Estimation of zooplankton mortality caused by an Arctic glacier outflow

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Abstract

The outflow of freshwater from underwater channels in the Kongsbreen tidal glacier in Kongsfjorden, Svalbard, 79° N, was measured as 138.8 m^3 s^{-1} at the peak of the melting season. Experiments on local marine plankton mortality show that when exposed to salinities below 9 PSU, all copepods die within 15 minutes. We estimate that during 100 days of the melting season, as many as 85 tonnes wet weight (WW) of plankton is removed from the water column due to osmotic shock, which makes up 15% of the standing zooplankton biomass of the fjord. The dead zooplankton sinks after exposure to low salinities and is probably an important food source for scavenging benthic fauna in the fjord. This mechanism could be responsible for the high numbers of *Onisimus caricus* near the glacier front.

1. Introduction

The impact of freshwater on marine organisms has been discussed in numerous papers dealing with estuarine systems (Khlebovitsch 1990, Kaartvedt & Aksnes 1992), sea ice and glacial meltwater (Aarset & Aunaas 1987, Polterman 1997). Recently, indirect evidence of glacier-caused zooplankton mortality was presented for a Svalbard fjord (Węsławski & Legeżyńska 1998). A number of direct measurements and estimations of glacial outflow were collected for the very active Kongsbreen glacier (Beszczyńska-Möller et al. 1997, Węsławski et al. 2000). Not so long ago, fine-scale measurements enabled the freshwater discharge profile from the

Kongsbreen to be drawn. Our aim was to estimate the importance of zooplankton mortality along the glacier front. Kongsfjorden, an area of extensive international studies, is a good place for such investigations, since data are available on almost every aspect of the local ecosystem (Hop et al. in preparation, Svendsen et al. in preparation).

2. Materials and methods

Salinity was measured from a rubber dinghy with a mini CTD Sensordata SD 200 sonde in the direct vicinity of glacial outflows in summer 2000. The velocity of the outflow stream was measured with a drifting buoy over a distance of 200 m. It was impossible to use a current-meter because of the considerable number of drifting icebergs and growlers. The buoy's position was determined by GPS Garmin 3 plus with an accuracy of 15 m. The buoy was supplied with two crossed aluminium plates joined to the float by a pipe of adjustable length (max 4 m). The stream velocity measurements at the two main Kongsbreen outflows were repeated ten times. The average velocity was used in working out the freshwater outflow. The freshwater volume was calculated according to the methods described by Ketchum (1950), Nut & Coachman (1956) and Beszczyńska-Möller et al. (1997). The layer of brackish water was divided into four sublayers: 0–0.5 m, 0.5–1 m, 1–2 m and 2–3 m. The average salinity in each sublayer was taken into account in the calculation of the freshwater fraction (FWF) according to the formula

$$FWF = (S_0 - S)/S_0 \times 100\%,$$

where S_0 – background salinity of water beneath the outflow = 34.9 PSU (Beszczyńska-Möller 1997), and S – salinity of brackish water.

The volume ratio of fresh water FWF to sea water SW_{equiv} in brackish water of salinity 24 and 9 PSU was calculated according to the formula

$$FWF/SWF = (S_0 - S)/S.$$

Zooplankton mortality due to salinity changes was measured on board r/v 'Oceania' in July 1999. Sets of eight 50 dm^3 glass vials were filled with seawater (34.5 PSU) and dilutions of seawater (4.9, 14, 20, 24, 28, 30, 34 PSU). Three to six calanoid copepods (older copepodit stages of *Calanus* spp.) were inserted into each vial and submerged in a large tank filled with outboard seawater at $3°$ C. At given time intervals (15, 30, 60, 180 ... 1440 minutes), the vials were checked for the presence of dead copepods. Any lying at the bottom of the vial and not moving were considered dead.

The scavenging fauna of the inner basin of Kongsfjorden was sampled at two stations during the summer seasons 1999 and 2000. Eleven traps were deployed on the bottom between 5 and 30 m for 6 to 7.5 h. Approximately 0.3 kg of beef per trap was used as bait. The lengths, weights and sex of ninety specimens of *Onisimus caricus* were determined. The gut contents were analysed of 30 specimens of *O. caricus* (mean length 17 mm SD 3.9) from traps with unavailable bait. The fullness index was estimated from 0 (empty) to 5 (full). Food items were identified during microscopic examination.

The oxygen consumption (R) of *O. caricus* (mm^3 O indiv.$^{-1}$ h^{-1}) was calculated according to the formula described for Arctic lysianassoids by Opaliński & Węsławski (1989):

$$R = 0.2\ W^{0.76};$$

W – wet weight of body (mg indiv.$^{-1}$).

For calculating the amount of carbon involved in respiration, the following formula was adopted: $1\ cm^3$ of oxygen = 0.43 mg of carbon (Grodziński et al. 1975) for a respiration quotient of 0.8.

For calculations of carbon consumption, an assimilation coefficient of 30% was used (Grodziński et al. 1975).

3. Study area

Kongsfjorden is situated at 79° N and opens to the Greenland Sea. The inner basin of the fjord receives meltwater from a complex of tidal glaciers: Kronebreen, Kongsvegen, Conwaybreen and Blomstrandbreen. SW Kronebreen and Kongsvegen form the largest and most active glacier front known as Kongsbreen (Lefauconnier et al. 1994). Two meltwater outflows were studied (Fig. 1). In Kongsbreen, meltwater is produced all the year round; however, maximum melting occurs during a 60-day period from the end of June to the end of August (Elverhøi et al. 1980, Węsławski et al. 1995)

Although the hydrographical conditions in the fjord have been studied in detail (Elverhøi et al. 1983, Ito & Kudoh 1997, Svendsen et al. in prep.), our knowledge of winter conditions is still limited. According to Elverhøi et al. (1983) homogeneous cold, saline water forms throughout the water column in late winter and early spring. During spring and summer, Atlantic water penetrates the southern side of Kongsfjorden with a velocity of 8–10 cm s^{-1}. The mechanism that causes this current is probably an outflow of meltwater together with tides controlled by the Coriolis force (Elverhøi et al. 1983, Svendsen et al. in prep.). While the down-fjord advection of freshened water is maintained during the whole tidal period, the tide does modify the strength of the flow (Svendsen et al. in prep.).

In Kongsfjorden, the 5–10 m thick summer surface layer has a salinity of 31–32 PSU, while in the inner part, its salinity falls to below 20 PSU. In the hollow of glacier bay (50–90 m depth) a winter – cooled water mass with a low temperature (–1.4° C) and high salinity (35 PSU) is noted.

4. Results

4.1. Meltwater discharge

The average velocities of the two main outflows of Kongsbreen (Fig. 1) were $0.36 \ \text{m s}^{-1}$ (outflow 1) and $0.8 \ \text{m s}^{-1}$ (outflow 2). Outflow 1 had a depth of 3 m and a width of 200 m; outflow 2 was 1 m deep, and 340 m wide.
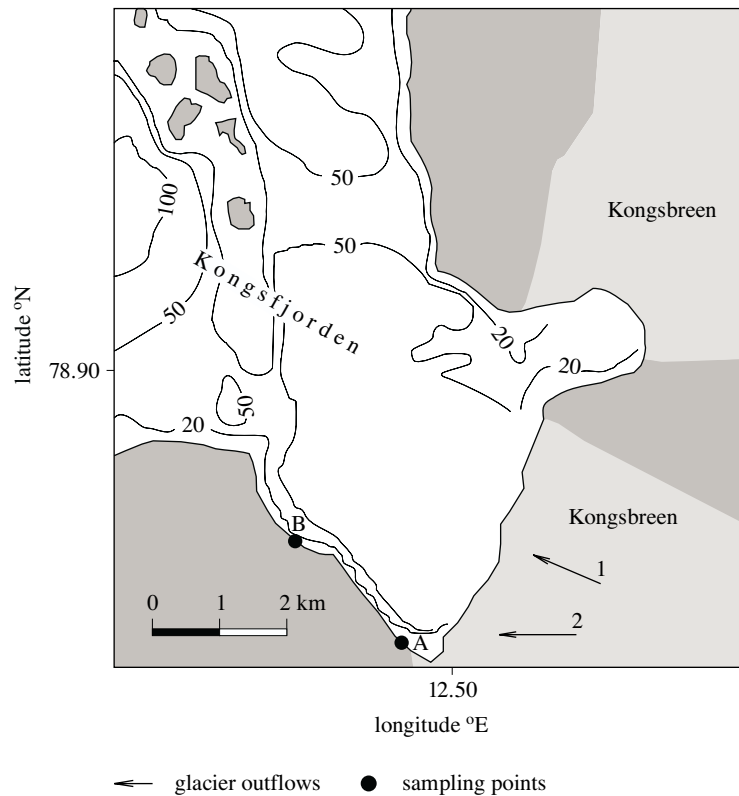

Fig. 1. Inner part of Kongsfjorden (glacial bay), location of sampling stations (A, B) and main glacier outflows (1, 2)

CTD profiles of both outflows were made at a distance of 250 m from the glacier front. The surface salinity varied from 1.5372 to 9.3915 PSU. Since the hydrological conditions in both outflows varied in relation to the depth
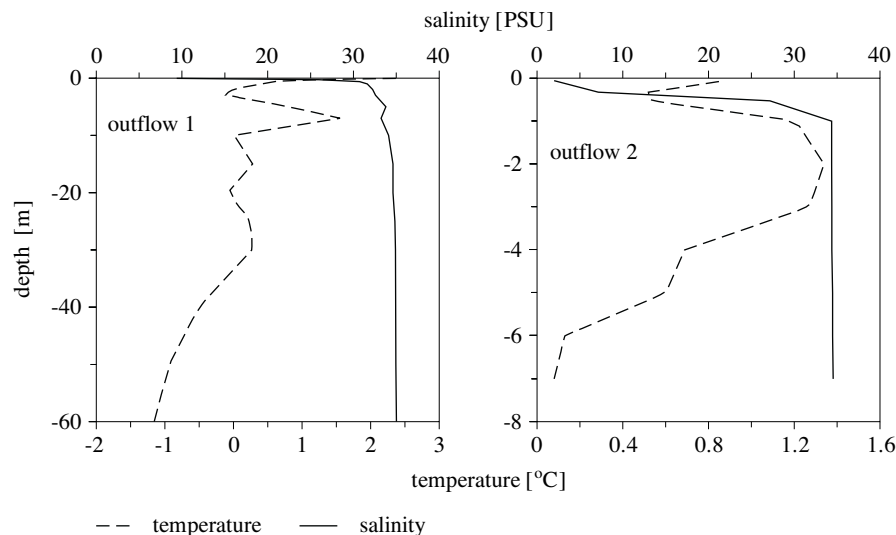
Fig. 2. Temperature and salinity profiles in the two main outflows of Kongsbreen

(Fig. 2), the average salinity of the 0.5 m layers was used in the calculation of freshwater volume (Table 1). The volume of freshwater in outflow 1 was smaller than in outflow 2, amounting to 30.2 m³ s⁻¹ despite the fact that the former stream was three times thicker. During summer 2000 the largest volume of meltwater of Kongsbreen passed through outflow 2 (108.6 m³ s⁻¹).

Table 1. Calculated freshwater fraction (FWF), its run-off from the front of Kongsbreen, and the seawater equivalent (SW$_{equiv}$) for different salinities

Layer [m]	Average salinity [PSU]	FWF [%]	Flow of FWF [m³ s⁻¹]	SW$_{equiv}$ 24 PSU [m³ s⁻¹]	SW$_{equiv}$ 9 PSU [m³ s⁻¹]
Outflow 1					
0–0.5	20.05	42.6	15.3		
0.05–1	31.16	10.7	3.9		
1.0–2.0	31.90	8.6	6.2		
2.0–3.0	32.57	6.7	4.8		
Total			30.2	67.1	10.5
Outflow 2					
0–0.5	11.61	66.7	90.8		
0.5–1.0	30.33	13.1	17.8		
Total			108.6	241.3	37.7

Given the magnitude of the two outflows from the glacier, the respective volumes of seawater required to obtain brackish water of 24 PSU and 9 PSU in Kongsbreen were found to be 307.9 m^3 s^{-1} and 48.2 m^3 s^{-1}.

4.2. Copepod mortality

When the salinity drops below 24 PSU – the survival threshold – copepods die within 1 hour; if the salinity drops below 9 PSU, they die within 15 minutes (Table 2). The survival of copepods at salinities above 24 PSU for 24 hours demonstrates their relative resistance to moderately reduced salinity.

Table 2. Mortality of *Calanus* spp. in relationship to salinity and time of exposure

| | | *Calanus* spp. – percentage of mortality | | | | | | | |
| | | time (minutes) | | | | | | | |
N	S	15′	30′	60′	180′	240′	720′	900′	1440′
18	34.5	0	0	0	0	0	0	0	0
18	31	0	0	0	0	0	0	0	0
18	27	0	0	0	0	0	0	0	0
61	24	25	57	100					
63	20	27	64	100					
62	17	25	58	100					
12	9	100							
18	4	90	100						

N – number of individuals, S – salinity [PSU].

4.3. Calculation of plankton mortality

Taking the average density of copepods in the inner basin of Kongsfjorden to be 210 (1996) – 792 (1997) individuals per 1 m^3 (Hop et al. in prep.) and 9 PSU to be the critical salinity level, we can conclude that 48.2 m^3 s^{-1} of seawater that becomes mixed with water < 9 PSU causes the mortality of 2×10^9 indiv. d^{-1}. Owing to the age structure of copepods (Hop et al. in prep.) and the wet mass of the different stages (Scott et al. 2000), the calculated biomass of dead zooplankton is 1.2×10^8 mg C d^{-1} (carbon/wet mass = 0.085). By dividing the number of dead copepods per day by the area of the glacier bay (c. 20 km^2), we obtain an estimated rate of sedimentation of dead copepods in this area of 44–165 indiv. m^{-2} d^{-1} (average 6 mg C m^{-2} d^{-1}).

4.4. Role of scavenging fauna

Over 46 000 specimens of scavenging fauna from 8 taxa were found in the baited samples. The lysianassoid amphipod *O. caricus* made up 99.4% of the animals collected. This species was especially abundant in the 10–20 m depth layer, where the maximum catch of 19 300 specimens after 6 h of exposure was noted (Table 3).

Table 3. Relative abundance of *Onisimus caricus* in the traps deployed between 5 and 30 m in sections A and B

Station \ Depth [m]	5	10	15	20	30
A 1999		418	17 800	19 300	
A 2000	1	270		526	16
B 1999	289	2 530	1 218	3 487	

The whole population spectrum of *O. caricus* was represented in the material: no depth-related segregation of different year classes was found. Juvenile specimens 5–15 mm long weighing on average 0.015 g WW made up 49% of this group. 35% of specimens belonged to the larger size class 19–24 mm in length, with a mean WW of 0.223 g. The remaining 16% of specimens were of intermediate size and weighed on average 0.121 g WW.

The mean fullness index was 2.33 (SD 1.06). Parts of crustaceans were the most frequent food items in *O. caricus* crops (Table 4). The consumed animals had been torn into small pieces such as single appendages. Over 70% of guts contained sediments.

Table 4. Frequency of occurrence (% of N) of food items in the guts of *Onisimus caricus* from Kongsfjorden

Food item	% of N
Algae	3.3
Amorphous material	13.3
Mysidacea	50
Copepoda	100
Detritus	13.3
Sediments	73.3
Gut examined (N)	30

N – number of *O. caricus* specimens.

The calculated organic carbon consumption for *O. caricus* (based on the oxygen consumption of Arctic amphipods) is 0.24 mg C indiv.$^{-1}$ d^{-1} for the mean wet weight of an individual weighing 104 mg. Knowing that the possible rate of sedimentation of dead copepods is 6 mg C m^{-2} d^{-1}, we can estimate that this source of food is sufficient for an abundance of *O. caricus* of 25 indiv. m^{-2} in Kongsbreen bay.

5. Discussion

The freshwater in Kongsfjorden comes from four sources: tidal glacier ablation and calving, land riverine outflow, melting of the fast ice and snow cover, and direct precipitation onto the fjord surface.

The detailed balance of freshwater entering Kongsfjorden has not been studied yet, but according to Węsławski et al. (1995) and Svendsen et al. (in prep.) we can assume that the largest source is glacial ablation. In this paper only two discharges of Kongsbreen have been included in the calculation of freshwater input into the glacial bay. The extent of the third one, located in the NE part of the glacier front, is not yet known.

According to our data, the hydrological situation at the front of Kongsbreen has changed in comparison to the description by Elverhøi et al. (1980), who described the outflow in the central part of the glacier front (outflow 1) as being the principal one. Changes in the location and extent of the main outflows in Kongsbreen could be due to the retreat of the glacier front and interseasonal changes in the rate of ablation. The amount of freshwater input to the glacier bay influences the rate of zooplankton mortality and sedimentation. Poltermann (1997) described the sinking rate of copepods as 120 m per day, which means that in a shallow glacier bay (70–90 m) dead zooplankton may reach the bottom in a few hours. Węsławski & Legeżyńska (1998) reported 10 to 120 dead copepods per square metre in the same area. In view of the sedimentation rate of dead zooplankton given here (104 indiv. m^{-2} d^{-1}), we can conclude that organisms settling at the bottom are almost instantly consumed.

Estimates of copepod biomass in Kongsfjorden range from 400 to 650 tonnes WW of copepods (Hop et al. in prep.). Therefore, 15% of the standing crop is removed by osmotic shock from the water column in the course of a single summer. The number of copepods killed by osmotic shock is probably higher than the number taken by local predators (carnivorous plankton, Polar cod) estimated by Hop et al. (in prep.).

Summer sampling of necrophagic fauna in Kongsfjorden has shown that *O. caricus* occurs only in the shallow waters of the glacial bays. The concentration of this species, known from its wide depth range (20–200 m) (Węsławski 1991) in the shallows, is probably a seasonal phenomenon

connected with the local mortality of marine zooplankton close to the glacier cliffs during summer. Being the dominant scavenging species of the glacial bays (Legeżyńska et al. 2000, Legeżyńska in press), *O. caricus* is very likely the most important species taking advantage of the sinking dead zooplankton. The importance of dead zooplankton in the diet of *O. caricus* was confirmed by the analysis of the gut contents. The copepods and other pelagic crustaceans often found in the guts of large *Anonyx*, *Onisimus* and *Orchomene* (Sainte-Marie & Lamarche 1985, Slattery & Oliver 1986, Carey & Boudrias 1987) may have come from predation or feeding on dead animals. The fact that crustacean parts in most guts examined in this study were mixed with the fine sediments typical of the glacial bay suggests that it is more likely they were taken dead from the bottom than alive from the water column.

Little is known about the feeding behaviour of *O. caricus*; however, it can be assumed that like other *Onisimus* spp. (Carey & Boudrias 1987), it is flexible in its diet. It seems probable that *O. caricus*, being a large and highly mobile species, may be more dispersed and use different food sources before and after the main melting season. Estimation of lysianassoid amphipod densities in occupied habitats is very difficult because of their behaviour and high mobility, which makes them almost impossible to collect with dredges and grabs.

Nevertheless, taking the calculated carbon consumption of *O. caricus* and the magnitude of dead copepods settling on the bottom into consideration, we can conclude that sinking zooplankton may supply the population of *O. caricus* with 52 tonnes WW (5×10^8 indiv.) in the inner basin of Kongsfjorden.

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