NERO

NUUK ECOLOGICAL RESEARCH OPERATIONS

2nd Annual Report 2008

National Environmental Research Institute
Aarhus University

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NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

Data sheet

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Back cover photo: Sediment core sampling on sea ice in Kobbefjord, 2008. Photo: Thomas Juul-Pedersen

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Nuuk Ecological Research Operations (NERO) is together with Zackenberg Ecological Research Operations (ZERO) operated as a centre without walls with a number of Danish and Greenlandic institutions involved. The two programmes are gathered in the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in NERO:
Asiaq - Greenland Survey: ClimateBasis programme
Greenland Institute of Natural Resources: BioBasis and MarineBasis programmes
National Environmental Research Institute, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
University of Copenhagen: GeoBasis programme

The programmes are coordinated by a secretariat situated at National Environmental Research Institute, Aarhus University, and it is financed with contributions from:
The Danish Energy Agency
The Danish Environmental Protection Agency
The Government of Greenland
Private foundations
The participating institutions

Contents

Executive Summary

Kisser Thorsøe, Mikkel Tamstorf, Peter Aastrup, Thomas Juul-Pedersen and Morten Rasch

Introduction

2008 was the second year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was expected to be the first year with complete annual time series for all sub-programmes. However, due to severe technical failures on different equipment belonging to especially the ClimateBasis and the GeoBasis programmes, many of the expected continuous time series for 2008 were broken.

Danish Polar Center closed down by the end of 2008 and as a consequence the secretariats of Nuuk Ecological Research Operations, Nuuk Basic, Zackenberg Ecological Research Operations and Zackenberg Basic were gathered in an organisation called Greenland Ecosystem Monitoring (GEM) with its own secretariat that was placed at National Environmental Research Institute at Aarhus University.

ClimateBasis

The ClimateBasic programme gathers and accumulates data describing the climatological and hydrological conditions in Kobbefjord. Data are measured by two automatic climate stations (C1 and C2), two automatic hydrometric stations (H1 and H2) and three diver stations (H3, H4 and H5).

The two climate stations are placed next to each other to ensure data continuity. After a few corrections during 2008 all the stations are working correctly now monitoring a total of 16 climate parameters.

In Kobbefjord measurement of the water level and manual discharge measurements at H1 started in 2006 and at H2, H3 and H4 in 2007. Manual measurements of discharge were continued at H1, H3 and H4 in 2008. In 2008 measurement of the water level and manual discharge measurements at H5 were added to the programme. H1 and H2 are measuring throughout the year, while measurements at H3, H4 and H5 starts up in early spring when the rivers are free of snow and ice, and ends in late fall before the rivers freezes.

The stage-discharge relation (Q/h-relation) established for H1 after season 2007 has been re-evaluated on the basis of measurements made in 2008, although there still is a lack of measurements at high water level. For H2, H3, H4 and H5 there still is a lack of discharge measurements to establish reliable Q/h-relations. For H1, which is placed at the main river in Kobbefjord, the total discharge during the hydrological year from 1 October 2007 to 30 September 2008 was 30.1 million m^3. The peak discharge in 2008 was recorded on 14 June caused by a combination of spring snow melt and precipitation.

GeoBasis

2008 is the first full season for the GeoBasis programme with a field season running from May to late September. However, due to cooperation with other research projects, the programme continued until late October. The programme has during 2008 unfortunately run into unforeseen problems (e.g. catabatic winds destroyed several installations, build up of snow drift in front of cameras prevented photo monitoring, high levels of melt water in the snow pack flooded the data loggers etc.). Although this has caused loss of data most of the experienced problems have now been solved or will be solved during the 2009 season. Installation of some stations had to be postponed in 2007 and they have therefore been installed during 2008.

The melting of snow and ice started in the second half of April and took speed in May. By 12 June all snow on the east side of the main river outlet had melted. The ice cover on the lakes in the area broke up during late May/beginning of June. As part of the snow monitoring three snow surveys were carried out during spring in cooperation with the ClimateBasis programme.

The micrometeorological station at 1000 m a.s.l., M1000, was installed on 4 September 2008. This installation completes installation of climate stations and we now collect climate data along the entire altitudinal gradient within the research area. Unfortunately, the SoilFen data logger was flooded and data between 18 March and late August was lost.

Three automatic soil stations are installed in the area; SoilFen, SoilEmp and SoilEmpSa. In 2008, soil water samplers (suction cup lysimeters) were installed at the same three sites. However, to allow for the soil to settle after the installation, sampling and analysis of soil water will first begin in 2009.

The methane (CH_4) flux pattern reflected a dome-shaped peak with maximum about a month after snow melt and a decline to about half of the maximum towards the end of the summer season (around 1 September). In the autumn the methane flux continued to decline and it decreased consistently during September and October. The peak summer emissions reached about 5 mg CH_4 m^{-2} h^{-1}.

The measurements of temporal variation in daily net exchange of CO_2 were initiated on 10 June and continued until 29 October. The estimated net uptake period was approximately 83 days and the maximum daily uptake reached 2.31 g C m^{-2} d^{-1} on 13 July.

BioBasis

2008 was the first year, in which BioBasis carried through the entire programme after the establishment of the programme in 2007.

We monitored reproductive phenology in three plant species: *Silene acaulis*, *Salix glauca* and *Loiseleuria procumbens*, each with four replicates separated into four sections. For *L. procumbens*, there was a large variation between plots in timing of flowering as the date of 50 % flowers in a plot ranged from 6 June to 2 July. In *S. acaulis* flowering peaked around 24 June in all four plots, indicating a longer period of maturing in the early snow free plots compared to the later snow free plots. In *S. glauca* budding peaked 4 June. Both female and male plants started to flower 17 June and kept having flowers for several weeks until 1 September. The timing of 50 % of female flowers with hair ranged over plots and sections from 26 August to 20 September.

For the four plant species *Silene acaulis*, *Salix glauca, Loiseleuria procumbens* and *Empetrum nigrum* we recorded total flowering at the time of peak flowering.

The vegetation greenness was monitored several times during the season by measurements of the NDVI in phenology plots as well as along the NERO line. In general, the vegetation greenness peaked around 1 August.

We have monitored the CO_2 flux between the soil/vegetation and the atmosphere in 'natural' as well as in 'manipulated' plots. Data has not yet been processed.

The study of potential effects of UV-B radiation on plant health showed that the ambient UV-B did not induce any differences in maximum quantum yield (Fv/Fm) for *Vaccinium* and *Betula*. However, screening off a major proportion of the ambient UV-B radiation increased the Performance Index (PI) in both species in the August measurements. These initial results indicate that the experimental setup works.

The basis for preparing a vegetation map for the study area was improved by classifying additional 115 points.

Four pitfall arthropod trap stations each consisting of 8 sub-plots were sampled. All samples are stored at the Greenland Institute of Natural Resources. The material is kept in 70 % ethanol. Microarthropods were sampled in three different habitat types with two replicates of each. Unfortunately, all samples from 2008 were unsuccessfully extracted at the Greenland Institute of Natural Resources due to insufficient quality of the apparatus and lack of practice. The results cannot give a precise estimate of population abundance.

The bird study consisted of three subprogrammes, i.e. an ornithological survey which provided an overview of birds in the study area, observations of breeding phenology of Lapland bunting *Calcarius lapponicus*, and censuses from census points.

Mammals are seen only rarely in the study area. Arctic fox was seen occasionally and two caribou were observed only once.

Lake monitoring is carried out in two lakes, Badesø, with arctic char *Salvelinus alpinus,* located at low altitude and Qassi-sø, without arctic char, at a higher altitude. The nutrient levels recorded in Badesø and Qassi-sø are comparable to those in other low arctic Greenland lakes. In general, Badesø is warmer than Qassi-sø. Conductivity and pH were almost similar in the two studied lakes and comparable to other Greenland lakes. The results indicate that very few ions are washed into the freshwaters in Kobbefjord. In Badesø Secchi depth was high, particularly in early summer following the ice melt. Qassi-sø receives its inflowing water from the nearby glaciers reducing the Secchi depth compared to that in Badesø. For both lakes, Secchi depth decreased over time. Chlorophyll levels were very low in the two lakes. No fish have been caught in Qassi-sø, while both arctic char and three-spined stickleback are found in Badesø. Submerged vegetation was dominated by mosses and real macrophytes *Callitriche hamulata* in both 2007 and 2008. In Qassi-sø submerged vegetation was sparse compared to Badesø.

In 2008 zooplankton was sampled monthly together with the other parameters. The samples have not been analysed yet, however.

MarineBasis

The programme was initiated in 2005 and comprises a consecutive monthly dataset of pelagic physical, chemical and biological parameters along with seasonal recordings of sea ice, benthic flux, fauna and flora, marine mammals and seabirds in Godthåbsfjord. The programme aims to link physiochemical conditions, marine production, re-mineralization, benthic-pelagic exchange and species abundance and composition with climatic forcing in Godthåbsfjord in a long-term perspective.

Satellite monitoring of sea ice conditions showed a prolonged maximum sea ice extent in Baffin Bay and a more extensive sea ice cover in parts of Godthåbsfjord during winter 2007/2008, compared to the two previous years. Nevertheless, minimum sea ice cover was as previously still observed in July/August in 2008 throughout the region. The ice cover in Baffin Bay is influenced by the West Greenland Current, which conveys warm water masses northwards.

Monthly monitoring of hydrographical conditions, at the main station near the entrance to Godthåbsfjord, showed a stratification of the water column lasting until May. Moreover, the annual monitoring at the length section conducted in May showed an inflow of coastal waters protruding as a sub-surface layer towards the inner parts of the fjord. Similar to the two previous years, release of melt water and heating of surface waters during the summer produced a fresher and warmer surface layer, thus reflecting a seaward export of freshwater along the northern coastline (Akia). This surface layer also sustains the highest phytoplankton biomass recorded throughout the year. Seasonally the phytoplankton biomass show two distinctive peaks occurring in May and July-September, which generally coincide with two separate bloom events in pelagic primary production. The pelagic primary production in summer depletes the different nutrients in the surface layer to varying degrees.

The complete dataset since 2005 of surface water pCO_2 shows levels consistently below the atmospheric content, indicating that Godthåbsfjord is a strong CO_2 sink. Moreover, surface pCO_2 levels declines towards the head of the fjord, reflecting a potentially increasing CO_2 uptake in surface waters along the fjord.

Vertical sinking flux of particulate material, measured monthly, showed a low organic material content dominated by lithogenic material. Although sinking fluxes of total particulate material show no clear seasonal patterns, sinking of phytoplankton based material coincided with the two distinctive peaks in phytoplankton biomass. Re-mineralization of organic matter in the sediment can be estimated by the oxygen flux, with the lowest rates generally observed in winter and highest rates in late summer/early autumn.

The phytoplankton community was dominated by diatoms throughout the year, except during the spring bloom in May/June when *Phaeocystis* sp. (*Haptophyceae*) dominated. The most abundant phytoplankton species observed throughout the year are typical species of arctic coastal waters.

Similar to the previous years, the zooplankton community showed a seasonal succession seemingly following the life cycle of copepods, with the abundance of eggs, nauplii and copepods peaking in that order. *Microsetella* sp. remained the most abundant copepod species throughout the year, except in June when *Calanus* spp. and *Oithona* spp. dominated.

The highest abundance of ichthyoplankton (fish larvae) was observed in March, with sand eel dominating from March to July followed by capelin in July/August. Cod larvae were only present in low numbers throughout the year, and at all stations along the length sections of the fjord. Furthermore, the species composition of ichthyoplankton along the fjord changed between the length sections conducted in May and July/August. Monitoring of crab and shrimp larvae was included in the MarineBasis programme for the first time in 2008, although data was obtained from ichthyoplankton samples collected in 2006-2008. In 2006 and 2007, the highest abundance of crab and shrimp larvae occurred in May, while only low numbers were found in 2008. Shrimp larvae dominated from March to July, followed by snow crab in August and sand crab in September/October during 2008. Along the length sections sampled in May 2006-2008, shrimp larvae dominated on the shelf slope, sand crab on Fyllas Banke, while both sand crab and snow crab were more abundant than shrimp larvae at the entrance to the fjord.

The physiological status of the two dominant benthic fauna species sea urchin *Chlamys islandica* and scallop *Strongolycentros droebachiensis* were studied in May 2007 and 2008. Indices of both species reflected a general reduction in their physiological fitness from 2007 to 2008.

The annual monitoring of the macroalgal community distribution showed that brown macroalga *Agarum clathratum* is the most widely distributed macroalgal species in the fjord, although other species are abundant. The annual monitoring of the macroalgal species *Laminaria longicruris* showed a similar annual blade production in 2007 and 2008.

Seabirds are annually monitored at different locations in and around Godthåbsfjord. Qeqertannguit showed a decrease in the number of breeding kittiwake and arctic tern from 2006 and 2007 to 2008. In parallel, Nunngarussuit showed a lower number of guillemots in 2008 than in 2006 and 2007.

Observations of humpback whales were conducted from May to October overlooking a cross-section of the entrance to Godthåbsfjord. Fewer whales were observed in 2008 than in 2007, although most were sighted between June and August in both years. Photo-ID indicates that the humpback whales are moving in and out of Godthåbsfjord during the season, thus representing an 'open population'.

Research projects

In 2008, eleven different research projects were carried out in cooperation with Nuuk Ecological Research Operations. The research projects all focussed on different biological topics in the marine compartment of the ecosystem.

1 Introduction

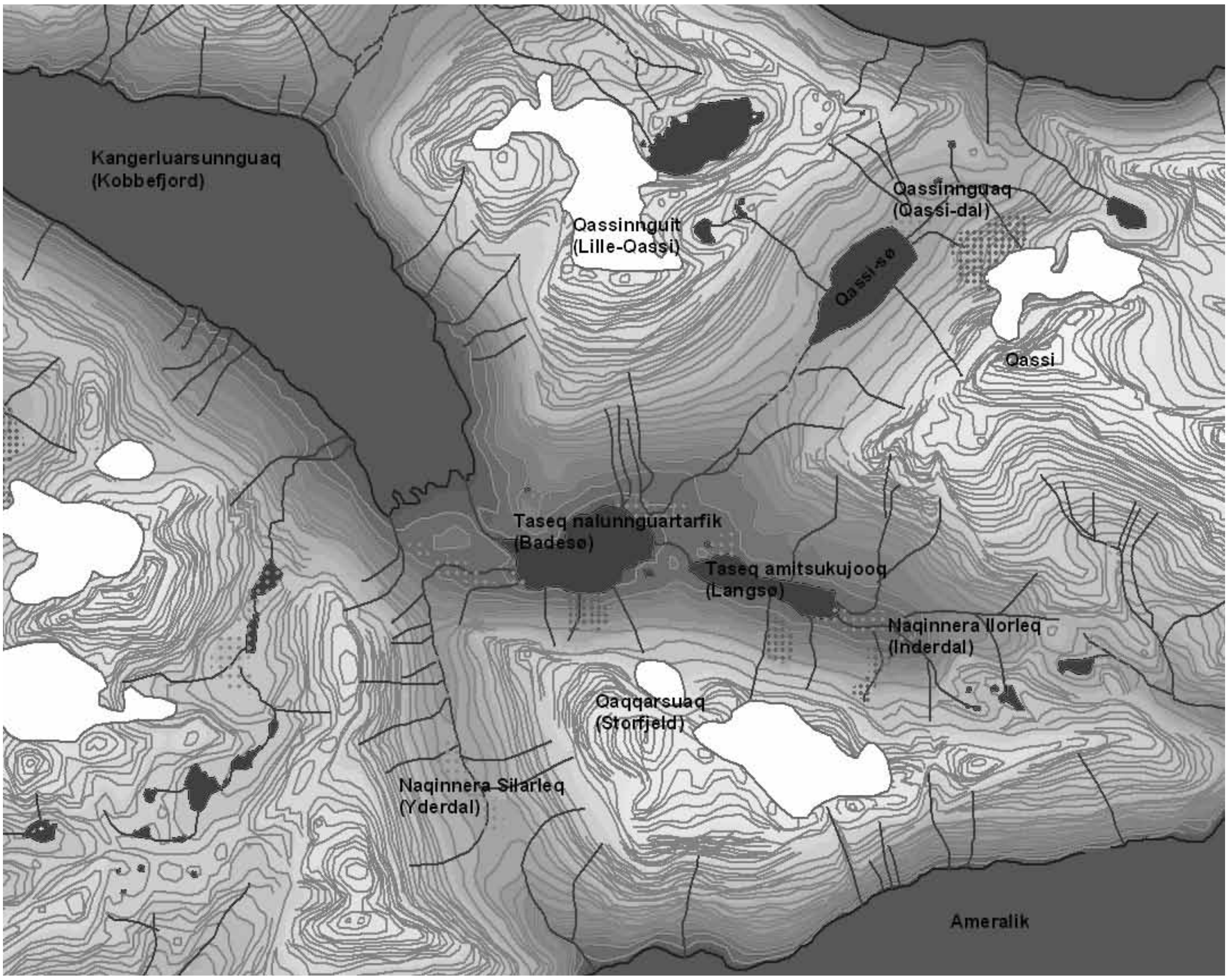
Morten Rasch

2008 was the second year of operation of the fully established Nuuk Basic programme. The marine component of the programme, i.e. MarineBasis, was already established in August 2005, but funding for the run of the terrestrial part of Nuuk Basic, i.e. ClimateBasis, GeoBasis and BioBasis, was not in place before early in 2007. In 2007 efforts in the terrestrial part of the programme was therefore mainly on establishing research plots, sites and installations.

2008 was expected to be the first year of run of the fully established Nuuk Basic programme, but due to severe technical failures on different equipment belonging to especially the ClimateBasis and the GeoBasis programmes, many of the expected continuous time series for 2008 were broken. However, most of the failures have now been corrected, and we therefore consider that the programme is more or less fully implemented by the end of the 2008 field season or early in the 2009 field season.

The 2008 field season in Kobbefjord started on 13 March and continued until 4 December. During this period approximately 30 scientists spend around 600 'man-days' in the study area.

Figure 1.1 Map of the Kobbefjord area with Danish and Greenlandic place names.



1.1 New research hut at Kobbefjord

On 18 October 2008 a topping-out ceremony for the new research hut at Kobbefjord was held. Hopefully, the 55 m^2 hut will for many years be the base for the research and monitoring activities under the framework of Nuuk Ecological Research Operations. The construction work continued until 14 November, and it is the plan to finish the construction work in the early part of the 2009 field season.

1.2 Scientific framework and organisation

The overall scientific framework and organisation of Nuuk Ecological Research Operations and Nuuk Basic are described in Nuuk Ecological Research Operations, 1st Annual Report (Chapters 1 and 8). However, a few structural changes have occurred since this report was published.

Danish Polar Center closed down by the end of 2008. The secretariats for both Nuuk Ecological Research Operations (NERO) and Nuuk Basic were together with the Zackenberg Ecological Research Operations (ZERO) and the Zackenberg Basic secretariats originally placed at Danish Polar Center, and as a consequence a new siting was needed. In late 2008, it was therefore decided to transfer the secretariats to National Environmental Research Institute at Aarhus University, together with the group of people working with the Zackenberg logistics. In relation to this move a new structure was developed. Now, the four secretariats are gathered in an organisation called Greenland Ecosystem Monitoring (GEM). GEM coordinates the work in ZERO, NERO, Nuuk Basic and Zackenberg Basic and takes care of secretariat tasks like publication of the relevant annual reports, maintenance of web pages, national and international representation of the programmes etc. GEM has a secretariat situated at National Environmental Research Institute at Aarhus University. The activities within GEM is led by a steering committee with representatives from Danish Energy Agency, Danish Environmental Protection Agency, Danish Agency for Science, Technology and Innovation, Greenland Institute of Natural Resources, Asiaq – Greenland Survey, National Environmental Research Institute at Aarhus University, Copenhagen University and Geological Survey of Denmark and Greenland. The practical work within GEM is coordinated by a coordination group consisting of the different managers involved in the practical work at Zackenberg and Nuuk.

1.3 Funding

Nuuk Basic is funded in by the Danish Energy Agency and the Danish Environmental Protection Agency with contributions from Greenland Institute of Natural Resources, Asiaq - Greenland Survey, National Environmental Research Institute at Aarhus University and University of Copenhagen.

Most of the necessary 'infrastructure', including boats, field huts etc. has generously been provided by Aage V. Jensen Charity Foundation.

1.4 Climate Centre in Nuuk

On 10 April 2008, the Danish and the Greenlandic ministers of research, Helge Sander and Tommy Marø, agreed on a model for establishment of a Climate Centre in Nuuk. It is the plan that the Centre will open before The United Nations Climate Change Conference in Copenhagen in December 2009. The Centre will be placed at Greenland Institute of Natural Resources, it will be led by a centre leader, and it will further employ five to ten scientists with place of employment in Nuuk. The terms of reference for the Climate Centre states specifically that cooperation with Zackenberg Basic and Nuuk Basic are considered relevant.

1.5 Plans for the 2009 field season

It is the plan for 2009 to finish the establishment of the different terrestrial programmes. In 2008, we experienced severe failures on especially field equipment and installations belonging to the ClimateBasis and GeoBasis programmes. These failures will in 2009 either be corrected or new installations will be established to fully implement the programme.

Further, it is the plan that the field hut at Kobbefjord should be taken in use early in 2009.

1.6 Further information

Further information about Nuuk Ecological Research Operations and Nuuk Basic is available on the Nuuk Basic homepage (www.nuuk-basic.dk) together with information concerning:

- The study area
- Access
- Publications
- Data
- Staff

Nuuk Basic is coordinated by the Greenland Ecosystem Monitoring Secretariat at National Environmental Research Institute at Aarhus University. For further information about Nuuk Ecological Research Operations and Nuuk Basic, please contact:

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Figure 1.2 Topping-out ceremony for the new research hut at Kobbejfjord, October 2008. Photo: Søren Rysgaard.

2 NUUK BASIC

The ClimateBasis programme

Karl Martin Iversen and Kisser Thorsøe

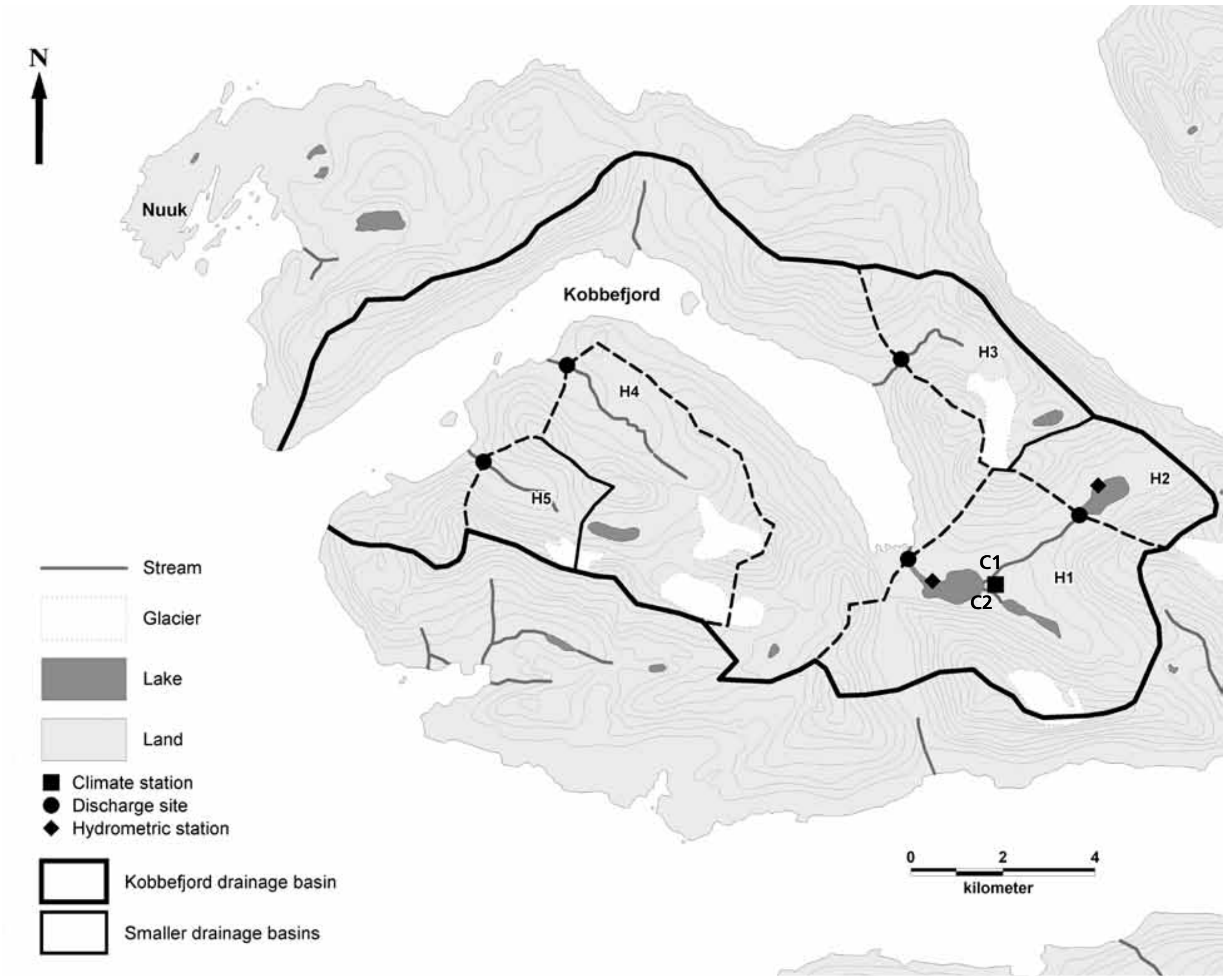
The ClimateBasis programme gathers and accumulates data describing the climatological and hydrological conditions in the Kobbefjord area. Two automatic climate stations (C1 and C2), two automatic hydrometric stations (H1 and H2) and three diver stations (H3, H4 and H5) monitor the physical parameters necessary to describe the variations in climate and hydrology. Location of the different stations can be seen in figure 2.1. ClimateBasis is operated by Asiaq – Greenland Survey.

2.1 Meteorological data

In 2008 a few changes have been made to the installations used for climate monitoring in the Kobbefjord area. For the full description of the stations see Jensen and Rasch (2008).

Since October 2007, the two climate stations have been visited five times by scientific personnel and two times by technicians. In September and October the technicians replaced the following sensors: Snow depth, RVI, PAR, net radiation (lite) and UVB. The snow depth sensors were mounted on new, separate masts.

Figure 2.1 Location of the climate (C1, C2), hydrometric (H1, H2) and diver stations (H3, H4, H5) in the Kobbefjord area together with the drainage basins of Kobbefjord and the drainage basin for the hydrometric stations and the diver stations.



The RVI and the wind speed sensors (2 m above terrain), were moved to allow the RVI-sensors to be mounted over uniform vegetation and the wind speed sensors to be mounted closer to the data loggers. The climate sensors have generally performed well during the second year of measurements. The only physical damage to the stations were a slight bending by the wind of the 2 m masts holding nearly all the radiation sensors and a crack in one of the net radiation sensors at C2. Furthermore, the software running all climate stations has been further developed and corrected to make it run more properly. A software error resulted in missing radiation data until 18 June 2008.

Meteorological data 2007-2008

This section describes data from the first full year of measurements for all essential climate parameters. Figure 2.2 gives an overview of the meteorological measurements in 2008.

The annual mean of recorded temperatures in 2008 was -1.5 °C, table 2.1. The coldest month was February with an average temperature of -14.1 °C and a minimum temperature as low as -31.0 °C, while the warmest month was July with temperatures averaging 10.1 °C and a maximum temperature as high as 21.0 °C. Compared with the climate normal, the recorded temperatures were below normal during winter months (November 2007 to March 2008) and above normal during summer months (April to August 2008) (Cappelen et al. 2001).

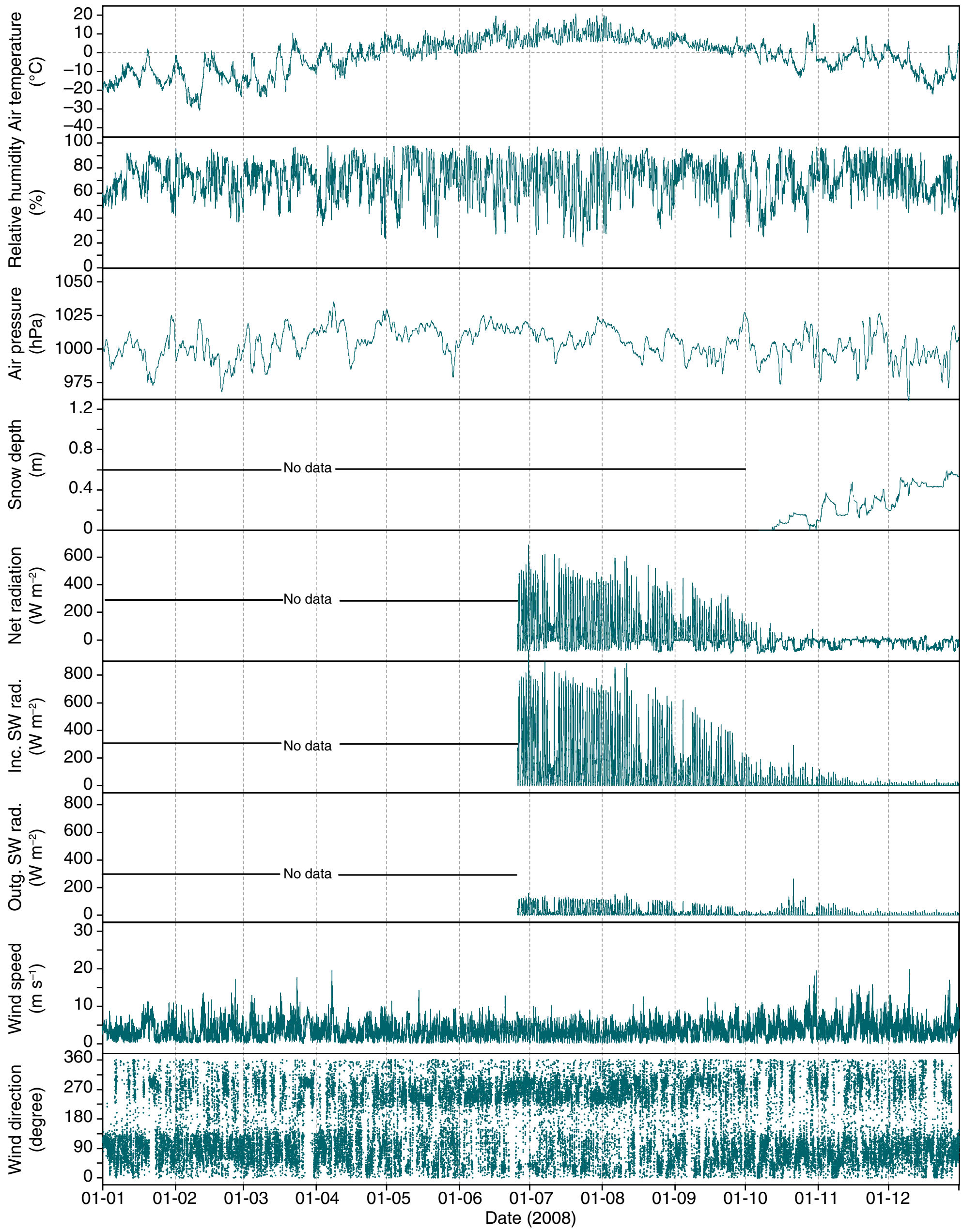
The general weather pattern observed from January to March 2008 was characterized by long periods with ENE winds and low temperatures. The stable weather situation was interrupted when low pressures occasionally passed over the area, which resulted in rising temperatures, WNW winds, high wind speeds and often precipitation. At the end of March and in the beginning of April higher frequency of winds from the WSW brought warmer and more humid air to the Kobbefjord area. Two thaw events occurred on 22 March and 8 April. The last day in the spring with a mean air temperature below the freezing point was recorded on 13 May.

From May until the end of July the dominant wind direction was WSW and air pressure was stable (table 2.1). Only two low pressures passed during this period and long periods with clear skies and stable winds occurred. From June to August, the air temperature had diurnal amplitudes of about 10 °C during clear sky conditions induced by high incoming radiation throughout the day and significant outgoing long-wave radiation throughout the night. In figure 2.2 this effect can be observed as periods with high positive net radiation during the day and negative net

Table 2.1 Monthly mean values of selected climate parameters from October 2007 to December 2008. For 2008 also mean relative humidity, annual mean temperature, mean air pressure, accumulated precipitation and mean wind speed. The precipitation data for January, March and December is incomplete.

Month-year	Rel. Hum (%)	Snow depth (m)	Air temp. (°C)	Air pressure (hPa)	Precip. (mm)	Wind ($m\ s^{-1}$)	Max 10 min. wind ($m\ s^{-1}$)	Wind dir. (most frequent)
Oct-07	63.7	---	–1.2	998.6	40	3.4	17.9	ENE
Nov-07	72.9	---	–4.3	1003.1	160	4.6	15.9	ENE
Dec-07	70.1	---	–9.5	992.4	63	3.6	11.6	ENE
Jan-08	71.9	---	–12.8	997.5	36	3.7	11.4	ESE
Feb-08	71.6	---	–14.1	995.1	69	3.3	17.2	ESE
Mar-08	75.0	---	–9.1	1003.5	---	3.9	17.7	WNW
Apr-08	69.2	---	–1.7	1011.9	19	3.2	19.7	NE
May-08	74.8	---	3.1	1010.2	55	3.0	14.3	WSW
Jun-08	72.2	---	7.2	1014.8	23	3.4	12.8	WSW
Jul-08	67.8	---	10.1	1007.8	45	3.2	10.2	WSW
Aug-08	73.3	---	7.9	1005.2	72	3.3	12.6	WNW
Sep-08	75.2	---	3.6	1000.4	172	3.8	12.2	WNW
Oct-08	66.6	0.07	–0.8	1000.7	210	4.3	19.5	ENE
Nov-08	76.9	0.25	–2.5	1001.6	281	4.7	15.8	ENE
Dec-08	68.7	0.44	–8.6	994.3	146	4.1	19.8	ENE
2008	71.8	---	–1.4	1003.6	1127	3.7	---	---

Figure 2.2 Variation of selected climate parameters in 2008. From top: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation, outgoing short wave radiation, wind speed and wind direction. Wind speed and direction are measured 10 m above terrain; the remaining parameters are measured 2 m above terrain.



radiation during the night. The fluctuating temperatures affected the relative humidity, which was often below 50 % during daytime and about 90 % during night. Also the wind speed had a diurnal variation in clear sky conditions (approximately 0 to 7 m s^{-1}), which is an effect of sea/land breeze. Comparing the mean air temperatures from June to September with measurements from last year show that June, July and September were warmer in 2008 than in 2007 (table 2.2). Other mean values for selected climate parameters are shown in table 2.1.

From mid-August the frequency of passing low pressures increased and the dominant wind direction turned to WNW in August and September and ENE in October to December. Even though the dominant wind direction gradually turned to ENE, the wind direction during low pressure was WNW. Passing low pressures in the autumn were often associated with very high wind speeds. Despite the fact that the climate stations are shielded by the surrounding mountains, the mean wind speed was above 15 m s^{-1} on six occasions from October to December 2008. As the frequency of passing low pressure increased in the autumn 2008, so did the amount of precipitation. The precipitation in September through December amounted to 70 % of the total precipitation in 2008. Recorded precipitation in 2008 was 1127 mm (table

Table 2.2 Comparison of monthly mean air temperatures 2007 and 2008 (May is incomplete in 2007).

Month-year	Air temp. (°C)	Month-year	Air temp. (°C)
May-08	3.1	Maj-07	-0.2
Jun-08	7.2	Jun-07	4.1
Jul-08	10.1	Jul-07	9.1
Aug-08	7.9	Aug-07	9.8
Sep-08	3.6	Sep-07	3.2

2.1). The first snow fall at the climate station was recorded on 14 October but melted away 27 to 29 October when a storm passed with air temperatures up to 11.3 °C. From November and the rest of the year the Kobbefjord area had full snow cover, which on 26 December reached a depth of 59 cm at the stations.

The levels of selected radiation parameters are shown in table 2.3. The net radiation shifted from positive to negative values around September/October, which is due to a combined effect of decreasing incoming radiation and the soil/vegetation system loosing thermal energy. The snow cover instantly changed the radiation properties of the surface by reflecting short wave incoming radiation (the albedo increased from approximately 0.2 to 0.9) further decreasing outgoing long wave radiation.

2.2 River water discharge

Hydrometric stations

In 2008, hydrological measurements were carried out at five locations in the Kobbefjord area. Two hydrometric stations were established in 2007 and divers are each year deployed in three minor rivulets running in to Kobbefjord. The drainage basins of the five locations cover a total of 58 km^2 corresponding to 56 % of the 115 km^2 catchment area to Kobbefjord.

The hydrometric station H1 is located at a lake in the bottom of Kobbefjord, and the hydrometric station H2 is located by a lake at Qasinnguaq northeast of the hydrometric station H1 (figure 2.1). The drainage basin of H2 is a sub-basin of the drainage basin of H1. The drainage basin of H1 covers 31 km^2 of which the drainage basin of H2 covers 7 km^2. For descriptions of the hydrometric stations see Jensen and Rasch (2008).

The diver station H3 is located by a small rivulet at Oriartorfik on the northern side of Kobbefjord. The drainage basin of H3 is 10 km^2. The diver station, H4, is located at Teqqinngallip Kuaa on the south side of the fjord. The drainage basin of H4 covers 17 km^2. The diver station H5, is located at Kingigtorssuaq also on the south side of the fjord, but further southwest than H4 (see figure 2.1 for all locations). The drainage

Table 2.3 Monthly mean values of selected radiation parameter. Values for June 2008 are incomplete.

Month-year	Albedo	Short wave rad		Long wave rad.		Net rad.	PAR	UVB
		W m^{-2} in	W m^{-2} out	W m^{-2} in	W m^{-2} out	W m^{-2}	µmol s^{-1} m^{-2}	mW m^{-2}
Oct-07	---	---	---	---	---	---	---	---
Nov-07	---	---	---	---	---	---	---	---
Dec-07	---	---	---	---	---	---	---	---
Jan-08	---	---	---	---	---	---	---	---
Feb-08	---	---	---	---	---	---	---	---
Mar-08	---	---	---	---	---	---	---	---
Apr-08	---	---	---	---	---	---	---	---
May-08	---	---	---	---	---	---	---	---
Jun-08	0.2	247.8	39.8	287.0	374.8	119.7	980.5	26.6
Jul-08	0.2	233.0	38.1	308.3	383.6	119.5	920.8	26.6
Aug-08	0.2	148.7	24.5	312.3	364.3	72.1	591.1	16.3
Sep-08	0.2	65.7	10.1	303.3	332.1	26.8	260.5	5.7
Oct-08	0.6	20.3	8.9	267.1	302.4	–24.1	90.4	2.0
Nov-08	0.9	6.1	5.7	282.4	294.8	–12.0	28.5	0.3
Dec-08	0.9	2.1	2.0	241.0	264.7	–23.6	9.2	0.0

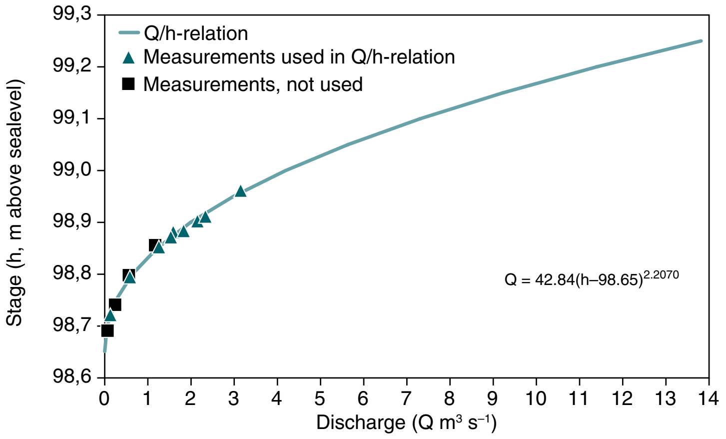


Figure 2.3 Discharge - water level relation curve (Q/h-relation) at the hydrometric station H1. The coefficient of correlation (R2) for the curve is 0.996

basin of H5 covers 6 km². H3, H4 and H5 were in 2008 equipped with one diver and one barodiver from Van Essen Instruments. The divers are placed in the rivulets in early spring and are collected in late fall before the rivulets freezes. The divers at H3, H4 and H5 are logging every 15 minutes.

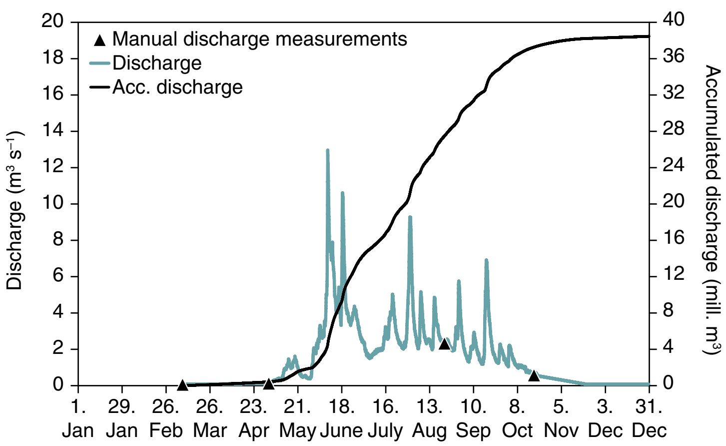
Q/h-relation

Manual discharge measurements have been carried out at stations H1, H3, H4 and H5. The purpose is to establish stage-discharge relations (Q/h-relations). It is generally recommended to base a Q/h-relation on a minimum of 12 to 15 discharge measurements covering the water levels normally observed at the station (ISO 1100-2, 1998). For H2, H3, H4 and H5 there still is a lack of discharge measurements to produce reliable Q/h-relations. Therefore, data from these stations are not presented.

In 2008, four discharge measurements were carried out at H1. Two of the measurements were carried out when the outlet were influenced by ice. The total number of measurements at H1 is now 13. Unfortunately, none of the measurements carried out in 2008 were at high water levels, so as was the case in 2007, the measurements span only over the lower half of the measured water level with discharges ranging from 0.02 to 3.15 m³ s⁻¹. The total measured span in the water level during ice free conditions in 2006, 2007 and 2008 is 0.59 m. As there still is a lack of measurements at high water level, the established Q/h-relation under ice free conditions presented is still preliminary and special care should be taken in relation to interpretation of water discharge especially at high water levels. The preliminary Q/h-relation for H1 is shown in figure 2.3. The preliminary Q/h-relation will be evaluated and refined when additional measurements have been carried out in 2009.

Two of the discharge measurements at H1 were carried out on the same day with two different instruments. As this is not two independent measurements, only one of them is used for establishing the Q/h-relation. Four other measurements were carried out when the lake was covered by ice. Three of these measurements are not used in the establishment of the Q/h-relation because the outlet was affected by ice and therefore not representative for ice free conditions. The aim is to establish Q/h-relation for H1 under both 'ice covered' and 'ice free' conditions.

Figure 2.4 River water discharge at H1 during 2007.



River water discharge at H1

When the outlet at H1 is not influenced by ice, the discharge is calculated from the measured water level by use of the established Q/h-relation.

The provisional studies indicate that water is running at H1 all year. Based on manual measurements, a base flow of 0.07 m3 s-1 is assumed during the winter. From 21 October 2007 it is assumed that the outlet is influenced by ice, and the Q/h-relation is therefore not valid. Furthermore, it is assumed that the discharge reaches base flow on 21 November. During the period 21 October to 21 November, the discharge is calculated by linear interpolation. From 21 March it is assumed that water discharge exceeds base flow and until the first manual discharge measurement on 10 April the discharge is found by linear interpolated between the base flow and the first manual measured discharge. The discharge is interpolated from 10 April until 16 May. Thereafter it is assumed that the Q/h-relation is valid.

From 22 October 2008 it is assumed that the outlet is influenced by ice, and the Q/h-relation is not valid. The discharge is interpolated from this day until the manual discharge measurement on 4 December and until the next manual measurement on 20 January 2009.

The river water discharges at H1 for 2007 and 2008 is shown in figure 2.4 and 2.5.

The total discharge from H1 during the hydrological year from 1 October 2007 to 30 September 2008 is then calculated to 30.1 million m^3. The peak discharge in 2008 was recorded on 14 June. This event was caused by a combination of spring melt and precipitation. From July and until 23 October, when the Q/h-relation is no longer valid, the discharge is characterised by a number of smaller peaks caused by rain events. The accumulated discharge of 30.1 million m^3 corresponds to a runoff of 994 mm from the entire catchment of H1. 18 % of the accumulated discharge is calculated using extrapolation of the Q/h-relation.

Comparison of discharge with precipitation has been made for the hydrologic year 2007/2008. The precipitation at the meteorological stations C1 and C2 was 753 mm, but there are two periods with no valid data (in total, data from about seven weeks are missing).

The difference between the runoff and the precipitation are caused by many uncertainties in the understanding of the hydrology in the Kobbefjord area. For example the lack of discharge measurements at high water levels induces errors, and the precipitation record is not complete and is not corrected for wind effects and therefore probably gives too low values. Furthermore, the contribution from the glacier in the area is not yet investigated. One of the aims for ClimateBasis is to understand the hydrological processes in the low arctic area around Kobbefjord and the above mentioned factors will, among others, be investigated in the following years.

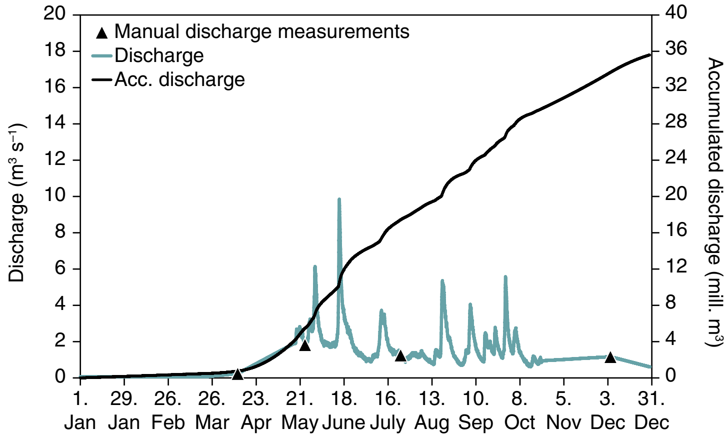


Figure 2.5 River water discharge at H1 during 2008.

3 NUUK BASIC

The GeoBasis programme

Mikkel P. Tamstorf, Karl Martin Iversen, Birger Ulf Hansen, Charlotte Sigsgaard, Mikkel Fruergaard, Rasmus H. Andreasen, Mikhail Mastepanov, Julie M. Falk, Lena Ström and Torben Røjle Christensen

The GeoBasis programme provides long term data of climatic, hydrological and physical landscape variables describing the environment in the Kobbefjord drainage basin close to Nuuk. GeoBasis was in 2008 operated by the Department of Arctic Environment at National Environmental Research Institute at Aarhus University, in collaboration with the Department of Geography and Geology at the University of Copenhagen. GeoBasis was in 2008 funded by the Danish Environmental Protection Agency as part of the environmental support programme *Dancea – Danish Cooperation for Environment in the Arctic*. A part-time position is placed in Nuuk at Asiaq - Greenland Survey. The GeoBasis programme includes monitoring of the physical variables within snow and ice, soils, vegetation and carbon flux. The programme runs from 1 May to the end of September with some year round measurements from the automated stations.

The 2008 season is the first full season for the GeoBasis programme. In 2007, the field programme was initiated during a three week intensive field campaign in August where most of the equipment was installed, although some installations had to be postponed until 2008.

Little knowledge was available about local topographic and microclimatic variations during the installation of sensors and stations in 2007. Therefore, the programme has run into unforeseen problems (e.g. very strong winds that have destroyed several installations, build up of snow drift in front of cameras, high levels of melt water in the snow pack with subsequent flooding of data logger etc.). Although this has caused gaps in the data series, most of the experienced problems have now been solved or will be solved during the 2009 season.

3.1 Snow and ice

Snow cover extent

Automatic cameras were installed in 2007 at 300 and 500 m a.s.l. to monitor the snow cover extent. The melting started in second half of April and took speed in May (figure 3.1). By 12 June all snow on the east side of the main river outlet had melted.

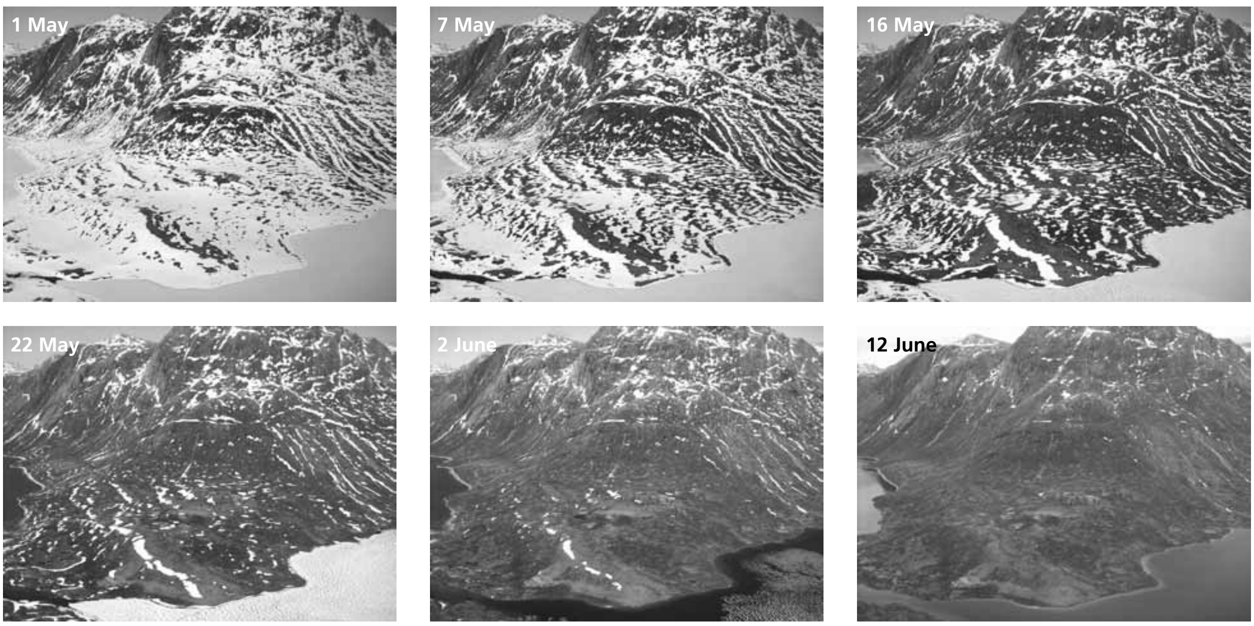


Figure 3.1 Snow cover melt as seen from the automatic camera (K3-500) at 500 m a.s.l.

Unfortunately, the camera that overlooks the outer part of the drainage basin (K1-300), where most monitoring and surveys are carried out, was covered by a big snow drift by mid-February. It did not melt free until late June and can therefore not be used for accessing the snow extent in 2008. Change of the setup has been planned for 2009. The central fen area was fully snow covered on 5 May and completely snow free on 28 May. The time of snow melt is therefore estimated to have occurred between 15 and 25 May.

Another unexpected camera problem was build-up of ice and snow on the lenses of north facing cameras. The K3-500 camera had ice crystals covering the lens for most of the winter until 30 April when the first positive temperatures melted the ice away.

One of the tasks for 2009 is to collect enough GPS positions for ortho-rectification of camera images to allow for quantitative analyses of the snow cover extent throughout the year. Snow cover extent for fall 2007 and entire 2008 will therefore be reported in the coming annual reports.

Snow cover

The snow cover depth and snow densities in the Kobbefjord drainage basin were surveyed on 4 April, 10 April and 5 May using a combination of ground penetrating radar and manual stake measurements. Snow depths varied from zero to more than two meters at maximum snow cover. Table 3.1 summarizes the depth and density results from the three snow pits and the cross section A on each of the survey dates (figure 3.2). In cross section A the deepest snow depths and densities were located on the northeast facing slopes near snow pit A2; the lower depths and densities were found on the south-

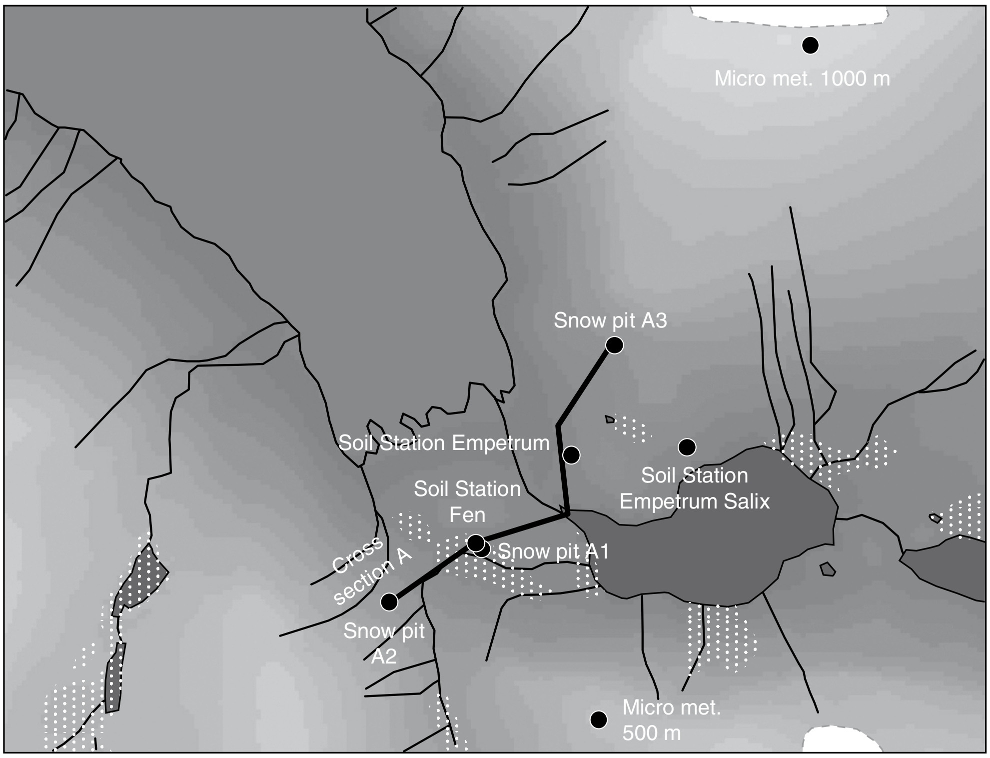


Figure 3.2 Location of snow transect, snow pits, soil stations and the micrometeorological station at 500 m a.s.l.

Table 3.1 Snow density and water equivalence of snow package at the four snow survey locations. The snow survey was carried out three times during the melting season.

	04 April 2008			10 April 2008			05 May 2008		
	Depth (cm)	Density (kg m^{-3})	Water eq. (mm)	Depth (cm)	Density (kg m^{-3})	Water eq. (mm)	Depth (cm)	Density (kg m^{-3})	Water eq. (mm)
Snow pit A1	100	401	401	98	341	334	60	409	245
Snow pit A2	165	410	677	175	453	793	85	407	346
Snow pit A3	80	358	286	40	336	134	0	0	0
Cross section A	95	390	370	85	377	320	53	408	216

Table 3.2 Snow temperatures from snow pit A2 at the three snow surveys.

Depth (cm)	4 April (°C)	10 April (°C)	5 May (°C)
–20	–1.5	–2.9	0.1
–40	–2.0	–1.9	0.1
–60	–1.9	–1.7	0.1
–80	–1.8	–1.5	0.1
–100	–2.0	–0.5	0.1
–120	–1.5	–0.8	---
–140	–1.5	–1.0	---
–160	–1.5	–1.3	---

west facing slopes near snow pit A3. This general pattern is mainly controlled by microclimate and small scale topography variations resulting in very heterogeneous snow cover conditions that changes within a few meters. Between the first two surveys in April, the snow pack volume generally decreased with rising snow densities in shaded terrain (A2) and decreasing densities in sites exposed to the sun (A1, A3). Precipitation resulted in a 14 mm increase of snow depth between the first two surveys. Snow profiles from April were generally dense with many ice layers in the top part and coarse grained ice crystals near the bottom. On 5 May, the snow cover water equivalent in cross section A was in average reduced by 154 mm since 4 April and the snow temperatures were isothermal (0 °C) in all profiles (table 3.2).

Ice cover

The ice cover on the lakes broke up in late May/beginning of June in 2008 (table 3.3).

*Table 3.3 Visually estimated dates for 50% ice cover on selected lakes within the Kobbefjord drainage basin and Kobbefjord. Dates are reported for perennial formation of ice cover in the fall and for the break-up of ice cover in spring. Badesø is the main lake in the area, Langsø is the long lake in the valley behind Badesø and Qassi-sø is the lake at 250 m a.s.l. in the northern valley of the drainage basin. *Due to low cloud cover and ice formation on the cameras it has not been possible to estimate the exact data of ice formation on Kobbefjord in 2007.*

	2007 Fall	2008 Spring	2008 Fall
Badesø	23 Oct	2 June	5 Nov
Langsø	22 Oct	31 May	5 Nov
Qassi-sø	22 Oct	9 June	4 Nov
Kobbefjord	Between 27 Dec and 12 Feb*	15 May	–

The smaller lake Langsø in the sheltered bottom of the main valley melted first; followed by Badesø two days later and the higher situated Qassi-sø a week later. The dates reported are the visually estimated dates for 50 % ice cover based on photos from the automatic cameras. Dates for the perennial formation of ice are also estimated. In 2008, thin ice formed early but disappeared again after a few days and therefore only the 'perennial' ice is reported here. Sea ice cover in Kobbefjord forms later but timing was difficult to estimate in 2007 due to ice on the camera lenses.

Micrometeorology

GeoBasis operates three micrometeorological stations in the area; SoilFen at 40 m a.s.l., M500 at approximately 550 m a.s.l. and M1000 at 1000 m a.s.l. The first two were installed in August 2007 (Tamstorf et al. 2008), while M1000 was installed on 4 September 2008 (figure 3.3). The new station is identical to M500 and includes air temperature, relative humidity, incoming short wave radiation and surface temperature. The purpose of the three stations is to monitor dynamics within the atmospheric boundary layer (e.g. temperature inversions). An example from September 2008 where all three systems were installed is shown in figure 3.4. During this period there were only few occasions with inversion (temperature rise with altitude).

The SoilFen station was installed in August 2007 and monitored successfully through the fall and winter. Unfortunately, due to very high levels of melt water in the snow pack at the fen site during spring melt, the data logger was flooded (figure 3.5) and all data after from 18 March and onwards were lost. The station was repaired in late August and the setup was changed to prevent future flooding. Summary of the data until September 2008 from the SoilFen, the M500 and the M1000 stations are given in tables 3.4, 3.5 and 3.6, respectively.

3.2 Soil

Soil water chemistry is likely to be affected by physical and chemical changes in the environment and also to have important effects on the ecosystem processes. In order to monitor such changes in the environment, the chemical composition of precipitation and soil water is monitored. By

Table 3.4 Air temperature, relative humidity, surface temperature and soil temperature at five depths (1 cm, 10 cm, 30 cm, 50 cm and 75 cm) from the SoilFen station in the fen area from August 2007 to September 2008. Lack of data from March to July 2008 is due to flooding of the station.

Month	Year	Air temp	Rel. Hum	Surface temp	Soil temp					Data coverage
		2.5 m (°C)	2.5 m %	0 m (°C)	–1 cm (°C)	–10 cm (°C)	–30 cm (°C)	–50 cm (°C)	–75 cm (°C)	%
Aug	2007	7.6	84.1	7.6	9.0	9.8	10.1	8.6	7.4	5
Sep	2007	3.8	70.1	1.9	3.4	4.3	5.3	5.9	5.8	100
Oct	2007	–0.5	64.6	–4.8	–0.6	0.2	1.1	2.3	2.8	100
Nov	2007	–3.5	74.2	–7.1	–0.3	–0.2	0.4	1.2	1.7	100
Dec	2007	–8.9	71.8	–13.1	–0.2	–0.2	0.3	0.9	1.3	100
Jan	2008	–12.1	73.2	–16.0	–0.3	–0.1	0.3	0.8	1.2	100
Feb	2008	–13.5	73.1	–15.7	–0.3	–0.1	0.2	0.7	1.0	100
Mar	2008	–8.8	75.7	–11.4	–0.3	–0.1	0.2	0.7	1.0	82
Apr	2008	---	---	---	---	---	---	---	---	0
May	2008	---	---	---	---	---	---	---	---	0
June	2008	---	---	---	---	---	---	---	---	0
July	2008	---	---	---	---	---	---	---	---	0
Aug	2008	7.4	76.6	7.4	9.3	9.2	8.6	8.3	7.6	76
Sep	2008	4.1	77.9	3.9	4.7	5.2	5.9	6.0	6.0	100

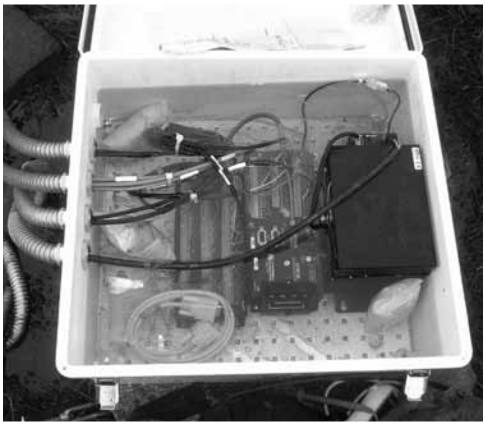


Figure 3.3 - left
A new micrometeorological station (M1000) was installed at 1000 m a.s.l. in September 2008. Photo: K. M. Iversen.

Figure 3.5 - right
The SoilFen data logger was temporarily out of order from late March 2008 to late May. The system has been changed to avoid similar problems in the future. Photo: K. M. Iversen.

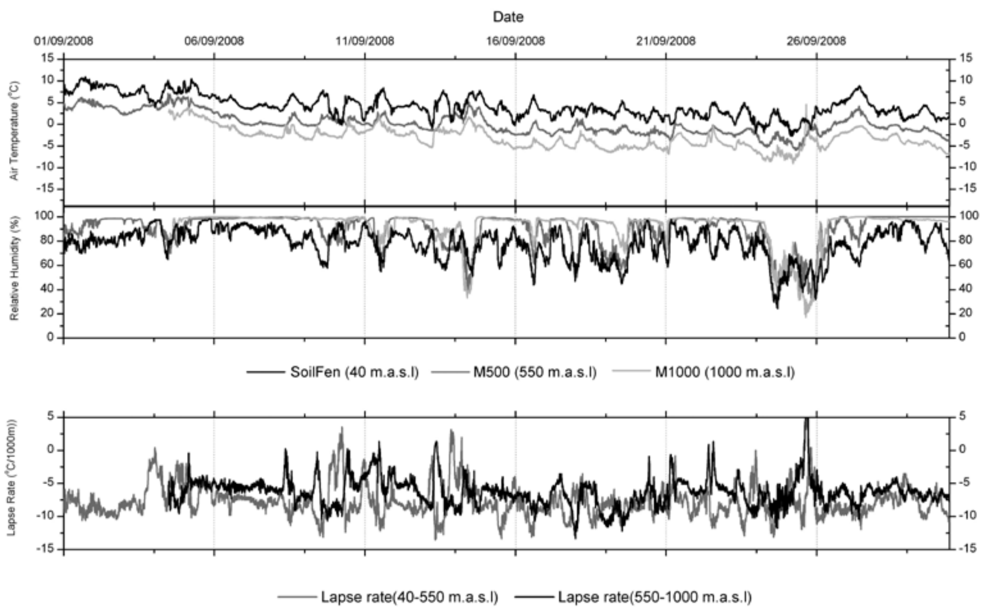


Figure 3.4 Air temperatures, lapse rate and relative humidity based on the three micrometeorological stations, SoilFen, M500 and M1000 from September 2008.

Table 3.5 Air temperature, relative humidity, surface temperature and short wave irradiance at the M500 station from August 2007 to October 2008.

Month	Year	Air temp	Rel. Hum	Surface irradiance temp	Short wave irrradiance	Data coverage
		2.5 m (°C)	2.5 m (%)	0 m (°C)	2.5 m (W m⁻²)	%
Aug	2007	5.2	83.5	6.4	45	13
Sep	2007	0.7	74.5	–1.7	85	100
Oct	2007	–2.4	63.4	–6.8	45	100
Nov	2007	–6.4	83.5	–8.3	10	100
Dec	2007	–11.6	79.6	–13.7	3	100
Jan	2008	–14.3	78.5	–16.3	7	100
Feb	2008	–15.6	78.2	–17.3	30	100
Mar	2008	–10.7	83.5	–12.3	77	100
Apr	2008	–2.4	67.2	–4.6	173	100
May	2008	2.4	73.2	3.5	237	100
June	2008	5.9	72.1	8.7	295	100
July	2008	8.9	64.3	10.5	254	100
Aug	2008	5.4	80.1	6.3	158	100
Sep	2008	0.1	90.0	–0.7	74	99
Oct	2008	–3.2	77.6	–6.2	38	100

Table 3.6 Air temperature, relative humidity, surface temperature and short wave irradiance at the M1000 for September 2008.

Month	Year	Air temp	Rel. Hum	Surface irradiance temp	Short wave irrradiance	Data coverage
		2.5 m (°C)	2.5 m (%)	0 m (°C)	2.5 m (W m⁻²)	%
Aug	2008	---	---	---	---	---
Sep	2008	–3.1	92.4	–3.1	84.9	100.0

such analyses plant nutrient status and ongoing soil forming processes are followed. Also physical dynamics are monitored by continuous measurements of variables like soil water content and soil temperature.

Physical soil properties

Three automatic soil stations are installed in the area; SoilFen, SoilEmp and SoilEmpSa. They cover the fen vegetation, the *Empetrum* heath and the mixed *Empetrum*/*Salix* heath types in the area. Together, the stations will give a detailed description of the physical soil conditions and soil water nutrient content in the area.

The final installation of the SoilEmpSa and the SoilEmp stations were carried out in June and July. Hence, data covers the period from June and onward (table 3.7).

Soil water

Soil water samplers (suction cup lysimeters) were installed at the three soil sites (SoilFen, SoilEmp and SoilEmpSa). The installations were tested, although the well drained Soil Emp site had relatively little water at most depths (<5 %). However, in order to allow the soil to settle after the installation, sampling and analysis of soil water will first begin in 2009.

River

River water samples were acquired every second week throughout the main season. Analyses of the samples and reporting of results are taken care of by the MarineBasis programme. Simultaneous with the sampling, GeoBasis also measures river water temperature, conductivity and pH. These data are reported in table 3.8. Temperature reached a maximum around 15 °C in mid/late August, and conductivity reached a minimum for the season during the same period.

From 2009 we will start measuring mercury content in the river water. Samples will be taken daily when possible from the first snow melt to the end of the monitoring season. The first results will be published in the next annual report.

Table 3.7 Soil temperature and soil moisture at four depths from the SoilEmp and SoilEmpSa stations. The SoilEmp station was not installed until late July 2008. Missing data from SoilEmpSa was due to sensors being destroyed by a fox.

Station	Month	Soil temp				Soil moist				Data coverage
		−1 cm (°C)	−5 cm (°C)	−10 cm (°C)	−30 cm (°C)	−5 cm (%)	−10 cm (%)	−30 cm (%)	−50 cm (%)	(%)
	May	---	---	---	---	---	---	---	---	0
	June	---	---	---	---	---	---	---	---	0
SoilEmp	July	12.9	12.2	11.8	10.7	2.7	26.5	3.9	1.6	21
	Aug	9.7	9.6	9.6	9.3	4.0	32.2	4.7	1.7	99
	Sep	4.6	4.8	4.9	5.2	13.2	41.8	17.6	13.5	99
	May	---	---	---	---	---	---	---	---	0
	June	11.4	10.9	10.6	9.3	---	38.3	38.3	---	42
SoilEmpsa	July	12.0	11.0	10.8	9.5	---	36.6	36.6	23.6	98
	Aug	10.8	9.5	9.5	8.9	47.2	36.7	36.7	33.1	98
	Sep	5.1	5.4	5.4	5.5	59.6	53.8	53.8	48.1	98

3.3 Vegetation

Vegetation in the Kobbefjord area is monitored both by the BioBasis and GeoBasis programmes. While BioBasis monitors individual plants and plant phenology using plot scale sites and transects, the GeoBasis programme monitors the phenology of the vegetation communities from satellite and automatic cameras imageries.

Satellite imagery

Due to frequent fog in the mornings of July and August it was not possible to obtain satellite imagery closer to the maximum of growth, around 1 August, than 17 July. An Ikonos image with 4 m multispectral resolution was acquired and geo-rectification was carried out. Atmospheric correction was also carried out but without topographic correction as the high resolution digital elevation model is not ready yet. An aerial survey was carried out in 2007, but processed images are still not available from the contractor.

Normalised Difference Vegetation Index (NDVI) has been calculated on the imagery from 17 July 2008. A subset of the central part of the monitoring area is shown in figure 3.6. In future reports, the fully pre-processed imagery will be used for extracting NDVI values in different regions at the time of peak greenness.

Camera imagery

Two automatic NDVI cameras were acquired and planned for installation in 2008. However, the cameras were defective and have been returned to the manufacturer for repair. Ortho-rectification of these camera images as well as the images from automatic snow cameras will be made as soon as a digital elevation model for the area is ready.

Table 3.8 River water temperature, conductivity and pH during the summer and fall of 2008.

Date	Time	Water temp (°C)	Conductivity (µS cm⁻¹)	pH
5 June	17:00			6.3
13 June	14:00	7.2	19.0	6.9
24 July	12:30	13.4	18.3	7.1
12 Aug	12:00	14.7	17.6	7.1
28 Aug	14:00	10.5	18.2	6.9
11 Sep	16:30	9.3	18.8	6.7
25 Sep	14:00	4.3	19.4	7.1
8 Oct	10:30	2.4	19.8	7.0

3.4 Carbon flux

Carbon fluxes are monitored on plot and landscape scale in the wet fen area using two different techniques:

- automatic chambers for methane (CH_4) and carbon dioxide (CO_2) plot measurements
- eddy covariance for CO_2/H_2O landscape measurements

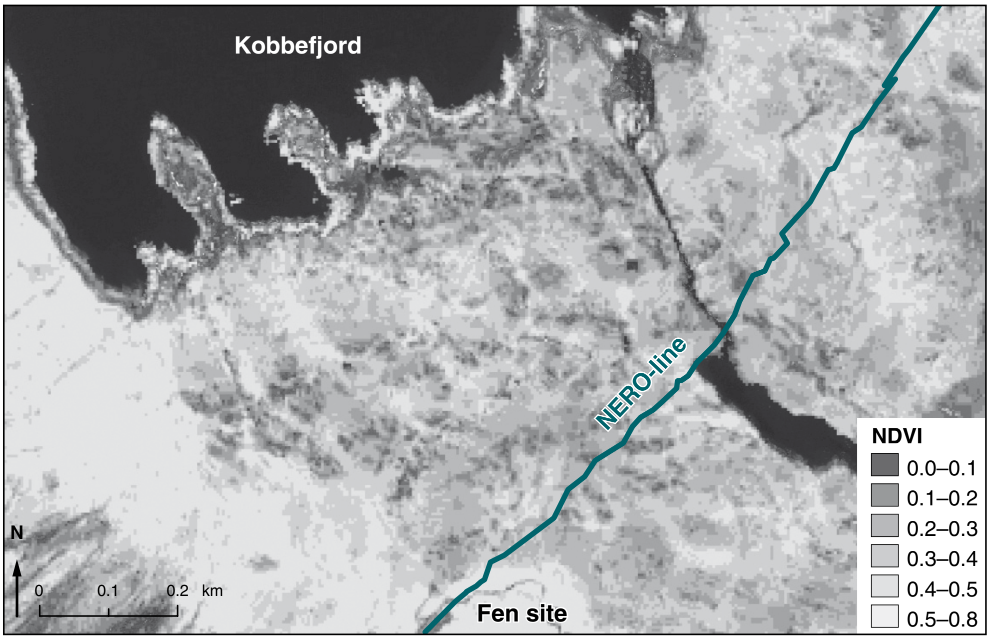


Figure 3.6 Normalised Difference Vegetation Index (NDVI) from 17 July 2008 covering the central part of the Kobbefjord monitoring area. The NERO-line and the fen site are shown. Data are atmospherically corrected but lack the topographic correction.

Carbon flux chamber monitoring

An automatic chamber system for monitoring of methane and carbon dioxide fluxes was installed in August 2007 (Tamstorf et al. 2008). The 2008 field season was planned as the first full season of monitoring. However, technical problems have caused a number of interruptions in the measurements. The data (figure 3.7) also carry a somewhat higher noise to signal ratio than usual for this method (Sigsgaard et al. 2007, Sigsgaard et al. 2008).

The flux pattern seems to be close to what is typical at e.g. Zackenberg, i.e. a dome-shaped peak with maximum approximately one month after snow melt, declining to approximately half of the peak maximum around 1 September. The autumn methane flux pattern at the Nuuk station is however very different from what is seen at Zackenberg in 2007 (Mastepanov et al. 2008, and Klitgaard and Rasch 2008). There was no detectable autumn burst at Nuuk. Hence, the fluxes continued to decline and they decreased consistently during September and October. Unfortunately, data from the start and the end of the season are lacking. Consequently, the annual CH_4 balance for 2008 can not be calculated. The peak summer emissions (approximately 5 mg CH_4 m^{-2} h^{-1}) were, however, in the range of what was measured at Zackenberg during 2006 and 2007 (approximately 7 and 5 mg CH_4 m^{-2} h^{-1}, respectively). Comparison with Zackenberg 2008 is not possible due to a very special flux pattern at Zackenberg during this year.

Data on carbon dioxide fluxes has still not been processed but will be reported in the 2009 annual report.

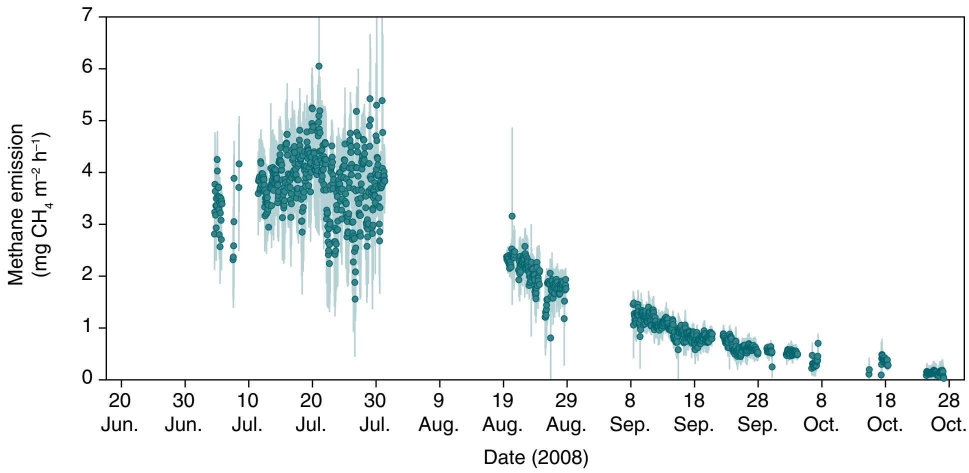


Figure 3.7 Methane (CH_4) emission from the fen site during the summer and fall of 2008. Missing data are due to running-in problems with the instrument.

CO_2 and H_2O eddy covariance monitoring

In order to describe the inter-annual variability of the seasonal carbon balance, the exchange of CO_2 between a wet fen ecosystem and the atmosphere is monitored using the eddy covariance technique. An eddy covariance tower equipped with a closed path LICOR 7000 analyzer for CO_2 and H_2O (LI-COR, Nebraska, USA) and a 3D sonic anemometer, Solent R3-50 (Gill Instruments, Lymington, United Kingdom) placed 2 m above the surface was installed in the wet fen area close to the automatic chambers (figure 3.8).

In 2008, measurements were initiated 10 June and continued until 29 October. The temporal variation in daily net exchange of CO_2 and mean daily air temperature for the period is shown in figure 3.9. The sum of the two processes, i.e. uptake of CO_2 by plants from photosynthesis and loss due to microbial decomposition in the soil and plant respiration, is denoted Net Ecosystem Exchange (NEE). The uptake is controlled by the climatic conditions during the growth season with solar radiation and temperature being the key controlling factors. The respiratory process is controlled by soil temperature in an exponential relationship.

When measurements were initiated 10 June, the fen area was completely free of snow and had been so since late May. Therefore, the net uptake period had already started. During the last weeks of June, the vegetation developed further and the net uptake lasted approximately 83 days (depending on the actual end of the snow melt) and was only interrupted by a few days in mid-August, when respiration exceeded the photosynthesis due to windy and cloudy weather and a low level of incoming solar radiation. Data are missing for several periods of three to five days due to different technical problems. Missing data from the SoilFen station prevents estimation of fluxes for specific periods. A maximum uptake of CO_2 was measured 13 July. By approximately 1 September, the ecosystem turned into a source of CO_2 when respiration gradually exceeded the fading photosynthesis. A summary of the summer season environmental variables are shown in table 3.9.

Table 3.9 Summary of summer season environmental variables and CO_2 exchange 2008.

	2008
Beginning of net uptake period	Before 10 June
End of net uptake period	Approximately 1 September
Length of net uptake period	Approximately 83 days
Beginning of measuring season	10 June
End of measuring season	29 October
Length of measuring season	141 days
NEE for net uptake period (g C m^{-2})	(–) 65.3*
NEE for measuring season (g C m^{-2})	(–) 60.6
Maximum daily accumulation (g C m^{-2} d^{-1})	(–) 2.31

*Due to missing data in parts of the season the NEE for the net uptake period is an estimate.

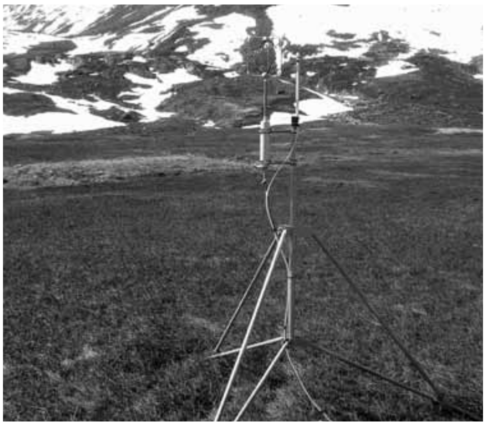


Figure 3.8 The new CO_2 eddy covariance mast was installed in the fen site close to the automatic chambers on 10 June 2008. Photo: K. M. Iversen.

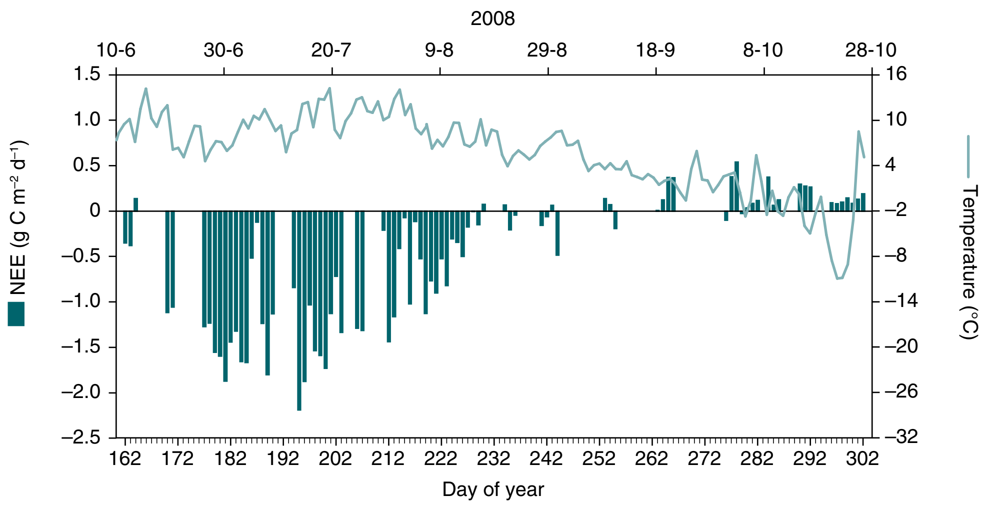


Figure 3.9 Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the fen site in 2008. The sign convention used is the standard for micro-meteorological measurements, i.e. fluxes directed from the surface to the atmosphere is positive, whereas fluxes directed from the atmosphere to the surface are negative.

4 NUUK BASIC

The BioBasis programme

Peter Aastrup, Josephine Nymand, Torben L. Lauridsen, Paul Henning Krogh, Lars Maltha Rasmussen, Katrine Raundrup and Kristian Albert

This is the second report from the BioBasis programme at Nuuk. The report gives an overview of the activities and presents some results as appetizers. We will make a more thorough analysis of data when we have at least one more monitoring season.

The programme was initiated in 2007 by the National Environmental Research Institute at Aarhus University, in cooperation with the Greenland Institute of Natural Resources. BioBasis is funded by the Danish Energy Agency as part of the environmental support programme *DANCEA – Danish Cooperation for Environment in the Arctic*. The authors are solely responsible for all results and conclusions presented in this report, which do not necessarily reflect the position of the Danish Energy Agency.

Methods and sampling procedures are briefly described in each section. For detailed methodology consult the Nuuk BioBasis Manual (www.nuuk-basic.dk).

4.1 Vegetation

Reproductive phenology

We followed the reproductive phenology of three plant species (*Silene acaulis*, *Salix glauca* and *Loiseleuria procumbens*) in plots established in 2007/08. For each species four phenology observation plots were set up to cover the ecological amplitude of the species with respect to snow cover, soil moisture and altitude. Table 4.1 summarizes the date of 50 % flowers for each section in each plot for all three species. Figure 4.2 illustrates the progression in phenology for all three species.

When the monitoring started on 4 June *Loiseleuria procumbens* had already passed the day of maximum number of buds in plots 1, 2, and 4, while the number of buds in plot 3 was at its highest at this time. Also in plot 1 and 4 flowering had already peaked on 4 June, whereas in plot 2 and

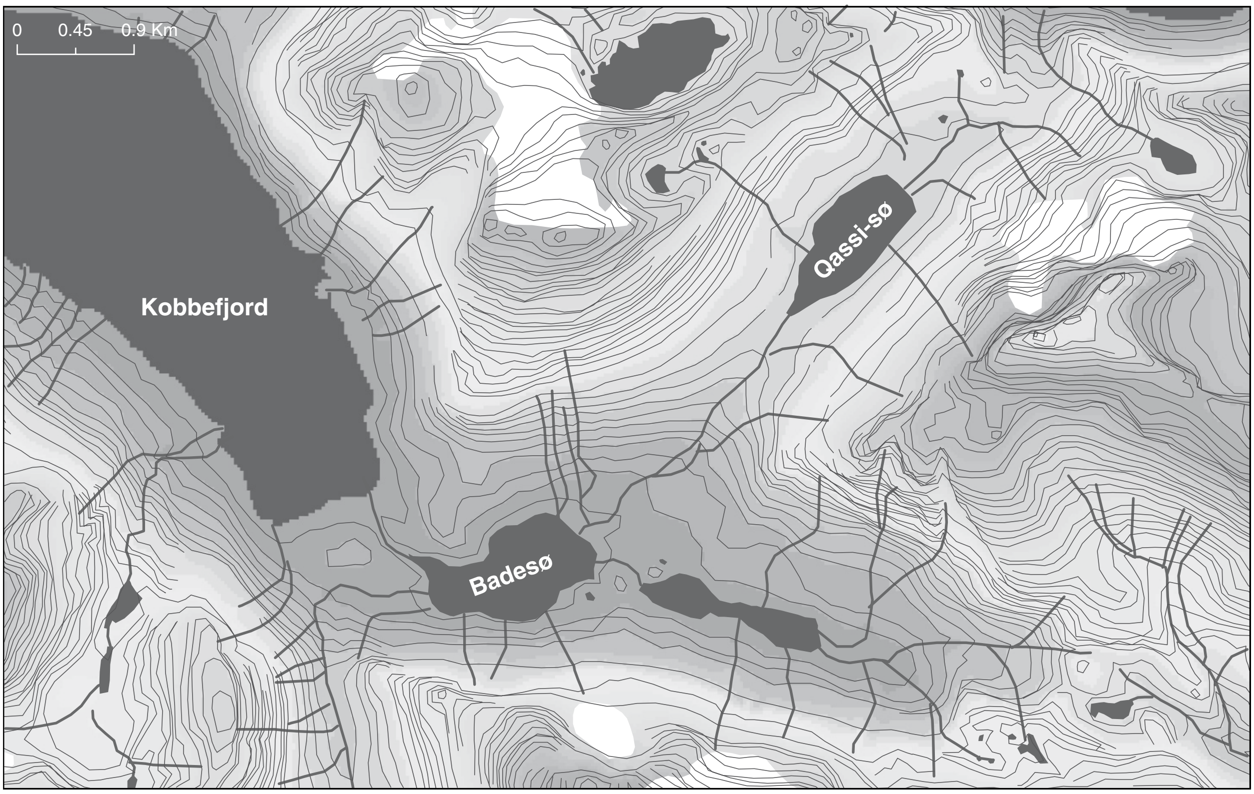


Figure 4.1 Map showing the study area of the monitoring programme 'Nuuk Basic – BioBasis' in Kobbefjord.

Table 4.1 Date of 50% flowers for each plot for all three species. Day of year (DOY) is shown in brackets (see Appendix). In Salix plots date of earliest and latest section are given when the variation is more than one day. Dates have been found by interpolation based on linear plots of percent flowering versus date.

Plot	2008	
Loiseleuria procumbens 1	13. June (165)	
Loiseleuria procumbens 2	16. June (168)	
Loiseleuria procumbens 3	2. July (184)	
Loiseleuria procumbens 4	6. June (158)	
		Date of 50% hairs in Salix female flowers
Salix glauca (f) 1	15. June (167)	26. Aug. (239)/ 18. Sep. (262)
Salix glauca (f) 2	16. June (168)	5. Sep. (249)
Salix glauca (f) 3	8. june (160)/15. June (167)	11. Sep. (255)/20. Sep. (264)
Salix glauca (f) 4	No female flowers	No female flowers
Silene acaulis 1	20. June (172)	
Silene acaulis 2	20. June (172)	
Silene acaulis 3	13. June (165)	
Silene acaulis 4	13. June (165)	

3 flowering peaked around 23 June and 1 July, respectively. Figure 4.2 a shows the progression in phenology in plot 3. There is large variation between plots in date of 50 % flowers ranging from 6 June in plot 4 to 2 July in plot 3.

Data indicate that budding in *Silene acaulis* peaked in plot 3 and 4 on 4 June, while plot 1 and 2 peaked one week later. Flowering peaked in all four plots around 24 June, indicating a longer period of maturing in plot 1 and 2. Figure 4.2 b shows the progression in phenology in plot 1. Date of fifty percent flowers (table 4.1) is 13 June in plot 3 and 4 and 20 June in plot 1 and 2. *Silene acaulis* is also monitored in Zackenberg and here the date of 50 % flowering varied between years and plots from 13 June to 19 August. This is one or two weeks later than we observed in 2008 in Kobbefjord.

In some sections of the *Salix glauca* plots only one gender is present. Therefore the presentation of data has been split up in sections, and male flowers have been omitted. Figure 4.2 c shows the phenological progression in 1, section B. In all plots budding peaked on 4 June or even earlier. Both male and female flowers start peaking at 17 June and have flowers for several weeks until 1 September. The dates of 50 % female senescent flowers with hairs ranged over plots and sections from 26 August to 20 September.

Total flowering

The total number of flowers of four plant species (*Silene acaulis*, *Salix glauca*, *Loiseleuria procumbens* and *Eriophorum angustifolium*) were counted at peak flowering. Results are shown in table 4.2 in the categories 'buds', 'flowers' and 'senescent flow-

Figure 4.2 The reproductive development in phenology plots. A: Loiseleuria procumbens *(plot 3). B:* Silene acaulis *(plot 1). C:* Salix glauca *(plot 1, section B). Percentages have been averaged over sections.*

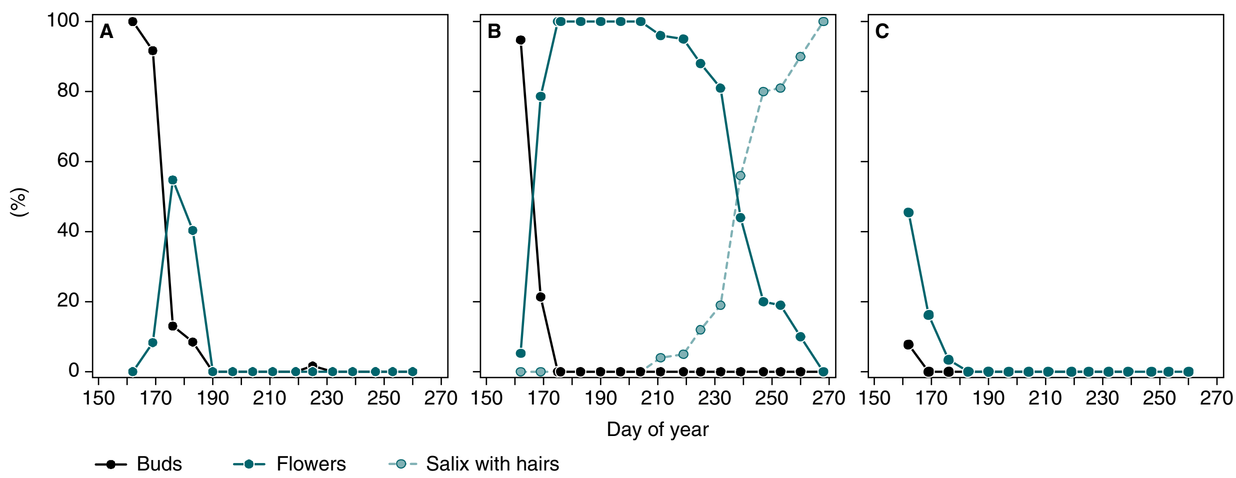


Table 4.2 Total flowering in phenology plots Loiseleuria procumbens, Silene acaulis *and* Eriophorum angustifolium. *Data are missing for* Loiseleuria procumbens *plot 1 and 4.*

Species	Plot	Section	Date	Snow	Buds	Flowers	Senescent	Total
Loiseleuria procumbens	Loi2	A	23.06	0	2	1657	821	2480
Loiseleuria procumbens	Loi2	B	23.06	0	2	212	166	380
Loiseleuria procumbens	Loi2	C	23.06	0	4	621	604	1229
Loiseleuria procumbens	Loi2	D	23.06	0	1	378	160	539
Loiseleuria procumbens	Loi3	A	01.07	0	7	118	94	219
Loiseleuria procumbens	Loi3	B	01.07	0	19	124	50	193
Loiseleuria procumbens	Loi3	C	01.07	0	6	77	136	219
Loiseleuria procumbens	Loi3	D	01.07	0	0	177	104	281
Silene acaulis	Sil1	A	08.07	0	0	0	32	32
Silene acaulis	Sil1	B	01.07	0	0	0	9	9
Silene acaulis	Sil1	C	08.07	0	13	50	3	66
Silene acaulis	Sil1	D	08.07	0	0	0	0	35
Silene acaulis	Sil2	A	24.06	0	0	7	0	7
Silene acaulis	Sil2	B	24.06	0	0	18	81	99
Silene acaulis	Sil2	C	24.06	0	0	0	31	31
Silene acaulis	Sil2	D	24.06	0	1	62	56	119
Silene acaulis	Sil3	A	.	.	.	.	.	.
Silene acaulis	Sil3	B	17.06	0	32	28	0	60
Silene acaulis	Sil3	C	.	.	.	.	.	.
Silene acaulis	Sil3	D	.	.	.	.	.	.
Silene acaulis	Sil4	A	23.06	0	0	0	0	0
Silene acaulis	Sil4	B	23.06	0	7	34	3	44
Silene acaulis	Sil4	C	23.06	0	0	224	40	264
Silene acaulis	Sil4	D	23.06	0	0	26	24	50
Eriophorum angustifolium	Eri1	A	15.07	0	.	.	.	16
Eriophorum angustifolium	Eri1	B	15.07	0	.	.	.	17
Eriophorum angustifolium	Eri1	C	15.07	0	.	.	.	6
Eriophorum angustifolium	Eri1	D	15.07	0	.	.	.	18
Eriophorum angustifolium	Eri2	A	15.07	0	.	.	.	79
Eriophorum angustifolium	Eri2	B	15.07	0	.	.	.	74
Eriophorum angustifolium	Eri2	C	15.07	0	.	.	.	96
Eriophorum angustifolium	Eri2	D	15.07	0	.	.	.	114
Eriophorum angustifolium	Eri3	A	15.07	0	.	.	.	347
Eriophorum angustifolium	Eri3	B	15.07	0	.	.	.	136
Eriophorum angustifolium	Eri3	C	15.07	0	.	.	.	26
Eriophorum angustifolium	Eri3	D	15.07	0	.	.	.	24
Eriophorum angustifolium	Eri4	A	15.07	0	.	.	.	152
Eriophorum angustifolium	Eri4	B	15.07	0	.	.	.	219
Eriophorum angustifolium	Eri4	C	15.07	0	.	.	.	261
Eriophorum angustifolium	Eri4	D	15.07	0	.	.	.	220

Table 4.3 Total flowering of Salix glauca. *None of the flowers were senescent at census time 23 June. None of the flowers were infected by fungi or larvae.*

Species	Plot	Section	Snow	Buds	M_flow	F_flow	Total
Salix glauca	Sal1	A	0	3	494	327	824
Salix glauca	Sal1	B	0	0	0	308	308
Salix glauca	Sal1	C	0	1	0	569	570
Salix glauca	Sal1	D	0	0	978	0	978
Salix glauca	Sal2	A	0	0	134	0	134
Salix glauca	Sal2	B	0	0	251	0	251
Salix glauca	Sal2	C	0	0	0	394	394
Salix glauca	Sal2	D	0	0	0	437	437
Salix glauca	Sal3	A	0	0	0	109	109
Salix glauca	Sal3	B	0	0	2	139	141
Salix glauca	Sal3	C	0	0	13	158	171
Salix glauca	Sal3	D	0	0	41	69	110
Salix glauca	Sal4	A	0	0	325	0	325
Salix glauca	Sal4	B	0	0	508	0	508
Salix glauca	Sal4	C	0	0	815	0	815
Salix glauca	Sal4	D	0	1	594	0	595

ers' for *Silene acaulis*, *Loiseleuria procumbens* and *Eriophorum angustifolium*. Results for *Salix glauca* is shown in table 4.3. Counts are missing for *Loiseleuria procumbens*, plot 1 and 4, and for *Silene acaulis*, plot 1 and 3. Generally, *Loiseleuria procumbens* produced by far most flowers while *S. acaulis* produced fewest flowers. In *Eriophorum* we did not discriminate between buds, flowers and senescent flowers.

Vegetation greening, NDVI

We followed the vegetation greening in the plant reproductive phenology plots, in *Empetrum hermaphroditum* plots, and along the NERO line using a handheld Crop Circle TM ACS-21 0 Plant Canopy Reflectance Sensor which calculates the greening index (Normalized Difference Vegetation Index - NDVI). Measurements were made in the plant phenology plots weekly and along the NERO line monthly.

Figure 4.3 shows examples of the measurements through the entire monitoring period. *Empetrum* and *Loiseleuria* plots generally have higher values than *Eriophorum* and *Silene* through out the season, and there is a general tendency, yet not very clear, that NDVI increases during the summer and decreases in the autumn. The *Silene* plots have a low proportion of vegetation. Many plots appear as having a NDVI-drop in July. The reason for this is still unclear. *Salix* plots have surprisingly low values.

The measurements at the NERO line were taken 5 m northeast of the actual line in order to avoid disturbance on the line. This means that the vegetation zones defined on the NERO line are not identical with the ones on the NDVI line. It appears that greening takes place along the entire line.

Summertime carbon budget

We have monitored the CO_2 flux between the soil/vegetation cover and the atmosphere under 'natural' and 'manipulated' conditions in six replicates, each with five different treatments: Control, increased temperature (ITEX Plexiglas hexagons), shading (hessian tents), prolonged growing season (removal of snow in spring) and shortened growing season (addition of snow in spring) in a mesic dwarf shrub heath dominated by *Empetrum nigrum* with *Salix glauca* as a subdominant species. The treatments 'prolonged growing season' and 'shortened growing season' were not run as such in 2008; results from these plots were treated as controls. Data have not yet been processed.

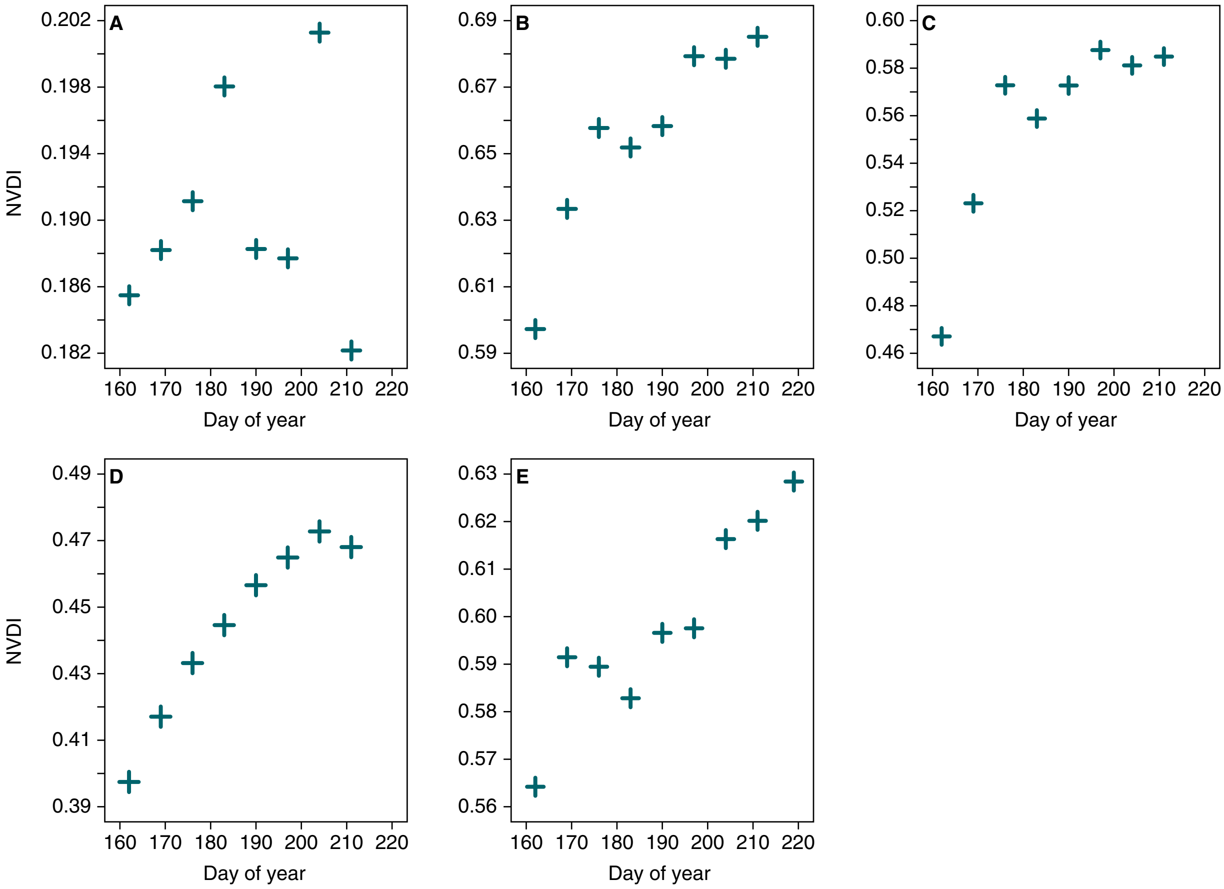


Figure 4.3 NDVI in Empetrum nigrum *(A),* Eriophorum angustifolium *(B),* Loiseleuria procumbens *(C),* Silene acaulis *(D) and in* Salix glauca *(E) plots. All the measurements shown for each species are from Plot 1, representing the period from 10 June to 16 September.*

All six replicates were monitored once a week during the 2008 season. Sampling procedures follows the Nuuk Basic Manual. The first sampling was on 6 June and the last on 23 September. On 9 July and 3 September, no measurements were made due to bad weather and on 13 August only the first four replicates were measured, while only the first was measured on 20 August, also due to bad weather.

UV-B exclusion plots

Since the 1970's there has been major concern about the depletion of the stratospheric ozone layer. Generally, the ozone layer is expected to recover towards the middle of 21st century, and this in combination with increased cloudiness is expected to mitigate the UV-B radiation reaching the biosphere. However, in the northern hemisphere the recovery of the ozone layer is uncertain due to the increased amount of greenhouse gasses, increasing the ozone destruction in polar stratospheric clouds, and due to the difficulty of predicting cloud coverage. Further, the earlier start of the growing season, due to warming, may increase the exposure to the higher spring UV-B fluxes.

The impact of ambient UV-B radiation on the vegetation is studied in a mesic dwarf shrub heath dominated by *Empetrum nigrum* and with *Betula nana* and *Vaccinium uliginosum* as subdominant species. The UV-B exclusion experiment setup comprises three treatments: open control, filter control (Teflon: UV-B and PAR transparent filter) and UV-B exclusion (Mylar: 60 % UV-B reduction and PAR transparent filter). Each treatment plot measures 60 × 60 cm. Filters are placed approximately 10 cm above the vegetation and the treatments are replicated in five blocks. The treatments were initiated at the beginning of the growth season early in June and beside periods with spells of strong wind the treatments were maintained during most of the season. It has previously been shown in high arctic Greenland that ambient UV-B has negative effects on photosynthetic performance and that these can be evaluated by monitoring the PSII performance. Therefore the plant responses to treatments were studied by conducting measures of chlorophyll *a* fluorescence and the derived JIP-test parameters (eg. Fv/Fm and PI) used to evaluate the impact on plant stress. The much reported parameter, maximal

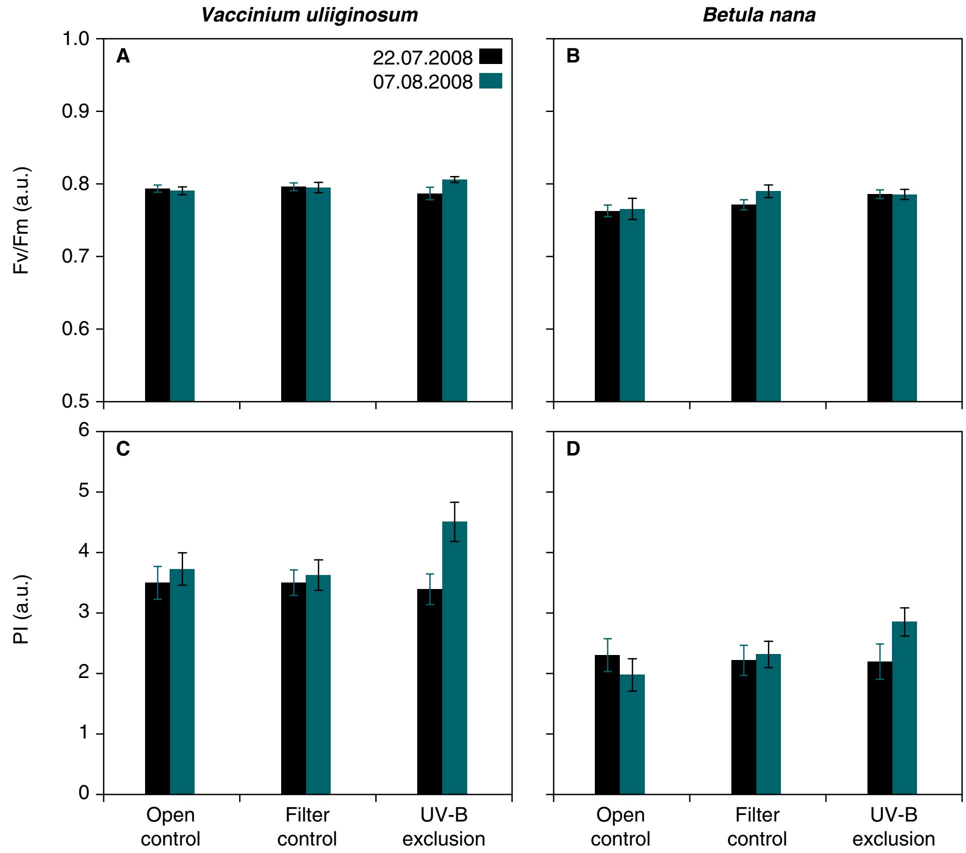


Figure 4.4 The upper diagrams show the maximal quantum yield (Fv/Fm) in Vaccinium uliginosum *(A) and* Betula nana *(B) on 22 July and 8 August. The lower diagrams show the Performance Index (PI) in* Vaccinium uliginosum *(C) and* Betula nana *(D) on 22 July and 8 August.*

quantum yield (Fv/Fm), closely relates to Photosystem II (PSII) functioning and is often interpreted as a proxy for plant stress. The Performance Index (PI) integrates into one parameter the proportional responses of energy fluxes related to trapping, and dissipation within the PSII and also to the energy transport behind PSII. Hereby the PI expresses the overall efficiency of energy processing through PSII and sum up accumulative effects on PSII.

Ambient UV-B did not induce any differences in maximal quantum yield (Fv/Fm) for *Vaccinium* and *Betula* at the days of measurement as there were no difference between the UV-B exclusion treatment and filter control (figure 4.4). However, screening off a major proportion of the ambient UV-B radiation increased the Performance Index (PI) in both species in the August measurement (figure 4.4). These initial results indicate the functioning of the experimental setup and potential for further monitoring of effects of ambient UV-B.

Vegetation mapping

In July 2007 we ground truthed the vegetation at 52 positions representing vegetation types as summarized in table 4.4.

In 2008 we sampled further 115 ground truthing points as shown in figure 4.5. Details will be available at www.nuuk-basic.dk. All ground truthing points were classified in vegetation types according to table 4.4.

Furthermore, we estimated the cover of *Empetrum nigrum*, *Salix glauca*, *Betula nana*, *Vaccinium uliginosum*, *Ledum groenlandicum*, Impediment (rock, boulders or stones), Moss, Soil, *Deschampsia flexuosa*, *Alnus crispa*, *Carex bigelowii* and graminoids at each point. The primary objective for these estimates was to provide data for evaluating the possibility of discriminating between heath types.

4.2 Arthropods

In Kobbefjord, all four pitfall trap stations established in 2007 were open during the 2008 season. Sampling procedures follow the Nuuk Basic Manual. Each station consists of eight subplots each with a yellow pitfall trap measuring 10 cm in diameter. Samples are kept unsorted at Greenland Institute of Natural Resources. The material is stored in 70 % ethanol.

Table 4.4 Classification of ground truthing points 2008.

"Gross" vegetation type	"Fine" vegetation type
Abrasion plateau	Abrasion Impediment
Copse	*Salix glauca* copse *Alnus crispa* copse
Grassland	Deschampsia type Gram-spot
Fen	Fen
Herb slope	Herb slope
Dwarf shrub heath	*Salix glauca* heath *Vaccinium uliginosum* heath *Empetrum nigrum* heath *Betula nana* heath

All pitfall traps, except one were opened on 4 June. 1A was opened one week later. They all stayed open until 24 September. The number of trapping days in 2007 was 3.580. By 24 September all the traps froze during the night with up to 2 cm of ice on top. Only three times were traps (1H twice and 4B once) removed or destroyed during the season. Whether it was due to animal (arctic fox) interaction or human disturbance is not known.

Microarthropods

Resources were directed to produce soil fauna extraction equipment at Greenland Institute of Natural Resources in Nuuk in order to keep down costs and avoid risks of transportation of soil samples to Denmark.

A high gradient extractor, originating from the Institute of Biology at Aarhus University, of the MacFadyen type was improved and equipped with an automatic programmable temperature regulator and shipped to Greenland Institute of Natural Resources. Samples collected at Kobbefjord during 2008 and extracted with this apparatus failed to give precise population abundance estimates. We need to adapt the extraction procedure to the laboratory facilities in Nuuk.

In November, we tested the extraction equipment (QA test) to ensure that the extractor performed well according to normal minimum standards for extraction efficiency, which is at least 95 % extraction of a known number of collembolans added to soil. For this purpose we used the laboratory species *Folsomia candida* that was produced in the soil fauna laboratory at National Environmental Research Institute at Aarhus University (Silkeborg) and send to Greenland Institute of Natural Resources. After running a standard extraction procedure the efficiency for adults were 83.1 % [73-96] (95 % confidence limits) and for juveniles 91.9 % [85.1-97.7] (95 % confidence limits). Both values were too low, so the heating and cooling will be improved as well as the handling of the test-animals to ensure that a better efficiency will be obtained. An additional QA test will be carried out during spring 2009 and if the extraction proves to fulfil the quality criteria, extraction of samples for 2009 will be

Figure 4.5 Ground truthing points 2008.

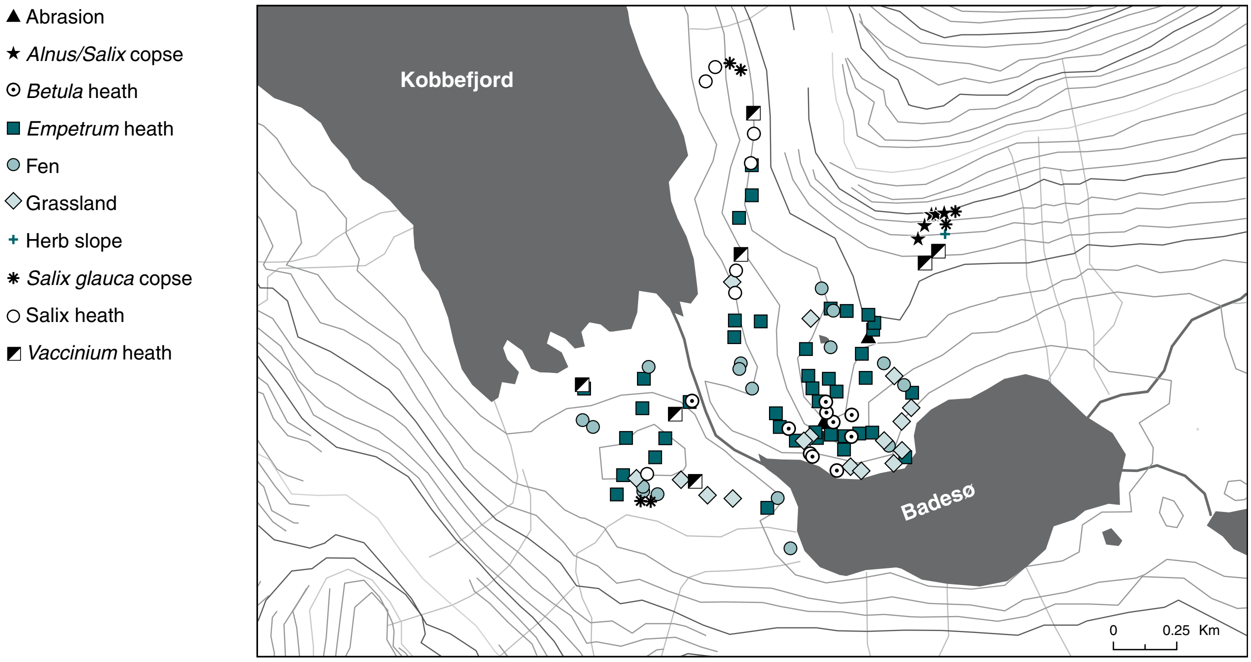


Figure 4.6 Bird census points.

made at Greenland Institute of Natural Resources. If the test fails, future extraction will be made at National Environmental Research Institute at Aarhus University.

4.3 Birds

The bird study consisted of three parts: An ornithological survey which provided an overview of birds in the study area, observations of breeding phenology of Lapland bunting *Calcarius lapponicus* and censuses from census points as shown in figure 4.6.

Ornithological survey

The survey took place on 10 June and lasted a little more than two hours. It covered the area between the fjord and Badesø below the 200 m curve. The survey concluded that the two most frequently occurring bird species were Lapland bunting and snow bunting, *Plectrophenax nivalis*. The number of breeding snow buntings was estimated to between six to ten pairs based on the number of singing males. This estimate fits quite well with the number of nests found in 2007, as shown in figure 4.7. In the main area surveyed for nests territory size was in the order of 1 to 1.5 ha.

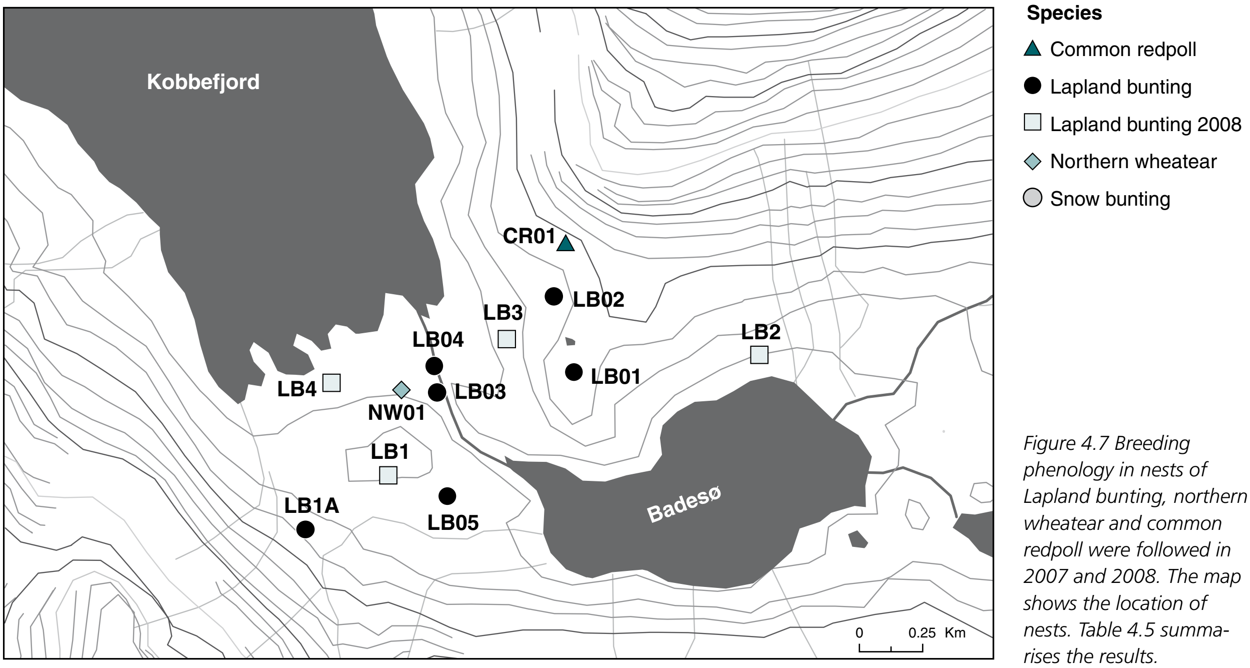


Figure 4.7 Breeding phenology in nests of Lapland bunting, northern wheatear and common redpoll were followed in 2007 and 2008. The map shows the location of nests. Table 4.5 summarises the results.

Table 4.5 Reproductive phenology of nests of Lapland bunting, northern wheatear and common redpoll.

Species	Nest	No. eggs	1st observed egg	1st observed hatchling	1st observation that hatchlings are leaving nest
Lapland bunting	LB01	6	14.06.2007	26.06.2007	04.07.2007
Lapland bunting	LB02	6	26.06.2007	04.07.2007	13.07.2007
Lapland bunting	LB03	5	.	29.06.2007	08.07.2007
Lapland bunting	LB04	6	.	29.06.2007	08.07.2007
Lapland bunting	LB1A	6	.	02.07.2007	11.07.2007
2008					
Lapland bunting	LB1	7	17.06.2008	25.06.2008	08.07.2008
Lapland bunting	LB2	6	.	20.06.2008	04.08.2008
Lapland bunting	LB3	5	20.06.2008	23.06.2008	.
Lapland bunting	LB4	6	27.06.2008	04.07.2008	13.07.2008
N. wheatear	NW01	6	.	26.06.2007	13.07.2007
C. redpoll	CR01	5	.	20.07.2007	.

Seastedt and MacLean (1979) found territories between 1.09 and 2.83 ha in tundra at Barrow in Alaska. It seems reasonable to believe that the intensive survey in 2007 actually discovered all or almost all of the territories of the Lapland bunting.

Breeding phenology

Both in 2007 and 2008 the breeding phenology of Lapland bunting, snow bunting, common redpoll *Carduelis flammea* and northern wheatear *Oenanthe oenanthe* was followed on an *ad hoc* basis. When a nest was located it was followed as often as possible with a maximum of two to three days between visits.

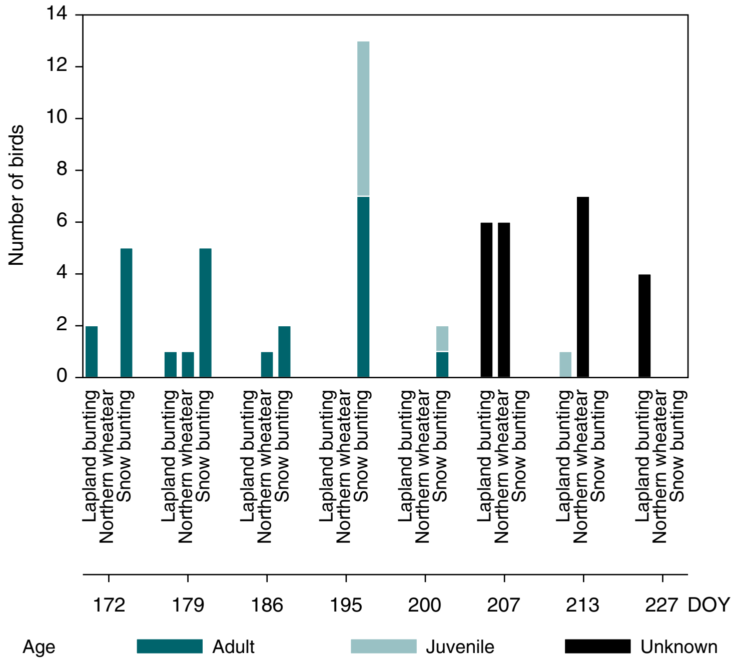


Figure 4.8 Results from bird census point A (see figure 4.7) through the entire monitoring season. The figure shows numbers of Lapland bunting, northern wheatear and snow bunting.

Data are summarized in table 4.5 which gives data for nests that we succeeded to follow from ‘egg` to the time when the nest was left. Positions of nests are shown in figure 4.8. Only nests from Lapland bunting gave adequate data.

The data gives the indication that Lapland bunting hatchlings appear during the last week of June and leave the nest nine to eleven days later, which is also what Madsen (1982) found in northern West Greenland where he recorded a mean incubation period of 11.5 days and a nestling period of 9.2 days. Otherwise, incubation time has been reported to 13 days corresponding to start of egg-laying about 10 June. Hussell (1972) found in the Canadian Arctic that dates where 50 % of the clutches had started, ranged from the first days of June at latitudes below 60°N to 26 June at 76°N.

Hussell (1972) reviewed factors affecting clutch size in arctic passerines in the Canadian Arctic. He found clutch sizes between one and seven with clutches of six and five being most common and with mean clutch size of 5.38. There was a general tendency that clutch size increased with latitude. However, the pattern was irregular. This is in accordance with what Madsen (1982) found in West Greenland. Here the mean clutch size of Lapland bunting was 5.18, ranging between three and seven.

Census points

We counted birds from 13 census points (figure 4.8) with special focus on the small passerines: Snow bunting, Lapland bunting, northern wheatear, and common redpoll. Each census lasted 10 minutes and we discriminated between observations in the first 5 minutes and the last 5 minutes of the census period. Only birds actually observed were recorded. Figure 4.8 illustrates the observations at census point A for the species Lapland bunting, northern wheatear, and snow bunting. The number of observations and the number of juveniles increases as expected through the summer. Also it appears that northern wheatear comes in later than the two other species. We observed very few common redpolls. Census point A is situated in the main monitoring area where the density of birds is highest. The smallest number of birds was observed in the inner valley at points L and M.

Bird observations

During the summer period the following bird species were seen: Mallard *Anas platyrhunchos*, common eider *Somateria mollissima*, red-breasted merganser *Mergus serrator*, white-tailed eagle *Haliaeetus albicilla*, rock ptarmigan *Lagopus mutus*, purple sandpiper *Calidris maritima*, red-necked phalarope *Phalaropus lobatus*, lesser black-backed gull *Larus fuscus*, Iceland gull *Larus glaucoides*, glaucous gull *Larus hyperboreus*, black guillemot *Cepphus grylle*, northern wheatear *Oenanthe oenanthe*, raven *Corvus corax*, common redpoll *Carduelis flammea*, Lapland bunting *Calcarius lapponicus* and snow bunting *Plectrophenax nivalis*.

The female Harlequin duck, which was seen at several occasions in Kobbefjordelven in 2007, was not seen during the 2008 season.

4.4 Mammals

Throughout the season, arctic fox *Alopex lagopus* was seen occasionally and most often close to the shore-line on evenings and nights. Arctic hare *Lepus arcticus* faeces were registered at several places 350 m a.s.l., but no animals were observed. In the afternoon on 4 July, two male caribou *Rangifer tarandus* were seen in the fen close to the methane chambers. This was the only sighting of caribou during the whole season, but fresh tracks were seen at one occasion on the shore of Qassi-sø on 26 August.

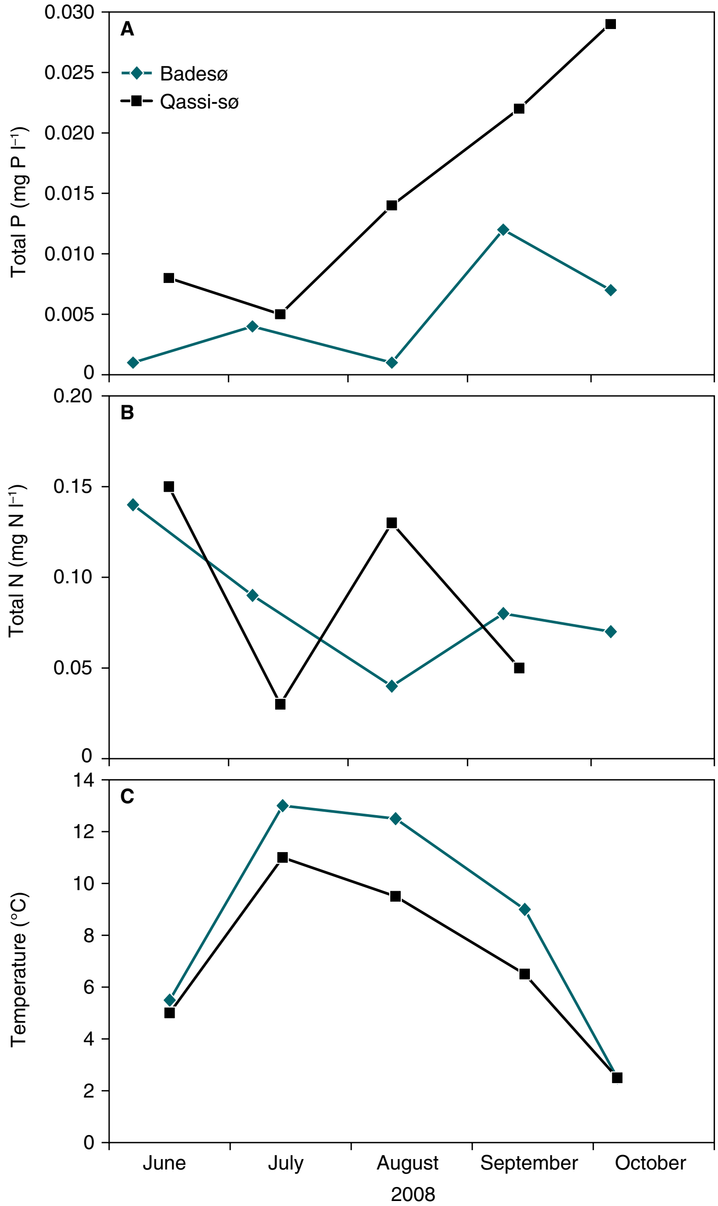


Figure 4.9 Total phosphorus level (A) and total nitrogen level (B) in the two lakes Badesø and Qassi-sø during the ice free period. Surface water temperatures measured during the ice free period in Badesø and Qassi-sø (C).

4.5 Lakes

Lake monitoring

The BioBasis programme includes monitoring of two lakes, Badesø with arctic char *Salvelinus alpinus* located at low altitude and Qassi-sø without arctic char at a higher altitude. The two lakes are located in the Kobbefjord catchment area in the bottom of Kobbefjord. Badesø is approximately 80 ha and 32 m deep, and Qassi-sø is approximately 52 ha and 26 m deep. They are connected by water running from Qassi-sø to Badesø.

Water chemistry and physical measurements

The nutrient levels recorded in Badesø and Qassi-sø are comparable to those in other low arctic Greenland lakes. However, compared with high arctic lakes, the nutrient levels of the two studied lakes are relatively high.

Total phosphorus levels varied between 1 and 22 µg l^{-1}. In general, the highest levels appeared in Qassi-sø, varying between 5 and 22 µg l^{-1}, whereas in Badesø total phosphorus varied between 1 and 12 µg l^{-1} (figure 4.9). The higher phosphorus levels in Qassi-sø are probably due to a higher content of suspended matter caused by the inlet of glacial water. In both lakes there was a tendency to an increase in concentrations over time, possibly due to enhanced production with increasing temperature.

The total nitrogen content varied between 0.03 and 0.15 mg l^{-1} (figure 4.9). There was no difference between the two lakes and the highest concentration was measured immediately after the ice melt. The nitrite and nitrate concentrations were approximately one tenth of the total nitrogen content, but the pattern was similar – with the highest concentration occurring right after ice melt. In Badesø, the concentrations of both nitrite/nitrate and orthophosphorus were negligible.

Water temperature

In general, Badesø is warmer than Qassi-sø. Except for the final measurements in October, the surface temperature was 1-3 °C higher in Badesø (figure 4.10). This difference in temperature is also reflected in the temperature profiles. Due to the warmer surface water, a weak thermocline was observed in Badesø in July and August, while

Figure 4.10 Temperature profiles measured monthly from the surface to the bottom in Qassi-sø and Badesø.

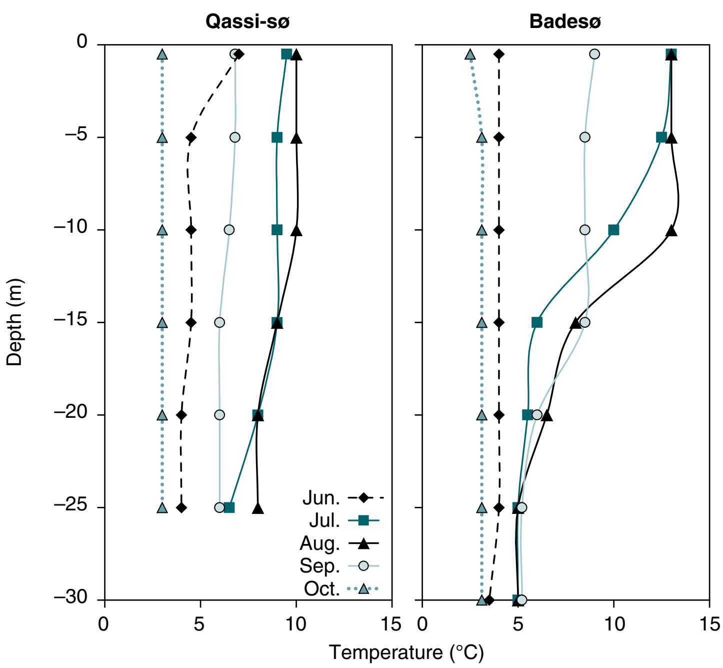


Table 4.6 Minimum and maximum conductivity and pH in Badesø and Qassi-sø during 2008.

Lake	Cond. µS cm⁻¹		pH	
	Min	Max	Min	Max
Badesø	18.6	21.6	6.6	7.1
Qassi-sø	15	24	6.4	6.95

Qassi-sø was almost fully mixed throughout the ice free period (figure 4.10).

If temperature increases in the future, we will expect the thermocline to be stronger and move deeper. Furthermore, a weak thermocline can be expected in Qassi-sø, unless the often strong northerly winds will keep the lake fully mixed.

Conductivity and pH

Conductivity and pH were almost similar in the two studied lakes. Conductivity varied between 19 and 22 µS $cm^{-1}s^{-1}$ in Badesø. In Qassi-sø it varied between 15 and 24 µS cm^{-1} s^{-1} (table 4.6). The conductivity in the lakes was compared to other Greenlandic lakes. The results indicate that very few ions are washed into the freshwaters in Kobbefjord. On the other hand, there is a potential for increasing conductivity in the future if productivity and degradation increase. pH was neutral in both lakes, varying between 6.4 and 7.1 (table 4.6).

Secchi depth

Water clarity is generally high in the nutrient poor Greenland lakes. However, lakes affected by glacial inflow may exhibit reduced visibility due to high silt content. In Badesø Secchi depth was high, particularly in early summer following the ice melt. In September and October Secchi depth decreased, however, from approximately 10 m to 5 m (figure 4.11). Qassi-sø receives its inflowing water from the nearby glaciers. Consequently, it also receives a lot of suspended material, reducing the Secchi depth compared to that in Badesø. In Qassi-sø Secchi depth varied between 2.3 m and 5.7 m, with the highest visibility occurring early in the season. For both lakes Secchi depth decreased over time (figure 4.11).

Chlorophyll *a*

Chlorophyll levels were very low in the two lakes. Throughout the ice free period it was below 1 µg l^{-1} (figure 4.11). Qassi-sø generally had lower concentrations than Badesø, which is indicative of fewer algae.

This information, combined with the lower Secchi depth in Qassi-sø, supports existing evidence that the reduced Secchi depth is due to suspended matter, which again can explain the higher phosphorous levels in Qassi-sø compared to Badesø.

Fish

According to preliminary data from 2005 and 2007, fish are present in Badesø but not in Qassi-sø. In 2008 a proper fish investigation was carried out in both Badesø and Qassi-sø; however, in Qassi-sø the investigation was reduced to one overnight period of gill netting due to the preliminary data indicating fish absence.

Gill nets

In Badesø, a total of nine gill nets, three benthic, three pelagic and three littoral nets, were set. Each net was set overnight, and the following day the fish were removed, weighed and measured in the laboratory and, finally, tissue samples were taken for stable isotope analyses. In Qassi-sø, two littoral gill nets, one pelagic and one benthic gill net were set overnight.

Catch

In Qassi-sø no fish were caught.

The catch in Badesø consisted of arctic char *Salvinus alpinus* and three-spined stickleback *Gasterosteus aculeatus*. Total catch per unit effort (CPUE) was 17.3 fish per net. Arctic char was by far the most dominant species with a CPUE of 16.

The CPUE value is comparable to catches from other lakes in the Kobbefjord area, where the CPUE varies between 3 and 53 fish per net with a median value of 10.7. In the Zackenberg area in Northeast Greenland, CPUE values typically vary between 0.5 and 8 fish per net, with a median value of 1.4 and a maximum of 13 fish per net.

Low and high arctic areas differs as to temperature, length of ice free period and, consequently, system productivity - the low arctic areas being the more productive due to higher degradation rates and higher nutrient inputs.

Arctic char

Arctic char is the dominant fish species in Badesø. It preferred the benthic part of the lake (deep near-bottom part) with a CPUE value of 27 fish, followed by the littoral (near-shore) part of the lake with a CPUE value of 16. The lowest catch occurred in the pelagic open water with a CPUE of 4.7 fish per net (figure 4.12).

The size of arctic char varied between the three habitats. The by far largest specimens were caught in the pelagic (figure 4.13). The benthic and littoral specimens were, on average, 10 to 15 cm smaller than the pelagic specimens (figure 4.13). The pelagic species of arctic char are typically piscivores or omnivores, whereas the littoral and benthic ones often will be benthivores or planktivores. However, results from the stable isotope sampling will give an indication of the food preferences of the fish in the different habitats.

The frequency distribution of length shows dominance of the smaller medium-

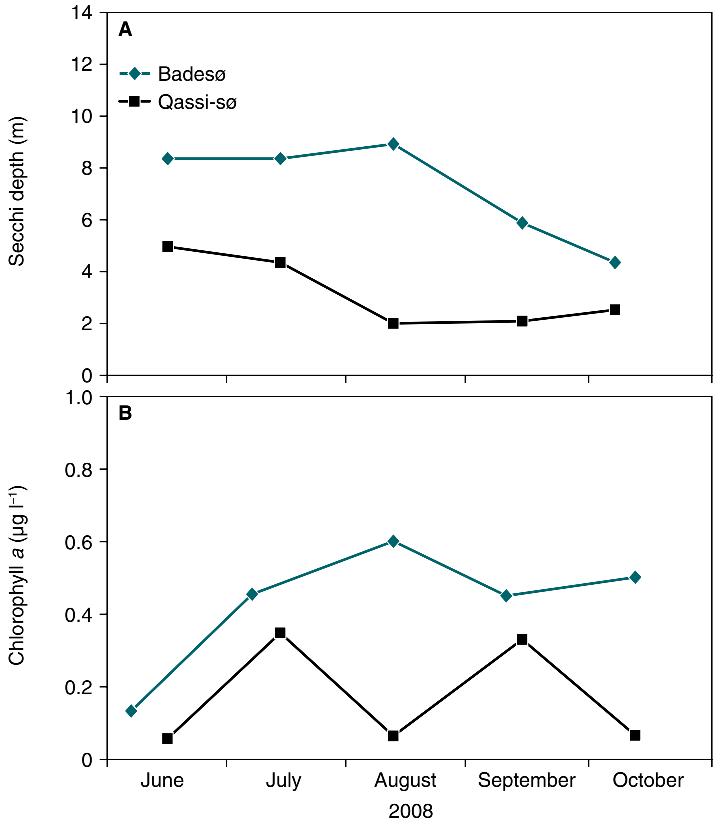


Figure 4.11 Secchi depth measured during the ice free period in Badesø and Qassi-sø (A). Chlorophyll a levels measured during the ice free period in Badesø and Qassi-sø (B).

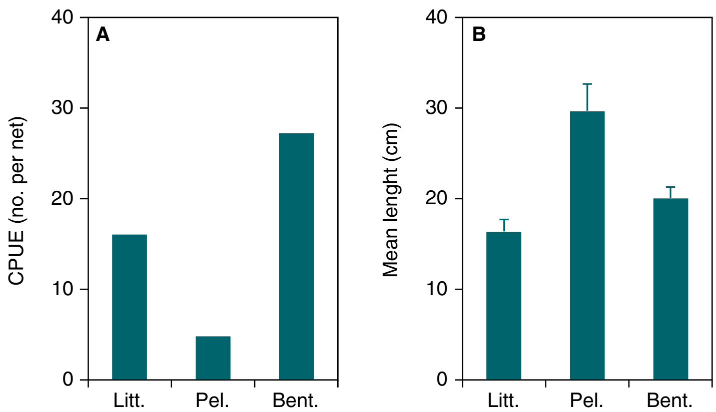


Figure 4.12 Catch per unit effort (CPUE) of arctic char in the three different habitats of Badesø (A). Mean length (+ standard error) of arctic char caught in the three habitats of Badesø (B). LITT = littoral, PEL = pelagic, BENT = benthic.

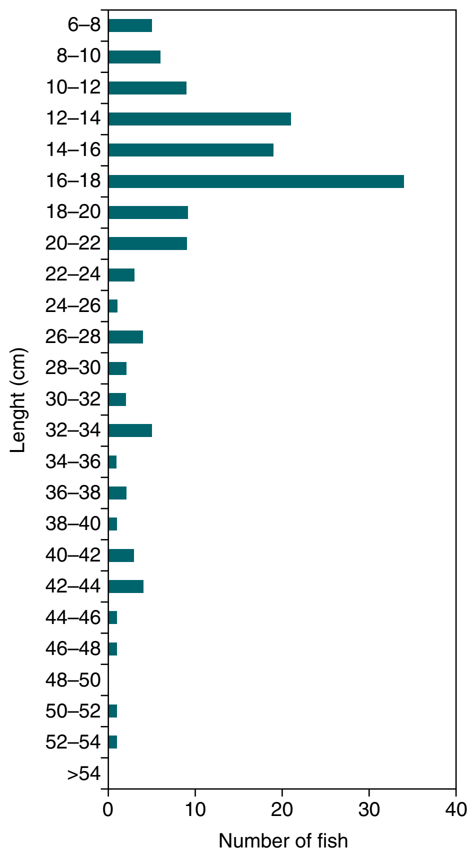


Figure 4.13 Length frequency distribution of the arctic char caught in Badesø in 2008.

sized specimens (figure 4.13). About 50 percent of the total catch ranged between 12 and 18 cm in length. Fourteen percent are evenly distributed between 22 and 44 cm. Only four individuals, all caught in the pelagic, were larger than 44 cm.

Three-spined stickleback

Sticklebacks were only caught in the littoral part of the lake, which is consistent with findings in other Greenlandic lakes (Riget et al. 2000). The catch was low with a littoral CPUE value of 4 fish per net. But this is probably not a true picture of stickleback vs. arctic char abundance because the 6.25 mm mesh size used is too large to capture most of the smaller individuals.

Vegetation

Submerged vegetation was dominated by mosses and Water-starwort *Callitriche hamulata* in both 2007 and 2008. Mosses and *Callitriche* were found in Badesø in the more shallow areas (between approximately one and four metres' depth) and had a depth limit of 5 and 5.5 m in 2007 and 2008, respectively. In Qassi-sø submerged vegetation was sparse compared to Badesø. However, the species were similar but the depth limit was reduced to 3.5 and 3.8 m in 2007 and 2008, respectively. In both lakes mosses were found in the very near shore areas, typically at depths below 2 m. Especially in Badesø mosses were common along the entire lake shore.

Zooplankton

Zooplankton was sampled monthly. The samples have not been analysed yet. However, based on the single sample from 2007 the zooplankton community is species poor and comparable to communities in low arctic systems. However, differences were observed between the two lakes: in Badesø *Daphnia pulex* was absent, while *Leptodiaptomus minutus* was common together with rotifers. In Qassi-sø *Daphnia pulex* is present, and *Leptodiaptomus* and rotifers are less numerous than in Badesø.

5 NUUK BASIC

The MarineBasis programme

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This chapter reports on the third year of the MarineBasis monitoring programme in Godthåbsfjord. The programme will establish long-term data series of physical, chemical and biological parameters essential for understanding the marine environment in the fjord system. In connection with the other programmes within Nuuk Basic, the MarineBasis programme aims to identify and describe changes in the marine environment induced by climatic forcing. Monthly pelagic sampling is conducted at the main station located near the entrance to the fjord, while bi-annual benthic sampling is carried out in Kobbefjord nearby (figure 5.1). Pelagic measurements are also carried out along a length and a cross section of the fjord in May. In addition, higher trophic levels of the marine ecosystem, e.g. marine mammals and colonial seabirds, are monitored in the fjord system. Methods are briefly described in each section. For a more detailed methodology please consult the MarineBasis Nuuk manual (www.nuuk-basic.dk). The field programme is complemented by monitoring sea ice conditions using satellite and supplementary digital camera systems.

5.1 Sea ice

Monitoring of sea ice conditions include daily AMSR-E satellite images (3-6 km resolution) of Baffin Bay and MODIS satellite images (250 m resolution) of the Godthåbsfjord system. Microwave-radiometer (AMSR-E) images show a prolonged maximum sea ice cover in Baffin Bay compared to the two previous years (figure 5.2). Maximum sea ice extent lasted until

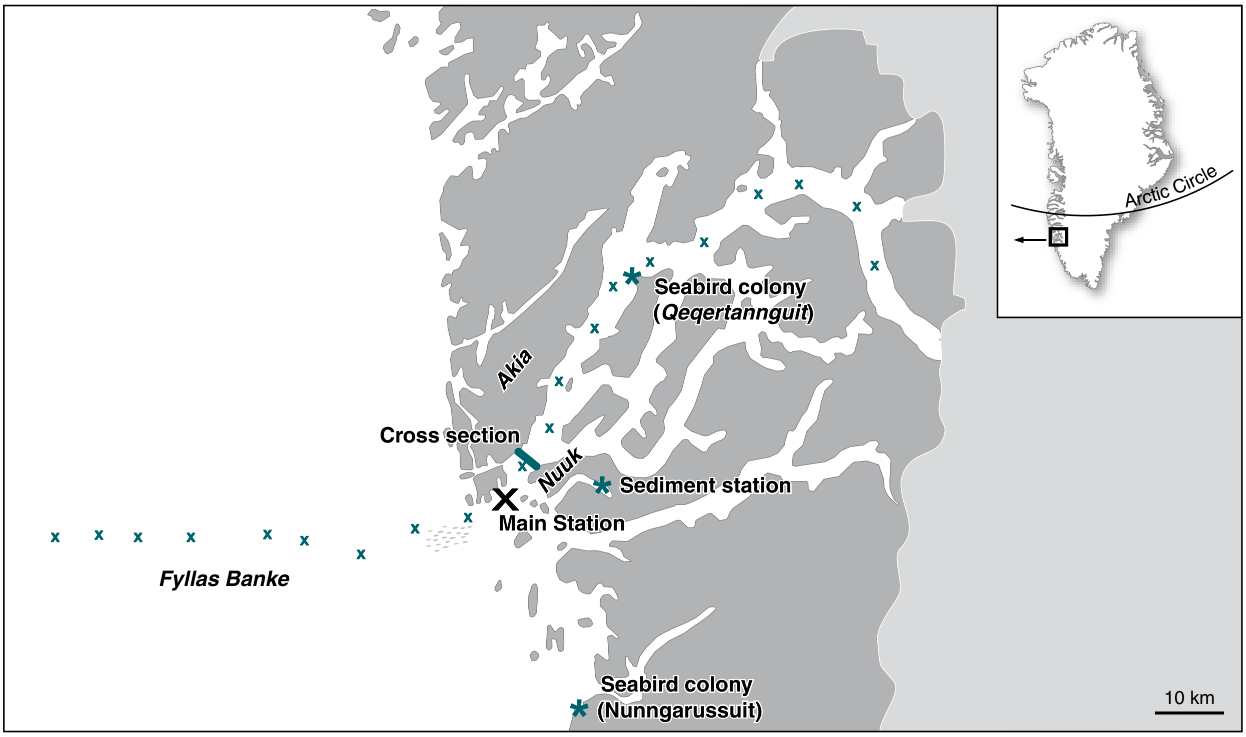

Figure 5.1 Map of sampling stations in and around the Godthåbsfjord system. X represent sampling stations along the hydrographical length section.

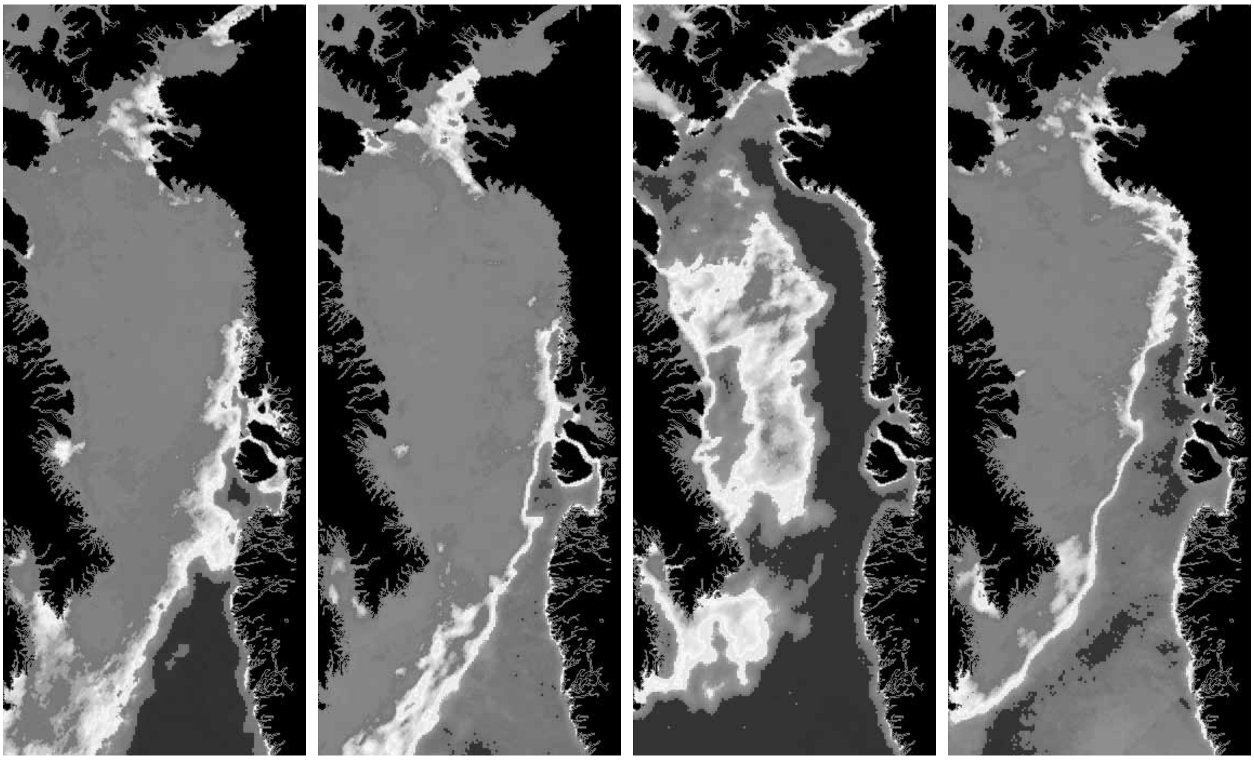

Figure 5.2 Satellite images (AQUA AMSR-E) showing sea ice extent in Baffin Bay in January, May, July and December 2008. Dark grey-grey represent open water and grey-white shadings represents different sea ice conditions.

May, covering the entire Baffin Bay with land-fast or drifting pack ice. Similar to the previous years, minimum sea ice extent occurred in July and August. MODIS images of Godthåbsfjord also showed a more extensive sea ice cover during winter 2007/2008, with the inner part and the smaller fjord branches showing land-fast sea ice (figure 5.2). Nevertheless, largely ice free condition was observed throughout the fjord system during summer, except for the inner part which experienced a build-up of glacial ice. Digital images overlooking a section of the fjord outside Nuuk, acquired with three hour intervals at the Greenland Institute of Natural Resources (figure 5.4), showed irregular bursts in discharge of glacial ice and sea ice throughout the year.

Analyses of the satellite data are currently conducted as a collaboration between the Greenland Institute of Natural Resources, the Danish Meteorological Institute and the FreshLink Project (http://freshlink.natur.gl). Thoroughly consideration is given to establishing monitoring parameters and ensuring optimal use of this extensive dataset. The monitoring parameters are expected to include seasonal transport of glacial ice, freshwater input to the inner parts of the fjord and the extent of sea ice cover.

5.2 Length and cross sections

Sampling of hydrographical parameters was conducted along a cross section (figure 5.5) from Nuuk to Akia in late-May 2008. Vertical profiles along the cross section showed a fresher and warmer surface layer towards Akia with salinities below 33.2 and temperatures up to 1.4°C. This surface layer also contained the highest phytoplankton biomass, as shown by maximum fluorescence values of 3.4. Fluorescence data are a proxy for the chlorophyll *a*, i.e. phytoplankton biomass in the water. This outgoing surface layer is thought to depict the seaward export of freshwater discharge mainly from the inner parts of the fjord. The more saline and colder water towards Nuuk and in the deeper parts of the cross section showed maximum salinities and minimum temperatures of 33.4 and 0.4°C, respectively.

A length section from Fyllas Banke to the inner part of Godthåbsfjord (approximately 200 km, figure 5.1) was sampled onboard 'I/K Agpa' in mid-May 2008. The northward flowing West Greenland Current was present at depths below 200 m outside Fyllas Banke resulting in the highest temperatures and salinities (4.8 °C and 34.5, respectively) measured along the length section (figure 5.6). Inflow of coastal water into the fjord produced a

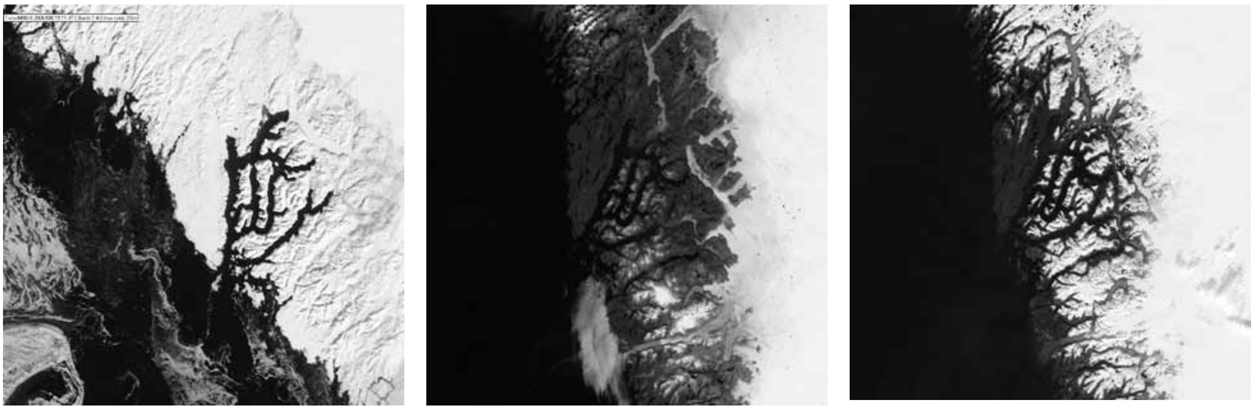

Figure 5.3 Satellite images (AQUA-MODIS) showing sea ice conditions in Godthåbsfjord in March, July and October 2008.

homogenous water mass with salinities from 33.3 to 33.5 and temperatures from 0 to 0.5 °C extending across Fyllas Banke; throughout the water column at the outer parts of the fjord and protruding inwards to the inner part of the fjord as a sub-surface layer. A fresher and warmer surface layer extending outwards from the inner part of the fjord constituted an outflow of freshwater from terrestrial runoff and melting ice. Surface waters showed a phytoplankton biomass, i.e. fluorescence, concentrated in the euphotic zone on Fyllas Banke and in the inner parts of the fjord with maximum fluorescence values of 9.1. In contrast, vertical mixing of the water column produced a homogenous distribution of phytoplankton throughout the entire water column around the entrance to the fjord.

The surface pCO_2 varied along the length section with the highest surface pCO_2 values encountered at the mouth of the fjord as observed in the previous years (figure 5.7). Towards the head of the fjord, the values decreased, reaching a minimum of 100 µatm. The values were slightly higher than in 2007, but still well below the atmospheric content (387 µatm) indicating that Godthåbsfjord is a strong CO_2 sink.

Figure 5.4 Digital images overlooking a section of Godthåbsfjord in January, May, July and October 2008.

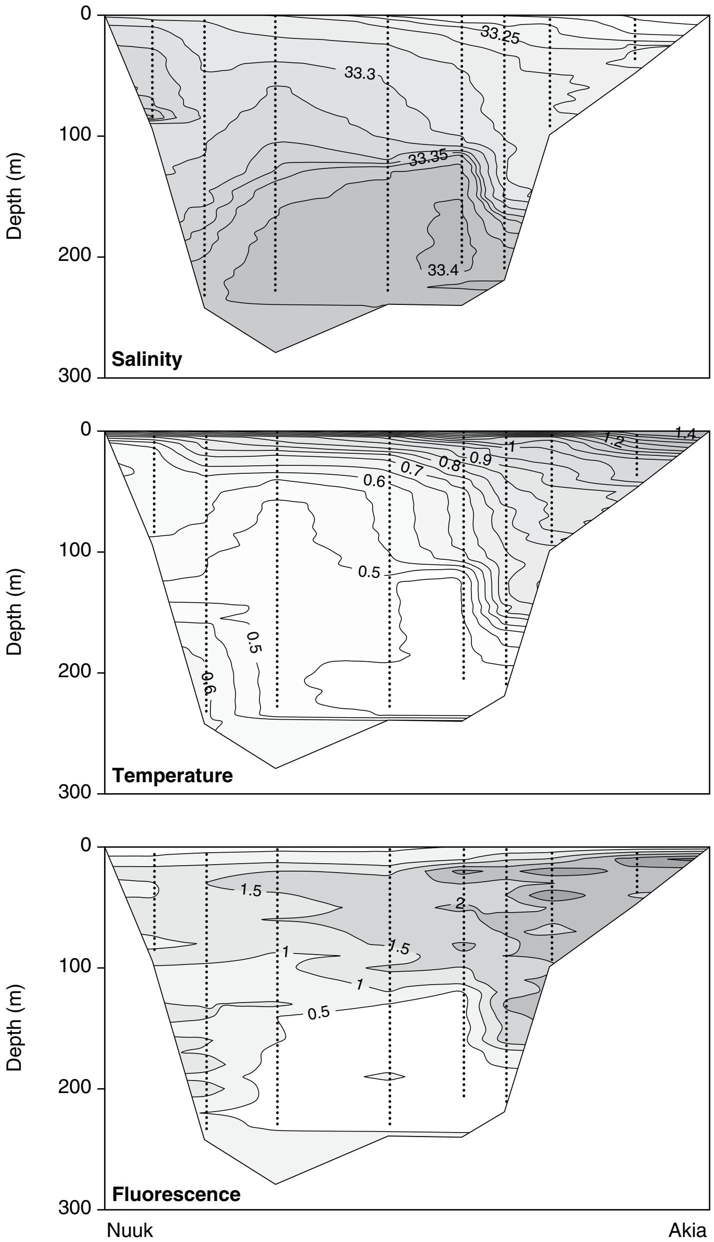

Figure 5.5 Salinity, temperature (°C) and fluorescence along the cross section from Nuuk to Akia in late-May 2008.

5.3 Pelagic sampling

A pelagic sampling programme was carried out on a monthly basis at the main station (64°07N 51°53W, figure 5.1). Vertical profiles of the salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence were collected using a SBE19+ CTD. Water samples collected at 1, 5, 10, 15, 20, 30, 50, 100, 150, 250 and 300 m were analyzed for concentrations of pigments (chlorophyll *a* and phaeopigments) and nutrients (NO_x, PO_4^{3-}, SiO_4), while dissolved inorganic carbon and total alkalinity was measured in the water samples from 1, 5, 10, 20, 30 and 40 m (i.e. surface and primary production depths).

Primary production measurements were done using the in situ C14 incubation method. Vertical sinking flux of total particulate matter, pigments (chlorophyll *a* and phaeopigments) and particulate carbon and nitrogen was studied with free-drifting sediment traps deployed at 65 m. Phytoplankton and zooplankton abundance and species composition were sampled using vertical tows with 20 and 45 µm plankton nets, respectively, while crab and fish larvae abundance and species composition were measured by oblique hauls using a 335 µm bongo net. Bongo net sampling was also conducted along the length section studied in mid-May 2008.

Abiotic parameters

Hydrographical conditions at the main station showed similar seasonal trends as observed in 2006 and 2007 (figure 5.8). Wintertime irradiance remained below 25 µmol photos m^{-2} s^{-1} mainly due to the latitude (64 °N), while the highest irradiance was observed in the surface water during summer. Irradiance remained below 5 µmol photos m^{-2} s^{-1} at depths below 50 m throughout the year. The significantly reduced irradiance levels on some sampling days during summer likely reflect lower incoming irradiance due to cloud cover.

A vertical stratification of the water co-lumn was observed in January and February with a pronounced warmer and more saline bottom layer (figure 5.8). In the following months, until May, vertical mixing produced homogenous conditions with temperatures remaining below 1 °C and salinities between 33.0 and 33.5. In summer, release of melt water from the inner part of the fjord, combined with heating of surface waters, resulted in a distinctive fresher and warmer surface layer with temperatures and salinities reaching 7.2 °C and 26.1, respectively. Autumn conditions resulted in a cooling of surface waters along with vertical mixing of the water column, thus gradually weakening stratification.

Surface pCO_2 values from 2005 to 2008 vary from 125 to 530 µatm (figure 5.9). However, only two sampling dates from January and February are above atmospheric content (387 µatm) in the time series. Average surface pCO_2 concentrations increases through the period investigated from 186 µatm in 2006, to 235 µatm in 2007 and to 275 µatm in 2008. At the same time surface waters became more fresh and colder. More data are needed to verify this relationship. Over the entire period, average pCO_2 values are below atmospheric concentration, indicating Godthåbsfjord is a strong CO_2 sink.

Nutrient conditions at the main station in 2008 displayed similar seasonal trends as during the two previous years (figure 5.10). The highest nitrate and nitrite concentrations (up to 20.8 µM) were observed at distinctive depths in April and May, while the highest phosphate and silicate concentrations were generally found at depths during winter and autumn (maximum of 0.92 and 9.8 µM, respectively). Nevertheless, the onset of primary production in spring caused a reduction in all surface nutrients which lasted throughout the summer resulting in minimum concentrations of 0.25, 0.02 and 0.13 µM for nitrate and nitrite, phosphate and silicate, respectively.

Biotic parameters

The biomass of phytoplankton expressed as the concentrations of chlorophyll *a* and phaeopigments, showed two distinctive peaks in spring and late summer, as was observed in 2006 and 2007 (figure 5.11). Chlorophyll *a* concentrations in surface waters peaked at 2.5 and 3.3 µg l^{-1} in late-May and late-September, respectively. Similar to previous years, vertical mixing combined with vertical sinking flux of phytoplankton based material, particularly in May, also resulted in elevated pigment concentrations at depth. The primary production peak in late-May (823 mg C m^{-2} d^{-1}) coincided with the first phytoplankton biomass peak, while the second production peak in early August (1149 mg C m^{-2} d^{-1}) preceded the second biomass peak in late-September (figure 5.11 and table 5.1). Combined with the primary production pattern observed in 2006, and the indication that a mid-summer decrease may have been missed in 2007, it appears that the Godthåbsfjord system generally display two distinct annual surface phytoplankton blooms. Note, daily primary production values from 2006 and 2007, as presented in Jensen and Rasch (2008), were corrected for averaged incoming irradiance (PAR) between sampling days and not irradiance specific to the deployment day. This has been corrected for 2008 (figure 5.11 and table 5.1). The estimated annual primary production for 2008 was within the estimates for 2006 and 2007 (75.1, 104 and 91.1 g C m^{-2} y^{-1} in 2006, 2007

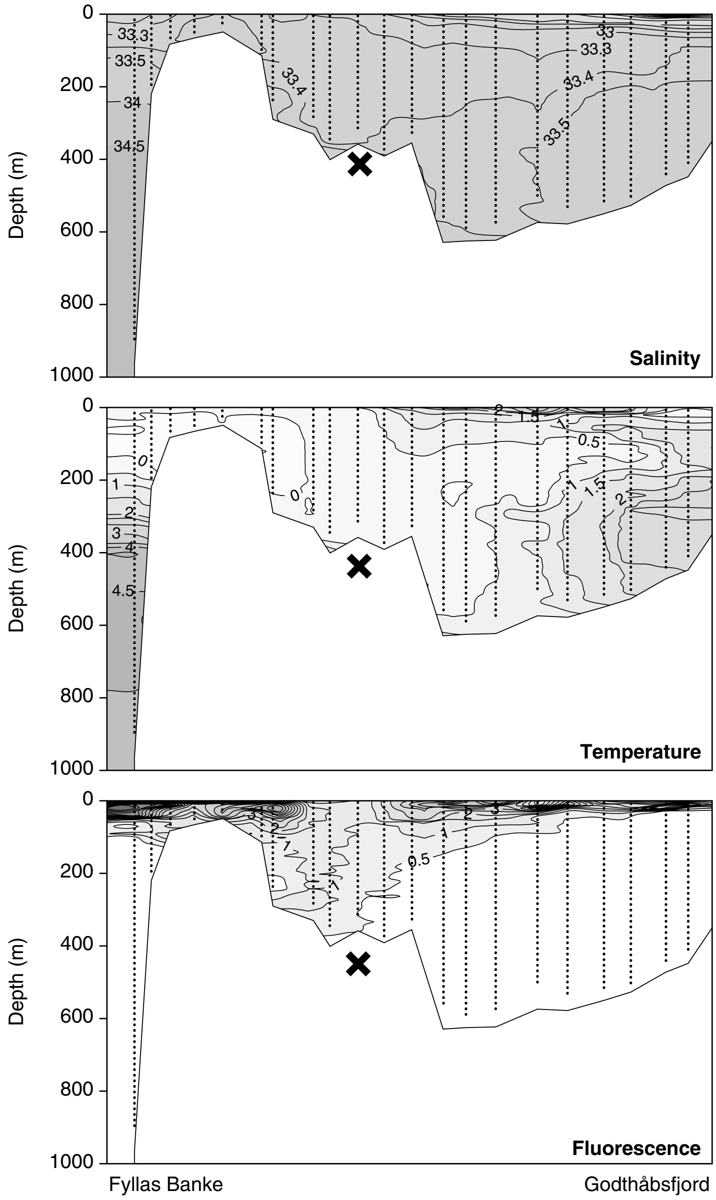

Figure 5.6 Salinity, temperature (°C) and fluorescence along the length section from Fyllas Banke to the inner part of Godthåbsfjord in mid-May 2008. Vertical dotted lines represent sampling days and depths in 5 m increments. X marks the location of the main station.

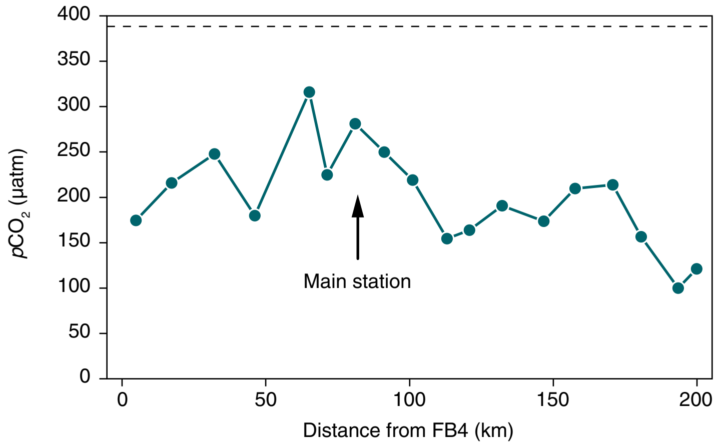

Figure 5.7 pCO_2 (µatm) in surface waters along the length section from Fyllas Banke (outermost station FB4, figure 5.1) to the inner part of Godthåbsfjord in mid-May 2008. Horizontal dotted line represents atmospheric content (387 µatm).

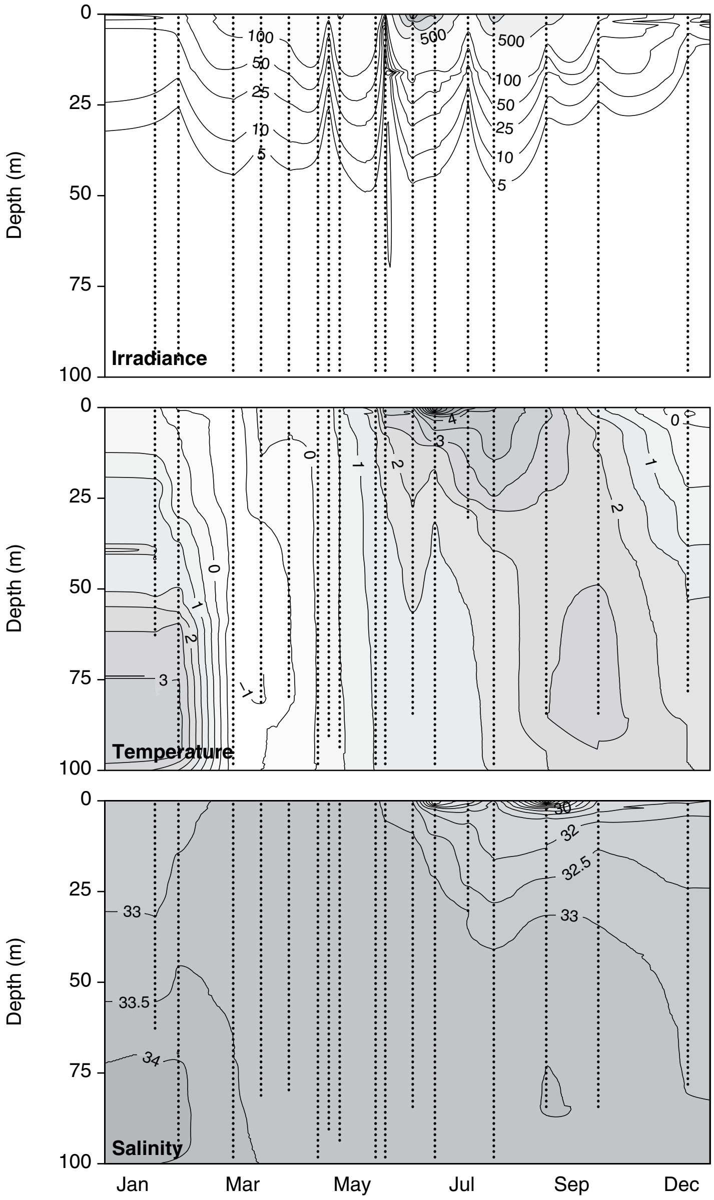

Figure 5.8 Annual variation in irradiance (PAR), salinity and temperature (°C) at the main station in 2008. Vertical dotted lines represent sampling days and depths in 5 m increments.

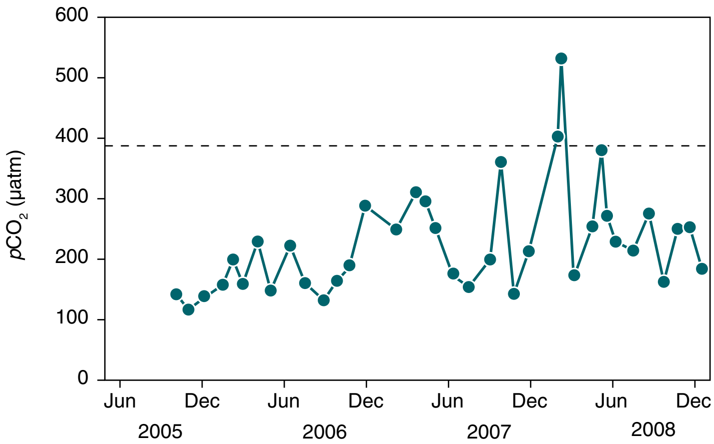

Figure 5.9
Annual variation in pCO2 (µatm) in surface waters at the main station from late 2005 to 2008. Horizontal dotted line represents atmospheric content (387 µatm).

and 2008, respectively); thus suggesting that annual primary production remains within this range of values.

The plankton community

The composition of the phytoplankton community was studied during the monthly sampling programme, however, due to shipping problems only samples from January to August 2008 were analysed in time for this report. Nonetheless, phytoplankton counts showed seasonal trends in the species composition similar to the two previous years (figure 5.12). Diatoms consistently dominated the phytoplankton community except during the spring phytoplankton bloom in May and June, contributing up to 98.5 % of total phytoplankton numbers. Species of *Thalassiosira*, *Fragilariopsis* and *Chaetoceros* were the most abundant diatoms. As seen in previous years, a distinctive *Phaeocystis* (*Haptophyceae*) bloom occurred in May and June which dominated the phytoplankton community (up to 97.0 %). However, dinoflagellates, particularly *Peridinella catenata* and species of *Protoperidinium* and *Dinophysis*, were also an important phytoplankton group especially during summer (up to 24.4 %). The most important phytoplankton species from January to August were the three diatoms *Thalassiosira*, *Fragilariopsis* and *Chaetoceros* and the distinctive *Phaeocystis* (table 5.2); these are all phytoplankton species typical of arctic coastal waters.

Seasonal patterns in the abundance of zooplankton during 2008 showed similarities with previous years, particularly 2007 (figure 5.13). Concentrations of copepod eggs and nauplii showed a single peak in July, about a month ahead of the peak in copepods (i.e. copepodites and adult stages). However, while the highest recorded concentration of copepod nauplii in 2008 (63002 individuals m^{-3}) was comparable to those observed in 2006 and 2007; the concentration of copepods remained lower than during the previous years (46217, 69882, 36284 individuals m^{-3} in 2006, 2007 and 2008, respectively). In contrast, maximum concentrations of copepod eggs in 2008 (55693 individuals m^{-3}) exceeded values from previous years by almost an order of magnitude. In spite of the inter-annual differences in abundances, the species composition of copepods (i.e. copepodites and adult stages) showed similarities between years. *Microsetella* sp.

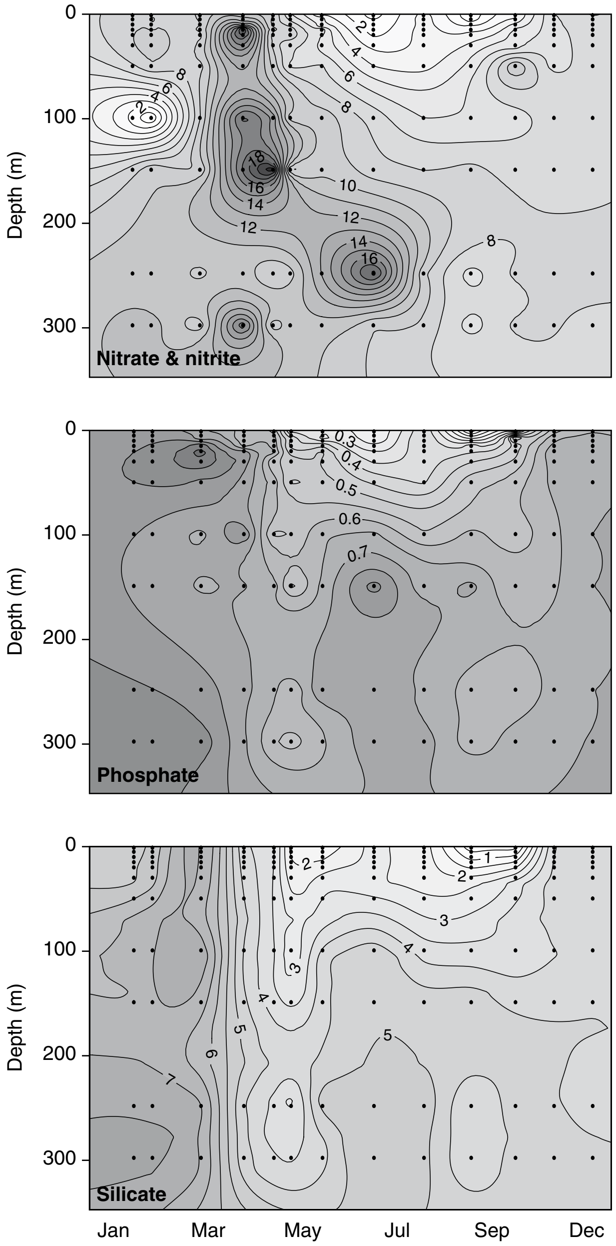

Figure 5.10 Annual variation in nitrate and nitrite (µM), phosphate (µM) and silicate (µM) concentration at the main station in 2008. Vertical dotted lines represent sampling days and depths.

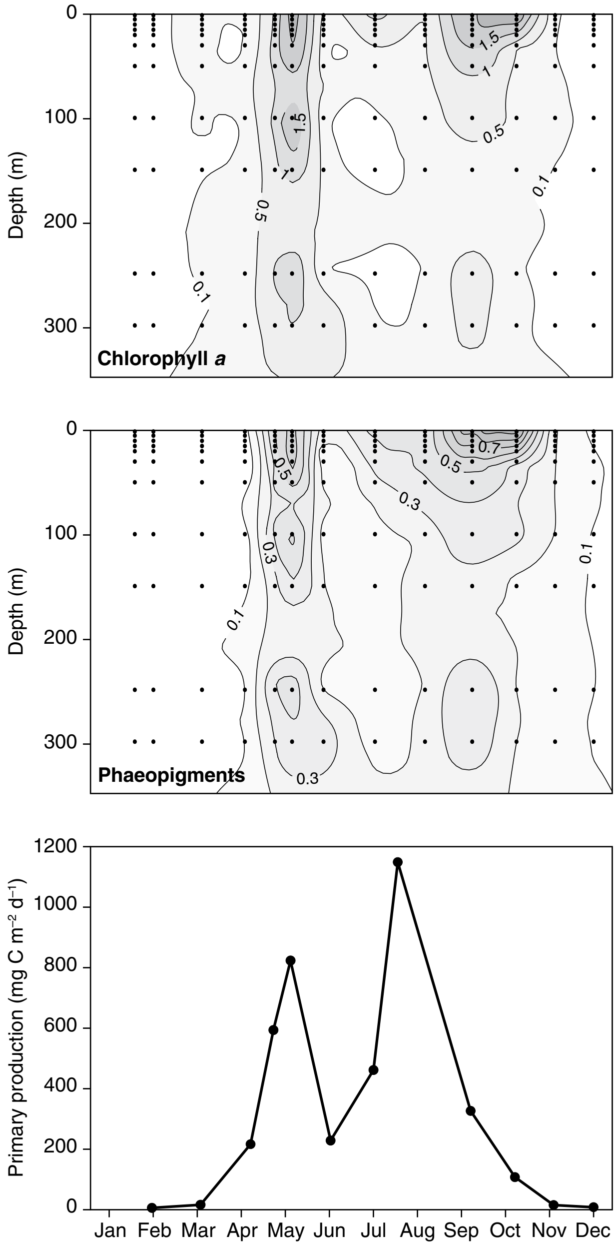

Figure 5.11 Annual variation in chlorophyll a concentration (µg l^{-1}), phaeopigments concentration (µg l^{-1}) and primary production (mg C m^{-2} d^{-1}) at the main station in 2008. Vertical dotted lines on the chlorophyll a and phaeopigments plots represent sampling days and depths.

remained the single most abundant species (up to 71 %), except during June (figure 5.13). While *Microsetella* is a pelagic copepod species, it is generally considered to be dependent on suspended and sinking particles, which are abundant in the Godthåbsfjord system. Another consistently abundant species was *Oithona* spp. (up to 34 %), while *Microcalanus* only contributed significantly during autumn and winter (up to 25 %). The only time when *Calanus* spp. was found in significant numbers was in early June, i.e. immediately after the first phytoplankton bloom. This species is considered an arctic key zooplankton species,

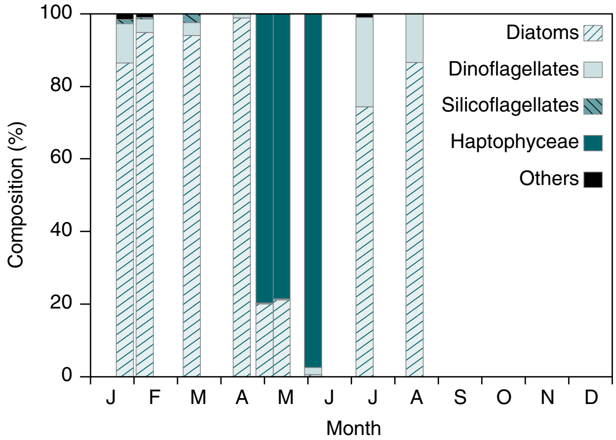

Figure 5.12 Seasonal variation in phytoplankton community composition (%) at the main station from January to August in 2008.

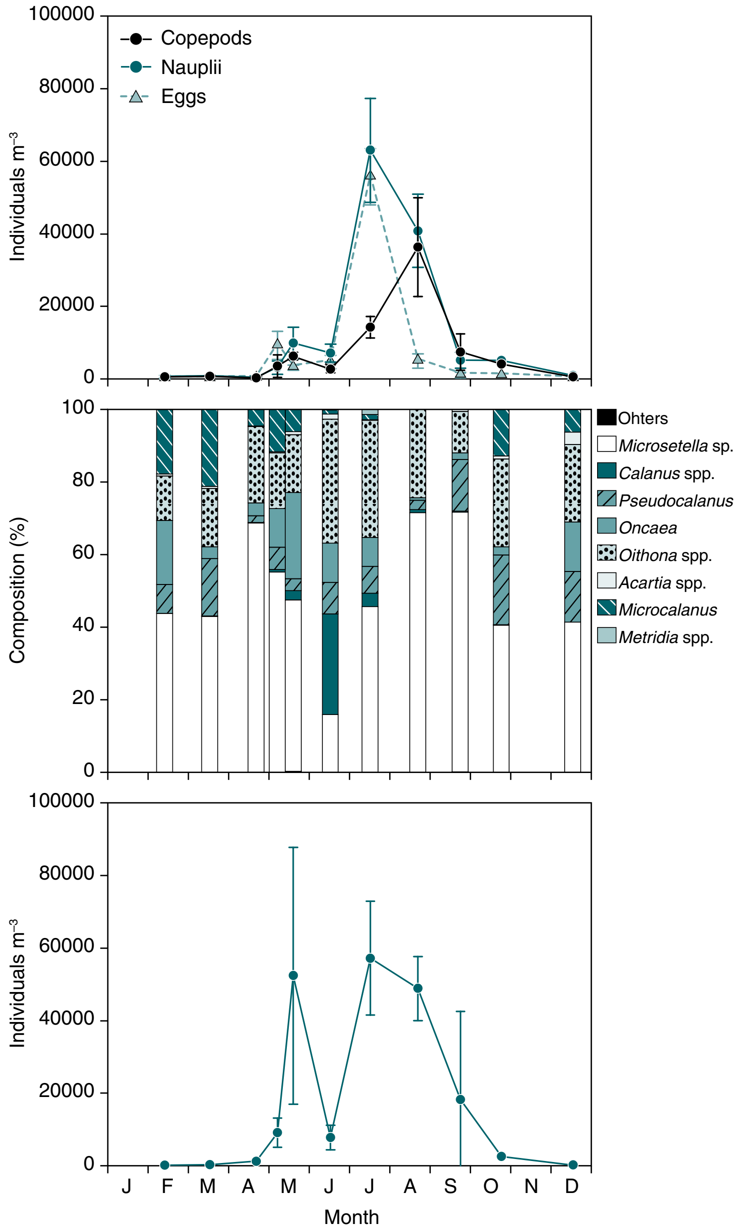

Figure 5.13 Annual variation in abundance (individuals m^{-3}) of copepod eggs, nauplii and copepods (i.e. copepodites and adult stages), copepod community composition (%) and abundance of other zooplankton groups (individuals m^{-3}) at the main station in 2008. Error bars represent standard deviation.

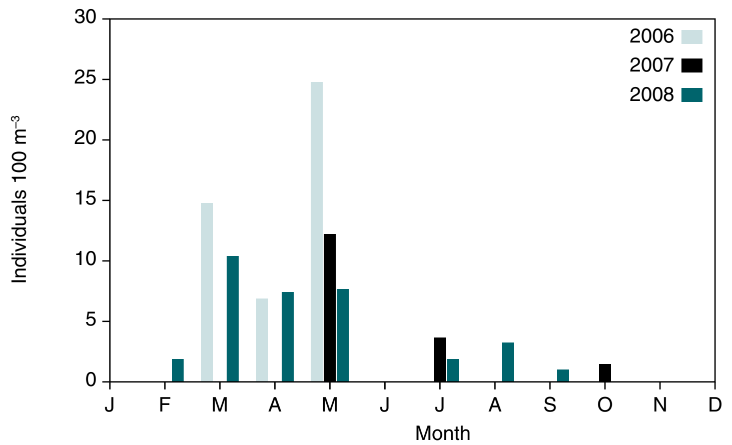

Figure 5.14 Number of fish larvae per 100 m^3 at the main station (GF3). Samples were taken in March, April and May 2006; May, July and October 2007 and each month in 2008 but January, June and November.

which often ascend from overwintering in deeper waters in time to utilize the surface spring bloom. The abundance of other plankton groups was generally high from May to September, with the exception of June (figure 5.13). Bivalvia and Cirripedia larvae were particularly abundant in May, while Rotaroria and Tintinnida peaked from July to September.

To assess the ichthyoplankton in Godthåbsfjord, double oblique sampling with bongo net (335 and 500 µm) was undertaken in the length section across Fyllas Banke and in the fjord in May 2006, 2007 and 2008. Thirteen stations were sampled in May 2006. Based on this, four stations were chosen for the monitoring programme, and sampled in May 2007 and 2008. A second length section was undertaken in the end of July 2008 when eight stations where sampled. Additional sampling was undertaken at the main station (GF3) throughout the year. Due to logistical problems, the samples taken in 2008 were done with single oblique bongo net (335 µm, 500 µm in May) except on the length section in the end of July.

At the main station (GF3) the highest concentration of fish larvae species was found in May in 2006 and 2007. In 2008 highest concentrations were found in March (figure 5.14). A temporal shift in species composition occurs during the summer months. Sand eel (*Ammodytes* sp.) was a dominating species from March to July, whereas capelin (*Mallotus villosus*) was dominating from July/August (table 5.3). Cod larvae (*Gadus morhua*) were found from April to July, although in low concentrations.

The highest concentration of ichthyoplankton was found at the inlet of the fjord in May 2006 where vertical mixing of offshore and inshore waters takes place (figure 5.15). The ichthyoplankton was mainly dominated by sand eel larvae and arctic shanny (*Stichaeus punctatus*) larvae in all years (tables 5.4, 5.5 and 5.6). However, in 2008, remarkably few sand eel larvae were caught in May which may explain lower concentrations of total number of fish larvae pr. 100 m^3 in 2008, compared to 2006 and 2007 at Fyllas Banke (figure 5.15, tables 5.4, 5.5 and 5.6). Furthermore, at the length section in July/August 2008 high numbers of Capelin larvae were caught deep within the fjord (GF10) but they were absent in the length section in May (figure 5.15, table 5.6). Changes in the species composition of

Table 5.1 Annual minimum and maximum values of primary production, surface pCO_2 and attenuation coefficients (PAR) at the main station in 2006–2008. Annual minimum and maximum values for salinity, temperature, nutrients and chlorophyll at depth intervals 0–5 m, 0–50 m and 50–300 m. Minima and maxima are shown with 95% confidence intervals, number of samples (n) and sampling date (dd/mm).

		2006		2007		2008	
Depth	**Parameter**	**min**	**max**	**min**	**max**	**min**	**max**
	Primary production (mg C m^{-2} d^{-1})	3.0 (08/02)	710.3 (04/05)	1.9 (28/11)	846.0 (17/07)	5.8 (13/02)	1148.6 (03/08)
	Surface pCO_2 (µatm)	131.9 (29/08)	288.9 (29/11)	153.7 (17/07)	360.5 (29/09)	107.5 (23/09)	531.7 (08/02)
	PAR attenuation (m^{-1})	0.078 (29/11)	0.191 (04/05)	0.088 (28/11)	0.175 (04/05)	0.077 (18/06)	0.131 (23/09)
0–5 m	Salinity	28.18±0.035 n=5 (29/08)	33.39±0.008 n=5 (04/04)	25.88±0.672 n=5 (03/09)	33.33±0.001 n=5 (13/06)	27.79±0.55 n=5 (23/09)	33.32±0.001 n=5 (08/05)
	Temperature (°C)	0.12±0.004 n=5 (08/02)	5.48±0.033 n=5 (24/07)	–0.37±0.003 n=5 (12/04)	5.54±0.145 n=5 (03/09)	–0.73±0.005 n=5 (18/03)	6.74±0.30 n=5 (17/07)
	Phosphate (µM)	0.02±0.001 n=2 (24/07)	0.54±0.046 n=2 (03/02)	0.24±0.13 n=2 (11/06)	0.60±0.047 n=2 (12/04)	0.07±0.10 n=2 (23/09)	0.69±0.06 n=2 (13/02)
	Silicate (µM)	0.29±0.086 n=2 (24/07)	4.73±0.340 n=2 (04/04)	0.79±0.341 n=2 (03/090)	4.17±0.289 n=2 (28/11)	0.16±0.07 n=2 (23/09)	7.34±0.60 n=2 (18/03)
	Nitrate (µM)	0.64±0.099 n=2 (24/07)	11.38±3.725 n=2 (08/02)	0.73±0.301 n=2 (11/06)	9.65±2.38 n=2 (26/10)	0.33±0.16 n=2 (23/09)	11.02±1.25 n=2 (17/04)
	Chlorophyll (µg l^{-1})	0.012±0.001 n=2 (08/02)	5.79±3.730 n=2 (04/05)	0.06±0.01 n=2 (06/02)	2.37±0.48 n=2 (04/05)	0.02±0.01 n=2 (14/02)	2.55±1.53 n=2 (23/09)
0–50 m	Salinity	30.49±0.157 n=50 (29/08)	33.40±0.002 n=50 (15/06)	29.82±0.216 n=50 (03/09)	33.35±0.001 n=50 (13/06)	31.20±0.19 n=50 (23/09)	33.32±0.001 n=50 (08/05)
	Temperature (°C)	0.27±0.007 n= (16/01)	4.50±0.057 n=50 (29/08)	0.05±0.004 n=50 (22/03)	4.30±0.074 n=50 (03/09)	–0.86±0.001 n=50 (18/03)	3.81±0.014 n=50 (21/08)
	Phosphate (µM)	0.06±0.031 n=7 (24/07)	0.57±0.020 n=7 (03/02)	0.34±0.06 n=7 (11/06)	0.59±0.024 n=7 (12/04)	0.29±0.08 n=6 (17/07)	0.81±0.08 n=6 (13/02)
	Silicate (µM)	0.80±0.390 n=7 (24/07)	4.99±0.194 n=7 (04/04)	1.02±0.127 n=7 (11/06)	4.12±0.151 n=7 (28/11)	1.32±0.72 n=7 (23/09)	7.51±0.77 n=7 (18/03)
	Nitrate (µM)	1.46±0.717 n=7 (24/07)	12.49±1.639 n=7 (16/01)	1.41±0.450 n=7 (11/06)	11.65±2.861 n=7 (28/11)	1.93±0.84 n=7 (17/07)	14.55±2.56 n=7 (17/04)
	Chlorophyll (µg l^{-1})	0.015±0.002 n=7 (08/02)	6.712±1.172 n=7 (04/05)	0.06±0.005 n=7 (06/02)	2.34±0.29 n=7 (04/05)	0.02±0.004 n=7 (14/02)	2.34±0.10 n=7 (20/05)
50–300 m	Salinity	32.80±0.039 n=251 (27/09)	33.78±0.030 n=230 (08/02)	32.80±0.038 n=251 (03/09)	33.66±0.018 n=251 (12/04)	32.77±0.014 n=232 (17/12)	33.61±0.024 n=251 (14/02)
	Temperature (°C)	0.55±0.006 n=248 (04/04)	2.94±0.022 n=251 (29/11)	0.14±0.005 n=251 (22/03)	3.53±0.012 n=247 (25/10)	–0.79±0.007 n=251 (18/03)	2.49±0.015 n=251 (24/10)
	Phosphate (µM)	0.35±0.057 n=5 (15/06)	0.88±0.053 n=5 (08/02)	0.50±0.144 n=5 (04/05)	0.72±0.055 n=5 (26/10)	0.55±0.04 n=5 (20/05)	0.75±0.05 n=5 (13/02)
	Silicate (µM)	2.13±0.545 n=5 (25/10)	5.41±0.365 n=5 (08/02)	1.58±0.388 n=5 (11/06)	4.55±0.783 n=5 (27/09)	2.76±0.48 n=5 (20/05)	7.21±0.26 n=5 (18/03)
	Nitrate (µM)	4.77±0.711 n=5 (04/05)	12.79±1.652 n=5 (16/01)	3.89±1.446 n=5 (11/06)	15.78±1.4 n=5 (28/11)	6.57 n=1 (20/11)	15.01±2.61 n=7 (17/04)
	Chlorophyll (µg l^{-1})	0.017±0.001 n=5 (08/02)	2.439±1.562 n=5 (04/05)	0.06±0.008 n=5 (06/02)	1.57±0.37 n=5 (04/05)	0.02±0.01 n=5 (14/02)	1.89±0.34 n=5 (20/05)

Table 5.2 Ten most dominant phytoplankton species integrated over the year as their relative accumulated proportion of total cell count (%) at the main station in 2006, 2007 and from January to August, 2008.

2006		2007		2008*	
Chaetoceros wighamii	30.5	*Chaetoceros* spp. (ex debilis)	20.1	*Thalassiosira* spp.	27.9
Phaeocystis sp.	45.5	*Phaeocystis* sp.	36.3	*Phaeocystis* sp.	50.4
Thalassiosira antarctica	53	*Thalassiosira* spp.	52.3	*Chaetoceros* spp.	62.1
Thalassionema nitzschioides	58.1	*Chaetoceros debilis*	65.5	*Fragilariopsis* spp.	70.0
Dictyocha speculum	62.7	*Thalassionema nitzschioides*	78.6	*Navicula* spp.	73.9
Pseudonitzschia cf seriata	66.2	*Fragilariopsis oceanica*	82.2	*Protoperidinium* spp.	77.5
Thalassiosira nordenskioeldii	69.1	*Dictyocha speculum*	83.6	*Pseudonitzschia* spp.	80.5
Nitzschia frigida	71.7	*Aulacoseira* sp.	84.9	*Podosira* spp.	83.2
Dinobrion balticum	74	*Cocconeis* spp.	86.1	*Leptocylindrus* spp.	85.7
Thalassiosira bioculata	76.1	*Ceratulina* sp.	87.0	*Peridenella catenata*	87.6

* From January to August

Table 5.3 Number of fish larvae per 100 m³ at main station (GF3).

Station	Date	*Gadus morhua*	*Stichaeus punctatus*	*Leptoclinus maculatus*	*Ammo-dytes* sp.	*Mallotus villosus*	*Aspidophoroides monopterygius*	*Pholis* sp.	*Myoxocephalus scorpius*	Uniden-tified	Total
GF3	02-03-2006				14.7						14.7
GF3	04-04-2006	0.1			6.6		0.1			0.2	6.9
GF3	15-05-2006	0.1	5.2	0.3	17.6		0.7	0.4		0.5	24.8
GF3	15-05-2007	0.1	7.1	0.4	1.6		2.1	0.3		0.7	12.2
GF3	01-07-2007	0.3	0.7	0.2	1.5		0.8				3.6
GF3	10-10-2007					1.4					1.4
GF3	14-02-2008				1.7	0.2					1.9
GF3	25-03-2008				10.3			0.1			10.4
GF3	16-04-2008				7.3		0.1			0.1	7.4
GF3	13-05-2008	0.1	2.2		4.0		0.4	0.4		0.5	7.7
GF3	18-07-2008	0.1	0.1		0.4	1.1	0.1		0.1		1.9
GF3	04-08-2008					3.1			0.1	0.1	3.2
GF3	19-09-2008					1.0					1.0
GF3	21-10-2008										0.0
GF3	22-12-2008										0.0

Table 5.4 Number of fish larvae per 100 m³ in 2006; length section starting at the outer Fyllas Banke (FB4).

Station	Date 2006	*Gadus morhua*	*Stichaeus punctatus*	*Leptoclinus maculatus*	*Ammo-dytes sp.*	*Aspidophoroides monopterygius*	*Bathylagus euryops*	*Pholis* sp.	*Reinhardtius hippoglossoides*	Uniden-tified	Total
FB4	16-05			0.4	2.4	.	0.4			0.4	3.5
FB3.5	16-05				0.7	0.8	1.1			2.6	5.2
FB3	16-05	0.2		0.2	167.8	1.3	0.8		0.2	0.4	170.8
FB2.5	17-05				112.5					0.7	113.1
FB2	17-05				21.2						21.2
FB1.5	17-05				59.2	0.2					59.4
FB1	17-05		0.3		167.4		0.4				168.1
GF1	18-05	1.9	21.3	1.3	271.3	0.9		0.4		1.3	298.3
GF2	15-05	9.5	74.9	8.1	981.1	8.5		3.8		7.2	1093.0
GF3	15-05	0.1	5.2	0.3	17.6	0.7		0.4		0.5	24.8
GF5	18-05		1.0	0.2	2.8	0.5					4.5
GF7	20-05	0.2	1.6			0.2					1.9
GF10	19-05		0.7		0.1						0.8

Table 5.5 Number of fish larvae per 100 m³ in 2007; length section starting at the outer Fyllas Banke (FB3.5).

Station	Date 2007	*Gadus morhua*	*Stichaeus punctatus*	*Leptoclinus maculatus*	*Ammodytes sp.*	*Aspidophoroides monopterygius*	*Bathylagus euryops*	*Cyclothone sp.*	*Pholis* sp.	*Uniden-tified*	*Total*
FB3.5	16-05						0.5	0.2		0.5	1.1
FB2.5	17-05				35.0					0.2	35.2
GF3	15-05	0.1	7.1	0.5	1.6	2.1			0.3	0.7	12.2
GF10	20-05	0.1	0.2			0.1					0.3

Table 5.6 Number of fish larvae per 100 m³ in 2008; length section starting at the outer Fyllas Banke (FB3.5).

Station	Date 2008	*G. morhua*	*S. punctatus*	*Ammodytes sp.*	*M. Villosus*	*A. monopterygius*	*B. euryops*	*Pholis sp.*	*R. hippoglossoides*	*M. scorpius*	*H. platessoides*	*Sebastes sp.*	*G. ogac*	Unidentified	Total
FB3.5	14-05			0.7			0.3			0.4		0.3			1.7
FB2.5	14-05			2.7									0.4		3.0
GF3	13-05	0.1	2.2	4.0		0.4		0.4						0.5	7.7
GF10	13-05		0.6	0.1		0.2							0.1		0.8
FB4	27-07														0.0
FB3.5	26-07				0.1				0.1						0.1
FB3	24-07														0.0
FB2.5	23-07								0.3						0.3
FB1	25-07			0.1					0.1	0.1					0.2
GF3	03-08				1.9					0.2					2.0
GF7	29-07	0.1		0.1	1.9						0.8				2.9
GF10	31-07				9.2						0.1				9.2

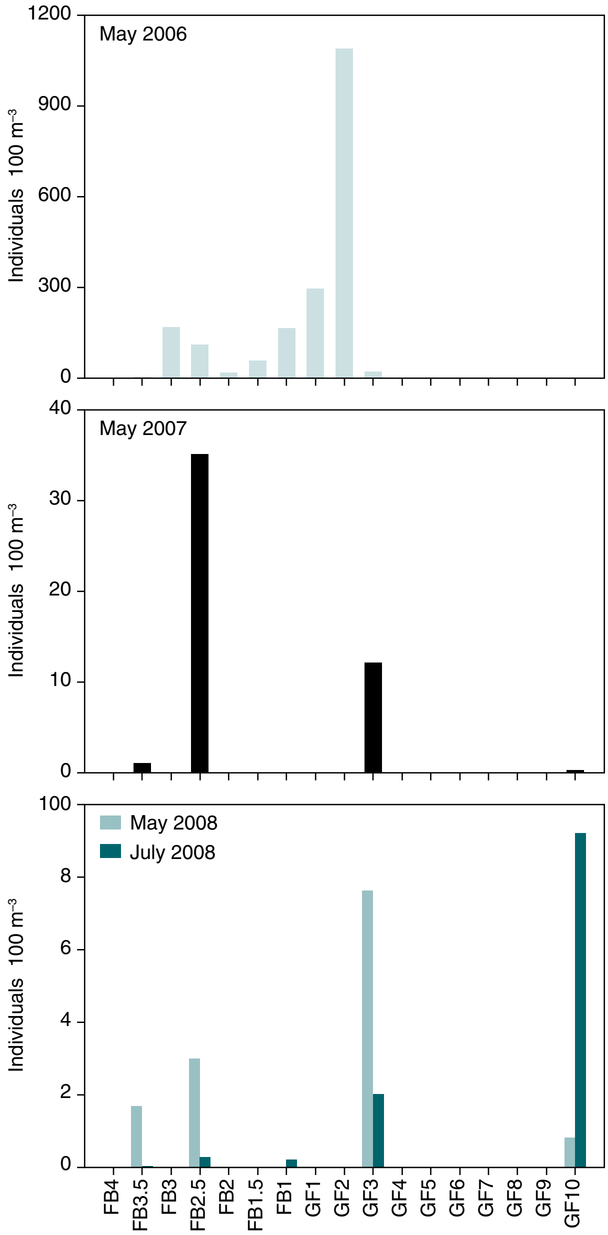

Figure 5.15 Number of fish larvae per 100 m³ in 2006, 2007 and 2008 from the length section starting at the outer Fyllas Banke (FB4).

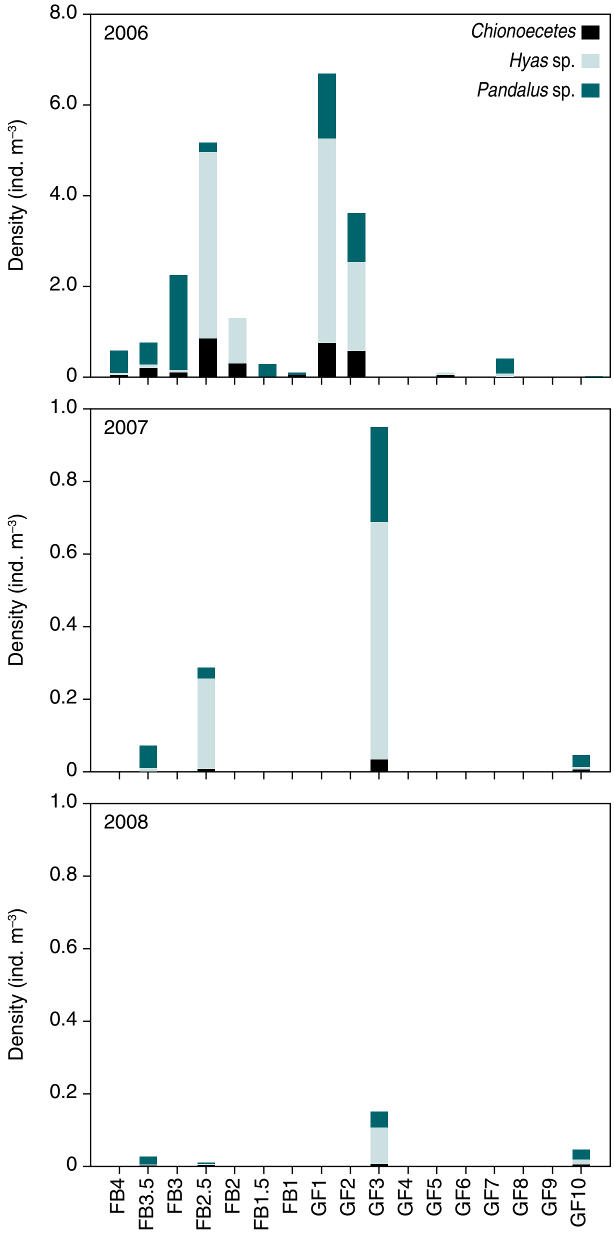

Figure 5.16 Density of Chionoecetes opilio, Hyas spp. *and* Pandalus spp. *larvae collected with 500 µm net in May 2006, 2007 and 2008 along the length section.*

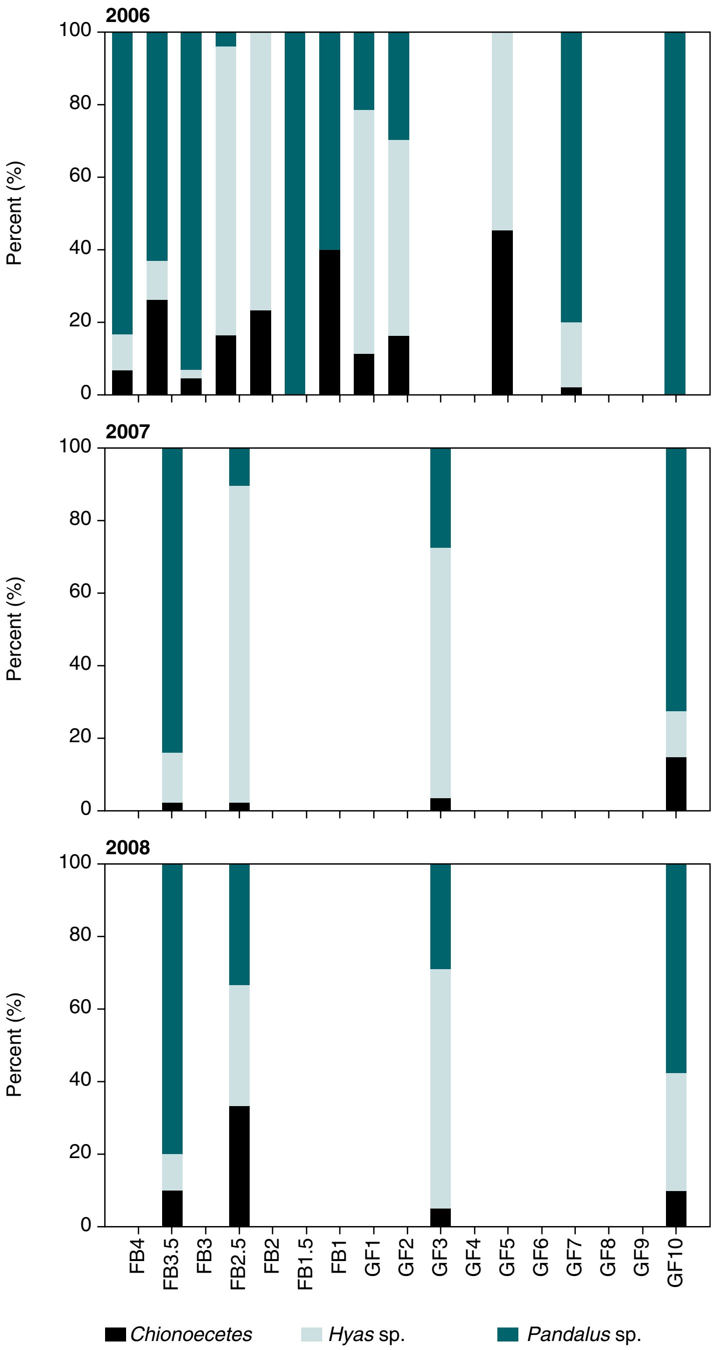

Figure 5.17 Composition of Chionoecetes opilio, Hyas spp. *and* Pandalus spp. *larvae collected with 500 µm net in May 2006, 2007 and 2008 along the length section.*

ichthyoplankton were found along the length section. Sand eel larvae were dominant at Fyllas Banke, whereas arctic shanny larvae were only found within the fjord. Cod larvae (*Gadus morhua*) were found on both Fyllas Banke and inside Godthåbsfjord, although in low concentrations. A single Greenland halibut larvae (*Reinhardtius hippoglossoides*) was found at Fyllas Banke in May 2006 and several large Greenland halibut larvae were caught at Fyllas Banke in 2008 in July/August.

At the main station (GF3) the highest concentration of shellfish (*Chionoecetes opilio*, *Hyas* spp. and *Pandalus* spp.) caught with the 335 µm bongo net were found in May 2006 and 2007, while the concentration at the same time in 2008 were low compared to the previous years (figures 5.16 and 5.18). The composition of the shellfish community varied throughout 2008. From March to July *Pandalus* spp. larvae (*Pandalus borealis* and *Pandalus montagui*) were dominant, whereas the snow crab larvae *Chionoecetes opilio* was dominating in August and the sand crab larvae *Hyas* spp. in September and October (figure 5.19).

Along the length section, concentration of crab and shrimp larvae were highest in 2006 but remarkably low in 2008, where only few individuals were observed in the samples (figure 5.16). Along the length section, spanning from the inner Godthåbsfjord, across the shallow Fyllas Banke and out to the slope of the continental shelf, the sampled stations were different in species composition. At the station (GF10) located in the inner fjord, only larvae of *Pandalus* spp. were found in the samples from 2006, whereas larvae of *C. opilio and Hyas* spp. also occurred in 2007 and 2008. In the outer fjord, larvae of *C. opilio* and especially *Hyas* spp. were more abundant than shrimp larvae, and *Hyas* spp. was dominant at the stations at the shallow bank. Throughout the years of sampling, larvae of *Pandalus* spp. dominates at the stations close to the shelf slope (figure 5.17).

Vertical sinking flux

Similar to previous years, vertical sinking flux of total particulate matter showed no clear seasonal pattern averaging 53.1 g m^{-2} d^{-1} in 2008 (figure 5.20). The carbon content of the sinking particulate material remained low (1.73 %), thus supporting the previously recognized importance of lithogenic material from glaciers and melt rivers at the inner part of the fjord. While the vertical sinking flux of total particulate carbon showed no clear seasonal pattern either (averaging 0.89 g m^{-2} d^{-1} in 2008), some parallel trends can be identified with sinking fluxes of total particulate matter. The peak vertical sinking flux of phytoplankton based material, i.e. chlorophyll *a*, in May and September-October (up to 10.8 and 8.6 mg m^{-2} d^{-1}, respectively) coincided with peak phytoplankton concentrations (figure 5.11). This was also reflected in C:N ratios of material collected during summer, which resembled that expected of fresh algal material (Redfield ratio 6.6 mol:mol).

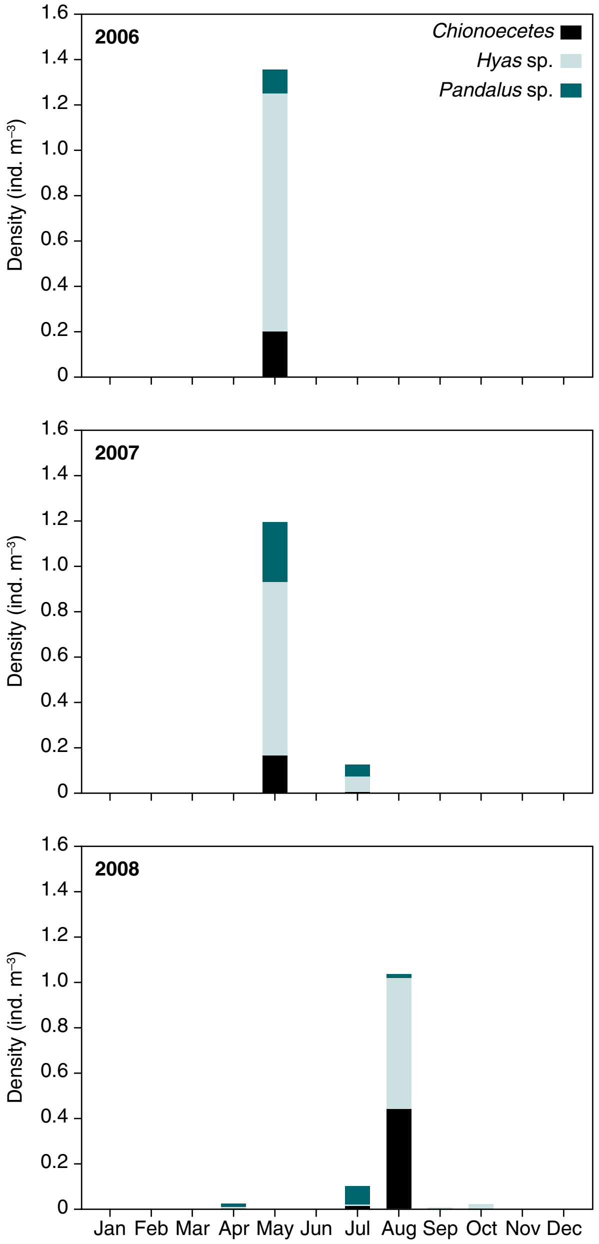

Figure 5.18 Density of Chionoecetes opilio, Hyas spp. *and* Pandalus spp. *larvae collected with 335 µm net at the main station (GF3) in May 2006, May, July and October in 2007 and all months, but January, May and November in 2008.*

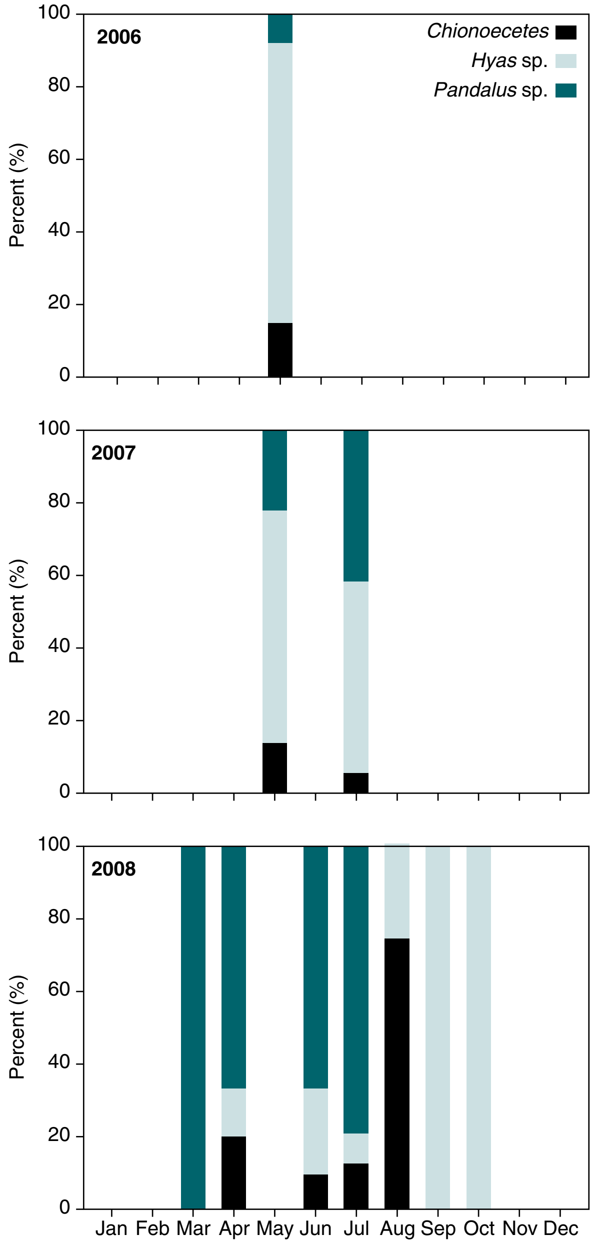

Figure 5.19 Composition of Chionoecetes opilio, Hyas spp. *and* Pandalus spp. *larvae collected with 335 µm net at the main station (GF3) in May 2006, May, July and October in 2007 and all months, but January, May and November in 2008.*

The estimated annual vertical sinking flux of total particulate matter were comparable to the two previous years (table 5.7), suggesting a stable input of terrestrial material to the pelagic system. Although the annual carbon sinking flux showed differences between the three years, the value estimated for 2008 is comparable to the estimate for 2007.

Table 5.7 Integrated annual vertical sinking flux of total particulate material and carbon at 65 m at the main station in 2006, 2007 and 2008.

Depth	Parameter	2006	2007	2008
65 m	Total particulate flux (×1000 g dw m^{-2} y^{-1})	21.4	24.9	20.2
	Carbon (g C m^{-2} y^{-1})	253.9	364.1	315.2

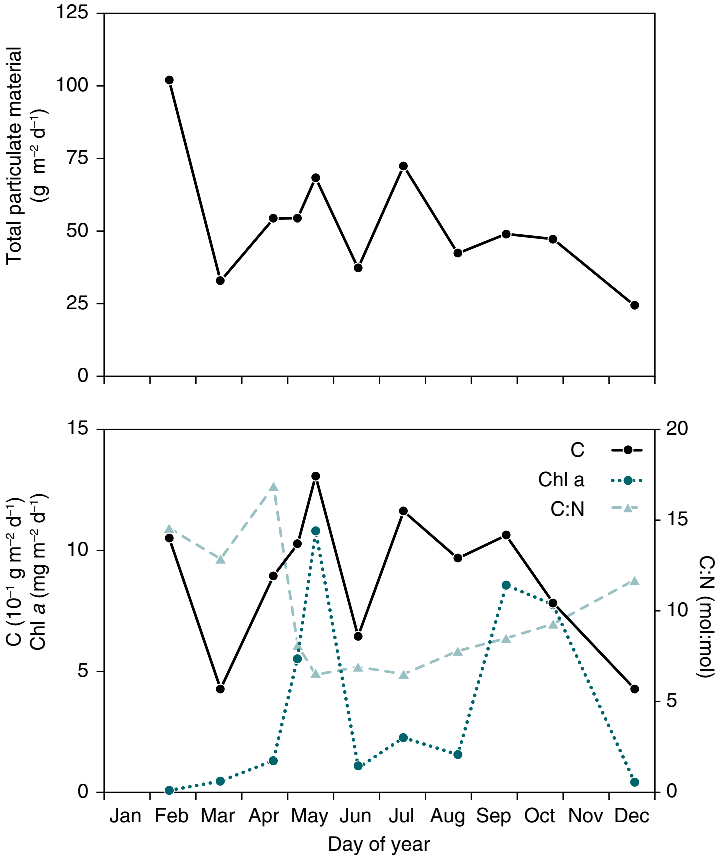

Figure 5.20 Annual variation in vertical sinking flux of total particulate matter (g m^{-2} d^{-1}), and carbon (10^{-1} g m^{-2} d^{-1}), chlorophyll a (mg m^{-2} d^{-1}) and carbon to nitrogen ratio (mol:mol) of the sinking particulate material collected at the main station in 2008.

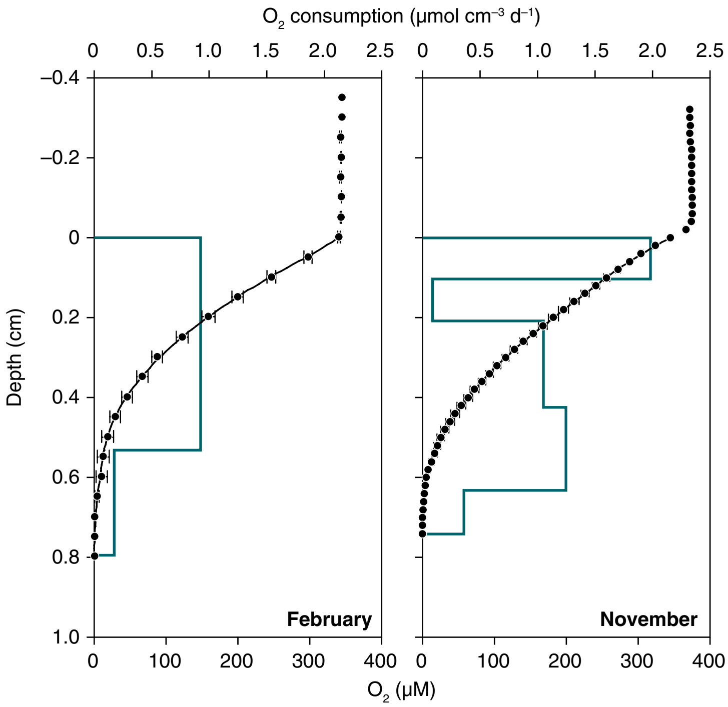

Figure 5.21 Vertical sediment profiles of oxygen concentrations (open circles) and modelled consumption rates (solid line) from microelectrode profiles with sediment depth in February and November 2008. Error bars represent standard deviation.

5.4 Sediments

Sediments

Arrival of fresh organic matter to the sea bed is either consumed by organisms or mineralized to reduced substances involving a number of different electron acceptors. At the sediment surface, oxygen is the key electron acceptor with sulphate as the key acceptor below the oxidised zone. This process leads to direct or indirect oxygen consumption, therefore the rate of organic matter remineralisation may be estimated by measuring the flux of oxygen into the sediment.

Intact sediment cores were recovered in February, August and November at a depth of 125 m (figure 5.1). Oxygen fluxes were measured by incubation and micro-profiling. Oxygen micro-profiles in August incurred technical problems and therefore data have been omitted. In both periods oxygen was depleted within 1 cm of the sediment surface, with maximum consumption at 0.5 cm in November (figure 5.21). Oxygen consumption by the sediment was 8.71 mmol m^{-2} d^{-1} in February (table 5.8) and was higher than DIC efflux due to reduced substances diffusing up from deeper layers in the sediment and reacting with oxygen.

Sediment sampling procedure review

Recent findings in November 2008 showed that dissolved oxygen (DO) near the sea bed was not saturated at the respective temperature and salinity. Bottom water DO was 255 µmol l^{-1}, while this has previously been assumed to be saturated. This may be caused by a number of factors. The bathymetry around the sampling location in Kobbefjord shows a basin. Hydrographical data show that seawater remains within the basin from late summer until the following spring when it is replaced by fresh oxygen rich seawater from outside the fjord. Subsequently, the seawater DO concentration decreases over time as it is consumed through a number of processes. Following this finding, the sampling procedure is currently being reviewed to also incorporate a control of DO to that of the in situ conditions. Temporal and spatial sampling resolution of oxygen micro-profiling will be standardised.

5.5 Benthic fauna and flora

Benthic fauna

The physiological status of two dominant benthic species, the sea urchin *Strongylocentrotus droebachiensis* and the scallop *Chlamys islandica*, are monitored each year in May at the entrance of Kobbefjord (position: N 64º 07.651' W51º 38.587', 50-60 m depth). In 2008 specimens were collected on 21 May. For both species two indices were computed; a condition index and a gonad index. The indices are measures of the ratio of gonad mass:total soft tissue mass to the mass of calcium carbonate shell. For sea urchins, both the condition and gonad index were significantly lower in 2008 compared to 2007 (figure 5.22). The scallops display a similar reduction in gonad index from 2007 to 2008 whereas the condition index was constant between the two years. Both indices are measures of physiological fitness. Individuals experiencing energetically favourable conditions can invest more energy into soft tissue growth and reproduction and therefore attain higher index values. Food availability is expected to be the primary factor affecting both indices indicating that food conditions were better in 2007 than 2008. Temperature could also be a contributing factor. During the winter, both species rely on stored energy. As the metabolic rate is dependent on temperature a higher temperature during the winter 2007/2008 would increase the energetic demand which would cause low index values.

Benthic flora

Distribution of the macroalgal community

A video-survey was conducted along 16 transect lines from the shore to the deepest occurrence of macroalgae. All video were kept on DV-tapes and data for depth and position were coordinated to the time codes on the tapes. Macroalgal samples for identification of dominant species were sampled by a diver using an anchor during the survey.

The survey documented that sub-littoral macroalgal communities occur along the entire coastline, but are most extensive and dense along the southern coast (figure

Table 5.8 Diffusive oxygen uptake (DOU), total oxygen uptake (TOU), TOU/DOU ratio and dissolved inorganic carbon (DIC) and nutrient exchange across the sediment-water interface measured from intact sediment cores collected in February and November 2008 at the sediment station in Kobbefjord. All rates are mmol m^{-2} d^{-1}. ± SE is the standard error of the mean, n denotes number sediment cores. Positive values indicate release into the water column, and negative values reflects uptake.

	February			November		
Parameter	Average	±SE	n	Average	±SE	n
TOU	8.71	3.04	8	5.40	0.84	6
DOU	5.42	-	3	7.44	-	3
TOU/DOU	1.61	-	-	0.73	-	-
DIC	1.07	0.51	8	11.08	2.10	6
PO_4^{3-}	3.13	2.47	8	0.28	0.14	6
$NO_3^- + NO_2^-$	0.01	0.06	7	0.30	0.06	6
SiO_4	2.44	0.36	8	1.64	0.34	6

Table 5.9 Macroalgal species found in Kobbefjord. The list is non-exhaustive.

Brown algae	Red algae	Green algae
Agarum clathratum	*Membranoptera dentriculata*	*Chaetomorpha linum*
Alaria esculenta		*Enteromorpha* sp.
Ascophyllum nodosum		*Ulva lactuca*
Chorda filum		
Chordaria flagelliformis		
Desmarestia aculeata		
Dictyosiphon foeniculaceus		
Ectocarpus siliculosus		
Fucus evanescens		
Fucus vesiculosus		
Laminaria longicruris		
Laminaria solidongula		

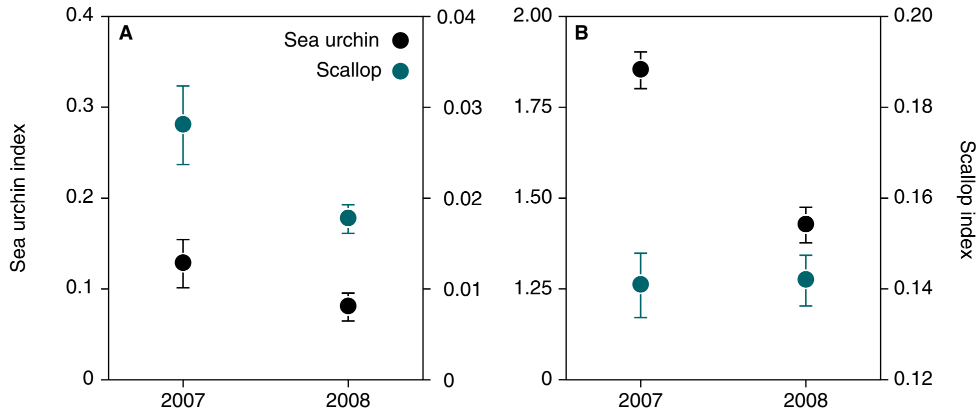

Figure 5.22 Gonad index for the sea urchin Strongylocentrotus droebachiensis *and the scallop* Chlamys islandica *collected in May at the 50-60 m depth in Kobbefjord (mean ± 95% CI) (A). Condition index for the same two species (B).*

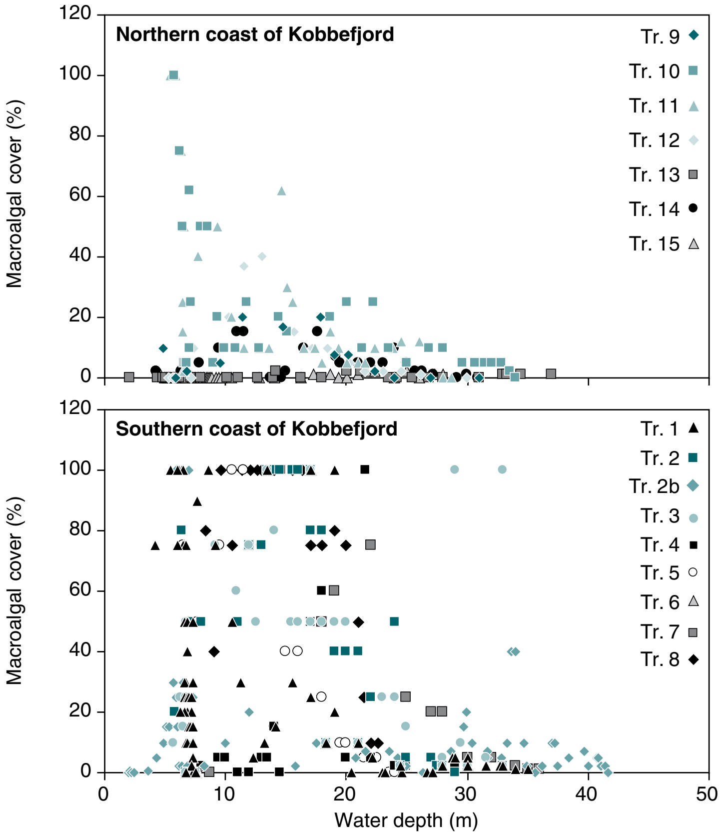

Figure 5.23 Cover of the macroalgal community along depth gradients in Kobbefjord as identified on underwater video. Cover is expressed in percentage of the sea bottom. The upper panel represents transect lines (Tr.) along the northern coast while the lower panel represents transect lines along the southern coast. Within each panel, the transects having the lowest numbers represent the outer part of the fjord while those with the highest numbers represent the inner part of the fjord.

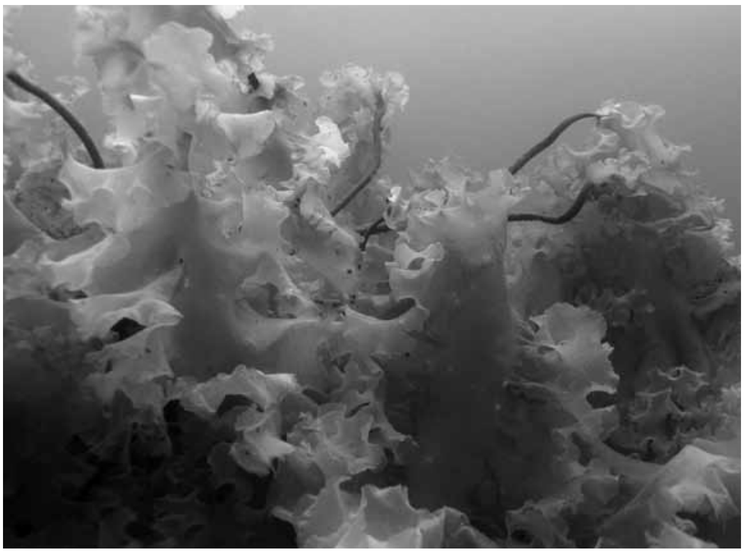

Figure 5.24 Laminaria longicruris. *Photo: Peter Bondo Christensen.*

5.23, upper panel) where the slope of the sea bottom is relatively gentle. Along the northern coastline, from where the mountains raise more abruptly, the algal belt is narrow and generally not as dense (figure 5.23, lower panel). The most scattered and least dense communities occur in the inner, northern part of the fjord.

The brown macroalga *Agarum clathratum* is the most widely distributed macroalgal species in the fjord. This species was easily distinguishable on the video due to its characteristic blade perforated with circular holes. *Laminaria longicruris* (see figure 5.24) and *Alaria esculenta* are also abundant kelps and the filamentous brown macroalgae *Desmarestia aculeata* and *Dictyosiphon foeniculaceus* also occurs in large quantity. Moreover, the green foliose *Ulva lactuca* forms large specimens particularly in the outer southern part of the fjord (table 5.9).

Erect macroalgae extent to maximum depths of about 40 m – deepest on the outer, southern coast, and small specimens of *Agarum cibrosum* typically penetrate deepest. With an average annual light attenuation coefficient of 0.11 m^{-1} (Rysgaard et al. 2008) about 1.2 % of surface irradiance is available at 40 m depth. This minimum light level is in accordance with information from the literature stating that *Laminaria* forests at e.g. Helgoland extend to water depths receiving 4 % of surface light, and that individuals may extend to water depths receiving as little as 0.7 % of surface light (Lüning 1990). The echo sounder surveys in 2007 identified macroalgae only down to 13-15 m depth, and this method is thus not sufficiently sensitive.

Growth, carbon and nitrogen content of Laminaria longicruris

A diver collected 15 fully grown specimens of *Laminaria longicruris* at a protected site where sea ice forms during winter (64° 08 408′; 35,158′ W) and at an exposed site with no sea ice (64° 07 908′N; 51° 37 074′W) at 5-6 m depth in the outer southern part of Kobbefjord. The size of the blades collected in August was used as a measure of annual blade production of the alga (Borum et al. 2002) since annual length growth is completed and the blade tips most likely are not yet degraded at this time of year.

Blade size and, thus, annual blade production was quite similar at the two sites in 2008 (figure 5.25). The size of the algae was also relatively similar in 2007 and 2008, except that blade width and biomass were higher at the protected site in 2008, most likely because the algae were more intact at the earlier sampling in 2008 (August) compared to the later sampling in 2007 (September) where the risk of blade degradation was higher. The diver samp-

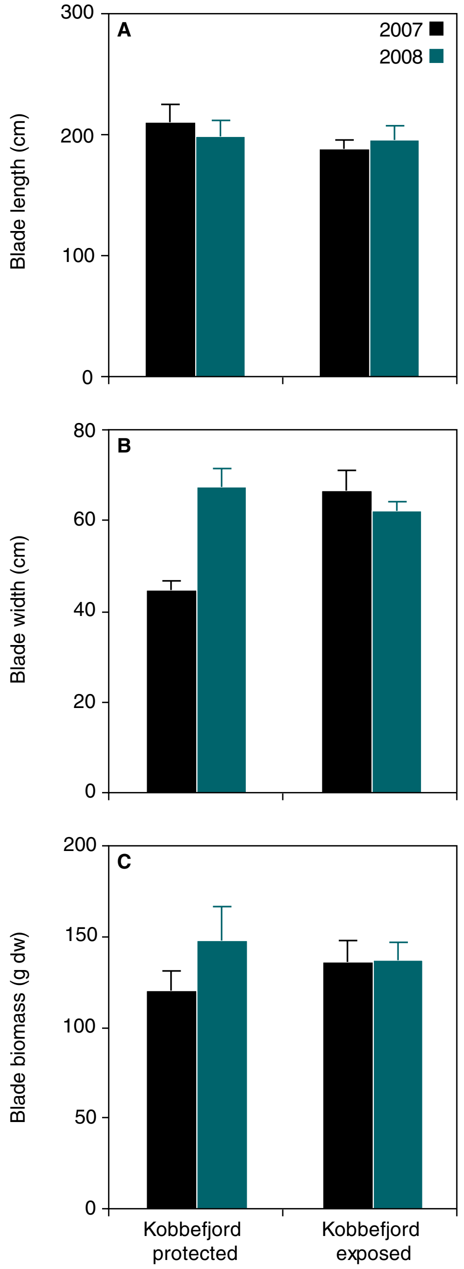

Figure 5.25 Length (A), width (B) and biomass of blades (C) of Laminaria longicruris *at a protected and an exposed site of Kobbefjord in September 2007 and August 2008. Only data from specimens with blades >1.50 m are included.*

ling in 2008 also increased the chance of collecting intact individuals. In order to increase the comparability between data from the two years, the comparison only includes individuals with blade lengths larger than 1.5 m and thereby excludes the smallest non-intact individuals of the September 2007 sampling. As blade size and thus algal growth was relatively similar among the two sites, ice cover did not seem to severely reduce growth at the protected site in Kobbefjord.

In 2008, carbon content, nitrogen content and C/N-ratio were similar at the two sites.

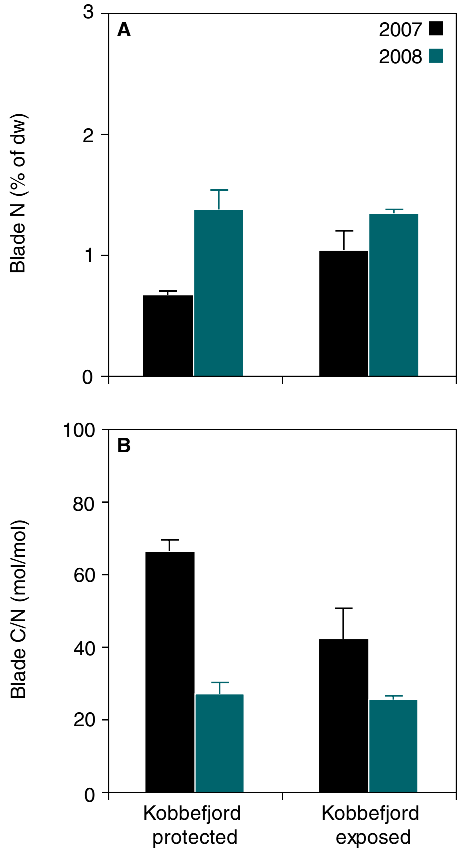

Figure 5.26 Nitrogen content (A) and C/N-ratio (B) of Laminaria longicruris *at a protected and an exposed site of Kobbefjord in September 2007 and August 2008.*

These results contrasted those of 2007 when blades from the exposed site were richer in nitrogen compared to the protected site and nitrogen contents were generally lower and C/N-ratios higher (figure 5.26).

The earlier sampling in 2008 as compared to 2007 may partly explain the higher N-content in the algae in 2008 since the N-content of Laminarians typically shows a minimum in September (Sjøtun 1993). This minimum may be due to sporulation that occurs in late summer/early autumn (Bartsch et al. 2008) and drains the nitrogen reserves of the algae. Differences in cover and composition of epiphytic communities may also influence nitrogen contents. In order to minimise such effects, Laminaria blades at the protected site which had a dense cover of encrusted epiphytes were dipped in a weak HCL solution in order to remove the epiphytes before drying and analysing the tissue.

5.6 Seabirds

Two major seabird colonies in the vicinity of Nuuk are included in the MarineBasis programme (figure 5.1). However, some

Table 5.10 Breeding seabirds; pairs (P), individuals (I) or adults on nests (AON)) at Qeqertannguit in 2008.

Species	Numbers	Unit
Black-legged kittiwake	20	AON
Iceland gull (south+north side of Island)	45 (33+12)	AON
Great black-backed gull	44	P
Lesser black-backed gull	25	I
Glaucous gull	13	P
Herring gull	2	P
Arctic tern	0	I
Arctic skua	2	P
Black guillemot	689	I
Red-throated diver	1	P
Red-breasted merganser	3	P

additional seabird colonies from 2007 in the Nuuk area were visited again in 2008. Amongst them, the kittiwake colonies of Godthåbsfjord (five in total) were censused and the results are included in this report. The seabird counts from MarineBasis are reported annually to the Greenland Seabird Colony Database maintained by the National Environmental Research Institute (http://www.dmu.dk/Greenland/Olie+og+Miljoe/Havfuglekolonier).

Qeqertannguit (colony code: 64035)

Qeqertannguit in the inner part of Godthåbsfjord (figure 5.1) is a low-lying island and holds the largest diversity of breeding seabirds in the Nuuk District. Especially surface feeders (gulls, kittiwake and arctic tern) are well represented at the site. Counts of the entire island's bird population were conducted on 5 and 6 June (early in the incubating period) using direct counts of Apparently Occupied Nests (AON) or territorial behaviour as a parameter of breeding pairs (table 5.10). The steep cliff in the middle of the southeast facing side of the island (kittiwake and Iceland gull) and a smaller cliff on the north facing side (Iceland gull) were counted from the sea using a boat as platform while all other counts were conducted on foot. The smaller north facing cliff side with Iceland gulls was counted at a later occasion (19 June).

Other birds observed on 5 and 6 June (not considered breeding or not systematically censused) included one mew/common gull, two couples of purple sandpiper with anti predator display, three pairs of red-breasted merganser, five mallard ducks, four long-tailed ducks, one northern wheatear, three pairs of ptarmigan, snow buntings and Lapland buntings.

The arctic tern colony was visited twice. On 5 June, a flock of birds was observed in a distance from the island and on 19 June there was no signs of arctic terns at the colony and the terns seemed to have skipped breeding entirely at this site in 2008.

The very low count numbers of breeding kittiwakes, Iceland gulls and arctic terns are noticeable. However, the count numbers of the other bird species are similar to the numbers of 2007 and 2006.

Qeqertannguit is influenced by legal egg harvesting (great black-backed gull and glaucous gull prior to 31 May) and illegal egg harvesting has been reported by other observers in 2008 as well (after 31 May and illegal species, e.g. Iceland gull, lesser black-backed gull, herring gull).

The southeast facing cliff with breeding kittiwakes and Iceland gulls was visited on several occasions during another research project which will be presented elsewhere.

Table 5.11 Breeding seabirds; individuals (I) at Nunngarussuit in 2008. Other seabird observations near Nunngarussuit.

Species	Numbers	Unit
Brünnich's guillemot (91.5%)	388	I
Common guillemot (8.5%)	36	I
Glaucous gull	14	I
Great black-backed gull	2	I
Northern fulmar	17	I

Nunngarussuit (colony code: 63010)

Nunngarussuit is located approximately 40 km south of Nuuk (figure 5.1). The north facing rock wall of the small island holds the only colony of guillemot in Nuuk District (the colony includes both Brünnich's and common guillemot). These alcids are deep divers preying on fish and large zooplankton. Both direct and photo counts of birds present on the rock wall were conducted from the sea by boat on 7 July (table 5.11). About 450 guillemots were estimated on the water. The number of guillemots (including both common and Brünnich's guillemot) present at the site in 2008 (table 5.11) is notably lower than both in 2007 (793 on the cliff and 450 on the water) and in 2006 (694 on the cliff and 2-300 on the water). Several previously occupied ledges were completely empty.

In order to address the proportion of boreal (common guillemot) versus arctic (Brünnich's guillemot) species in the colony, an analysis of digital images photographs was performed. This is interesting in the context of climate change because the proportion of common guillemot could be expected to increase in a warmer climate. Of 395 guillemots, which could be identified to species, 8.5 % were common guillemots.

Other seabird observations near Nunngarussuit

Simiutat (63011, 63012 and 63013) on 7 July: The birds observed at these small islands just north of Nunngarussuit were summed to about 75 puffins, 92 razorbills, 10 black guillemots, 30 great cormorants (non-breeding), 12 glaucous gulls, 27 great black-backed gulls, two arctic skuas, two lesser black-backed gulls, 33 harlequin ducks, two common guillemots and about 100 common eiders (three of them on land and one nest observed).

Qarajat qeqertaat (63019) on 4 July: This site consists of two islands: West Island: 26 nests of common eider found (seven empty, average of 3.2 eggs in the remaining. No chicks). 16 great black-backed gulls, 12 lesser black-backed gulls, two glaucous gulls, three arctic skuas (one dark and two light morph) and 327 black guillemots. All were potential breeders. No breeding arctic terns in 2008.

East Island: 20 nests of common eider found (13 empty, none with chicks, average of 3.0 eggs in nests with eggs). Two great black-backed gulls, two lesser black-backed gulls, six arctic skuas (four light morphed and two dark, some might be visitors from the west island), two purple sandpipers and 402 black guillemots. No breeding arctic terns this year. 450 common eiders were counted on the water around both islands.

The puffin island at Ravneøerne (63020) on 4 July: 60 puffins, three razorbills, one mallard duck (seven eggs in nest), black guillemots, several gulls and snow buntings.

Other kittiwake colonies in Godthåbsfjord

Innaarsunnguaq (64015) on 6 June: 961 individuals of Iceland gull, 33 pairs of kittiwake and 25 razorbills.

Kangiusaq (64018) on 5 June: 450 pairs of kittiwake and 494 individuals of Iceland gull.

Alleruusat (64022) on 5 June: 381 pairs of kittiwake and 140 pairs of Iceland gull. It was too early for great cormorant.

Innajuattoq (64019) on 5 June: 309 pairs of kittiwake, 1497 individuals of Iceland gulls and 40 black guillemot. Too early to count great cormorant nests but at least 25 individuals were observed.

Results on breeding success of the kittiwakes will be presented elsewhere.

5.7 Marine mammals

Humpback whales *Megaptera novaeangliae* migrate from their breeding grounds near Equator to feeding grounds in West Greenland Waters (Pomilla and Rosenbaum 2005). Some visit Godthåbsfjord where they feed on zooplankton and capelin *Mallotus villosus* (Heide-Jørgensen and Laidre 2007).

Observations of humpback whales were carried out between May and October from a lookout point overlooking a cross section of the entrance to Godthåbsfjord. In 2007 and 2008, 166 (83 hrs) and 174 (87 hrs) surveys were carried out, respectively. More whales were sighted in 2007 during the surveys compared to 2008 - 16.9 % whale positive surveys in 2007 compared to 6.3 % whales positive surveys in 2008 (figure 5.27). In both years, most whales were sighted from June to August, with the majority of whale positive surveys in June (23.9 % in 2007 and 9.4 % in 2008). August tended to have a few more whale positive surveys than July; 17.1 % (2007) and 5.9 % (2008) compared to 13.2 % (2007) and 5.6 % (2008) in July. Fewer whales were spotted in May (in 2008) and October (in 2007). No pattern was found between time of day and the number of whale positive surveys.

Figure 5.27 Number of surveys (%) in the months of both field seasons, where humpback whales were seen. N is the total number surveys conducted in the given month (A).Number of surveys (%) at the different time periods, where humpback whales were seen. N is the total number of surveys conducted at the given time (B). From Boye 2009.

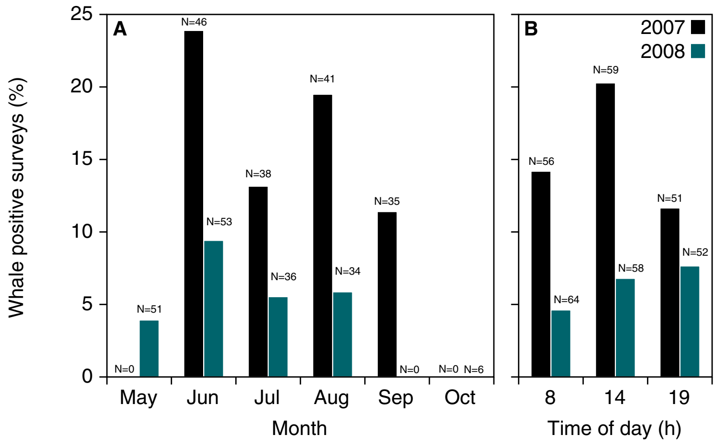

Figure 5.28 Photo ID picture of a humpback whale in Godthåbsfjord.

Photo-identification is a technique used to identify individual animals based on photographs showing natural markings such as scars, nicks and coloration patterns (Katona et al. 1979). The technique can, in combination with mark-recapture analysis be used for estimating abundance of marine mammals in specific areas. Photo-ID is also used to investigate residence time (i.e. how long the animals stay in a given area) and site fidelity (i.e. individuals returning to an area in different years) (e.g. Bejder and Dawson 2001). In humpback whales, the ventral side of the fluke is used for identification as the tail contains individual colour patterns which are different in a way comparable to human fingerprints (figure 5.28). Here, we use photo-identification to quantify the number of humpback whales feeding in the fjord each summer and the turnover of whales in a season.

Photo-ID pictures were taken with a 350 EOS Canon camera with a 300 mm Canon lens. In addition to dedicated surveys, guides on the local whale safari boats and the general public also kindly contributed with photos. A total of 47 and 126 ID-photos were collected during 2007 and 2008, respectively, with 20 individuals identified in both 2007 and 2008. Of the 20 individuals identified in 2007, a total of eight (40.0 %) were re-identified in 2008. In both years, most individuals had been identified by the beginning of July, but new individuals were identified throughout both field seasons (figure 5.29).

Our results indicate that the humpback whales in Godthåbsfjord constitute an 'open population', meaning that the whales move in and out of the fjord during the season. In order to make use of mark-recapture models to estimate population size of open populations, several years of data are needed and the collection of photo ID pictures will continue in 2009.

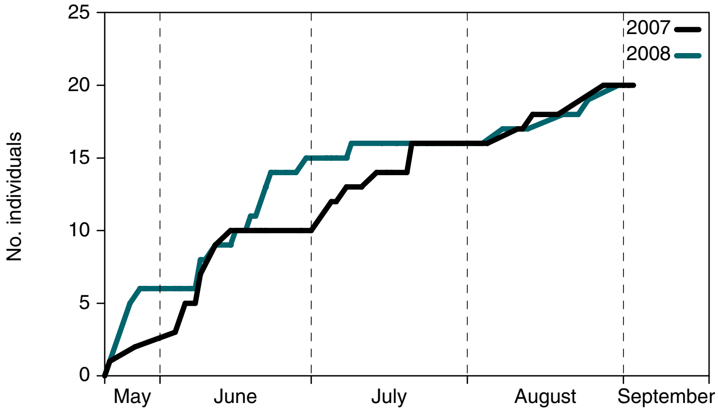

Figure 5.29 Number of new individual whales identified in 2007 (black) and 2008 (green) over the season. From Boye 2009.

6 Research Projects

6.1 ECOGREEN; function of the marine ecosystem in West Greenland Waters

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Ecogreen is a joint project between Greenland Institute of Natural Resources, National Environmental Research Institute at Aarhus University, Danish Meteorological Institute, Technical University of Denmark among other Danish and International collaborators. The project is financed by the Technical University of Denmark and The Danish Agency for Science, Technology and Innovation (FNU). The project is a part of the International Polar Year (IPY), to enhance scientific work in the Arctic. The project will provided important know-ledge and data that would support the understanding and interpretation of the MarineBasis Nuuk programme.

The overall goal of Ecogreen is to establish a multi-disciplinary scientific basis for a long-term ecosystem-based management of marine resources in West Greenland Waters. Increased human impact on marine ecosystems combined with effects of global climate change intensifies the need for a sustainable ecosystem-based management approach.

Most of the organisms living in West Greenland Waters live in the periphery of their distribution area. The boreal species has their northern border limit in the area whereas the arctic species has their southern border limit in the area. Therefore, relatively small variations in sea current patterns, temperature and other climatic or environmental parameters could have immediate effect on the species composition and food web structure.

During a 13 day cruise with 'R/V Dana' in July/August 2008 from the off-shore fishing area of Fyllas Banke and into the Godthåbsfjord system towards the Greenland Ice Sheet, a team of international scientists worked together to achieve a superior understanding of the food web function, pelagic-benthic coupling and the influence of runoff from the Ice Sheet to the low arctic off-shore and fjord systems.

Oceanography

Altogether 56 full depth hydrographic stations were occupied during the cruise, employing a SeaBird SBE911plus CTD with double sensor sets, attached to a SeaBird carousel 12 bottle water sampler. Beside the standard sensors, the CTD was equipped with double O_2 and fluorescence sensors and a single PAR sensor. Profiles were run to 5-10 m above the sea bed, though never below 950 m. During the cruise, data from a 75 kHz and a 600 kHz ship-mounted ADCP as well as the ship's echo sounder were continuously recorded. Warmer water found over the outer slopes of the fishing bank was brought northward by the West Greenland Current. The high frequency occupation of stations reveals that an intense upwelling takes place in this region. Modified Polar Water observed during the cruise was mainly found over the shallower part of the fishing bank. Inside the sills of the Godthåbsfjord system a thin and fresh surface layer was obvious. In the sill region it became less pronounced due to tidal mixing. Throughout the entire cruise, measurements of CO_2 concentration in the atmosphere and pCO_2 in the surface water were collected continuously. Water was continuously pumped onboard to collect associated biological and oceanographic data in order to determine the role of biological processes in sea uptake of atmospheric CO_2.

Processes in the pelagic

Chlorophyll *a* and pelagic primary production were determined from water samples and *in situ* experiments. Primary production was lowest on top of the fishing bank, while the highest production

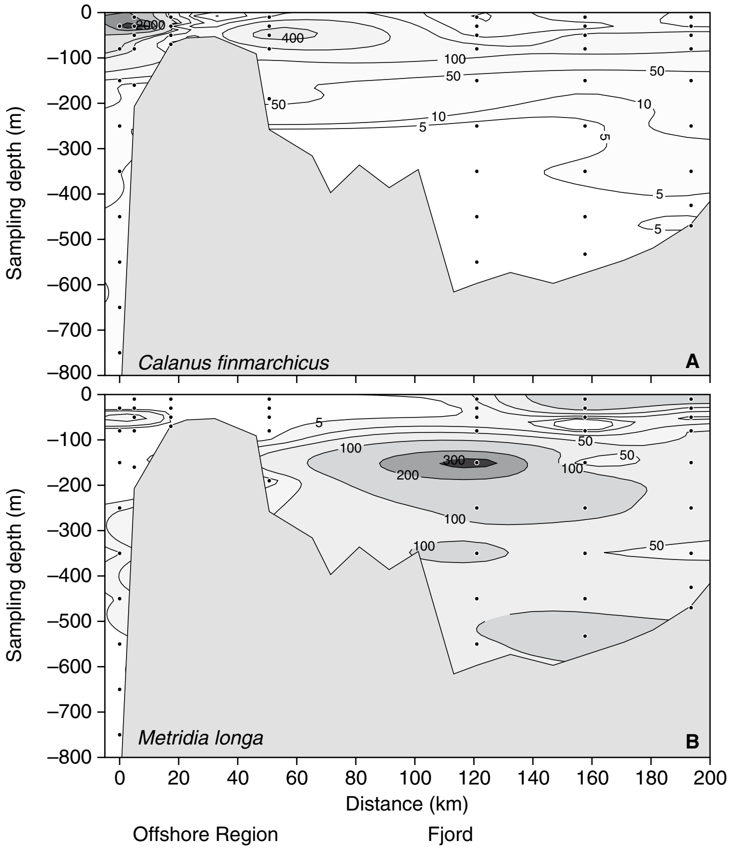


Figure 6.1 Vertical distribution of copepods (individuals m^{-3}) along the transect. Dots represent sample intervals.

was found in the outer-part of the fjord decreasing towards the Ice Sheet.

The role of zooplankton in carbon cycling was investigated and special emphasis was put on the role of zooplankton driving the vertical flux of organic matter and recycling of nutrients in the surface layer. Depth distribution of zooplankton showed a general shift in species composition at the entrance of the fjord (figure 6.1). The species distribution seems to follow the hydrography with dominance of *Calanus finmarchicus* in the West Greenland Current water in the off-shore region (figure 6.1A) and with other copepod species e.g. *Metridia longa* in the fjord (figure 6.1B).

Secondary production and grazing rates of the copepod community of *C. finmarchicus* and *M. longa* were measured. None of the species were very active, i.e. they had very low egg and faecal pellet production and they did not graze significantly on the phytoplankton. The grazing experiment shows that especially *M. longa* feed on large protozooplankton. Growth rates of juvenile copepods were measured using the artificial cohort method. Furthermore, the role of copepods as regenerators of nutrients was tested by incubations with ^{15}N and ^{13}C labelled phytoplankton.

The role of carnivorous zooplankton was investigated and if they exert a predation control on copepods. Two groups were analyzed for gut content: chaetognaths (*Sagitta elegans* and *Eukrohnia hamata*) and carnivorous copepod (*Pareuchaeta norvegica*). Feeding by the carnivorous copepod *P. norvegica* was assessed by measuring excretion of faecal pellets and gut evacuation time. Feeding rates for *P. norvegica* ranged from 1.8 to 6.4 prey d^{-1}.

To test the hypothesis that bacterial communities are influenced by the transport of bacteria associated with migrating zooplankton species, changes in the bacterial genetic community composition was investigated throughout a diurnal cycle. The samples will be extracted and the bacterial DNA will be analyzed by DGGE and PCR finger-printing. On-board experiments were also conducted to investigate microbial utilization of zooplankton faecal pellets.

Vertical flux

Faecal pellet production of the entire copepod community was measured and will be linked to measured faecal pellet flux. Results from the particle interceptor traps show sinking fluxes of total particulate material, i.e. organic and inorganic material, ranging from 17-49 g m^{-2} d^{-1} in the off-shore and central fjord region, while a considerably higher sinking flux up to 348 g m^{-2} d^{-1} was observed near the glacial output. The complete dataset will allow a detailed assessment of how much of the primary production is sinking as intact algal material, faecal pellets and amorphous detritus. Furthermore, these results provide information on the sinking flux of inorganic material, i.e. sediments, in this fjord system strongly influenced by glacial out.

Fish larvae and macroplankton

In order to evaluate the role of fish larvae/juveniles and the larger macroplankton in the ecosystem this group was sampled by oblique hauls of a 2 m ring net (MIK) along the entire transect. Samples were re-sorted for fish larvae; both larvae and macroplankton were preserved in alcohol and stored for later sorting and identification. Generally the abundance of fish larvae/juvenile was small. On the fishing bank, large (5-6 cm) Greenland halibut were caught in abundances of 1- 5 per haul and a number of other species e.g. *Stichaeus punctatus* were of the same low abundance. In Godthåbsfjord the more abundant species was from the family

Cottidae - capelin and a few cods were also observed. The fish will be quantified and measured, and for some species we will carry out investigations on prey preference. The macroplankton was very abundant, and several litres were often caught in each haul. Frequently during the cruise only a subsample was preserved of the macroplankton. In the offshore area large copepods, amphipods and cephalopods dominated, while krill was very abundant in the fjord.

Processes in the sediment

Ultimately, a fraction of the pelagic production settles at the sea bed where it either undergoes mineralization or becomes buried in the sediment. We measured the carbon and nitrogen mineralization using 'state of the art' *in situ* lander technology (figure 6.2). A total of approximately 400 *in situ* microprofiles were obtained and they clearly reflected differences in the mineralization rates along the section. The O_2 penetration depth into the sediment varied from approximately 6 to approximately 12 mm from the most to the least active station. *In situ*, total benthic exchange of O_2, DIC and nutrients was successfully measured at four station (data await analysis). Together, these data sets will allow quantification of benthic infauna for benthic solute exchange and mineralization. The *in situ* investigations were complemented by laboratory based incubations and profile measurements in sediment cores recovered by a multiple corer, but most importantly by tracer addition experiments for resolving the denitrification and anammox rates at the respective stations. Together with data on sediment accumulation rates and C/N ratios the data set will allow a quantitative assessment of the benthic C and N mineralization along a rarely studied low arctic fjord system. Sediment cores were sampled for quantification of selected meiofauna with presumed impact on especially the benthic N turn over.

Marine geological coring

The programme focused on the inner Godthåbsfjord, in order to directly link the transport of melt water and sediment from the adjacent Greenland Ice Sheet to the fjord system. Sediment coring were performed with multicorer (70 cm tubes), rumohr corer (1 m tubes), and gravity corer (6 m core liner). The multicorer was used to recover intact surface-near sediment sequences. Successful gravity coring was accomplished at station 18 (238 cm core), 19 (370 cm core), and 20 (478 cm core). Further sediment analysis of ^{14}C, ^{210}Pb and ^{137}Cs shall determine the sediment accumulation rates under present and past conditions. In addition, quantification of sediment physical and chemical conditions, e.g. grain size, density, porosity, magnetic susceptibility, chl *a*, ^{15}N and ^{13}C isotopes, as well as microfossil investigations, will enable the data-set necessary to validate models of past conditions in the fjord system.

The combined results of the work on Ecogreen will contribute to increase the knowledge of the role of the pelagic-benthic coupling and provide a better understanding of the low arctic marine ecosystem.

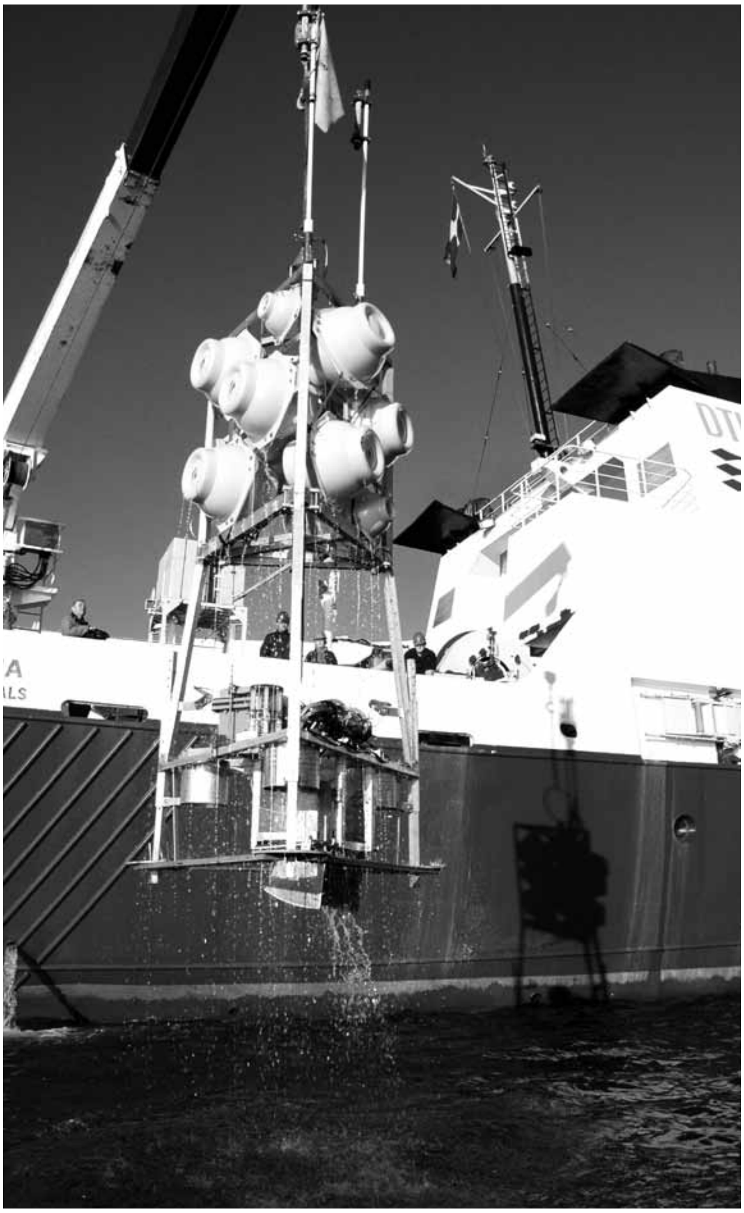


Figure 6.2 Benthic Lander being recovered next to 'R/V Dana'. Photo: Søren Rysgaard.

6.2 FreshLink; linking Ice Sheet thinning and changing climate

Søren Rysgaard, Carl E. Bøggild, Roland Kallenborn, Naja Mikkelsen, Niels Nørgaard-Pedersen, Anton Kuijpers, Dirk van As, Rene Forsberg, Susanne Hanson, Sine M. Hvidegaard, Henriette Skourup,John Mortensen, Dorthe Petersen, Kisser Thorsøe, Martin Truffer, Monika Trümper and Kunuk Lennert

The FreshLink is a consortium of Greenlandic/Danish institutions and a number of international partners. The project aims at performing research on the thinning of the Greenland Ice Sheet margin, which clearly has a global impact. Several different techniques will be combined to estimate the freshwater flux from the Greenland Ice Sheet and surrounding land in a local area in Southwest Greenland near Nuuk. Focus is on analyzing different freshwater contributions to the sea, represented here by the inner part of Godthåbsfjord referred to as 'Icefjord', and to evaluate the historical and future magnitude as well as seasonal distribution. Finally, attempts to match freshwater runoff from land with measured freshwater flux in the upper layers of the fjord, facilitates an independent test of the performance of the ice/land discharge modelling. The programme was initiated in the spring 2008 and will run for three year. In Fresh Link, Greenland Institute of Natural Resource is focused on the hydrographical part, aiming at providing a freshwater flux estimate for the Icefjord.

A check of ICES hydrographic database revealed that only a handful of hydrographic stations existed from Icefjord before 2005. All of them were sampled during a single cruise by 'RV Adolf Jensen' in May 1988. Since 2005 the number of hydrographic station has increased steadily. In June 2008 the first SBE37 was deployed in the freshwater layer measuring continuous time series of pressure, temperature and salinity. In February 2009 the first mooring measuring current profiles was deployed in the entrance to the Icefjord. During a trip in February 2009 to the very inner ice covered part of Icefjord a single hydrographic station was occupied less than 12 km off the summer terminus of the Kangiata Nunata Sermia glacier (figure 6.3). For more information see www.freshlink.natur.gl

6.3 FreshNor; the freshwater budget of the Nordic Seas

Søren Rysgaard and John Mortensen

The sea water circulation has a central role for global atmospheric circulation, controls the global energy cycle (through the release of latent heat) as well as the carbon,

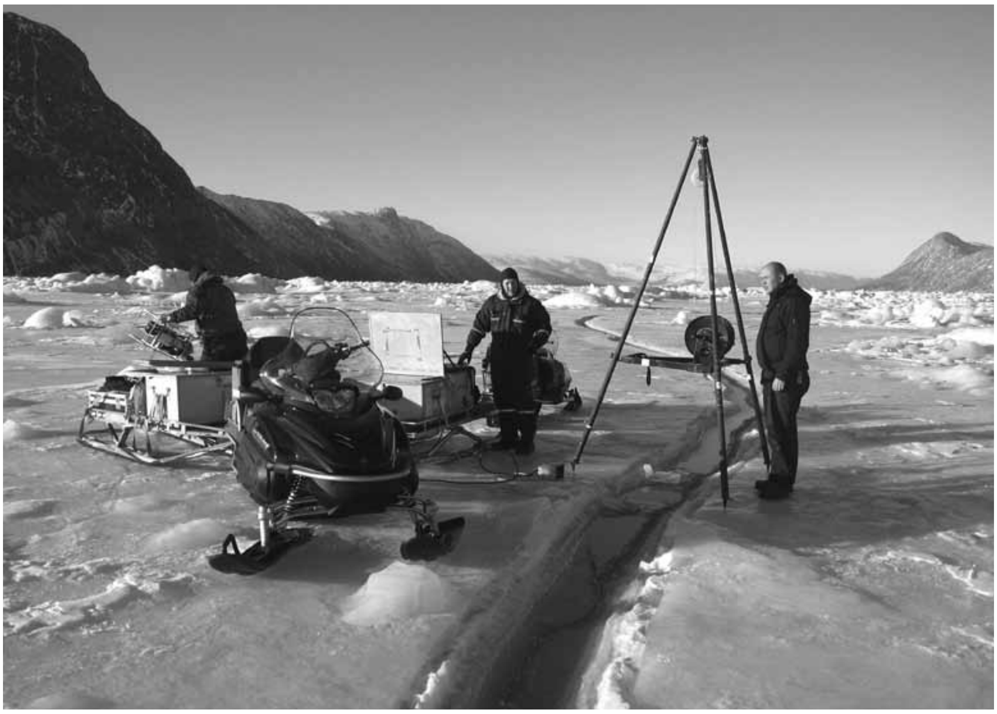


Figure 6.3 Hydrographic work in the inner parts of the Icefjord. February 2009.
Photo: Henrik Philipsen.

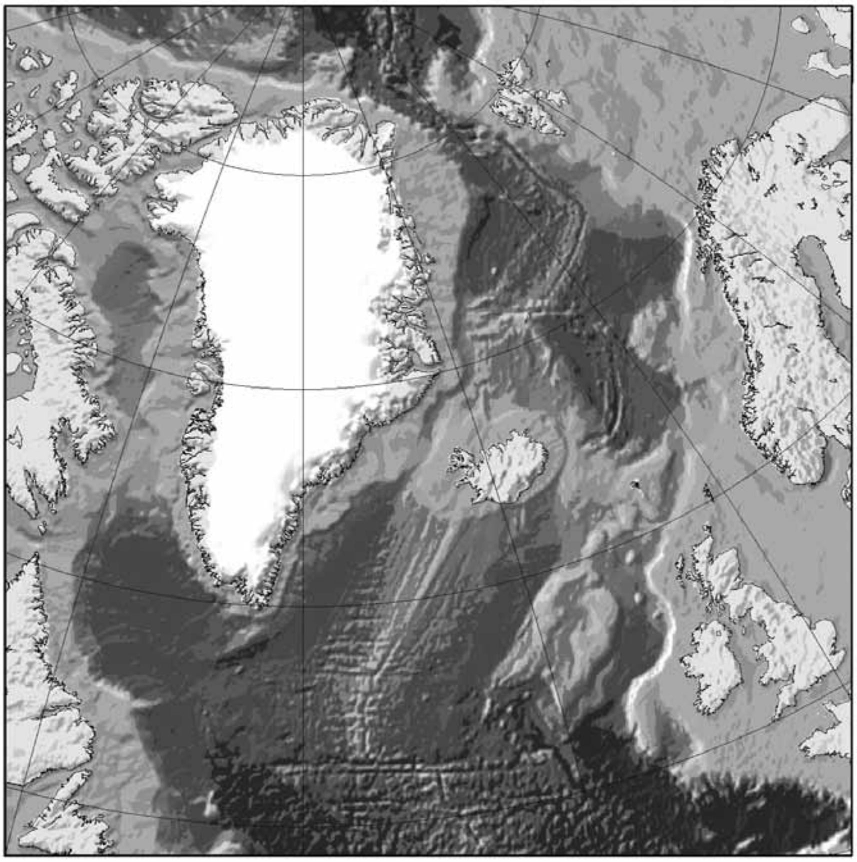


Figure 6.4 A sketch of the regional coverage adopted in FreshNor.

nutrient and sediment cycles. Increasing CO_2 levels and temperatures are intensifying the global hydrological cycle, with an overall net increase of rainfall, runoff and evapotranspiration. This may in turn lead to more droughts and large-scale flooding events, while the ocean will be affected by changes in runoff, surface fluxes and ice.

The FreshNor is a coordinated effort within the Nordic countries to improve the understanding and description of the hydrological cycle in the Nordic Seas, in climate change model simulations for the Arctic Region, and for the Nordic countries in climate change scenarios. This work aims of improving existing atmospheric regional climate models (RCMs) for the Nordic regions as well as for the Arctic (figure 6.4). The intention is to enhance the ongoing development of a regional modelling system with components of the entire climate system, e.g. incorporating all of the following components:

- Atmosphere
- Oceans
- Sea ice
- Cryosphere
- Biosphere
- Lakes and rivers
- Soils

The FreshNor project is funded by the Nordic Council of Ministers' Arctic Co-operation Programme. The last meeting will take place in Nuuk August 2009. For more see http://freshnor.dmi.dk/afb2009/

6.4 Molecular characterization and diversity of dissolved organic matter along a transect of Godthåbsfjord

Michael Gonsior, Ditte M. Mikkelsen, William T. Cooper and William J. Cooper

Godthåbsfjord receives substantial freshwater input from glaciers, rivers and snow melt. It is not clear what influence the terrestrially-derived dissolved organic matter (DOM) has on the fjord and to what extent additional glacial melt water influences the fjord DOM. Only recently, ultra-high resolution electrospray ionization Fourier Transform ion cyclotron resonance mass spectrometry became available to investi-

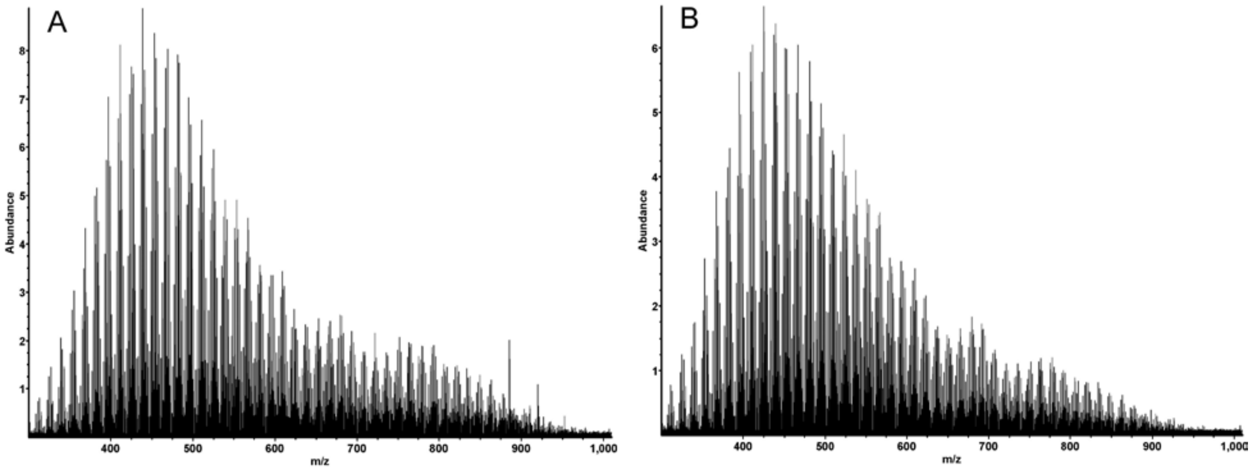


Figure 6.5 Typical mass spectra of DOM from the inner fjord station GF10 (A) and from the offshore sample station FB04 (B).

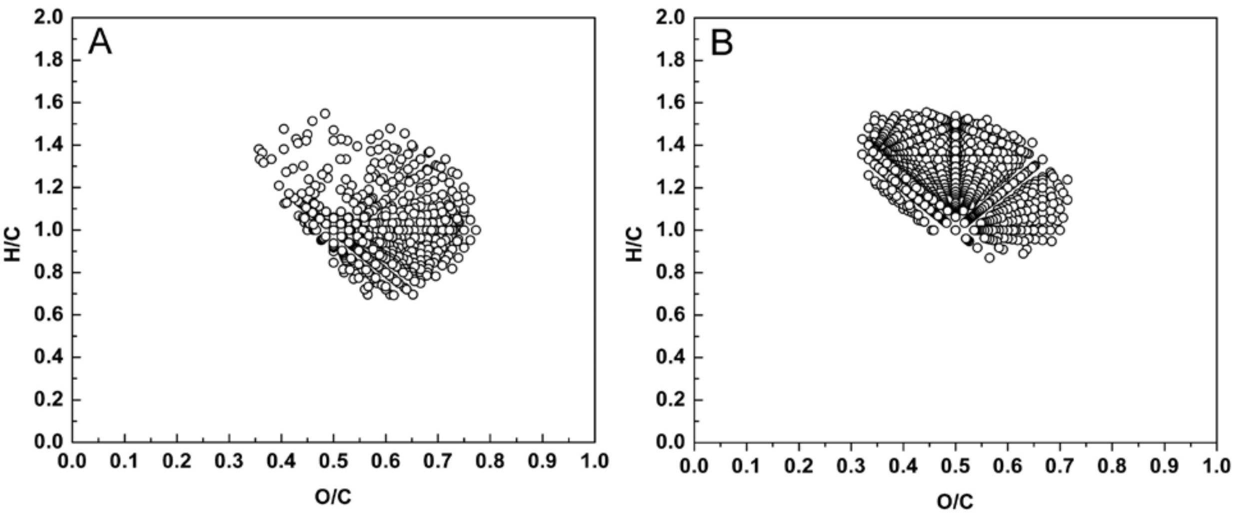
gate the molecular composition of DOM. The ultra-high mass resolution allows the investigation of bulk DOM without separation, and several thousand different molecular formulae can be unambiguously assigned to masses up to approximately 600 Dalton. This technique is arguably the most powerful technique available in terms of the molecular characterization of DOM.

However, there have been no previous studies undertaken of arctic/sub-arctic DOM in general and in fjords in particular using this technique. This research investigated the diversity of DOM along a transect from the inner Godthåbsfjord toward the open sea in June 2008 to characterize the transition of terrestrially-derived DOM within the fjord toward purely marine-derived DOM in the open sea.

The mass spectrometric data were combined with optical properties such as UV/Vis absorbance and excitation emission matrix (EEM) fluorescence data to better evaluate the chromophoric coloured DOM (CDOM) within the fjord. Terrestrially-derived DOM has a much higher portion of the CDOM compared to marine-derived DOM.

Examples of ultra-high resolution mass spectra from the inner fjord (GF10) and the open sea (FB04) are given in figure 6.5. The overall appearance of the mass spectra between the inner fjord and the offshore DOM sample was similar. However, a detailed analysis of all assigned molecular formulae revealed that 30 % of all molecular formulae for the GF10 sample were unique to this DOM sample and seemed to be indicative for the terrestrial/fjord component of the DOM pool. The molecular formulae only found in the DOM sample from station GF10 are visualized using a Van Krevelen diagram (see figure 6.6A) where the oxygen/carbon ratio (O/C) is plotted against the hydrogen/carbon ratio (H/C). These unique molecular formulae for DOM from station GF10 also appear in a distinctly different area within the Van Krevelen Diagram (lower H/C ratios)

Figure 6.6 Van Krevelen diagrams of the unique (A) and common/shared (B) molecular formulae assigned for sample GF10 and compared to sample FB04.



compared to the shared or common formulae (see figure 6.6B) assigned for both samples GF10 and FB04. These are only preliminary results and samples from other sample stations along the transect from the inner fjord toward the open sea will be analyzed, and a more in depth data mining of the mass spectrometric results will be undertaken in the near future.

6.5 Melting sea ice for taxonomic analysis: A comparison of four melting procedures

Ditte M. Mikkelsen and Andrzej Witkowski

The sea ice habitat is highly variable (both regarding chemical and physical parameters) and the primary producers of the system are diverse. Variations in the taxonomic composition of different sea ice algal communities may be factual (e.g. geographic or temporal), but could also be caused by differences in methodology. Melting sea ice is an area of particular concern. When sea ice samples are melted, the algae are exposed to a salinity change and thus osmotic stress which may cause cells to lyse. Taxonomic analysis by microscopy subsequent to sea ice melting may thus be biased depending on the susceptibility of the cells, – and accordingly organisms with rigid cell material could be overestimated.

The influence of four melting procedures on the taxonomic composition of the sea ice algal community in Kobbefjord, Southwest Greenland, was investigated in April 2008. The sea ice algal community consisted of diatoms, cysts and several flagellate groups. Direct melting (at 4 and 20 °C) was compared to melting in buffering seawater (with a salinity of 10 and 30). Direct melting at 20 °C differed significantly from one or more melting procedures regarding the flagellate groups chrysophytes, chlorophytes, dinoflagellates and unidentified flagellates; while diatom, cyst and cryptophyte abundance was similar regardless of melting procedure. Apart from chrysophytes, the three other melting procedures (direct melting at 4 °C and buffered in seawater with a salinity of 10 and 30) were not statistically different. While direct melting at 20 °C should be avoided, the three 'slow' melting procedures can be applied and are considered comparable.

6.6 Survey on the inshore spawning of North Atlantic cod (*Gadus morhua*) in West Greenlandic fjords

Suna S. Thomsen and Kirstine H. Olesen

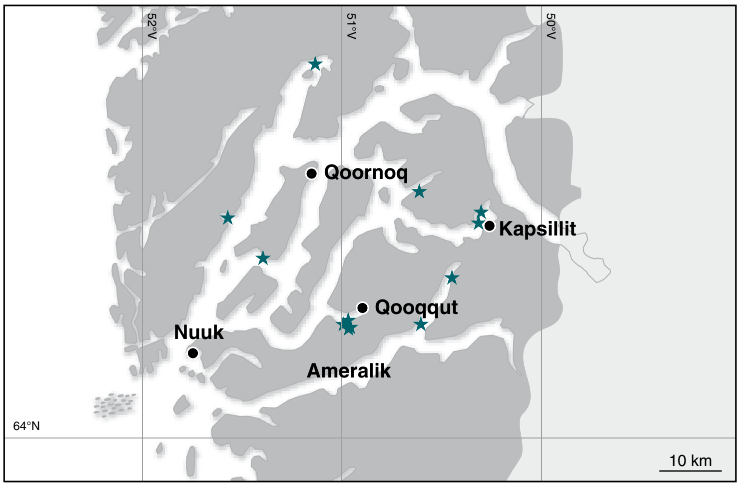
The North Atlantic cod (*Gadus morhua)* is fished by the inshore commercial fishing industry in the Godthåbsfjord system and it is therefore important to know the reproductive characteristics, e.g. spawning patterns and spawning probability, as well as the features of spawning, i.e. fecundity and energy allocation of this species for an adequate stock assessment.

This study defines the temporal development of spawning by analysing the reproductive progression in maturity, and includes the properties of fecundity and energy allocation of female cod preparing to spawn.

A total of 1112 cod (529 females and 583 males) were sampled from December 2007 to July 2008 and additionally a sampling was conducted in November 2008 (figure 6.7). The cod were staged according to the maturity scale developed by Tomkiewicz et al. (2003), and age, fish length, fish weight (full weight and gutted weight), liver weight and gonad weight were recorded. From a subsample of randomly selected male and female gonads, sampled between December 2007 and June 2008, a tissue section was preserved for histological verification of the macroscopic classifications.

The study showed that the main spawning period is from May to June. Males spawn at a younger age (3-4 years) and at a smaller size (approximately 41 cm) than females (age 4-5 and approximately 53 cm).

Figure 6.7 Location of Atlantic cod sampled.



The fecundity and energy measurements were conducted during the period February to April. Sub-samples of ovary tissue for fecundity were taken from females in the stage just prior to spawning (Kjesbu et al. 1991) and for comparison samples from the same ovaries were taken for energy content. The investigation found that close to spawning initiation more energy was allocated to reproduction, which also explains a drop in liver energy content observed during spawning. The analysis also showed great significance when looking at energy and fecundity in relation to fish length. Larger fish had more oocytes compared to smaller fish, and the energy content was correspondingly higher in large fish than in small fish.

All of these parameters help to establish the overall picture of the spawning properties concerning inshore Atlantic cod in the Greenlandic fjords, and participating in laying down guidelines for an adequate stock assessment.

6.7 West Greenland gillnet survey for juvenile Atlantic cod (*Gadus morhua*)

Anja Retzel

The objective of the programme is to assess the abundance and distribution of pre-recruit Atlantic cod (*Gadus morhua*) in inshore areas of Greenland including Godthåbsfjord. The results are used in the management of the Atlantic cod.

A survey using gangs of gill nets with different mesh-sizes (16.5, 18, 24, 28 and 33 mm) has been developed and used since 1985. The selectivity of the gill-nets has shown that the main target group is age group 2 and 3 whereas only larger individuals of age 1 cod are adequately selected. The nets are set perpendicular to the coast in order to keep depth constant. The survey effort is evenly allocated between the depth zones of 0-5 m, 5-10 m, 10-15 m and 15-20 m. The abundance index used in the survey is defined as 100*(no. caught/net*hour).

The data from 2008 has not yet been processed, but the results from the previous survey in 2006 showed that the gill-net abundance indices increase for both age 2 and 3 and the indices are generally above the levels observed during the 1990's.

The abundance indices in 2006 are below those found in the mid 1980's when the large 1984 year class were pre-recruits. This year-class, that is believed drifting from Icelandic spawning grounds was observed in all inshore areas south of Sisimiut (Storr-Paulsen et al. 2004) and gave rise to a considerable fishery for the artesian fisheries that predominately take place inshore.

6.8 The trophic coupling between overwintering eider ducks and macrobenthos in Nipisat Sund in Godthåbsfjord, Greenland

Martin E. Blicher, Lars Maltha Rasmussen and Mikael K. Sejr

Every year during the autumn thousands of common eider and king eider (*Somateria mollissima borealis* and *S. spectabilis*) arrive from their breeding sites in Northwest Greenland to winter in Godthåbsfjord in the South-western part of Greenland.

Eiders forage on macrobenthos by diving in shallow areas. Preliminary studies have indicated that Nipisat Sund is particularly favourable as an overwintering site for eiders. The area is one of only few shallow soft-bottom areas in a fjord system dominated by steep slopes. In order to quantify the trophic coupling between eiders and macrobenthos we initiated a monitoring study running from 2008 to 2009.

In 2008 we carried out a benthic programme in Nipisat Sund with the specific aim to identify and quantify the potential food items for overwintering eiders. The programme included analyses of taxonomy and biomass as well as sediment characteristics. These data together with temperature and depth of the sampling sites can be combined in an empirical model to estimate annual production of the macrobenthic community. From autumn 2008 to spring 2009 we monitored the number of eiders in Nipisat Sund in monthly intervals. By combining the number of bird days and previously published estimates of respiration, we are able to estimate the total energetic demand of the overwintering eider population.

Separately, the two sets of data on eiders and macrobenthos will function as reference data in a unique and ecologically important habitat in Southwest Greenland. In combination, we will have a very strong data set describing the coupling between two ecological compartments at a relatively high trophic level.

6.9 Mallard (*Anas platyrhynchos*) gene pool connectivity between Greenland, eastern Canada, Great Britain and the Netherlands

Anne Zeddeman, Pim Van Hooft, Herbert H.T. Prins and Robert H S. Kraus

The mallard (*Anas platyrhynchos*) seems to have an important role in the spread and maintenance of Avian Influenza Viruses. Mallard migration, both on fine and coarse scale, is poorly understood. Our study aims to contribute to the understanding of the migration patterns of the mallard duck, especially between North-America and Europe, considering Greenland as a possible mixing site. During summer 2008 we trapped mallards in Greenland, Nuuk (city pond; 64.190, -51.708), and collected blood samples for DNA isolation. Mitochondrial control region DNA sequence of these individuals was obtained and compared to those of populations from Canada, Great Britain and mainland Europe as part of our ongoing wild mallard gene pool project (http://www.reg.wur.nl/UK/Staff/Kraus).

Preliminary comparison results of sequences from eastern Canada (n=13), Greenland (n=22), Great Britain (n=19) and the Netherlands (n= 19) show that these 73 individuals comprise 22 haplotypes (h). The eastern Canada population harbours the highest diversity of haplotypes (11), and the Greenland population the lowest (3). The Great Britain population counts eights haplotypes and the Dutch population four. Haplotype diversity (H) in these populations varies from 0.18 in Greenland to 0.96 in Canada. Pair wise F_{st} values (a measure of genetic differentiation) are listed in table 6.1; all results are statistically significant ($p < 0.001$). These values suggest that the genetic difference between Greenland and each of the other populations is largest. The gene pools of eastern Canada and Europe seem to be more connected to each other than to the population from Greenland, which is much more isolated.

Table 6.1 Pair wise Fst values (a measure of genetic differentiation); all results are statistically significant (p < 0.001).

Locality	East Canada	Greenland	Great Britain
East Canada	-	-	-
Greenland	0.43959	-	-
Great Britain	0.27141	0.47941	-
The Netherlands	0.31044	0.62066	0.04785

Further analysis will include sequences from mallard populations from Canada, mainland Europe and archive sequences from western Russia, North Asia, together with the Aleutian Islands and Alaska (available at GenBank, NCBI). Our ultimate goal is to study the direction and extent of gene flow in the world wide mallard population. We will do this not only with mitochondrial DNA as applied so far, but also using a set of 384 single nucleotide polymorphisms (SNPs) as autosomal genetic markers. Additionally we are interested in the immunogenetic make-up of the mallard in different parts of the world with different life histories (migratory vs. resident). This is particularly interesting in the light of the interplay of migration and avian influenza dispersal.

6.10 Humpback whale foraging in Godthåbsfjord

Malene Simon and Peter T. Madsen

Humpback whales (*Megaptera novaeangliae*) migrate to feed in West Greenland Waters during summer. They only feed during this part of the year, and must therefore build large energy reserves to support reproduction as well as the long migrations between the foraging areas in the Arctic and the breeding areas near Equator (Pomilla and Rosenbaum 2005). Godthåbsfjord is a well-known foraging

Figure 6.8 Humpback whale tagged with a DTAG in Godthåbsfjord summer 2008. The tag is attached with four suction cups.Photo: Malene Simon.

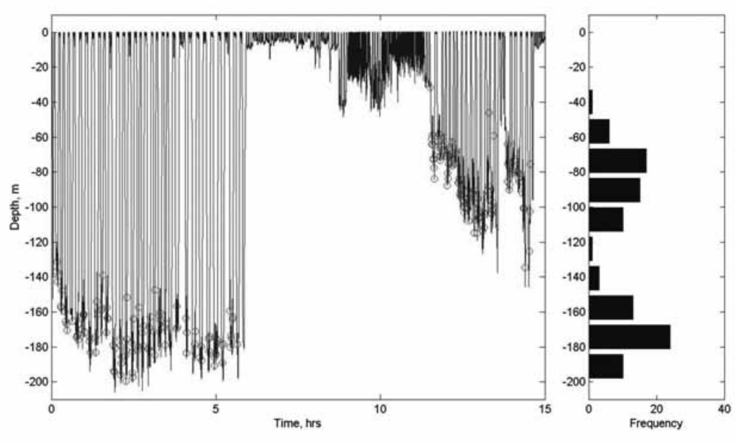


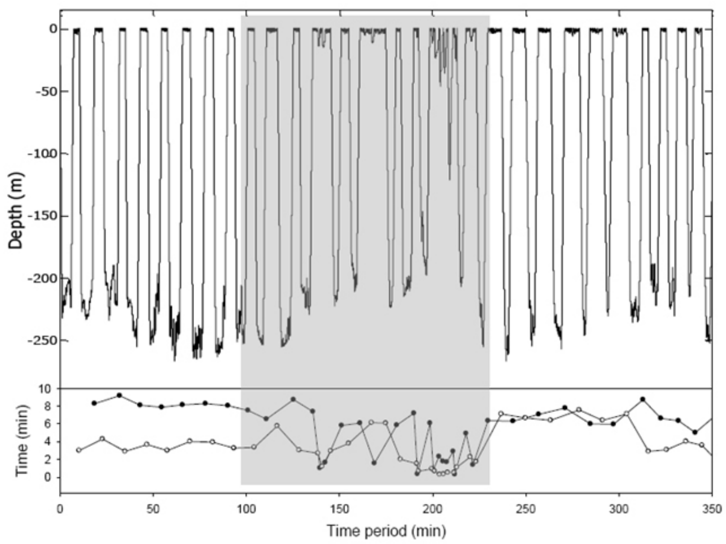
Figure 6.9 Dive profile of tagged humpback whale feeding in Godthåbsfjord. Circles are lunges and the histogram shows the frequency distribution of lunges in depth. During the 15 hours of tagging the whale was feeding in two distinct prey layers. The depth of the prey is reflected in the bimodality of the histogram.

area for humpback whales and they inhabit the fjord from May to October (Heide-Jørgensen and Laidre 2007).

Rorquals, including the humpback whales feed on zooplankton and fish by engulfing tens of tonnes of prey-laden water in a single mouthful. This process, coined *lunge feeding* (Croll et al. 2001, Goldbogen et al. 2006) is normally carried out several times during each feeding dive. This study aimed to investigate the humpback whales ecological influence and importance in the Godthåbsfjord ecosystem by looking at the foraging behaviour, feeding depth and lunge frequency of these apex predators.

We use non-invasive digital tags (DTAG) to quantify the detailed kinematics of lunge feeding and the overall diving behaviour of the humpback whales. D-tags are digital, acoustic and inertial-sensing tags containing tri-axial accelerometers, magnetometers and depth sensors sampled at 50 Hz, recording sounds and 3-D movements of the tagged animal (Johnson and Tyack 2003). We tagged 11 humpback whales with DTAGs in Godthåbsfjord during the summer of 2007 and 2008 (figure 6.8). Figure 6.9 shows typical feeding sequences of a humpback whale feeding in two distinct prey layers with five hours in between. The prey layers were centred at 170 m and then 80 m depth.

Figure 6.10 Dive profile of humpback whale. The shadowed area illustrates the time period where the whale was exposed to whale watching and where high levels of engine noise was measured on and off. Top: Illustrates the diving pattern of the whale over time. Bottom: Illustrates diving duration (•) and time spent at the surface (o) over time.



6.11 Interactions between humpback whales and whale watchers in Godthåbsfjord

Tenna K. Boye, Malene Simon and Peter T. Madsen

North Atlantic humpback whales migrate from low latitude breeding grounds to four different high latitude feeding areas to which individuals display large scale site fidelity. In Godthåbsfjord, West Greenland, humpback whales are present from early spring to late autumn. To study small scale site fidelity and residence time in this habitat, ID-photos were collected from May to September in 2007 and 2008 and compared with an older catalogue. Individual humpback whales, in the presence and absence of boats, were tracked from land using a theodolite to test if whale watching had an effect on whale behaviour. We found a strong degree of small scale site fidelity where 40 % of the whales present in 2007 were re-sighted in 2008. The re-sight rate from 1992 to 2008 was 30.2 %. Individuals did not stay in the fjord the entire season and residence time was highly variable amongst individuals varying between 6.7 and 60 % of the time from May to September. Whale watching was shown to significantly increase swimming speed, cause abbreviated foraging dives and diminish the ratio between surfacing and foraging dives (figure 6.10). In conclusion the same foraging whales use this fjord system year after year, which calls for regulation of whale watching and for consideration when discussing the reopening hunt of humpback whales in West Greenland Waters.

7 Disturbances in the study area

Peter Aastrup

The study area at Kobbefjord is situated approximately 25 km south of Nuuk and can be reached by boat within half an hour. It is a public area and admittance is free to anyone.

Public disturbance falls in the following categories:

- Visits by boats at the bottom of the fjord – no landing.
- Visits by boats in the bottom of the fjord – the persons take a short walk inland and returns within a few hours or less.
- Visits by boats in the head of the fjord – the persons go on land and spend the night in a tent close to the coast.
- Hiking through the area – there is a hiking route from Nuuk to the inland passing through the area.
- Visits by snow-mobile – during winter people visit the area from Nuuk.
- Ordinary flights by fixed winged aircrafts passing over the study area at cruising altitude or in ascent or descent to or from Nuuk.
- Helicopter flights at cruising altitude passing over the study area.
- The electrical power transmission line between Nuuk and the hydro power plant in Buksefjord runs through the area.

In 2008 there have been only few interactions between visitors in the study area and the different setups and the camp. The worst disturbance was when someone had pulled up some of the marking pegs in one study plot and moved an ITEX chamber belonging to the BioBasis programme. Furthermore, three times during the season, while unattended, the camp was used by hikers as shelter during bad weather.

The GeoBasic programme has had incidents with foxes eating cords for sensors.

Between 1 August and 3 August recording of a movie took place, and we removed all the sleeping tents to make room for this. Up to 20 people was in the area close to the river during the filming, which had no relation to the monitoring activities. Until 15 August there were filming activities on and off with a few people attending.

On 17 October 2008, a helicopter made 33 slings from the shore of Kobbefjord to the building site with materials for construction of the huts. On 10 November 2008, a helicopter made one sling from Nuuk to the building site at Kobbefjord with materials for construction of the huts.

The monitoring programme itself has brought disturbance to the area by transportation between Nuuk and the bottom of the fjord, housing of personnel, walking between study plots etc.

In 2008, transportation between Nuuk and the study site in Kobbefjord was on an irregular basis, but most of the season there was transportation several times per week. The base camp was used temporarily by 2 to 10 persons, and it consisted of two to four sleeping tents and a kitchen tent. By the end of the season, the kitchen tent was destroyed by a snowstorm.

Walking between the study plots has had a wearing effect on the vegetation and it should be considered to mark permanent trails between the different study sites. Portable boardwalks shall be used in the future, especially in the fen areas and especially around the flux measuring plots.

In conclusion, it is estimated that the second years' monitoring activities only had minor impacts on the vegetation and terrain.

8 Logistics

Henrik Philipsen

In 2008, Greenland Institute of Natural Resources took care of the logistics related to Nuuk Basic in Kobbefjord.

The 2008 field season in Kobbefjord was from 13 March to 4 December. During this period 30 scientists spend approximately 600 'man-days' when in the study area. Accommodation, measured in bed nights, of Nuuk Basic scientists in the accommodation building at Greenland Institute of Natural Resources were 457 in total.

Transportation of staff, construction workers and scientists from Nuuk to the research area in Kobbefjord was carried out by Greenland Institute of Natural Resources boats 'Aage V. Jensen II Nuuk' and 'Erisaalik'. Total number of days with boat transport related to Nuuk Basic was 124; including the 21 days spend by MarineBasis on investigations in Kobbefjord and Godthåbsfjord. The two boats, which are both financed by Aage V. Jensen Charity Foundation, proved to be very efficient for their purpose.

In 2008 scientists were accommodated in Alaska tent with a heating own. Unfortunately the tent blew in to the sea during a storm on 30 October.

Water for drinking and other purposes was taken from the nearby river. Electric power was provided by a portable 2000 W generator. Communication to/from Nuuk was done by Iridium satellite telephones. While local communication within the study area was by VHF-radios.

Aage V. Jensen Charity Foundation has financed two huts for Nuuk Basic at Kobbefjord, i.e. one 8 m^2 hut for a generator and one 55 m^2 hut with laboratory and accommodation facilities. The huts were planned to be raised in August 2008 but the building materials did unfortunately not arrive in Nuuk before early October 2008.

Foundations for the huts were constructed between 22 and 30 September 2008 by a local entrepreneur, BJ Enterprise, and staff from Greenland Institute of Natural Resources. Timber for the foundations was sailed from Nuuk to Kobbefjord with 'Aage V. Jensen II Nuuk' and from the shore transported to the hut sites by hand.

On 17 October 2008, the building materials, a 5 KWA generator and fuel for the run of the field camp were sailed by a tug boat with two barges from Nuuk to Kobbefjord. In Kobbefjord an Eurocopter AS 350 Ecureil helicopter from Air Greenland made on the same day 33 slings with materials to the building site.

Carpenters from BJ Enterprise started raising the huts on 18 October 2008, and on 29 October 2008 a topping-out ceremony with 40 participants and a speech from director Klaus Nygaard from Greenland Institute of Natural Resources was held.

On 10 November 2008, a helicopter made one sling from Nuuk to Kobbefjord with doors and windows for the huts. In 2008, the carpenters spend in total 85 working days in Kobbefjord from 22 September to 14 November.

In 2009, the inside of the building will be furnished with rooms – living room, bathroom, laboratory and entrance.

9 Acknowledgements

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11 Publications

Compiled by Lillian Magelund Jensen

Scientific papers

Mikkelsen, D.M., Rysgaard, S. and Glud, R.N. 2008. Annual variation in algal composition, primary production and nutrient dynamics of an arctic sea ice community. Marine Ecology Progress Series 368:65-74.

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Appendix

Julian Dates

Regular years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

Leap years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366