir cells aggregating or dispersing plankton, most often in the vicinity of glaciers or underwater sills (Dunbar 1941, Węsławski *et al.* 1989).
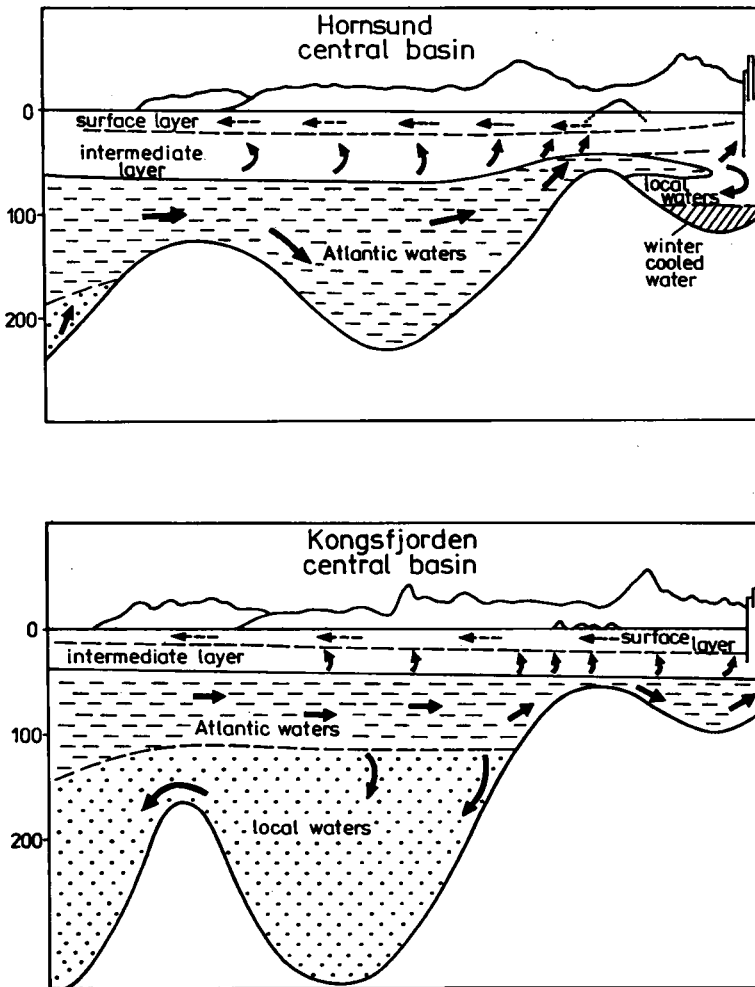
Fig. 6. Scheme of water dynamics in both fiords

Idealished scheme of water dynamics is presented on Fig. 6. Plankton aggregations were found in the vicinity of glaciers especially there, where local upwellings are indicated in the figure.

When comparing Hornsund and Kongsfjorden (Tabs. 1 and 2) on can see the more oceanic character of Hornsund with greater amount of zooplankton and generally colder waters. However one should bear in mind that at least some of the differences might be linked with the fact that data were collected in different years. Kongsfjorden is rather stable, with large amount of local waters and low pelagic productivity dominated by small plankters. Few large pelagic species (krill) are allochthonous. Such fiord may support seasonally abundant fish stock being a suitable feeding ground for Ringed seals (Węsławski, *unpubl.*). Hornsund, with its massive and variable inflows of shelf Atlantic waters, is much

richer in large large plankton, more productive in the pelagial and hence better for feeding of marine birds. Such a division resembles "*Calanus*" fiords and "non-*Calanus*" fiords described by Fosshagen (1980).

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Streszczenie

W pracy scharakteryzowano zooplankton i jego rozmieszczenie na tle dwóch spitsbergeńskich fiordów — Hornsundu i Kongsfjorden. Obliczono też wartości energentyczne zespołów planktonowych jako bazy pokarmowej ptaków.

Stwierdzono, że wody Hornsundu były bogatsze o zooplankton niż wody Kongsfjorden. Jednakże, w obydwu fiordach obserwowano dwa podobne zgrupowania zooplanktonu — zgrupowanie *Pseudocalanus* w częściach wewnętrznych fiordów i zgrupowanie *Calanus* w zewnętrznych częściach tych akwenów. W obydwu fiordach ilość dopływającej do nich wody słodkiej oceniono na 10% objętości górnych warstw wody.

Na rozmieszczenie planktonu miały wpływ przede wszystkim zjawiska dynamiczne takie, jak upwellingi i prądy powierzchniowe, w mniejszym stopniu zasolenie i temperatura.