NERO

NUUK ECOLOGICAL RESEARCH OPERATIONS

3rd Annual Report 2009

National Environmental Research Institute
Aarhus University

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NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

Data sheet

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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 under the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in NERO:
National Environmental Research Institute, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
Greenland Institute of Natural Resources: BioBasis and MarineBasis programmes
Asiaq - Greenland Survey: ClimateBasis programme
University of Copenhagen: GeoBasis programme

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The Government of Greenland
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Executive Summary

Kisser Thorsøe, Birger Ulf Hansen, Peter Aastrup, Thomas Juul-Pedersen, Lillian Magelund Jensen and Morten Rasch

Introduction

2009 was the third year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was the first year with complete annual time series for all sub-programmes. The new research hut in Kobbefjord was taken in use during August 2009.

ClimateBasis

The ClimateBasis programme gathers and accumulates data describing the climatological and hydrological conditions in Kobbefjord. Two automatic climate stations (C1 and C2), two automatic hydrometric stations (H1 and H2) and three diver stations (H3, H4 and H5) measure data.

The two climate stations are placed next to each other to ensure data continuity. Sixteen climate parameters, including two derived parameters, are monitored, and data are stored in a database.

In Kobbefjord, measurements of the water level and discharge started in 2006 at H1, at H2, H3 and H4 in 2007 and at H5 in 2008. Manual measurements of discharge were in 2009 continued at H1, H3, H4 and H5. 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 autumn before the river freeze.

In both 2007 and 2008, stage-discharge relations (Q / h-relation) were established for H1, but after the 2008 season there was still a lack of measurements at high water level. In 2009, measurements were made at high water levels and a new Q / h-relation was established. For H2, H3, H4 and H5 there are still 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 2009 was 39.2 million m^3. The peak discharge in 2009 was recorded on 27 June and was caused by precipitation. In late September, a combination of snowmelt and precipitation resulted in a water level just one centimetre lower than the one recorded in June. During this event, five manual discharge measurements were carried out.

GeoBasis

The 2009 season was the second full season for the GeoBasis programme with a field season between May and late September. However, due to cooperation with other research projects, the programme continued until late October. In the previous year, the programme unfortunately ran into several unforeseen problems (e.g. catabatic winds destroying several installations, snowdrifts preventing the automatic cameras from monitoring expected areas, high levels of melt water in the snow pack with following flooding of data logger etc.). Most of these problems were solved during the 2009 season. A new micrometeorological station M1000 at 1000 m a.s.l. was installed in October 2009 in collaboration with ClimateBasis. The station (M1000) will serve as both a microclimate station and a data communication link to Nuuk.

Melting of snow and ice started in the beginning of May and by mid-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 in early to late June 2009, eleven to thirteen days later than in 2008. Due to logistical problems, only one snow survey was carried out in mid-April 2009 in cooperation with the ClimateBasis programme. Snow depth varied from 37 cm to 163 cm. The general pattern of snow distribution is mainly controlled by microclimate and small-scale topography variations resulting in very heterogeneous snow cover conditions.

The micrometeorological station at 1000 m a.s.l. (M1000) completes the installation of the climate stations along the altitudinal range represented in the study area. Normal temperature lapse rate with decreasing temperatures with altitude prevails on an annual basis in 84 % of the time. Inversion prevailed up to 33 % of the time in March due to shadows from surrounding mountains and snow cover with a subsequent radiative cooling of the valley floor.

At the three automatic soil stations in the area i.e. SoilFen, SoilEmp and SoilEmpSa, the inter-annual variations in the different parameters were documented in 2009. Due to the effect of lesser snow cover in the last quarter of 2009 soil temperatures in the upper 30 cm averaged –1.0 °C at the *Empetrum* site compared to 0.3 °C in 2008. In 2009, thirty soil-water samples were collected from two depths at the fen site and the *Empetrum* site.

The temporal methane (CH_4) flux pattern in 2009 was similar to the pattern observed in 2008 with a dome-shaped peak with maximum about a month after snow melt and declining to about half of the peak 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 in 2009 were approximately 8 mg CH_4 m^{-2} h^{-1} compared to 5 mg CH_4 m^{-2} h^{-1} in 2008.

The temporal variation in daily net exchange of CO_2 were initiated 15 May and continued until 31 October. In 2009, the period with net CO_2 uptake lasted until 27 August, which was 11 days later than in 2008. During this period the fen accumulated 42.5 g C m^{-2}. The estimated net uptake period was approximately 57 days in 2009 and the maximum daily uptake reached 1.48 g C m^{-2} d^{-1} compared to 2.27 g C m^{-2} d^{-1} in 2008.

In 2009, GeoBasis Nuuk has completed the installation of instruments necessary for the run of the programme. The second full year has provided valuable learning lessons that will improve the programme even further in the following years.

BioBasis

We now have two years of data collected by the BioBasis programme. Generally, there is a high consistency in data collected during the two years indicating that the data and the procedures used are reliable and sound.

The year 2009 had a later snowmelt than 2008. A preliminary review of data related to flowering and plant reproductive phenology indicate that 2009 was characterised by later flowering. However, flowering terminated at roughly the same time as in 2008 resulting in a shorter flowering season. The two species on sparsely vegetated plots, *Silene acaulis* and *Loiseleuria procumbens*, produced more flowers in 2009 than in 2008, while the two species on highly vegetated plots, *Eriophorum angustifolium* and *Salix glauca,* produced fewer flowers.

The general pattern is that vegetation greening (measured as NDVI) starts as soon as the snow has melted in June with a peak of greenness in mid-summer (20 July to 5 August) and a gradual decrease in greenness resulting in more or less bell-shaped curves and gradually levelling off during autumn until the frost sets in.

Measurements of the land-atmosphere exchange of CO_2 using the closed chamber technique, soil temperature, soil moisture and phenology of *Salix glauca* have been conducted weekly during June-September since 2008. All plots generally functioned as sinks of CO_2. The net CO_2 uptake was generally higher in control plots compared with plots with increased temperature and plots with shading. These results show the initial response of the heath ecosystem to the treatments, and may not be indicative of long-term trends. It is thus important to run the experiment for several years to be able to study possible changes over time.

Arthropods were sampled during the period 28 May to 2 October. No identifications of specimens have been carried out yet. Soil characterisation of the microarthropods plots was completed showing significant differences between plots. Extraction efficiency was satisfactory and species determinations have been double-checked with good results. There is a striking absence of epigeic collembolans, which may probably be a common feature of many arctic tundras and heaths. The *Salix* and *Empetrum* plots were very similar in terms of abundance and diversity when comparing the two sampling years 2007 and 2009. Only few distinct phenological patterns were detected in the data over the two to three months sampling period.

The most common breeding passerine bird species were snow bunting and Lapland bunting with about 20 territories each. Only one territory of northern wheatear was observed and two to five redpoll individuals were seen. Censuses from bird observation points revealed fewer birds in 2009 compared to 2008.

Lake ecology is studied in two lakes: Badesø (with fish) and Qassi-sø (without fish). Nutrient levels are generally low in the two lakes. However, in 2009 especially nitrogen levels were lower than in 2008. In contrast, the Secchi depth decreased in Badesø in 2009, whereas it increased, as expected, in Qassi-sø from 2008 to 2009. Temperature differs slightly with the lowest temperature in Qassi-sø. In Qassi-sø the zooplankton biomass was, in general, higher than in Badesø. The ratio between zooplankton and phytoplankton is higher in Qassi-sø than in Badesø. This reflects the fish predation on the zooplankton in Badesø, which in turn are less effective in grazing the phytoplankton.

MarineBasis

The MarineBasis programme has collected monthly and seasonal data on abiotic and biotic parameters in the marine environment since October 2005, along with annual observations on seabirds and marine mammals since 2007 in Godthåbsfjord. The aim of the long-term monitoring programme is to understand the link between dynamics in abiotic and biotic parameters (i.e. physiochemical conditions, marine productivity, sinking flux and re-mineralization, benthic-pelagic exchange, species abundance and composition) and climatic forcing.

Monitoring of the sea ice conditions, using satellite imagery, shows maximum sea ice cover in Baffin Bay lasting until April / May and followed by a decrease in sea ice cover, reaching a minimum in July / August. By December, sea ice had again covered much of the northern and western parts of Baffin Bay. Local satellite observations showed a more pronounced sea ice coverage of the inner part of Godthåbsfjord during the winter 2008 / 09 compared to previous years.

Pelagic sampling showed the re-occurring seaward export of freshwater from glacier and snowmelt forming a fresher and warmer surface layer towards Akia. This surface layer contained the highest phytoplankton biomass values observed throughout the year. Nevertheless, local vertical mixing at the entrance of the fjord created largely homogenous hydrographical conditions throughout the water column at the 'Main Station' in spring, and resulted in elevated phytoplankton biomasses at depth. The reoccurring spring phytoplankton bloom in May, led to an abrupt decrease in nutrient levels. Nonetheless, a minor secondary phytoplankton bloom occurred in August, as observed in previous years. Nutrient levels were only completely replenished during autumn, primarily through introduction of offshore nutrient rich waters. Primary production levels (i.e. peak and annual levels) were lower than in previous years, and annual primary production varied by a factor 2.7 during the four annual time series (i.e. 2006-09).

The highest temperatures and salinities along the length section during spring were recorded in the West Greenland current flowing northward outside Fyllas Banke, as observed in previous years. Still, the annually highest measured temperatures and lowest salinities were observed at the 'Main Station' during summer. As seen in previous years, the freshwater export declined during autumn and colder weather conditions resulted in a cooling of the surface waters.

Several stations outside Fyllas Banke and within the fjord showed surface water pCO_2 levels above atmospheric concentrations. Also monthly pCO_2 values during autumn exceeded atmospheric levels. Hence, the Godthåbsfjord system was not as strong a CO_2 sink as seen in previous years. Moreover, the average annual surface pCO_2 concentrations at the 'Main Station' have been constantly increasing during the four year time series (i.e. 2006-09), although it remains below the atmospheric concentrations.

The phytoplankton community was dominated by diatoms throughout the year. Contrary to previous years, diatoms dominated during spring when *Phaeocystis* (i.e. Haptophyceae) previously has been most abundant. Zooplankton showed significantly lower concentrations than in previous years, although a similar seasonal succession between copepods, nauplii and other zooplankton was observed. Again, *Microsetella* sp. remained the most abundant copepod species throughout most of the year. Fish larvae generally occurred in highest numbers at the 'Main Station' along the length section from Fyllas Banke to the inner part of the fjord. Previously, the highest concentrations of fish larvae at the 'Main Station' were recorded in spring, but in 2009, the highest numbers were found during autumn. This was primarily due to a decrease in sand eel larvae during spring and a slight increase in capelin larvae du-ring autumn. A seasonal species succession, from arctic shanny to capelin, occurs at the 'Main Station' between spring and autumn. Cod larvae were only observed in May and July. Seasonal patterns in shellfish larvae showed similarities with 2008, although species concentrations differed. Preliminary data indicate that jellyfish were more abundant from May to August in 2009 than in the previous year. The length section generally showed low numbers of crab and shrimp larvae in 2008 and 2009 compared to 2007, although they remained present at the 'Main Station' in all three years.

The vertical sinking fluxes of total particulate material remained comparable with previous years, but showed significantly less monthly variability. The low carbon content of the sinking material through all years reflects the strong influence of lithogenic material from terrestrial sources in the inner part of the fjord. Moreover, two distinct peaks in sinking flux of total particulate carbon in August and October may be related to the release of particulate material during draining of two glacial melt ponds in the inner part of the fjord. The estimated annual carbon sinking flux remains the highest on record largely driven by the two distinct peaks in carbon sinking fluxes. Sinking fluxes of chlorophyll *a* followed the seasonal phytoplankton production in the water column.

The sediment (sampled four times per year) showed the highest oxygen consumption in May when biological activity (e.g. bioturbation) and the sinking flux of organic material were high. Oxygen consumption was comparable during the other periods, and oxygen was depleted within 1 cm of the sediment surface during all sampling periods. The physiological status of the dominant sea urchin remained similar to previous year, while the dominant scallop showed a small but significant increase in physiological status. Food availability and water temperature seem to be the key parameters for their physiological conditions, although this cannot yet be statistically verified. The large brown kelp *Laminaria longicruris* showed a tendency towards larger individual biomass, although the blades had similar length, during the three-year sampling period (2007-09). Moreover, the nitrogen content and C / N ratio of the algae varied significantly between years, reflecting differences in the supply and demand of nitrogen and of carbon storage.

Seabird monitoring at a colony (*Qeqertannguit*) in Godthåbsfjord indicated that kittiwakes, Iceland gulls and arctic terns seemed to do better than in 2008, although some counts where still lower than in 2006-07. Similarly, at the colony (*Nunngarussuit*) south of Godthåbsfjord the number of guillemots (i.e. common and Brünnich's guillemot) were higher than in 2008, but remained lower than in 2007. Picture analysis showed that 9 % of the identified guillemots were boreal common guillemots, while the rest was arctic Brünnich's guillemots.

Monitoring of humpback whales was changed to focus only on photo identification based on individual fluke colour patterns. Photo identification will later be used for mark-recapture analyses to estimate numbers of humpback whales in Godthåbsfjord. Photo identification can also be used for investigating 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). In 2009, seven individuals were re-identified from 2007-08 and eight new individuals were identified. Preliminary data suggest that fewer animals re-enter the fjord from year to year, although this cannot yet be conclusively established with the small available sample size.

Research projects

In 2009, eight different research projects were carried out in cooperation with Nuuk Ecological Research Operations. The research projects all focused on different biological topics in the limnic compartment of the ecosystem. The research projects are presented in Chapter 6.

1 Introduction

Morten Rasch and Lillian Magelund Jensen

2009 was the third year of operation of the now fully established Nuuk Basic programme. During the 2009 field season, the establishment of the terrestrial programmes – ClimateBasis, GeoBasis and BioBasis – were completed. The severe failures we experienced in 2008 on especially the field equipment and the automatic installations belonging to the ClimateBasis and GeoBasis programmes have been corrected or new installations have been established.

The 2009 field season in Kobbefjord started 14 January and continued until 16 December. During this period 34 scientists spend approximately 242 'man-days' in the study area.

1.1 New research hut at Kobbefjord

The new research hut at Kobbefjord was taken in use during August 2009. The hut, which was generously funded by Aage V. Jensen Charity Foundation, includes excellent field facilities for accommodation, storage and preliminary laboratory analyses. As such, the 55 m^2 hut is a perfect base for the research and monitoring activities under the framework of Nuuk Ecological Research Operations, which will allow for a more efficient execution of the field activities related to the Nuuk Basic programme.

1.2 Nuuk Basic Secretariat

After the closure of the Danish Polar Centre 31 December 2008, the Secretariats for Nuuk Ecological Research Operations (NERO), Nuuk Basic, Zackenberg Research Station, Zackenberg Ecological Research Operations (ZERO), Zackenberg Basic and Greenland Ecosystem Monitoring (GEM) have been accommodated at the National Environmental Research Institute at Aarhus University.

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 research infrastructure, including boats, research hut, office and accommodation facilities at Greenland Institute of Natural Resources etc., have generously been provided by Aage V. Jensen Charity Foundation.

1.4 Greenland Climate Research Centre in Nuuk

On 23 November 2009, the Greenlandic Minister for Culture, Education, Research and Church Affairs, Mimi Karlsen, inaugurated the Greenland Climate Research Centre. The Centre, which is funded by the Danish Ministry of Science, Technology and Innovation, is placed at Greenland Institute of Natural Resources and led by Professor Søren Rysgaard. A major aim of the centre is to make use of the data provided by Greenland Ecosystem Monitoring (GEM) to evaluate the effects of climate change on Greenland nature systems and society. It is the vision of the centre to *'be a leading international centre for studies on the impact of climate change in Arctic ecosystems and society'*. Further information concerning Greenland Climate Research Centre is available on www.natur.gl.

The Greenland Climate Research Centre Logo.

1.5 Nuuk Climate Days

The Nuuk Climate Days conference was held in Nuuk between 25 and 27 August 2010. The conference was organised by the Technical University of Denmark, Danish Meteorological Institute and Greenland Climate Research Centre. 150 world-leading scientists were attending the conference to discuss climate change and its consequences in Greenland. Several presentations included data from Greenland Ecosystem Monitoring.

1.6 International cooperation

Nuuk Ecological Research Operations has been involved in the ongoing international work with the overall purpose of establishing a Sustaining Arctic Observing Network (SAON), an initiative approved by Arctic Council. Many bottom-up driven initiatives are taken for establishment of observing platforms to become components of a future SAON. Greenland Ecosystem Monitoring is involved in two of the larger initiatives, i.e. Svalbard Integrated Arctic Earth Observing System (SIOS) and International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT). SIOS is a network of different organisations working with earth observations on Svalbard and in its nearest surrounding. INTERACT is a programme launched by the network SCANNET (a circumarctic network of 32 terrestrial field bases) to coordinate their activities. Both projects applied for extensive funding through EU 7th Framework Programme late in 2009, and we hope to be able to launch both programmes during 2010. Greenland Ecosystem Monitoring has a relatively limited role in SIOS but a significant role in the leadership of INTERACT together with Abisko Scientific Research Station.

1.7 United Nations Climate Change Conference in Copenhagen (COP15)

In December 2009, Denmark hosted the United Nations Climate Change Conference in Copenhagen (COP15). Nuuk Ecological Research Operations was visible during the conference with exhibitions and several lectures at two side events, i.e. 'Arctic Venue' (a Danish side event) and 'In the Eye of the Climate' (a Greenlandic side event).

1.8 Further information

Further information about the Nuuk Basic programme is collected in previous annual reports (Jensen and Rasch 2008 and 2009). Much more information is available on the Nuuk Basic website: www.nuuk-basic.dk including manuals for the different monitoring programmes, a database with data from the monitoring, up-to-date weather information, a Nuuk Basic bibliography and a collection of public outreach papers in PDF-format.

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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

During 2009, the climate stations in Kobbefjord were visited twice by Asiaq technicians and fourteen times by other Asiaq personnel. The maintenance of the stations included reference test of important parameters, among them the UV-B radiation, and replacement of the following sensors: Snow Depth, RVI, PAR and Net Radiation (Lite). On C2, the four component net radiometer (CNR1) was also replaced. A full description of the climate stations are given in Jensen and Rasch 2008.

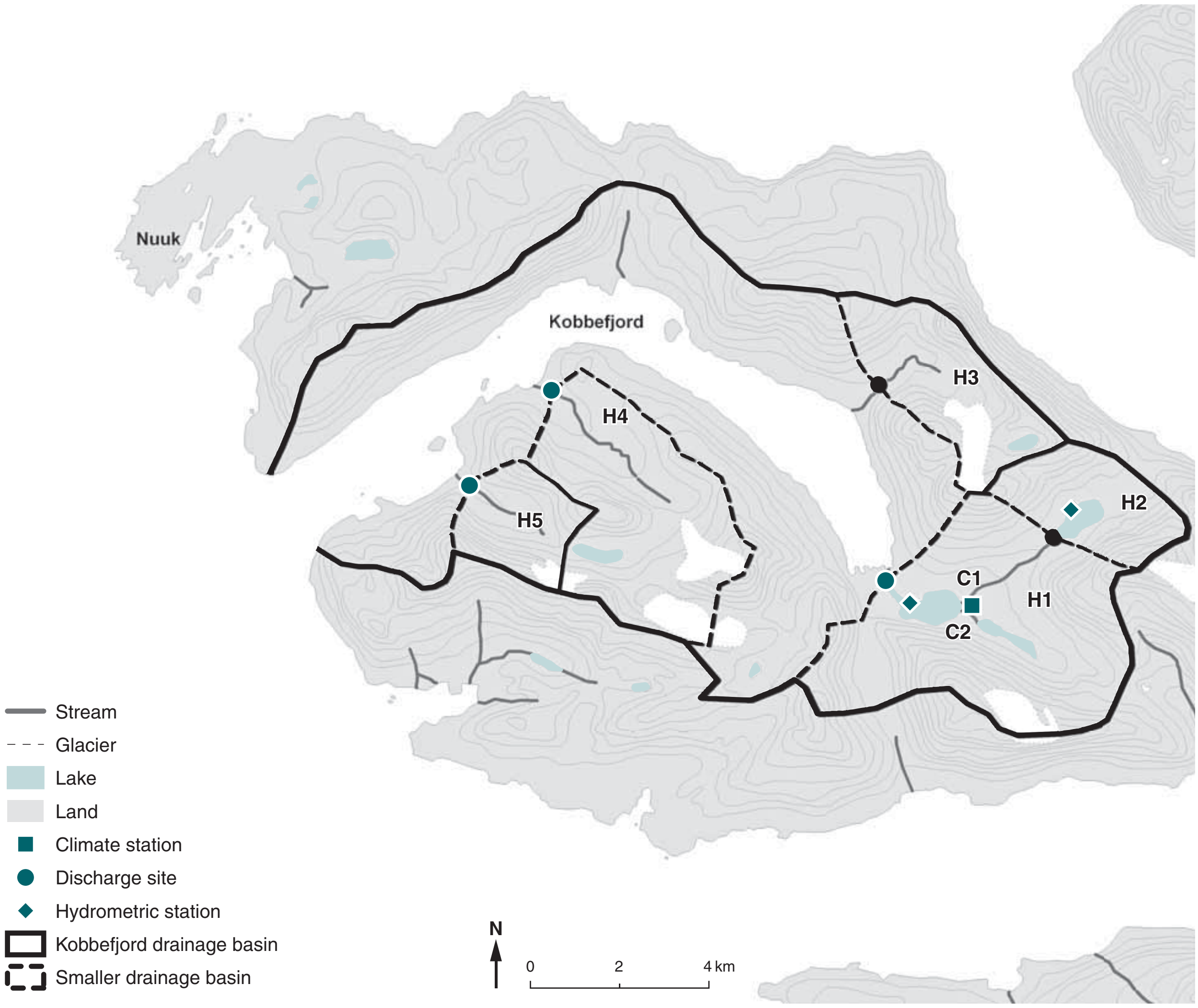


Figure 2.1 Location of the climate (C1, C2), hydrometric (H1, H2) and diver stations (H3, H4, H5) in Kobbefjord together with the drainage basin of Kobbefjord and the drainage basin for the hydrometric stations and the diver stations.

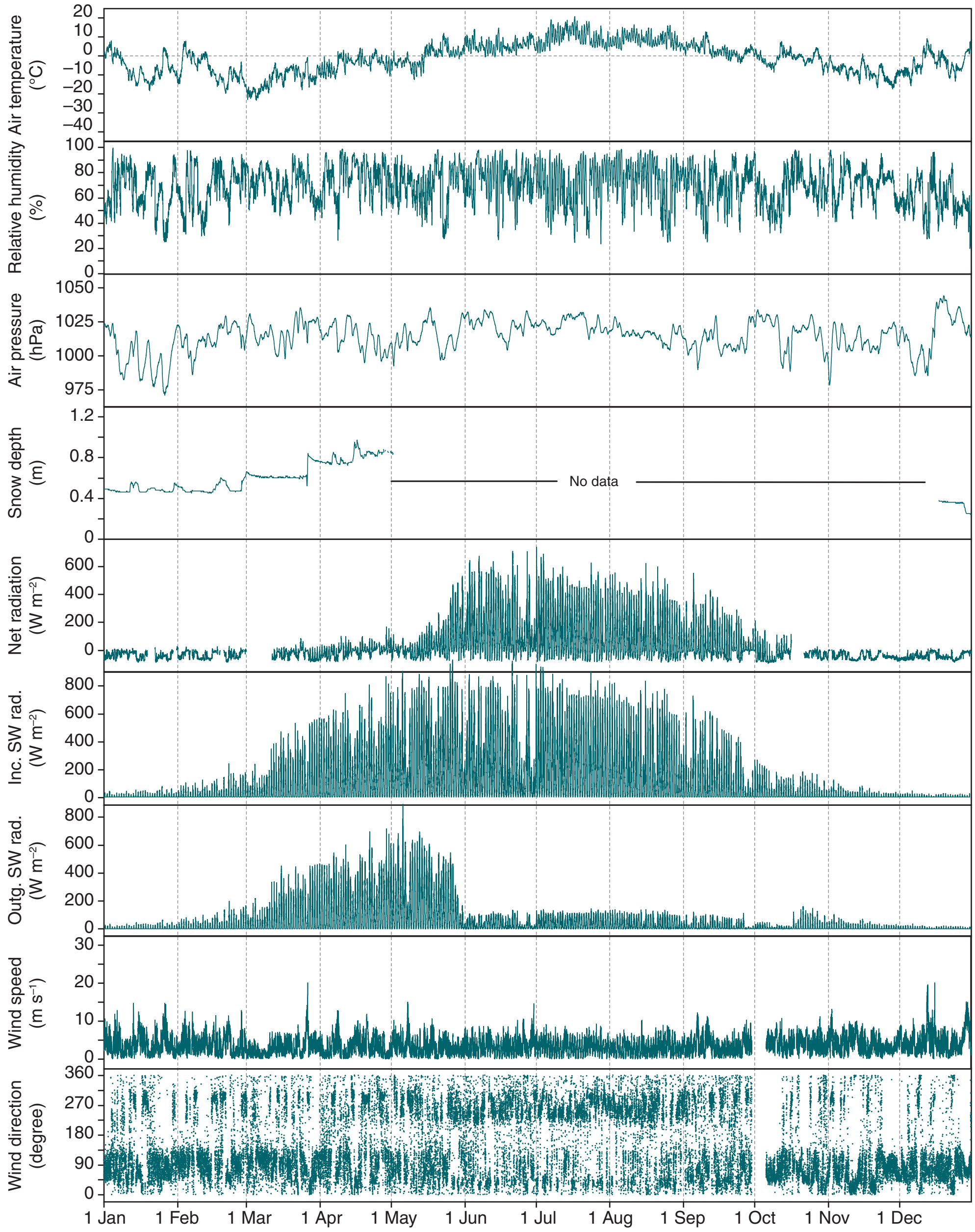


Figure 2.2 Variation of climate parameters measured in 2009. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation, outgoing short wave radiation, wind speed and wind direction. Wind speed and direction are measured 10 m above terrain; the remaining parameters are measured 2 m above terrain.

Further work was made on developing technical solutions to improve measurements of precipitation and RVI, and to facilitate automatic data retrieval from Nuuk. The automatic data retrieval system was tested in 2009, and when it becomes operational in 2010, it will directly improve the data resilience for all connected stations, which will be C1, C2, H1 and H2 and some stations run by GeoBasis.

Meteorological data 2009

This annual report describes data from the second full year of measurements collected during the period 1 January to 31 December 2009. Figure 2.2 gives an overview of the meteorological parameters measured in 2009.

The annual mean of recorded air temperatures in 2009 was –1.3 °C, table 2.1. The coldest month was March with an average temperature of –12.1 °C and a minimum temperature as low as –24.0 °C. The warmest month was July with temperatures averaging 9.9 °C and a maximum temperature as high as 21.0 °C. Compared with the climate normal for Nuuk (1961-90), the recorded temperatures in Kobbefjord 2009 were below normal during spring and autumn (March to May and September to November) and above normal during the months January, February, June to August and December (Cappelen et al. 2001).

The general weather pattern observed from January through March does not differ from previous described winter

Table 2.1 Monthly mean values of climate parameters from January to December 2009. For 2009 also annual mean temperature, mean relative humidity, mean air pressure, mean wind speed and accumulated precipitation.

Month 2009	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
January	65.5	0.484	–6.1	986.9	45	3.5	15.0	ENE
February	67.5	0.492	–6.9	1001.2	36	3.5	12.6	ESE
March	71.3	0.634	–12.5	1005.8	67	2.6	19.8	ESE
April	76.3	0.807	–4.0	1001.4	110	2.9	12.4	WNW
May	70.1	0.846	–0.5	1002.0	55	2.8	14.9	ENE
June	73.9	---	5.6	1011.3	129	3.0	14.4	WSW
July	69.2	---	9.9	1011.5	1	3.0	8.8	WSW
August	73.8	---	8.5	1004.3	5	2.5	9.5	WSW
September	70.6	---	3.0	998.5	202	3.0	11.3	NE
October	66.5	---	–1.3	1005.7	57	3.4	11.1	NE
November	72.0	---	–8.7	999.3	33	3.6	12.9	NE
December	58.9	0.331	–3.5	1005.4	99	4.2	20.0	ENE
2009	69.6	---	–1.3	1002.8	838	3.2	---	---

conditions. This period was characterized by long periods with easterly winds and low temperatures. Occasionally, the stable winter weather situation was interrupted when low pressures passed over the area, bringing rising temperatures, westerly winds, high wind speeds and often precipitation. The most frequent wind direction in April was WNW, and the precipitation amounted to 110 mm. March and May had easterly winds and average precipitation around 61 mm. The average temperature in May was 3.6 °C lower than in May 2008, though the last day with a mean air temperature below the freezing point was recorded 15 May which was approximately the same as in 2008 (13 May). The last three years the mean air temperature in July has not varied more than 1.0 °C (table 2.2). During the same period May and June mean air temperatures have varied more than 3.1 °C. In fact, May 2009 was the coldest May recorded since 2007.

From June until the end of August the dominant wind direction was WSW and air pressure was stable and relatively high (table 2.1). Especially July and August had very stable weather characterized by almost no precipitation, a high frequency of clear sky conditions and an almost harmonic diurnal variation in wind speed, temperature and relative humidity. In figure 2.2, clear sky conditions can be observed as periods with high positive net radiation during the day and negative net radiation during the night.

In September, the most frequent wind was from NE but low pressures brought humid air in from west resulting in plenty of precipitation by the end of September. A total of 202 mm was recorded in September, which was the wettest month in 2009. Passing low pressures during autumn are often associated with very high wind speeds. From October to December, three occasions with mean wind speed above 15 m s^{-1} were registered compared with six in 2008.

The first snow fall was recorded 26 September and permanent snow cover at the climate stations started 17 October, although rain and above zero temperatures around 30-31 December almost melted away all snow at the stations and partially exposed soil and vegetation underneath the radiation masts.

The levels of selected radiation parameters are displayed in table 2.3. The table presents a new parameter: *the Normalized Differential Vegetation Index* or NDVI (Asiaq Report 2010). The vegetation underneath the radiation masts had its maximum greenness in August (0.33). The period with positive month mean net radiation was, as in 2008, May to September.

Table 2.2 Comparison of monthly mean air temperatures, 2007 to 2009 (May is incomplete in 2007).

Month 2009	Air temp. °C	Month 2008	Air temp. °C	Month 2007	Air temp. °C
May	–0.5	May	3.1	May	–0.2
June	5.6	June	7.2	June	4.1
July	9.9	July	10.1	July	9.1
August	8.5	August	7.9	August	9.8
September	3.0	September	3.6	September	3.2

Table 2.3 Monthly mean values of selected radiation parameters in 2009.

Month 2009	NDVI	Albedo	Short wave rad.		Long wave rad.		Net rad.	PAR	UVB
			in (W m^{-2})	out (W m^{-2})	in (W m^{-2})	out (W m^{-2})	(W m^{-2})	(µmol s^{-1} m^{-2})	(mW m^{-2})
January	–0.01	0.90	4.3	3.8	243.8	274.0	–31.2	11.7	0.2
February	–0.06	0.90	17.7	15.9	239.9	271.4	–30.6	46.6	1.0
March	–0.11	0.93	72.4	64.7	222.3	247.4	–26.7	172.7	4.4
April	–0.11	0.86	159.8	136.7	260.8	290.6	–5.4	390.6	12.8
May	–0.11	0.70	239.6	167.0	270.5	306.9	36.4	568.4	23.1
June	0.21	0.13	203.9	27.2	304.0	354.2	126.5	475.8	21.4
July	0.31	0.15	263.7	41.4	300.0	384.1	134.3	594.9	26.0
August	0.33	0.16	181.2	30.5	306.1	369.5	87.3	389.9	15.5
September	0.28	0.15	80.3	14.0	292.0	328.7	29.9	175.6	5.7
October	0.05	0.52	24.6	11.1	253.9	298.4	–28.0	60.1	2.0
November	–0.11	0.96	7.1	6.7	220.4	261.0	–39.8	19.2	0.4
December	–0.03	0.89	1.8	1.7	240.3	279.7	–39.2	5.2	0.1

2.2 River water discharge

Hydrometric stations

In 2009, hydrological measurements were carried out at five places in the Kobbefjord area. Two hydrometric stations were established in 2007, and divers are each year deployed in three minor rivulets to Kobbefjord. The drainage basins of the five locations cover 58 km^2, corresponding to 56 % of the 115 km^2 catchment area to Kobbefjord.

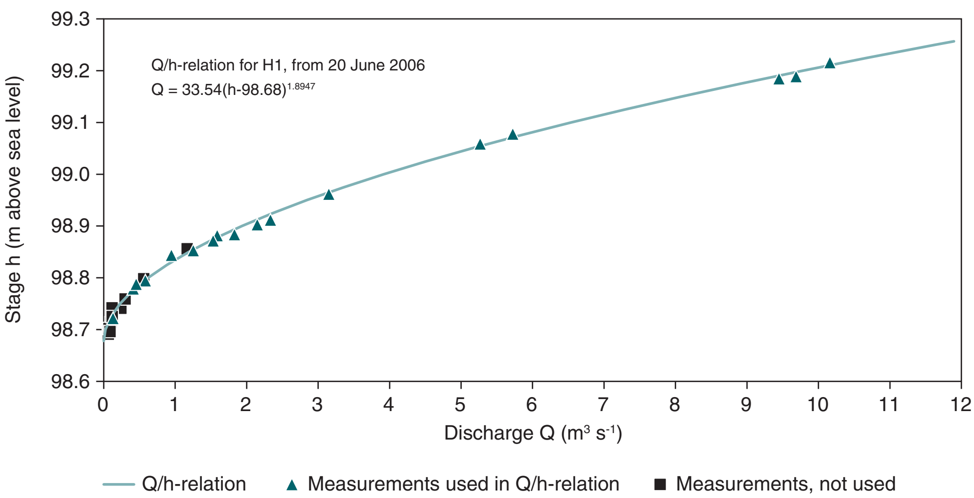
In figure 2.1, the location of the hydrometric stations (H1, H2) and the diver stations (H3, H4, H5) can be seen. For further descriptions of the stations and their respective drainage area, see Jensen and Rasch 2009. For descriptions of the hydrometric stations, see Jensen and Rasch 2008.

Q/h-relation

Manual discharge measurements were carried out at station H1, H3, H4 and H5 (respectively 14, 4, 4 and 4 times) during 2009, with the purpose of establishing a stage-discharge relation (Q / h-relation). It is generally recommended to base a Q / h-relation on a minimum of 12-15 discharge measurements covering the water levels normally observed at the station (ISO 1100-2, 1998). For H2, H3, H4 and H5 these numbers of discharge measurements have still not been carried out. Therefore, data from these stations are not presented.

In 2009, 14 discharge measurements were carried out at H1. Six of the measurements were carried out during winter when the outlet was influenced by snow and ice. The hope for 2009 was to measure discharge at high water levels. As

Figure 2.3 Discharge – water level relation curve (Q/h-relation) at the hydrometric station H1. The coefficient of correlation (R^2) for the curve is 0.998.



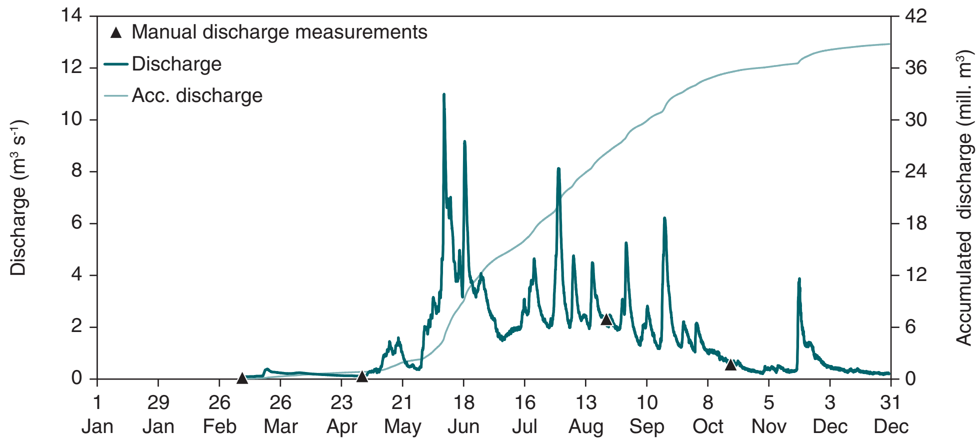


Figure 2.4 River water discharge at H1 during 2007.

2009 was very dry with almost no rain we had almost given up, but a snowfall in late September followed by rain and temperatures above zero gave high water levels. On 30 September and 1 October, five discharge measurements were carried out during falling water. With the measurements carried out in 2009, the manual discharge measurements spans over water levels ranging from 0.07 to 10.16 m^3 s^{-1} (discharges under ice-free conditions range from 0.13 to 10.16 m^3 s^{-1}). The total measured span in water level under ice free conditions during 2006 to 2009 are 0.54 m (differs from earlier publication).

A new Q / h-relation was established after the 2009 season. Manual discharge measurements now cover the total span of the registered water levels and accordingly the Q / h-relation is considered final. The Q / h-relation for H1 is shown in figure 2.3.

River water discharge at H1

Figures 2.4 and 2.5 shows the re-evaluated discharges from H1 in 2007 and 2008, while figure 2.6 shows data from 2009. The re-evaluated data has been calculated by use of the new Q / h-relation. During the period March 2007 to February 2010, eleven measurements have been carried out when the outlet was affected by ice and / or snow. These measurements indicate that the Q / h-relation based on discharges measurements made under ice and snow free conditions can be used under normal winter conditions (periods without heavy thaw and rain events) to estimate the discharge accurately but will overestimate the discharge during thaw and rain.

In 2009, the period with ice / snow free conditions at the outlet was from 28 May to 22 October.

The total discharge from H1 during the hydrological year from 1 October 2008 to 30 September 2009 was 39.2 million m^3, which is 17 % lower than in 2007 / 2008. The total discharge corresponds to a runoff of 1265 mm when assuming that the drainage basin covers 31 km^2. The peak discharge (12.0 m^3 s^{-1}) was recorded 27 June and was caused by precipitation. July and August were rather dry with almost no precipitation. After a small peak 15 July caused by melting of the snow in the

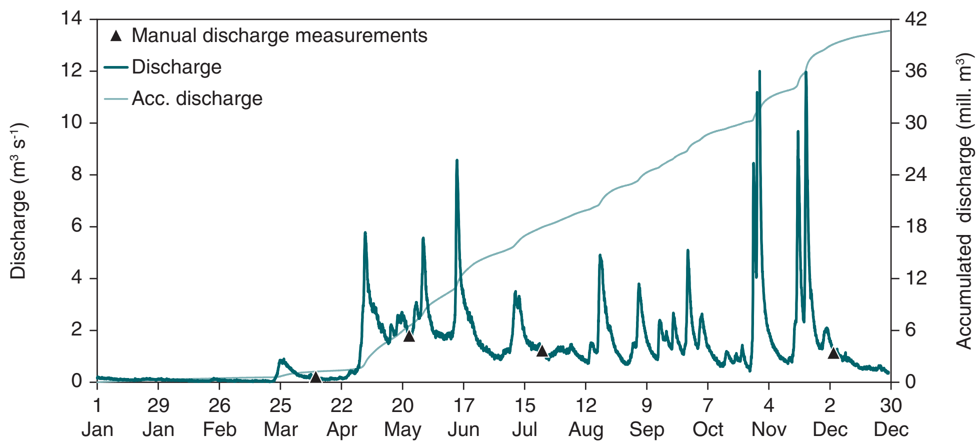


Figure 2.5 River water discharge at H1 during 2008.

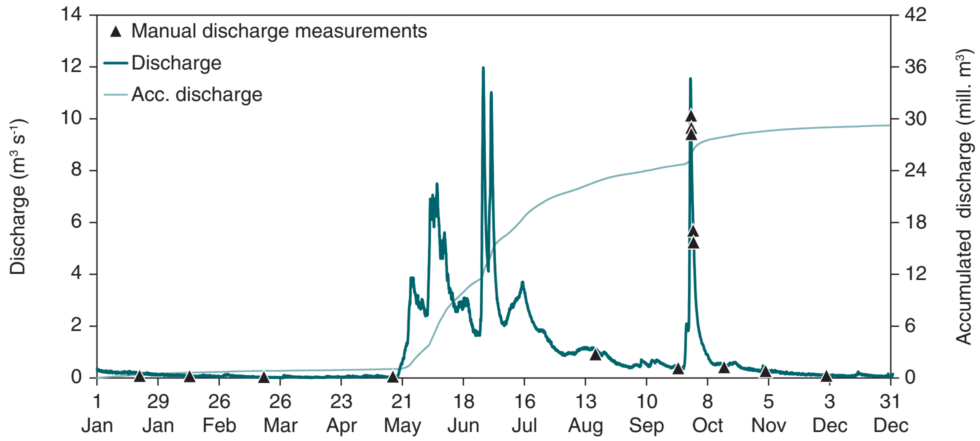


Figure 2.6 River water discharge at H1 during 2009.

higher lying areas of the catchment, the discharge decreased almost continuously to 0.36 $m^3 s^{-1}$ on 27 September. During 26 September, it started to rain and the temperature rose to above 0 °C resulting in melting of the 11 mm w.e. snow precipitation. The following days the temperature remained above 0 °C, and rain continued almost constantly until 1 October which caused the discharge to rise to 11.6 $m^3 s^{-1}$ (30 September) before falling to approximately 1 $m^3 s^{-1}$ a week later. After this event, only small variations in the discharge were recorded as most precipitation fell as snow.

A comparison of discharge with precipitation has been made for the hydrological year 2008 / 2009. The precipitation at the meteorological stations, C1 and C2, was 1285 mm whereas the runoff from H1 equalled 1265 mm. The difference between the precipitation in the catchment and the runoff at H1 is, as can be seen, minimal, but that does not mean that all the hydrological processes in the low arctic area in Kobbefjord are understood. Even though the new Q / h-relation has strongly improved the validity of discharge under ice-free conditions there remain uncertainties when it comes to describing discharges during wintertime. In addition, difficulties in measuring precipitation, especially the geographical distribution, have to be considered. Furthermore, the catchment area has to be recalculated when the digital elevation model for the area is complete. One of the aims for the ClimateBasis programme 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.

3 Nuuk Basic

The GeoBasis programme

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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 2009 operated by the Department of Geography and Geology, University of Copenhagen and the Department for Arctic Environment, National Environmental Research Institute at Aarhus University. GeoBasis was in 2009 funded by the Danish Ministry for Climate and Energy 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 automated stations.

The 2009 season is the second full season of the GeoBasis programme. In 2007, the field programme was initiated during a three-week intensive field campaign in August when 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 ran into unforeseen problems (e.g. very strong winds that destroyed several installations, build up of snowdrift in front of cameras, high levels of melt water in the snow pack with subsequent flooding of data logger etc.). Although these unforeseen problems have caused gaps in the data series, most of the experienced problems have been 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 in the central parts of the Kobbefjord drainage basin. Lack of information on the snow conditions at the cameras positions resulted in K3 and K4 to be installed to close to the ground, and subsequently a big snowdrift from mid-February to late June 2008 covered them. In 2009, these cameras melted free around 1 July. In September 2009, both cameras were elevated 2 m above the ground but the field of views are kept alike (figure 3.1). In the same operation, the last two snow monitoring cameras (K5 and K6) were installed. Both cameras were installed at 770 m a.s.l. (N64 °9'06.25'' W51 °20'46.47'') (figure 3.2). K5 monitors Qassisø in the northern valley of the drainage basin while K6 is facing south monitoring the central parts of the drainage basin including Badesø and Langesø.

One of the main advantages of camera-based snow monitoring is that it is relatively insensitive to cloud cover (in contrast to satellite-based techniques). Only low clouds and foggy conditions can make the image data unsuitable for mapping purposes. A new updated and more user-friendly algorithm for snow cover monitoring has been developed in MatLab, making it possible for each melting season to construct snow cover depletion curves for user specified regions of interest (ROI) on the basis of image data obtained at daily frequency. Figure 3.3 show the results for three ROI at respectively 200, 250 and 300 m a.s.l. seen from camera K2. The ROI at 300 m a.s.l. is facing west against the dominating wind direction which causes a smaller snow accumulation and an earlier

Figure 3.1 Reinstallation of snow camera K3 500 at 530 m a.s.l. (N64°7´21.27" W51°22'18.60"). The old placing is seen to the right. The new camera has been raised approximately 2 m above the terrain to avoid snow formation in front of the camera. Photo: Karl Martin Iversen.

snowmelt with 50 % of the snow cover gone by 2 May in 2008. A more extensive snowfall during the winter and spring 2008/2009 caused a delay in the snow melt, and 50 % snow cover was reached 23 days later in 2009 compared to 2009. The ROI's at 200 and 250 m a.s.l. are facing to the north which cause a leeward accumulation of snow and a much later snowmelt due to a shading effect from the surrounding mountains. An altitudinal delay of four days in the snowmelt is also seen in figure 3.2, where the 50 % snow cover fraction in 2009 is reached 16 and 20 days later in the regions of interest (200 and 250 m a.s.l.).

Snow cover

Due to logistical problems, snow cover depths and snow densities in the Kobbefjord drainage basin were only surveyed on 15 and 16 April 2009 using a combination of ground penetrating radar and manual stake measurements.

In order to compensate for the lack in temporal monitoring the spatial monitoring was extended to three new transects. The three new transects were established close to the three soil monitoring stations, SoilFen, SoilEmpSa and Soil Emp. In order to achieve a precise geographical reference of the GPR measurements, the transects were established using a Leica SR530 RTK GPS which received corrections from a GPS base placed on the reference point KOBBEFJORDFIX. This yielded a horizontal precision of a few centimetres for the section nodes. Each of the three transects had four line sections as displayed in figure 3.4 and the section nodes were labelled 1-5. The four line sections (1-2, 1-3, 1-4 and 1-5) were measured both with the GPR with a spatial resolution of 20 cm and with manual stake measurements for every 10 m. Close to Position 1 at each of the three sites, a snow pit was dug to investigate density, texture and temperature.

Table 3.1 Snow depths, densities, temperatures and water equivalents at the three soil stations (SoilFen, SoilEmp and SoilEmpSa) measured 15 and 16 April 2009.

Site	Snow pit depth (cm)	Avg. density (kg m^{-3})	Snow depth (min-avg.-max) (cm)	Standard dev. of snow depth (cm)	Avg. snow temperature (°C)	Avg. water eq. (mm)
Soil Fen	98.0	260	64–91–128	10	n.a.	237
Soil *Empetrum*	85.0	323	68–102–163	18	–1,7	329
Soil *Empetrum Salix*	65.0	306	37–90–150	21	–0,9	275

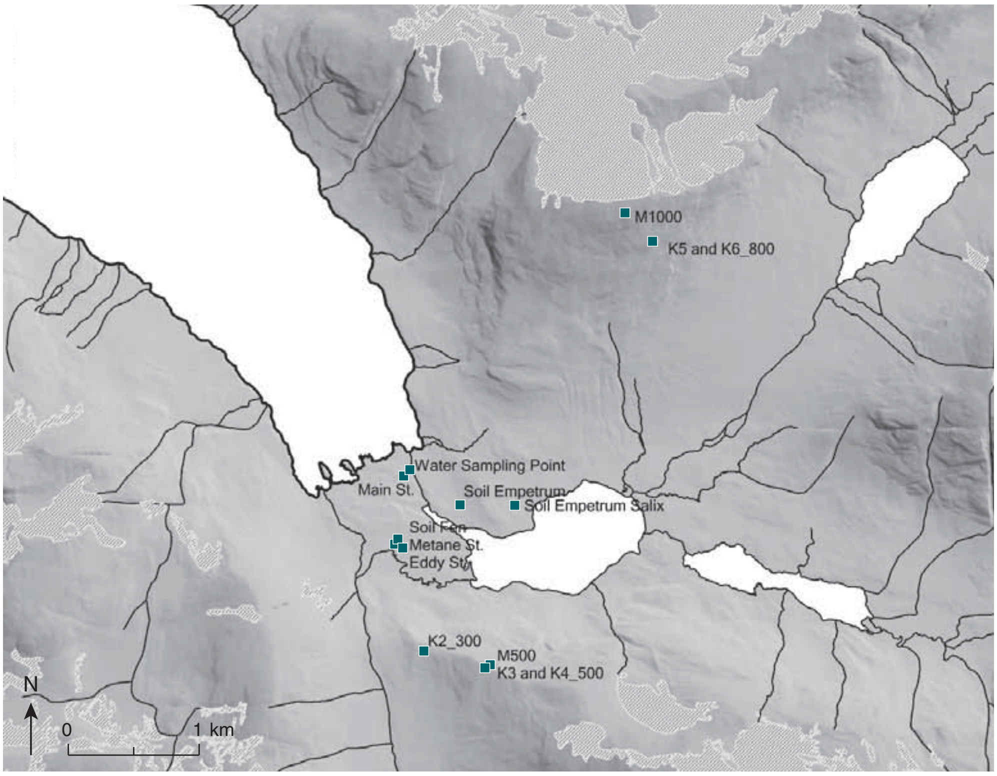


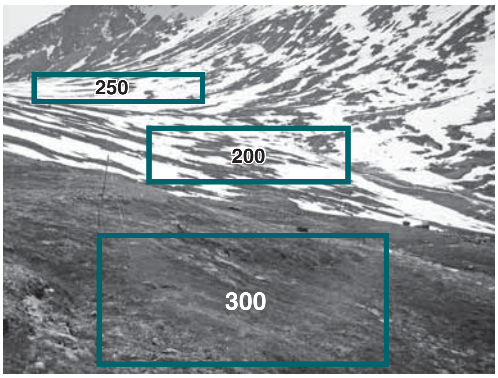
Figure 3.2 Location of GeoBasis stations in Kobbefjord. The base map is created from new elevation and feature data.

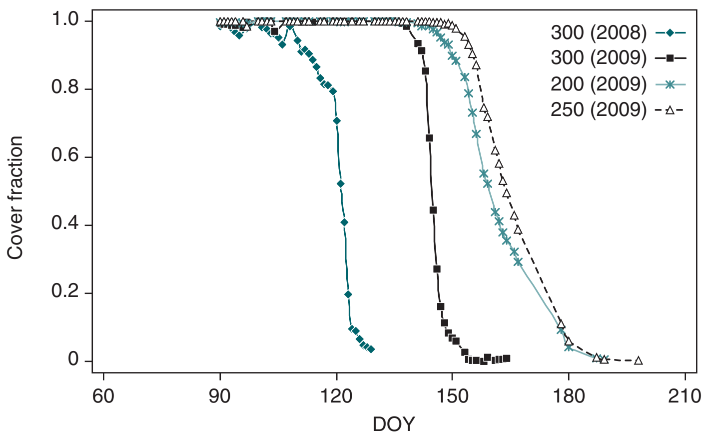
Snow depths varied from 37 cm to 163 cm at maximum snow cover. Table 3.1 summarizes the depth and density results from the three snow pits. The SoilFen site had the lowest snow density with only 260 kg m^{-3} (STD = 10 cm) and a maximum snow depth of only 128 cm. SoilEmp had the deepest maximum snow depth (163 cm) and the highest snow density of 323 kg m^{-3} (STD=18 cm). The SoilEmpSa site had the smallest snow depth of only 37 cm (STD = 21 cm). 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 metres.

Ice cover

The ice cover on the lakes within the drainage basin broke up in early to late June 2009, i. e. 11-13 days later than 2008 (table 3.2). The smaller lake 'Langesø' in the sheltered bottom of the main valley melted first, followed by 'Badesø' two days later and the higher situated 'Qassisø' a week later. The dates reported are visually estimated dates for 50 % ice cover based on photos from the automatic cameras. Dates for the perennial formation of ice are also estimated. Sea ice cover in Kobbefjord developed later but timing was difficult to estimate in 2008 due to ice on the camera lenses. No sea ice was observed during the last visit

Figure 3.3 Snow cover depletion for three regions of interest (at approximately 200, 250 and 300 m a.s.l.) have been analysed using a new snow cover algorithm. The regions are specified on the image to the left, and the depletion curves for each region are shown in the diagram to the right. DOY (day of year).





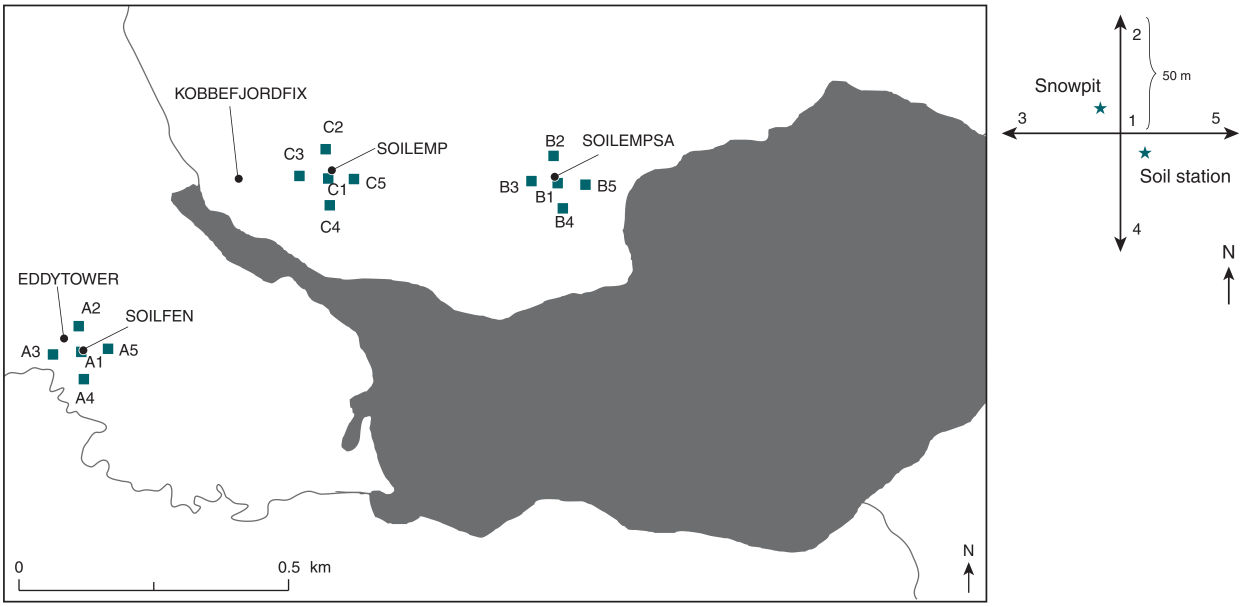


Figure 3.4 Map showing the three snow survey sites. The figure, on the right, outlines the strategy at each site.

to Kobbefjord 17 November 2008, but reports from visitors in the area stated sea ice 100 metres from the shore-line at the bottom of the fjord 4 December. A 3000-meter wide and 30 cm thick sea ice cover was reported 20 January and again 12 February 2009. The fjord was ice-free again 4 June 2009.

Micrometeorology

GeoBasis operates three micrometeorological stations in the area i.e. 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 4 September 2008. The new station is identical to M500 and includes air temperature, relative humidity, incoming short wave radiation and surface temperature. Unfortunately, the mast and several sensors on M1000 were damaged in a severe storm in January 2009. On 15 October 2009, a new installation replaced the existing M1000 at 1000 m a.s.l. (figure 3.5). The new station was installed in collaboration with ClimateBasis, and the station serves as both a microclimate station and a data communication link to Nuuk.

The purpose of the three stations is to monitor dynamics within the atmospheric boundary layer (as for example temperature inversions). Table 3.3 shows temperature gradients and frequency of inversion in the first year with temperature measurements at both SoilFen and M500. The normal temperature lapse rate with decreasing temperatures with altitude prevalls in 84 % of the time on an annual basis. Inversion prevalled up to 33 % of the time in March due to shadows from the surrounding mountains, and due to snow cover leading to radiative cooling in the valley floor. The spring period before snow melt also has the longest occurrence of inversions with 33 hours as a maximum in March. The autumn has the lowest occurrence of inversions with only 1 % in September and with a maximum of only three hours.

*Table 3.2 Visually estimated dates for 50 % ice cover on selected lakes within the Kobbefjord drainage basin and in Kobbefjord. Dates are reported for perennial formation of ice cover in the autumn and for the break-up of ice cover in spring. ´Badesø´ is the main lake in the area. ´Langesø´ is the long lake in the valley behind ´Badesø´. ´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 ice formation on Kobbefjord in 2008.*

	2007	2008	2008	2009
	Fall	**Spring**	**Fall**	**Spring**
Badesø	23 Oct	2 Jun	5 Nov	13 June
Langesø	22 Oct	31 May	5 Nov	11 June
Qassi-sø	22 Oct	9 June	4 Nov	22 June
Kobbefjord	Between 27 Dec and 12 Feb*	15 May	After 17 Nov	4 June

Figure 3.5 A new micro-meteorological station (M1000) was installed at 1000 m a.s.l. in October 2009. Photo: Karl Martin Iversen.

3.2 Soil

Soil water chemistry is likely to be affected by physical and chemical changes in the environment and 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 such analyses plant nutrient status and ongoing soil forming processes are followed. In addition, physical dynamics are monitored by continuous measurements of variables like soil water content and soil temperature.

Physical soil properties

The continuous monitoring of soil physical properties at the three different locations SoilEmp, SoilEmpSa and SoilFen has now continued for more than a full year. The stations have been continuously maintained to assure data quality, see procedures in Iversen et al. 2010.

The results of selected parameters are summarized in tables 3.6, 3.7, and 3.8. Already the monitoring has documented important differences between all three soil stations. For example, the winter soil temperatures at the SoilFen site are higher than

Table 3.3 Monthly air temperature gradients between SoilFen station (40 m a.s.l.) and M500 (550 m a.s.l.). Frequency and duration of inversions are shown in % and hours, respectively.

Month-year	Decreasing lapse rate with altitude		Increasing lapse rate with altitude		Mean lapse rate	Longest period with inversion
	(°C per 100 m)	(% of time)	(°C per 100 m)	(% of time)		(hours)
2008						
August	–0.71	90	0.30	9	–0.61	16
September	–0.79	99	0.15	1	–0.78	3
October	–0.70	92	0.32	8	–0.62	20
November	–0.71	92	0.31	8	–0.62	7
December	–0.65	87	0.27	12	–0.54	7
2009						
January	–0.61	80	0.31	19	–0.43	17
February	–0.54	79	0.35	19	–0.36	20
March	–0.59	67	0.56	33	–0.21	33
April	–0.65	77	0.63	22	–0.36	21
May	–0.68	87	0.33	13	–0.55	9
June	–0.73	85	0.46	15	–0.55	15
July	–0.62	69	0.50	30	–0.28	15
Annual	–0.66	84	0.38	16	–0.49	15

Table 3.4 Air temperature, relative humidity, surface temperature and short wave irradiance measured at the M500 station from October 2008 to August 2009. (The data from September to December 2009 are not yet retrieved).

Month–year	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface irradiance temp. 0 m (°C)	Shortwave irrradiance 2.5 m (W m^{-2})
2008				
October	–3.2	77.6	–6.2	38.0
November	–5.0	91.5	–6.2	8.5
December	–10.8	82.2	–13.0	3.3
2009				
January	–7.7	72.0	–11.5	6.9
February	–8.1	69.7	–11.8	30.1
March	–13.1	76.5	–16.1	95.1
April	–5.3	83.9	–7.6	166.9
May	–2.5	79.9	–3.1	254.2
June	3.4	83.2	5.5	220.7
July	8.8	67.8	11.0	287.7
August	7.3	77.4	8.4	194.2

at both the SoilEmp and SoilEmpSa sites. The soil stations have also documented inter-annual variations – among them the likely effect of less snow cover in the last quarter of 2009. In this period soil temperatures in the upper 30 cm averaged –1.0 °C at the SoilEmp site compared to 0.3 °C in 2008. The same comparison with the air temperature reveals that the last quarter of 2009 was 0.5 °C colder than in 2008.

In addition, the progression of soil water content has been recorded to be different among the soil stations. The *Empetrum* dominated site is well drained and retained less moisture than the *Empetrum-Salix* dominated site. In 2009 only 6 mm precipitation was recorded in July and August, and the *Empetrum* dominated site quickly dried out. However, at the *Empetrum-Salix* dominated site, the soil water content was generally higher and retained for a longer period.

Soil water

In 2009, thirty soil water samples were collected from two depths at the SoilFen site and at the SoilEmp site. The results from the analysis of the physical chemistry in the soil water are not yet ready. The small laboratory in Kobbefjord will make analyses of soil water pH and alkalinity easier, and in 2010, GeoBasis will accordingly try to streamline the procedures used for soil water chemistry.

River water

In 2009, 45 river water samples were collected at the water sampling point (figure 3.2), with the purpose of analyzing for mercury (Hg) content. Results from these analyses are reported separately in section 6.8. Simultaneous with the sampling, GeoBasis also measures river water temperature, conductivity and pH. These parameters are presented in figure 3.6. The river water has an average conductivity of 19.8 µS cm^{-1} and there is a tendency towards a lower pH in the snow melt period, although all pH values are close to neutral.

Digital Elevation Model

In December 2009, Asiaq – Greenland Survey received a new and precise digital elevation model (DEM) with a spatial resolu-

Table 3.5 Air temperature, relative humidity, surface temperature and short wave irradiance measured at the M1000 station from October 2009 to December 2009.

Month 2009	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface irradiance temp. 0 m (°C)	Shortwave irrradiance 2.5 m (W m^{-2})
October	–6.2	90.1	–6.8	25.5
November	–10.4	67.4	–13.2	15.8
December	–5.2	55.4	–10.2	4.5

Table 3.6 Air temperature, relative humidity, surface temperature and soil temperatures at four depths measured at SoilFen from October 2008 to December 2009.

Month-year	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface temp. 0 m (°C)	Soil temp. –1 cm (°C)	Soil temp. –10 cm (°C)	Soil temp. –30 cm (°C)	Soil temp. –50 cm (°C)	Soil temp. –75 cm (°C)
2008								
October	–0.1	69.3	–2.4	0.1	0.9	2.6	2.9	3.5
November	–1.9	79.8	–4.4	–0.1	0.2	1.3	1.6	2.1
December	–8.1	71.8	–11.9	–0.2	0.1	1.0	1.2	1.6
2009								
January	–5.5	67.6	–10.1	–0.2	0.1	0.9	1.1	1.4
February	–6.2	69.3	–10.7	–0.3	0.0	0.7	0.9	1.2
March	–12.0	73.7	–16.8	–0.5	–0.1	0.6	0.7	1.1
April	–3.4	78.8	–6.7	–0.2	–0.1	0.5	0.7	1.0
May	0.3	71.7	–3.3	0.0	0.0	0.5	0.7	1.0
June	6.3	76.6	7.2	7.0	4.7	2.6	2.3	2.0
July	10.2	72.1	13.1	14.3	12.7	8.7	7.8	6.3
August	8.7	77.2	10.1	10.8	10.6	9.1	8.6	7.7
September	3.5	73.9	2.9	3.9	4.7	5.8	5.9	5.9
October	–0.7	69.2	–3.2	–0.2	0.5	2.2	2.5	3.1
November	–8.1	74.2	–13.6	–0.3	0.0	1.1	1.4	1.9
December	–2.9	61.0	–8.7	–0.6	–0.2	0.8	1.0	1.5

Table 3.7 Soil temperature and soil moisture at four depths measured at SoilEmp from October 2008 to December 2009.

Month-year	Soil temp. –1 cm (°C)	Soil temp. –5 cm (°C)	Soil temp. –10 cm (°C)	Soil temp. –30 cm (°C)	Soil moist. –5 cm (%)	Soil moist. –10 cm (%)	Soil moist. –30 cm (%)	Soil moist. –50 cm (%)
2008								
October	0.3	0.5	0.7	1.1	18	39	24	20
November	0.2	0.3	0.4	0.6	29	45	33	31
December	–0.2	0.0	0.1	0.3	10	34	16	14
2009								
January	–0.9	–0.7	–0.5	–0.1	2	12	4	3
February	–1.3	–1.1	–1.0	–0.5	1	9	2	2
March	–2.5	–2.3	–2.2	–1.7	1	7	1	1
April	–1.4	–1.4	–1.3	–1.1	1	8	1	1
May	0.0	0.0	0.0	0.0	14	21	15	14
June	7.5	7.0	6.7	5.6	32	45	40	41
July	12.4	11.8	11.5	10.4	9	35	14	12
August	10.3	10.1	10.0	9.5	3	17	4	3
September	4.0	4.4	4.6	5.0	6	26	6	5
October	–0.5	–0.3	–0.1	0.4	12	25	17	15
November	–1.5	–1.3	–1.1	–0.4	2	13	3	3
December	–1.9	–1.8	–1.7	–1.2	1	10	2	2

Table 3.8 Soil temperature and soil moisture at four depths measured at SoilEmpSa from October 2008 to December 2009.

Month-year	Soil temp. –1 cm (°C)	Soil temp. –5 cm (°C)	Soil temp. –10 cm (°C)	Soil temp. –30 cm (°C)	Soil moist. –5 cm (%)	Soil moist. –10 cm (%)	Soil moist. –30 cm (%)	Soil moist. –50 cm (%)
2008								
October	---	---	1.4	1.6	60	55	49	51
November	---	---	0.7	0.8	61	55	49	51
December	---	---	0.3	0.5	58	48	48	50
2009								
January	---	---	–0.4	0.2	37	27	41	38
February	---	---	–1.1	–0.3	15	13	33	32
March	---	---	–1.5	–0.7	13	12	12	25
April	---	---	–0.4	–0.2	15	13	13	14
May	---	---	0.1	0.0	30	21	17	16
June	---	---	4.1	3.5	59	52	38	35
July	---	---	11.0	9.5	51	42	45	45
August	---	---	10.3	9.1	40	30	38	33
September	---	5.3	5.0	5.5	---	32	38	33
October	0.4	0.9	0.8	1.0	60	53	44	48
November	–0.4	0.2	–0.1	0.3	52	37	41	42
December	–0.7	–0.2	–0.4	–0.1	28	21	38	35

tion of 10×10 m and with mapped features such as coast line, lakes, glaciers, rivers, and buildings (figure 3.2). Collaboration between Asiaq – Greenland Survey and GeoBasis has been established to check the quality of the data before distributing the DEM to interested users through http://www.nuuk-basic.dk.

3.3 Vegetation

Vegetation in the Kobbefjord area is monitored by both the BioBasis and GeoBasis programmes. BioBasis monitors individual plants and plant phenology using plot scale sites and transects. GeoBasis monitors the phenology of the vegetation communities by use of satellite images.

Satellite imagery

Successful acquisition of satellite imagery requires cloud free conditions. In 2009, the conditions for a successful acquisition were met on 17 July, which happened to be the same date as the image acquired in 2008. Unfortunately, this is almost two weeks from the maximum of growth (see section 4.1) and the reasons for inter-annual differences between greenness are therefore difficult to access although a comparison will give an indication of inter-annual

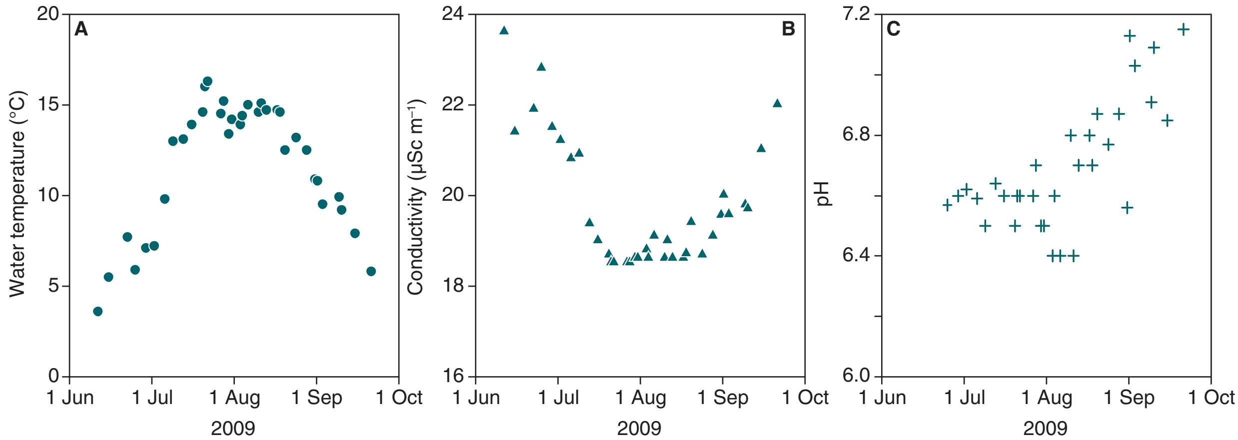


Figure 3.6 A) River water temperature, B) conductivity and C) pH measured at the water sampling point by the main station (conductivity measurements are temperature compensated with a standard temperature coefficient of 2.1 % per °C).

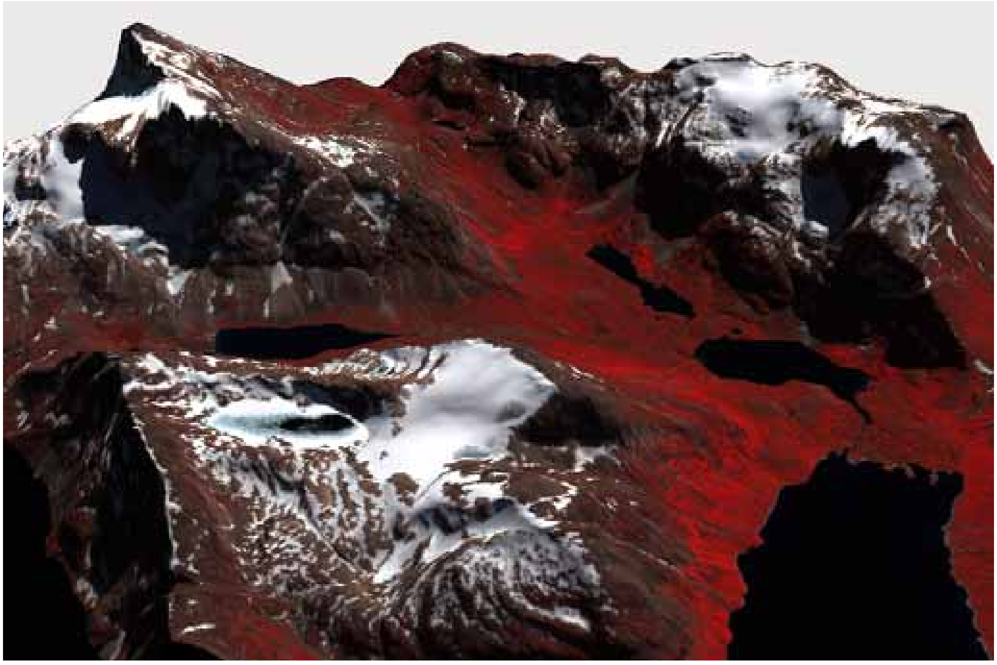


Figure 3.7 QuickBird imagery from 17 July 2009 draped on the new digital elevation model. The false colour representation used here enhances the vegetation in red, bare surface in brown and snow in white colours.

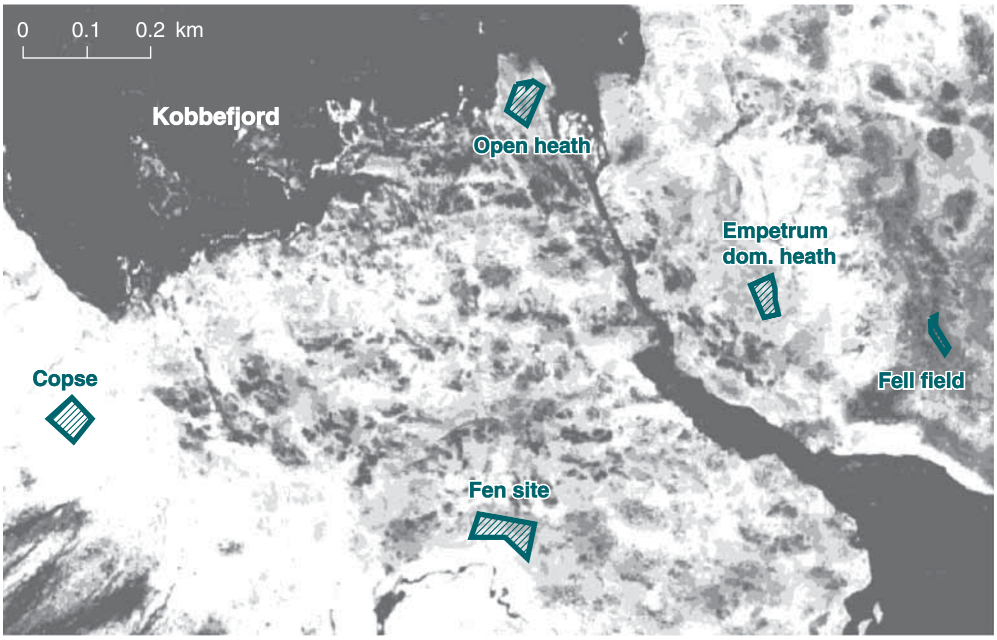


Figure 3.8 Normalised Difference Vegetation Index (NDVI) from 17 July 2009 covering the central part of the Kobbefjord monitoring area and with boxes for the five different vegetation types shown in figure 3.9. Data is atmospherically corrected but lack the topographic correction.

differences in greenness. A QuickBird multispectral image with 2.4 m resolution was acquired and geo-rectification carried out. Atmospheric correction was performed but without topographic correction as the preliminary version of the high resolution, digital elevation model was available only shortly before the deadline of this report. Figure 3.7 shows an example of the QuickBird imagery from 17 July 2009 draped on the preliminary DEM.

Normalised Difference Vegetation Index (NDVI) has been calculated from the imagery 17 July 2009. A subset of the central part of the monitoring area is shown in figure 3.8. The areas on the imagery represent five different vegetation types from the area i.e. fell field, open mixed heath; *Empetrum* dominated heath, fen, and copse. In future reports, the fully pre-processed imagery will be used for extracting NDVI values in these different regions at the time of peak greenness.

Figure 3.9 shows the difference in NDVI for the five different vegetation types (Notice that images are not topographically corrected and that date of acquisition is outside the maximum greenness peak). Only the fell field area has a tendency to lower NDVI in 2009 than in 2008. All the other types have a higher NDVI in 2009. Although direct compari-

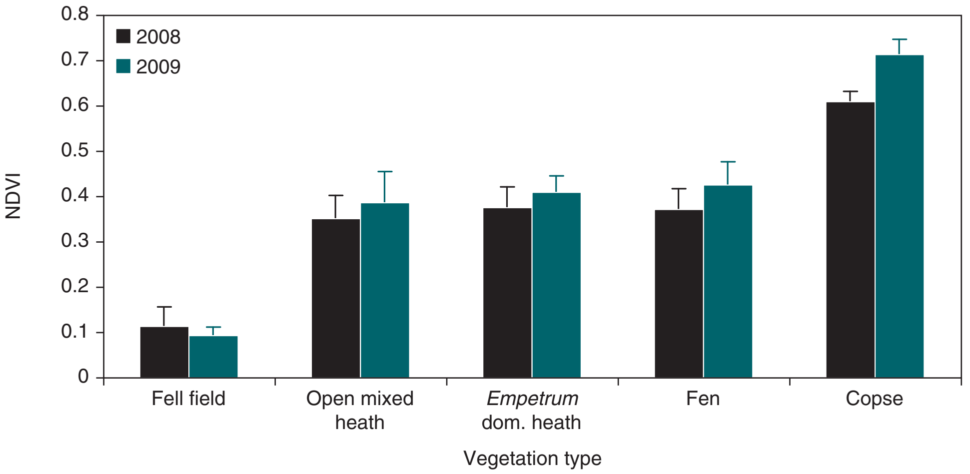


Figure 3.9 NDVI from 17 July 2008 and 2009 for the five different vegetation types. Notice that changes between greenness are due not only to phenology differences between years but also to seasonal phenology as the image is acquired approximately two weeks before the maximum greenness occurs.

son is difficult, these results are similar to the results made by hand held measurements by the BioBasis programme along the NERO-line (see chapter 4).

3.4 Carbon gas fluxes

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

- Automatic chamber measurements of the CH_4 and CO_2 exchange on plot scale
- Eddy covariance measurements of the CO_2 and H_2O exchange on landscape scale

Automatic chamber measurements

An automatic chamber system consisting of six flux chambers for monitoring of the exchange of CH_4 and CO_2 was installed in August 2007 (Tamstorf et al. 2008). Due to technical problems, only data on the CH_4 exchange is reported here (figure 3.10). In 2009, the system was operated from 2 July to 17 October. Gaps in data originate from maintenance, calibration and malfunction due to various errors such as fox bites and instrument failures.

The spatial and temporal variation in CH_4 emissions is primarily related to temperature, water table depth and net primary production. The fen in Kobbefjord is a source of CH_4 due to the permanently wet conditions that promote anaerobic decomposition of which CH_4 is a product.

The observed temporal CH_4 flux pattern in 2009 was similar to the pattern observed in 2008; i.e. a dome-shaped peak with a maximum approximately one month after snow melts. However, the emissions in 2009 were generally higher compared to 2008. The peak summer emissions were approximately 8 mg CH_4 m^{-2} h^{-1} in 2009, compared to 5 mg CH_4 m^{-2} h^{-1} in 2008. One explanation for this phenomenon may be that the primary production was higher in the fen in 2008 compared to 2009 (see next section and figure 3.11) resulting in more carbon in the soil to be converted into CH_4. The peak summer

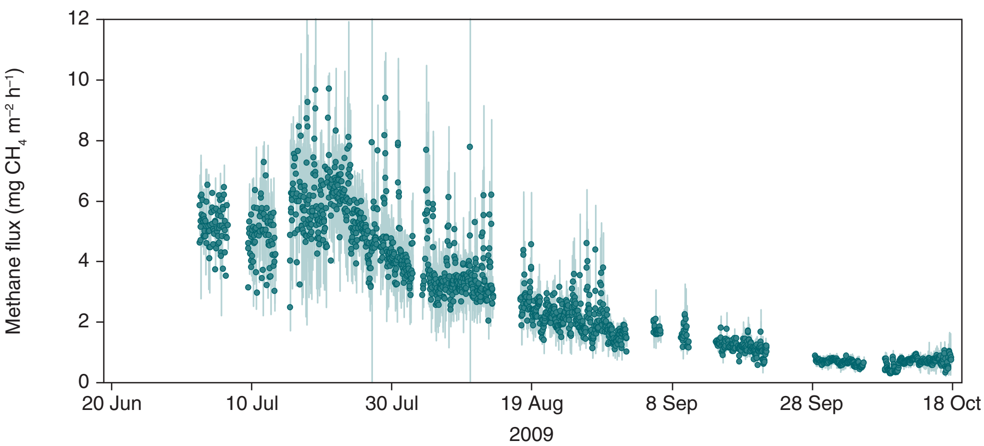


Figure 3.10 Methane (CH_4) emissions from the fen during summer and autumn 2009.

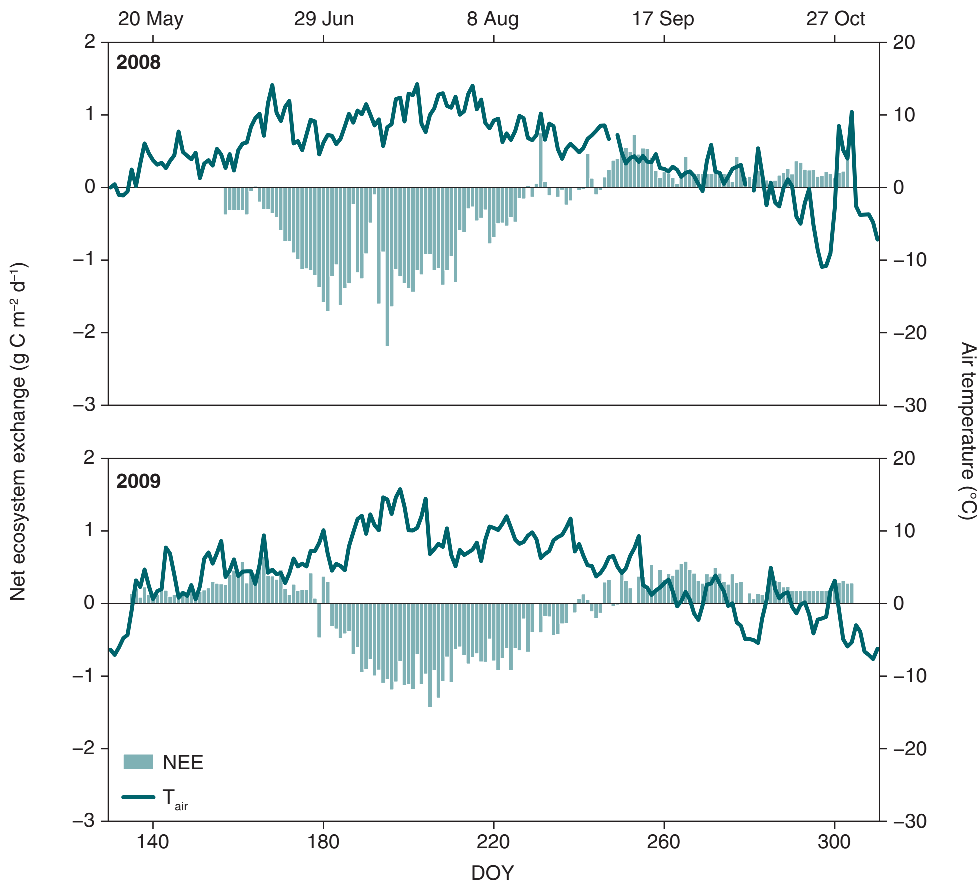


Figure 3.11 Diurnal net ecosystem exchange (NEE) and air temperature (T_{air}) measured in the fen in 2008 (upper panel) and 2009 (lower panel).

CH_4 emissions from the fen in the Kobbefjord area are comparable to the emissions in a fen in Zackenberg, NE Greenland. Since we lack measurements from the start of the season in 2009, the annual CH_4 budget cannot be estimated.

Eddy covariance measurements

In order to describe the inter-annual variation of the seasonal CO_2 balance, the soil-atmosphere CO_2 exchange in a fen has been monitored using the eddy covariance technique since 2008. The eddy covariance system consists of a 3D sonic anemometer and a closed path infrared CO_2 and H_2O gas analyzer (Tamstorf et al. 2009).

In this report, all eddy covariance data from 2008 from both sites have been calculated using the software package EdiRe (Robert Clement, University of Edinburgh). EdiRe can easily be adapted to cope with various measurement set-ups and allows the user to choose which calculations and corrections to perform. Data post-processing include storage term calculation, screening for low friction velocity (u*) and gap filling using linear interpolation, light response curves and mean diurnal variation.

The temporal variation in the mean diurnal net ecosystem exchange of CO_2 (NEE) and air temperature for the period 2008-2009 for the fen site is shown in figure 3.11 and various variables summarized in table 3.9. NEE refers to the sum of all CO_2 exchange processes including photosynthetic CO_2 uptake by plants, plant respiration and microbial decomposition. The CO_2 uptake is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), whereas respiratory processes are controlled mainly by temperature, soil moisture and the amount of biomass. The sign convention used in figures and tables is the standard for micrometeorological measurements i.e. fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

Eddy covariance measurements of the CO_2 and H_2O exchange in the fen were initiated 15 May and lasted until 31 October. During this period, 10 % of data were lost due to malfunction, maintenance and calibration. When measurements started, the snow depth was 135 cm. All the snow at the site had melted 8 June. Early in

Table 3.9 Summary of the measuring period variables and CO_2 exchanges 2008-2009 in the fen. Please notice that the measuring period varies from year to year.

Year	2008*	2009
Measurements start	5 Jun	15 May
Measurements end	29 Oct	31 Oct
Length of measuring period (days)	146	169
Start of net uptake period	–	1 Jul
End of net uptake period	16 Aug	27 Aug
Length of net uptake period (days)	–	57
NEE for measuring period (g C m^{-2})	–45.5	–14.0
NEE for net uptake period (g C m^{-2})	–	–42.5
Max. daily accumulation (g C m^{-2} d^{-1})	–2.27	–1.48

*Re-calculated compared with 2nd Annual Report 2008 (see text)

the season, before snow had melted and plants began photosynthesizing small CO_2 emissions were measured. Maximum spring diurnal emission was measured 15 June to 0.66 g C m^{-2} d^{-1}. As the vegetation developed, the photosynthetic uptake of CO_2 started, and 1 July, the fen ecosystem switched from being a net source to a net sink of CO_2.

The period with net CO_2 uptake in 2009 lasted until 27 August (table 3.9), which was 11 days later than in 2008. During this period, the fen accumulated 42.5 g C m^{-2}. However, the summer net CO_2 uptake began earlier in 2008 and was generally higher. This may be related to earlier snow melt in 2008 (occurred during late May) allowing plants to establish their photosynthetic apparatus early, and thus enable them to assimilate CO_2 effectively when incoming solar radiation is at its maximum. The air temperatures in May and June were 1.6 °C and 3.5 °C lower, respectively, in 2009 compared to 2008. Altogether this resulted in a lower accumulated uptake and a lower maximum diurnal net CO_2 uptake in 2009 (–1.48 g C m^{-2} d^{-1}) compared to 2008 (–2.27 g C m^{-2} d^{-1}).

By 27 August, respiration exceeded the fading photosynthesis and the system returned to a net source of CO_2. In the beginning of autumn, there is plenty of fresh litter available and soil temperatures remain comparably high, allowing decomposition processes to continue at a decent rate. Highest autumn diurnal emission was measured 22 September (0.60 g C m^{-2} d^{-1}). During the entire measuring period (169 days), the total CO_2 accumulation amounted to –14.0 g C m^{-2}.

4 NUUK BASIC

The BioBasis programme

Katrine Raundrup, Peter Aastrup, Josephine Nymand, Torben L. Lauridsen, Liselotte Sander Johannsson, Paul Henning Krogh, Magnus Lund and Lars Maltha Rasmussen

This is the third report from the BioBasis programme at Nuuk. The report gives an overview of the activities and presents some examples of results. We now have two years of data and we find a high data consistency between years. This indicates that the data and the procedures used are reliable and sound. A thorough statistical analysis will follow when we have longer time series. Methods and sampling procedures are described in detail in the manual 'Conceptual design and sampling procedures of the biological programme of Nuuk Basic' (Aastrup et al. 2009).

The programme was initiated in 2007 by the Department of Arctic Environment, National Environmental Research Institute at Aarhus University, in cooperation with the Greenland Institute of Natural Resources. BioBasis is funded by the Danish Environmental Protection 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 Environmental Protection Agency.

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 plots were set up to cover the ecological amplitude of the species with respect to snow cover, soil moisture and altitude.

Loiseleuria procumbens budding and flowering occurred one to two weeks later in 2009 than in 2008 (figure 4.1). The sequence of flowering by plot was the same as in 2008 with plot Loi4 being the earliest followed by plot Loi1, Loi2, and Loi3.

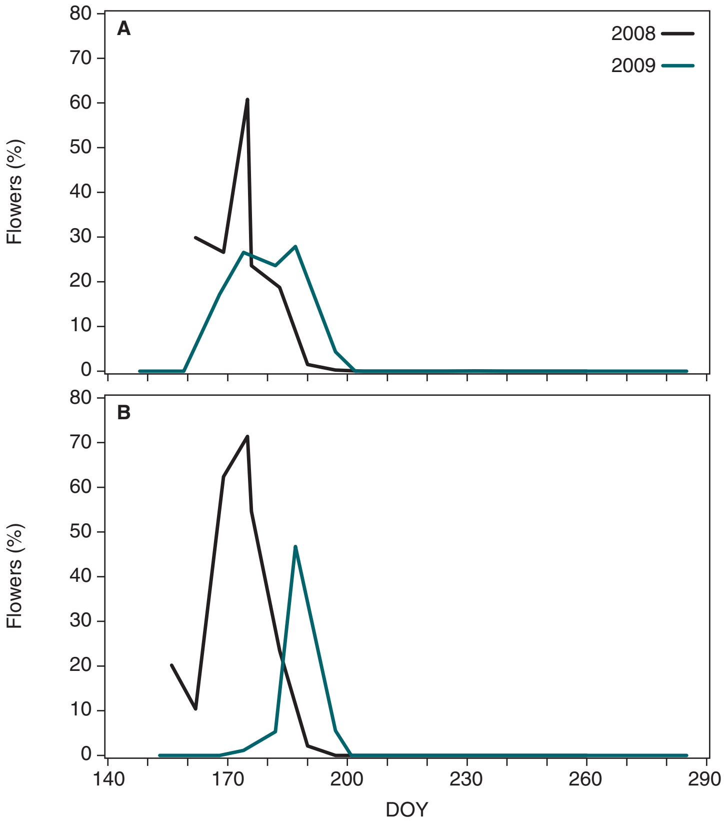


Figure 4.1 The progression in phenology shown as the percentage of flowers by day of year (DOY) in 2008 and 2009. A: Loiseleuria procumbens. *B:* Silene acaulis. *Percentages have been averaged over plots.*

In plot Loi3, we never recorded counts of 50 % flowers. However, the date of 50 % flowers must have been between 6 July and 16 July. The dates of 50 % flowers ranged from 15 June to 4 July (table 4.1).

Flowering in *Silene acaulis* peaked within two days in plot Sil2, Sil3, and Sil4 (figure 4.1 and table 4.1). In plot Sil1, a high proportion of buds were eaten before peak flowering. In 2009, peak flowering occurred about two weeks later than in 2008 without any variation between plots. In 2008, peak flowering date varied only one week within plots. *Silene acaulis* is also monitored in Zackenberg, NE Greenland, and here the date of 50 % flowering varied between years and plots from 13 June to 19 August. This is one to two weeks later than we observed in 2008 in Kobbefjord but almost the same as in Kobbefjord in 2009.

Table 4.1 DOY (day of year) of 50 % flowers (and senecent flowers in Salix glaica*) in plant reproductive phenology plots of* Silene acaulis *3,* Salix glauca *2, and* Loiseleuria procumbens *1 in 2008 and 2009.*

Plot	2008	2009
Loiseleuria procumbens 1	165	175
Loiseleuria procumbens 2	168	185
Loiseleuria procumbens 3	184	–
Loiseleuria procumbens 4	158	166
Salix glauca (f) 1	167	188
Salix glauca (f) 2	168	187
Salix glauca (f) 3	160/167	185
Salix glauca (f) 4	No female flowers	–
Salix glauca (hairs) 1	239/262	246
Salix glauca (hairs) 2	249	262
Salix glauca (hairs) 3	255/264	262
Salix glauca (hairs) 4	No female flowers	–
Silene acaulis 1*	172	*
Silene acaulis 2	172	186
Silene acaulis 3	165	185
Silene acaulis 4	165	186*

*Flowers eaten

The phenological progression in female flowers in *Salix glauca* occurred 19 to 22 days later in 2009 than in 2008, while the progression of formation of hairs followed almost exactly the pattern as seen in 2008 (table 4.1 and figure 4.2).

Phenology of *Salix glauca* in CO_2-flux plots

In 2009, *Salix glauca* produced female flowers in 11 of 30 CO_2-flux plots. In most of the plots, *Salix glauca* specimens produced less than 15 flowers. Most flowers were produced in Control plot C4 (Figure 4.3). In 2009, none of the flowers in this plot produced hairs indicating that no mature seeds were produced. However, hairs were produced in three of the other plots.

Total flowering

The total numbers of flowers in four plant species (*Silene acaulis, Salix glauca, Loiseleuria procumbens,* and *Eriophorum angustifolium*) were counted at peak flowering (table 4.2). Generally, *L. procumbens* and *S. acaulis* produced more flowers in 2009 than they did in 2008, while *E. angustifolium* and *S. glauca* produced less flowers than in 2008.

Summing up reproductive plant phenology

The year 2009 had a later snow melt than 2008, and a preliminary review of data related to flowering and plant reproductive phenology indicates that 2009 was characterised by:

- Later flowering.
- Termination of flowering at the same time as in 2008.
- Shorter flowering season (flowering terminated at almost the same time as in 2008).
- The two species on sparsely vegetated plots, *Silene acaulis* and *Loiseleuria procumbens*, produced more flowers in 2009 than in 2008, while the two species on highly vegetated plots, *Eriophorum angustifolium* and *Salix glauca*, produced less flowers.

Vegetation greening, NDVI

We followed the greening of the vegetation in *Empetrum nigrum ssp. hermaphroditum* plots, in plant phenology plots and along the NERO line. We used a handheld Crop Circle TM ACS-210 Plant Canopy Reflectance Sensor, which calculates the greening index (Normalized Difference Vegetation Index – NDVI). Measurements were made weekly in the *E. nigrum* plots and in the plant phenology plots, and monthly along the NERO line (Bay et al. 2008).

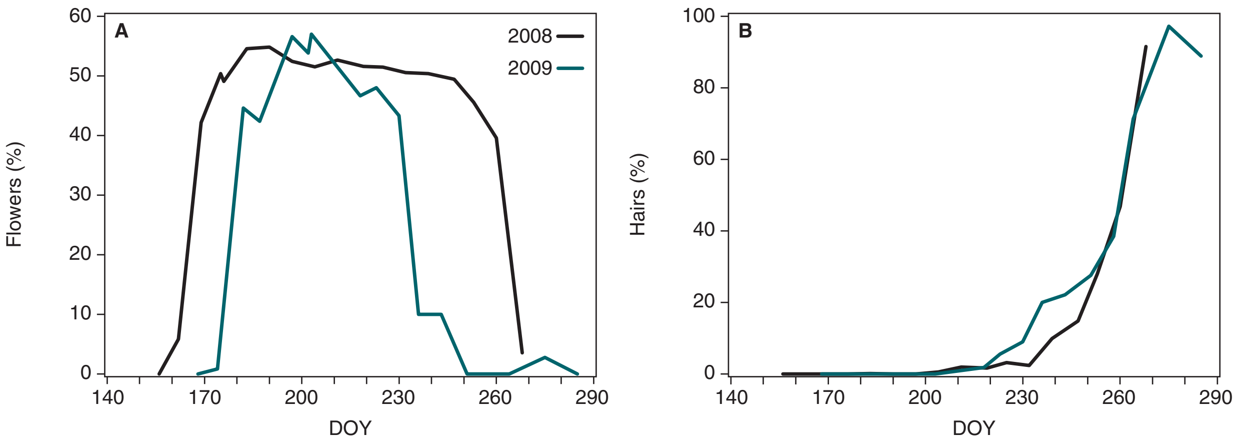


Figure 4.2 A) Salix glauca *flowers and B) senescent flowers in 2008 and 2009 averaged over all plots (1-3 since only male flowers are present in plot 4).*

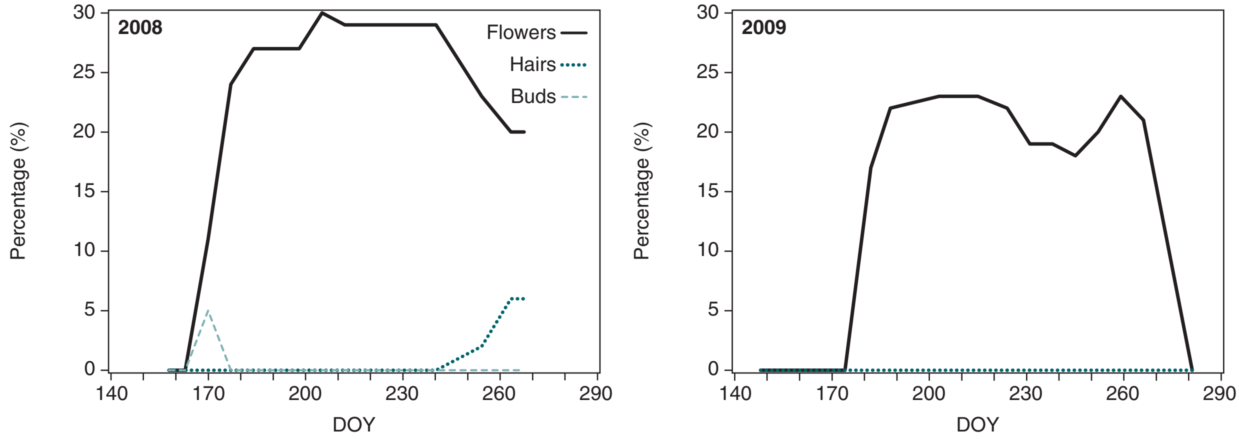


Figure 4.3 Phenology of Salix glauca *in the CO_2-plot control C4 in 2008 and 2009.*

NDVI in *Empetrum nigrum* and plant phenology plots

Vegetation greening followed three different patterns depending on the species monitored. The evergreen *E. nigrum* (figure 4.4a) has no clear peak time of greenness. Plot 4, however, had a weak indication of a peak in both years. *Eriophorum angustifolium* (figure 4.4b) and *Salix glauca* (figure 4.4c) exhibited more or less bell-shaped greening curves with a tendency of later greening in 2009 than in 2008. However, greening seemed to attain higher values in 2009 compared to 2008. *Loiseleuria procumbens* plots have sparse vegetation and greening only show weak time dependence (figure 4.4d). *Silene acaulis* plots have the lowest NDVI-values through all seasons without any dependence of DOY (figure 4.4e).

NDVI along the NERO line

Figure 4.5 outlines the NERO line (Bay et al. 2008) which covers eight vegetation types (dwarf shrub heath, snow patch, herb slope, fen, copse, *Deschampsia-Juncus* community, lake and pond vegetation and salt marsh). Vegetation greenness is measured monthly along a line, 5 m north of the NERO line. Figure 4.6 presents the results from parts of the NERO line representing four vegetation types. In copse, fens and heaths we see more or less bell shaped greenness curves with a slightly later greening in 2009 compared to 2008 (figure 4.6). Despite the later greening, all three vegetation communities attained higher NDVI-values in 2009 than they did in 2008. Vegetation exposed to late snow melt exhibited a different pattern with greening continuing to increase through

Table 4.2 Total flowering in plant phenology plots.

Species	Plot	2008	2009
Loiseleuria procumbens	Loi1	no data	2566
Loiseleuria procumbens	Loi2	4628	8334
Loiseleuria procumbens	Loi3	912	247
Loiseleuria procumbens	Loi4	no data	3128
Silene acaulis	Sil1	142	376
Silene acaulis	Sil2	256	2797
Silene acaulis	Sil3	60	1829
Silene acaulis	Sil4	358	804
Eriophorum angustifolium	Eri1	57	332
Eriophorum angustifolium	Eri2	363	213
Eriophorum angustifolium	Eri3	533	565
Eriophorum angustifolium	Eri4	852	1239
Salix glauca	Sal1	2680	1151
Salix glauca	Sal2	1216	469
Salix glauca	Sal3	531	323
Salix glauca	Sal4	2243	931

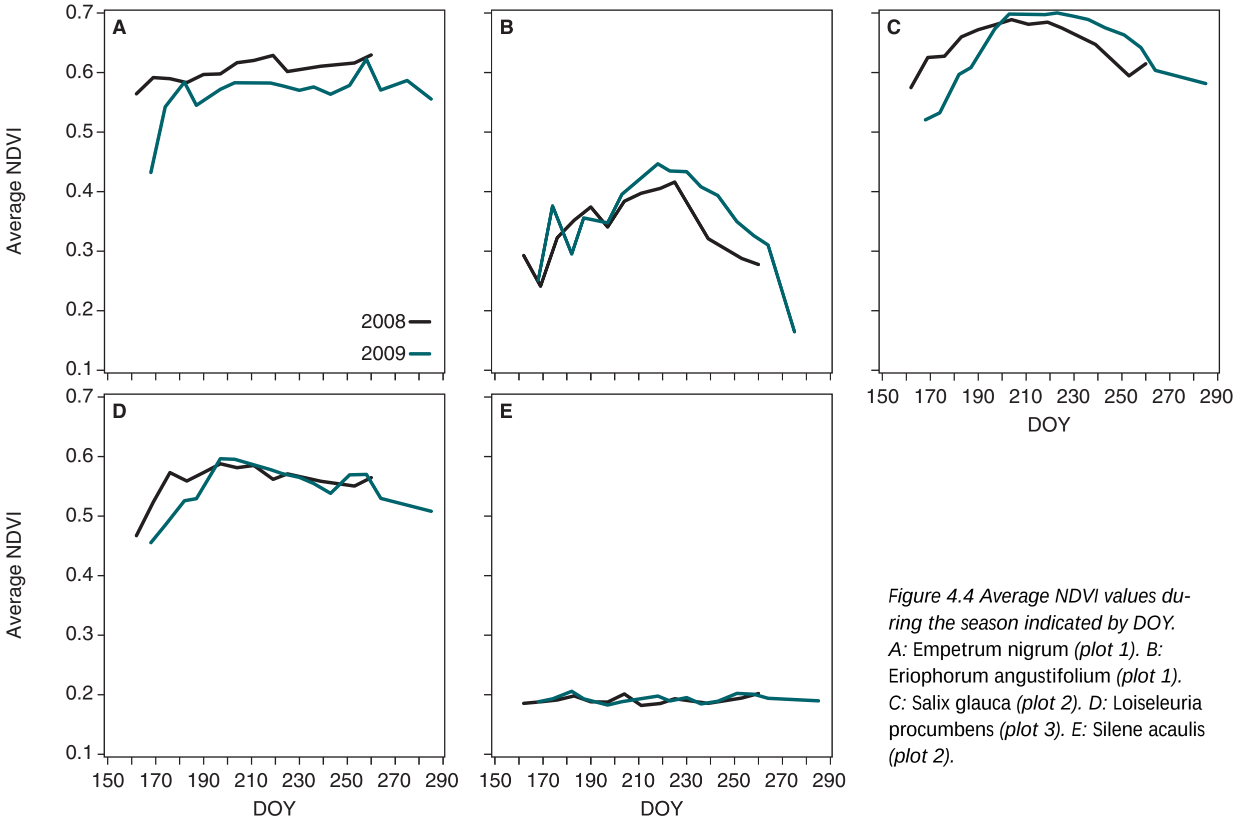
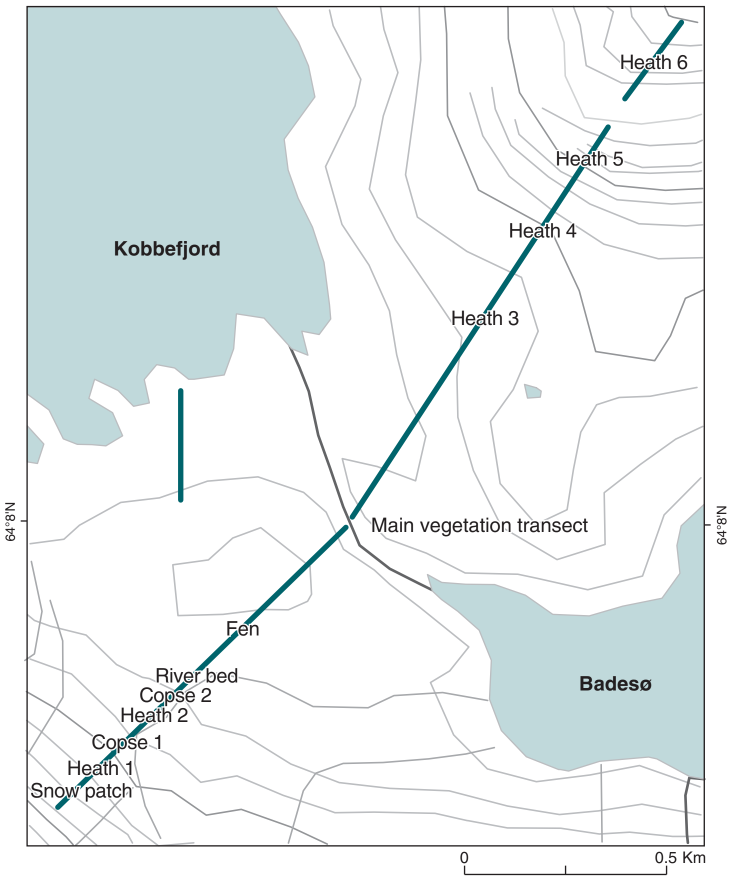


Figure 4.4 Average NDVI values during the season indicated by DOY. A: Empetrum nigrum *(plot 1). B:* Eriophorum angustifolium *(plot 1). C:* Salix glauca *(plot 2). D:* Loiseleuria procumbens *(plot 3). E:* Silene acaulis *(plot 2).*

Figure 4.5 Positions of vegetation communities along the NERO line. The accuracy of GPS positions is relatively low in the area, probably due to local topography. This also affects the positions acquired by the GPS-unit in the Crop Circle resulting in inaccurate positions in the data files created by the Crop Circle. To overcome this we excluded 15 m at each end to avoid including measurements from neighbouring parts of transect.



the entire monitoring period. As in the other vegetation types, greening started later and attained higher values in 2009 than in 2008.

Summing up – vegetation greening

After only two years of monitoring vegetation greening by NDVI, we have still no firm conclusions. Generally, data appear consistent and reliable, and we see some tendencies that will be interesting to follow in the future and in comparison with equivalent data from Zackenberg, NE Greenland, and other monitoring sites.

The general pattern is that greening starts as soon as the snow has melted in June with a peak in greenness in mid-summer (20 July-5 August) followed by a gradual decrease in greenness until the frost sets in during the autumn. There are exceptions from this pattern:

- At snow patches, greening increase through the complete growing season.
- *Silene acaulis* plots have constant greenness throughout the entire season.
- *Loiseleuria procumbens* plots have constant greenness throughout the entire season.
- *Empetrum nigrum* plots have constant greenness throughout the entire season.

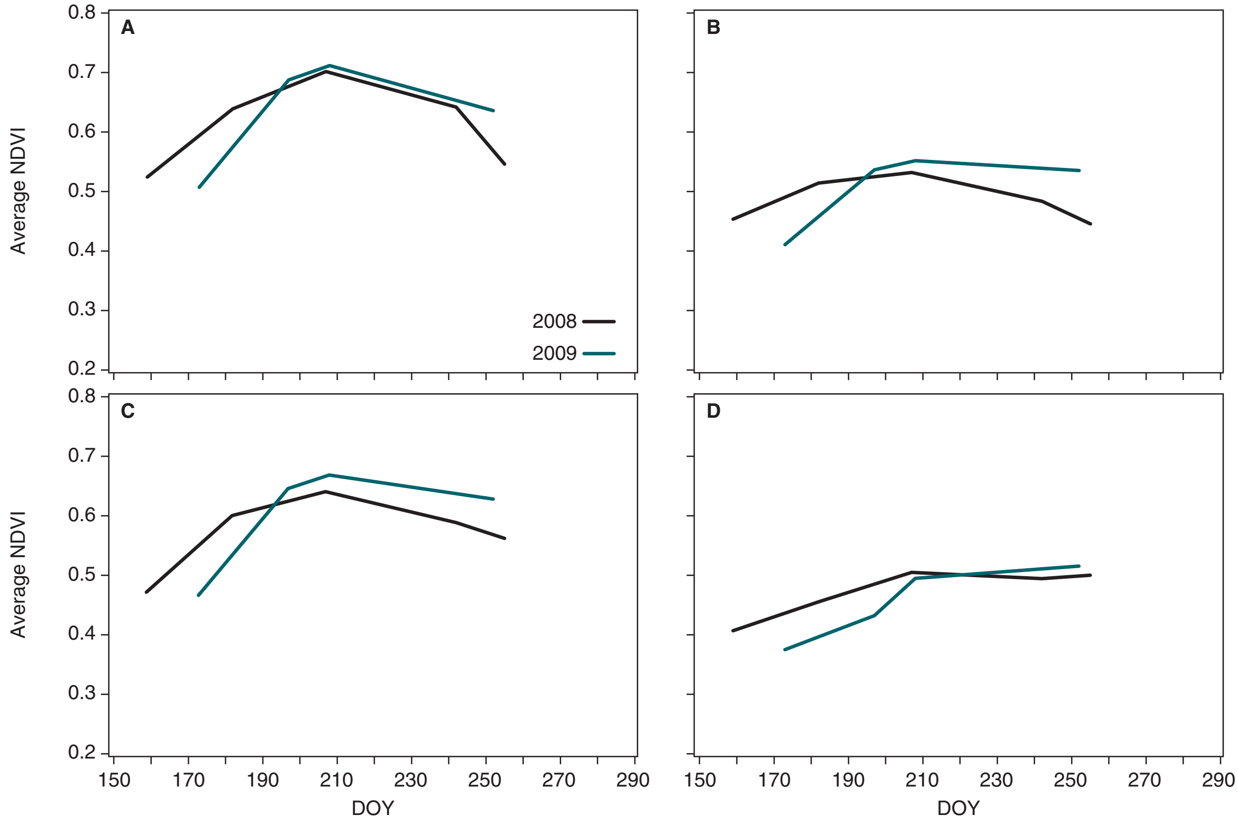


Figure 4.6 NDVI measurements along the NERO line for four vegetation types in 2008 and 2009. A: Copse. B: Fen. C: Dwarf shrub heath. D: Snow patches vegetation. For location of the different vegetation types, see figure 4.4.

In the first three of these cases (see above), the vegetation cover is very low resulting in low NDVI values. In a long time perspective, these sites may be important for documenting and monitoring effects of possible future increased vegetation cover.

Monitoring of *S. glauca* and *E. angustifolium* is considered useful for studying the greening process through the season, while monitoring of the evergreen *Empetrum*, *Silene* and *Loiseleuria* plots with sparse vegetation cover are more relevant for monitoring changes over a longer time perspective.

Carbon dioxide exchange

In 2008, a manipulation experiment was initialized with five different treatments, each with six replicates using the closed chamber technique. The experiment is located in a mesic dwarf shrub heath dominated by *Empetrum nigrum* with *Salix glauca* as a subdominant species. Treatments include control (C), shortened growing season (SG: addition of snow in spring), prolonged growing season (LG: removal of snow in spring), shading (S: hessian tents) and increased temperature (T: ITEX Plexiglas hexagons). We conducted measurements of the land-atmosphere exchange of CO_2 (flux), soil temperature, soil moisture and phenology of *Salix glauca* weekly during June-September. The net ecosystem exchange (NEE) was measured with transparent chambers while the ecosystem respiration (R_{eco}) was measured with darkened chambers. The SG and LG treatments have not been applied in 2008-2009, so results from these plots can be considered as controls.

All plots generally functioned as sinks of CO_2 at the time of measurements, as the net ecosystem exchange values were generally negative (figures 4.7 and 4.8). The net CO_2 uptake was generally higher in C plots compared to T and S plots. The ecosystem respiration showed a constant pattern of higher emissions in T plots compared to C plots, which can be explained by warmer and drier conditions leading to increased decomposition rates. In the T plots, however, there were no visual effects in gross primary production (GPP: difference between NEE and R_{eco}); while S plots showed slightly lower GPP rates compared with the other treatments. As photosynthesis is driven by solar radiation, a decrease in incoming radiation decreases GPP and build-up of biomass.

These results show the initial response of the heath ecosystem to the treatments, and may not be indicative of long-term trends. It is thus important to run the experiment for several years to be able to study possible changes with time.

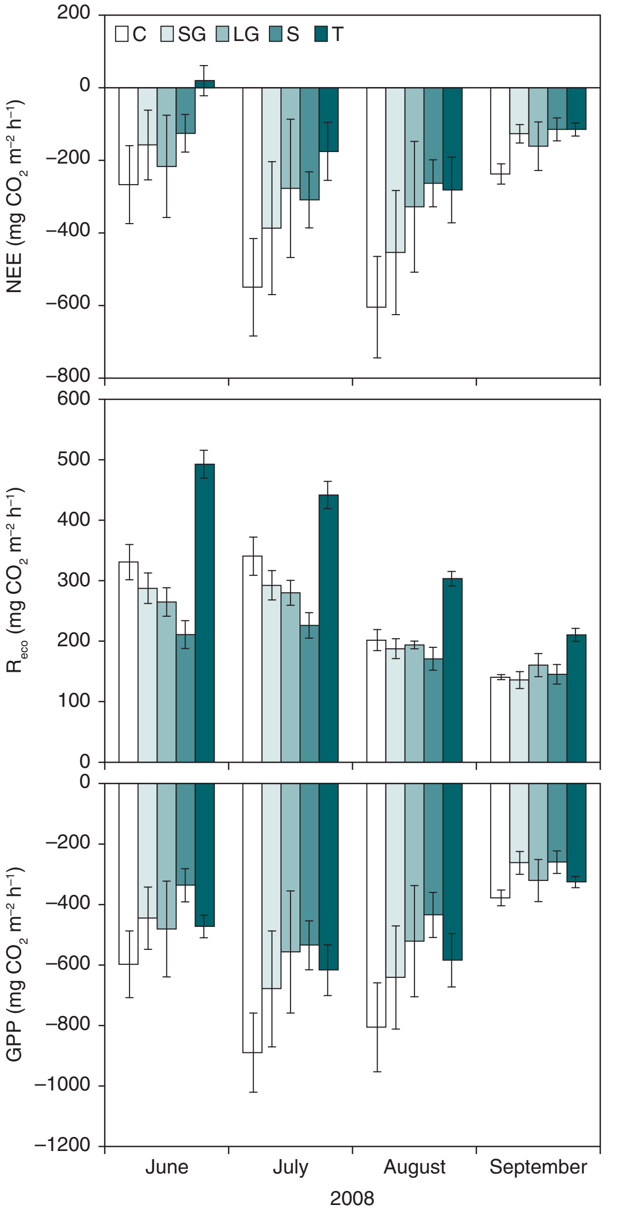


Figure 4.7 Monthly averages of net ecosystem exchange (NEE: upper panel), ecosystem respiration (R_{eco}: middle panel) and gross primary production (GPP: lower panel) in 2008 in the manipulation experiment plots. Error bars refer to standard errors in spatial variability (six replicates). Negative fluxes indicate CO_2 uptake by the ecosystem, while positive fluxes indicate CO_2 release to the atmosphere.

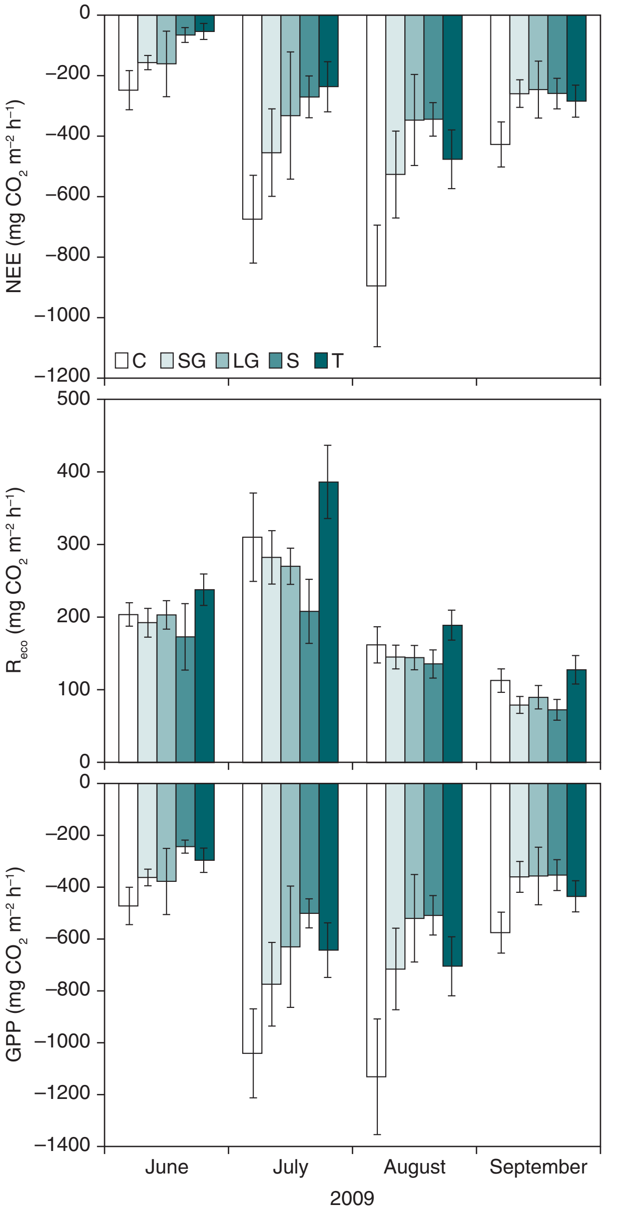


Figure 4.8 Monthly averages of net ecosystem exchange (NEE: upper panel), ecosystem respiration (R_{eco}: middle panel) and gross primary production (GPP: lower panel) in 2009 in the manipulation experiment. Error bars refer to standard errors in spatial variability (six replicates). Negative fluxes indicate CO_2 uptake by the ecosystem, while positive fluxes indicate CO_2 release to the atmosphere.

4.2 Arthropods

In Kobbefjord, all four pitfall trap stations were open during the 2009 season. Sampling procedures follows the BioBasis manual (Aastrup et al. 2009). Each station consists of eight subplots each with a yellow pitfall trap with a 10 cm diameter. Samples are kept unsorted at the Greenland Institute of Natural Resources. The material is stored in 70 % ethanol. The traps have so far been open for sampling in the following periods: 5 June to 25 September 2008 and 28 May to 2 October 2009.

Microarthropods

Soil characterisation

On 24 September 2009, soil was collected along two diagonal lines in each of the eight plots covering the four plant communities. Due to very stony soil, the sampling at plot MArt8 was made outside the plot. All soil data are presented in table 4.3. No pairs of plots of the *E. nigrum* and the *S. glauca* communities were similar in their composition of mineral particles. The *E. nigrum* plots differed in fine sand and silt content and the *S. glauca* plots differed in clay content (table

Table 4.3 Percentage of soil texture fractions, C, N and pH for the eight individual monitoring plots.

Plant community key species	Plot name	Coarse sand 2000-200 µ	Fine sand 200-20 µ	Silt 20-2 µ	Clay < 2 µ	Humus	C	N	C/N	pH ($CaCl_2$)
Empetrum nigrum	MArt1	37.4	33.9	7.0	3.7	18.0	9.7	0.609	16	4.1
	MArt2	45.1	29.5	3.6	3.5	18.3	10.2	0.524	19	4.1
Salix glauca	MArt3	3.7	14.8	2.3	2.7	76.5	40.0	1.029	39	4.1
	MArt4	3.6	0.2	5.3	3.7	87.2	48.4	0.57	85	4.6
Silene acaulis	MArt5	55.2	35.1	4.3	2.8	2.6	1.5	0.07	21	4.6
	MArt6	86.0	6.2	2.9	2.8	2.2	1.3	0.132	9.8	4.6
Loiseleuria procumbens	MArt7	75.3	16.1	2.4	2.8	3.4	2.0	0.072	28	4.6
	MArt8	56.1	33.6	3.7	2.1	4.5	2.6	0.218	12	4.4

4.3). There was a remarkable difference in organic matter content between the two *Salix* plots, maybe related to the different levels of elevation (MArt3: 26 m a.s.l. and MArt4: 44 m a.s.l.). MArt3 contained matter that is five times more organic and one third of the clay (relative to the other mineral fractions) compared to MArt4. Water content, hydrology and snow may explain these differences. The *S. acaulis* and the *L. procumbens* plots were much less organic, with a humus content of 2-4 % (table 4.3). The mineral fractions were very similar with total sand content about 95 %.

Quality assurance of extraction efficiency and taxonomy

The high gradient microarthropod extraction equipment established at the Greenland Institute of Natural Resources in 2009 was tested and proved satisfactorily to extract adults by 99 %. Extraction of juveniles is expected to be efficient as well, but data are not available.

Species identifications were double-checked and improved during a three days training workshop, 16-18 November 2009, led by the world's leading collembolan taxonomist Arne Fjellberg from Norway. A validated species list is presented in this report (table 4.4).

Population and community trends

An updated species list is presented for the four habitats covered during the 2009 samplings (table 4.4). There is a striking absence of epigeic (above the soil surface) collembolans which may probably be a common feature of many arctic tundras and heaths. This was also observed at the high arctic Zackenberg location (Sørensen et al. 2006). The typical arctic species *Tetracantella arctica*, *Folsomia coeruleogrisea* and *Oligaphorura ursi* are now included in the species list.

Table 4.4 Mean abundances ×1000 individuals per square meter of the mites, at order level, and collembolans, at species level. Microarthropods are the sum of mites and collembolans. S: Collembolan species richness; $H' = -\sum p_i \log_2 p_i$, where p_i is the proportion of species in the sample to total collembolans; Evenness, $E = H/\log_2 n$, where n is number of collembolan species.

	Salix	*Empetrum*	*Silene*	*Loiseleuria*
S, species richness	15	11	8	8
H', diversity index	2.85	2.58	1.56	1.97
E, evenness	0.73	0.74	0.52	0.66
Microarthropods	96	146	71	68
Collembola	18	31	11	6
Acari	78	115	60	63
Actinedida	33	60	33	34
Oribatida	35	50	26	28
Folsomia quadrioculata	2.2	10		0.5
Gamasida	8.1	4.1	0.3	0.4
Tullberginae	2.1	2.6	6.9	2.8
Tetracanthella arctica	0.3	8.3	0.9	1.6
Isotomiella minor	5.9	2.9	0.02	0.03
Willemia spp.	2.4	0.9	1.8	0.3
Folsomia sensibilis	0.8	3.4	0.3	0.2
Pygmephoridae	2.2	0.3	1.2	0.9
Desoria olivacea	1.8	1.6		0.03
Micranurida pygmaea	0.03	1	0.5	0.3
Isotoma notabilis	1.4	0.1		
Arrhopalites principalis	0.4			
Sminthurides schoetti	0.2	0.11	0.02	
Acaridida	0.1	0.1		
Desoria tolya	0.1		0.04	
Onychiurinae	0.1			
Tarsonomidae	0.01			
Sminthurinae	0.01			
Folsomia coeruleogrisea		0.01		
Orchesella sp.	0.01			

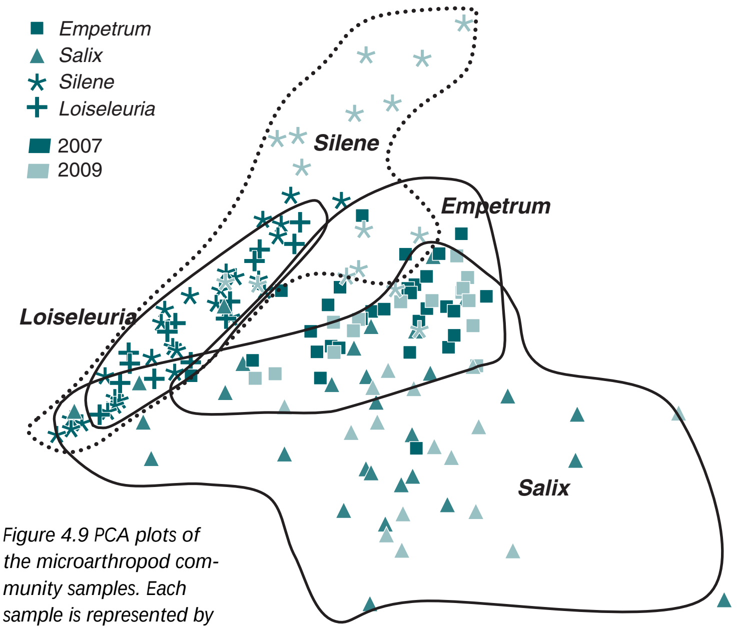


Figure 4.9 PCA plots of the microarthropod community samples. Each sample is represented by a symbol. Lines are drawn around clusters comprising the microarthropod samples within the plant communities. Light green symbols 2007, dark green symbols 2009.

The *Salix* and *Empetrum* plots were very similar in relation to abundance and diversity when comparing the two sampling years 2007 and 2009. Figure 4.9 is a PCA plot of all log-transformed data (SAS Institute Inc. 2004) including the two sampling years. The figure illustrates this similarity by the overlapping PCA clusters of samples from these two habitats. The very sandy *Silene* and *Loiseleuria* plots formed a common cluster delineated by a broken line in figure 4.9. Within this cluster, the 2007 *Silene* samples created a cluster of the gray stars separate from the 2009 samples. This is caused by the very abundant collembolan community in 2007 of 110,000 collembolans m^{-2} dominated by *T. arctica* (table 4.1 in Nymand et al. 2008), which had dropped to a tenth in 2009 (Table 4.4).

Only few distinct phenological patterns were detected in the data during the two to three months sampling period (data not shown). *T. arctica* populations increased in the MArt2 *Empetrum* plot and *Isotomiella minor* declined in both *Empetrum* plots, both significantly as detected by linear regression analyses (SAS Institute Inc. 2009). In the MArt4 *Salix* plot, *Folsomia quadrioculata* increased and *Arrhopalites principalis* declined significantly. The declines may be explained by the very low precipitation in July (1 mm) and August (6 mm) (Weather archive at http://www.dmi.dk/dmi/vejr-arkiv-gl) which could influence drought sensitive species.

Some distinct differences between the four plant communities were reflected in the microarthropod communities. *Salix* had the highest diversity index (H') equalling 2.85, and *Silene* and *Empetrum* had an H' of 1.5-2.0. The lower evenness (E) in the *Silene* and *Empetrum* plots may indicate stressed conditions caused by decreased species richness and the dominance by a few tolerant opportunistic species. The two *Salix* plots differ from the other plant habitats concerning soil properties by holding the largest sand and soil carbon content (table 4.3). This is also reflected in the microarthropod biodiversity as *F. quadrioculata* and *Isotoma notabilis* were more abundant in the MArt4 plot while the Tullberginae, *Willemia* spp. and *Folsomia sensibilis* were more abundant in the MArt3 plot.

The absence of *F. quadrioculata* from *Silene* plots as observed in 2007 (Nymand et al. 2008) was confirmed. These plots are particularly vulnerable to drought and at the second sampling occasion in July no collembolans were collected, while mites were still present but in reduced numbers. This is a pattern often observed for microarthropods, e.g. Krogh (1991). The figures from the July sampling have been omitted from the mean estimates in table 4.4.

The very low abundance of collembolans in the *Loiseleuria* plots is, as in the *Silene* plots, likely related to drought and the vulnerability of the communities to extreme water conditions in the very sandy soils, containing approximately 95 % sand and 3 % organic matter.

4.3 Birds

Survey for breeding passerines

The survey took place 2 and 8 June 2009 when a transect crossing 14 waypoints was followed (figure 4.10). At every waypoint five minutes is spent making observations. Birds are mapped on field maps. Both days observations started approximately 9.30 am and lasted five hours.

Birds observed from the transect within a distance of up to 300 m were mapped. Individuals of snow bunting, Lapland bunting and northern wheatear were sexed and singing activity recorded.

Based on singing and the number of males, the number of territories of snow bunting and Lapland bunting were estimated (table 4.5). Redpolls were not sexed.

The most common species were snow bunting and Lapland bunting with about 20 territories. Only one territory of nor-

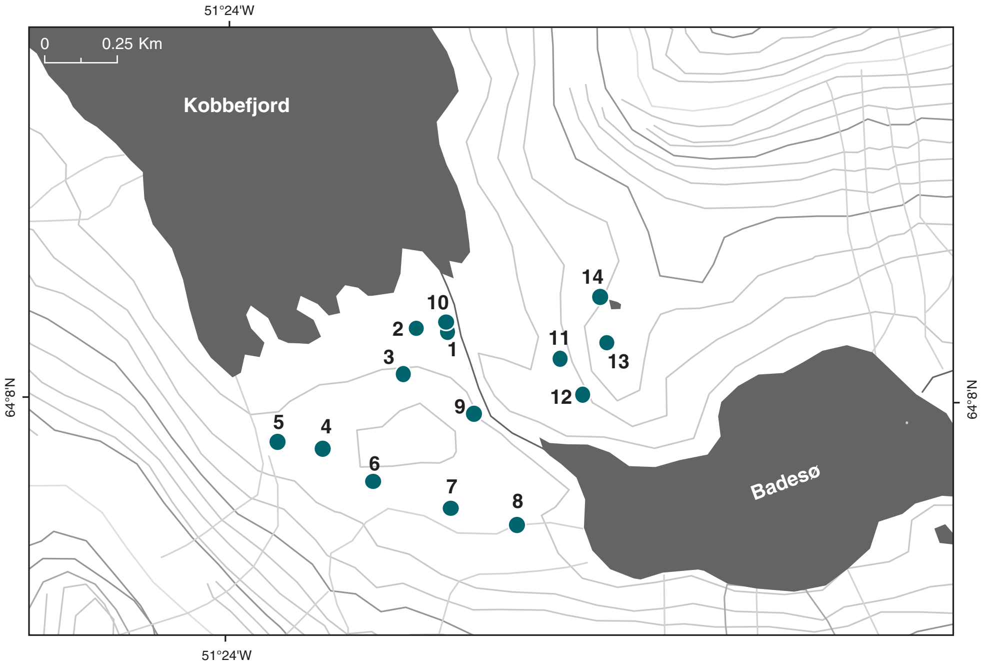


Figure 4.10 The transect with waypoints for the breeding bird census.

Table 4.5 Number of territories of Lapland bunting, snow bunting, and northern wheatear within the research area. Redpolls were not sexed so we do not know the number of territories.

Date	2 June	8 June
Snow bunting ♂	29	21
Lapland bunting ♂	17	19
Wheatear ♂	1	1
Redpoll indviduals	2	5

thern wheatear was observed and two to five redpoll individuals were seen.

The distribution of singing males differs between the two sampling occasions; both snow buntings and Lapland buntings are rather contagious distributed within the research area 2 June. On 8 June, they are distributed more widely and evenly. The total number of singing males is approximately the same on the two sampling occasions and therefore it must be considered a rather accurate number of territories.

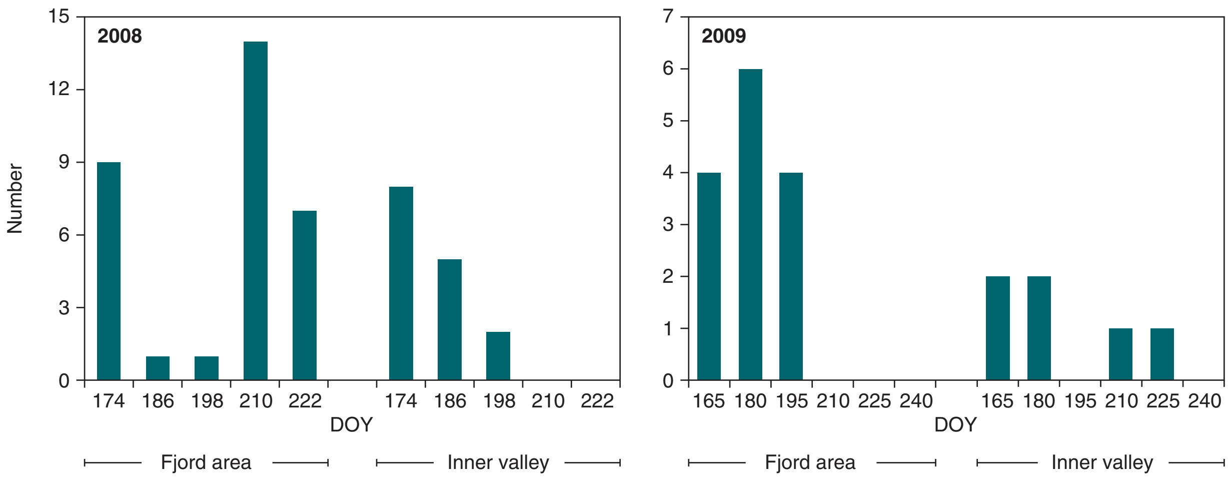
Bird census points

Passerine birds were counted at 13 census points during the entire season. When arriving at a census point, five minutes were used as a 'settling period' and five minutes were used for counting the birds.

Lapland bunting

As in 2008, Lapland buntings were observed at most points during almost the entire season, except for the latest part. We observed fewer birds in 2009 than in 2008. In 2009, most birds were seen in the fjord area in the beginning of the season, while in 2008 more birds were seen in the latter half of the season (figure 4.11).

Figure 4.11 Number of Lapland buntings observed in the fjord area (Point A-H) and in the inner fjord (Point I-M) in 2008 and 2009.



Northern wheatear young. Photo: Katrine Raundrup.

Snow bunting

We observed fewer snow buntings in 2009 than in 2008. As in 2008, most observations were made in the earliest half of the season.

Redpoll

Redpolls were only seen at three points late in the season in 2008. In 2009 redpolls were seen at eight census points. Most observations were late in the season as in 2008, but at point D and F they were observed early in the season. These points are located close to *Salix* copses and possibly used by breeding birds.

Northern wheatear

Compared to 2008 only few northern wheatears were observed in 2009. Most observations were of single birds and most birds were observed late in the season. Point C close to the shore-line is an exception, as more than 10 birds were observed here late in the season.

4.4 Mammals

No mammals were observed during the field season. Fresh caribou faeces were observed between plot Sal3 and plot Emp4 under the electrical power transmission line 31 August 2009 by Karl-Martin Iversen. Furthermore, tracks of arctic fox and polar hare were observed, mainly during winter.

4.5 Lakes

The two lakes included in the BioBasis programme are Badesø (approximately 50 m a.s.l.) and Qassi-sø (approximately 250 m a.s.l.). Both lakes are situated in the Kobbefjord catchment area. Maximum depths are similar, 33 and 26 m, respectively (table 4.6). The main difference between the two lakes, besides the altitude, is the presence of fish in Badesø and absence of fish in Qassi-sø.

Nutrient levels are generally low in the two lakes. However, in 2009 especially nitrogen levels were lower than in 2008 (table 4.6). Despite of this Secchi depth decreased in Badesø in 2009, whereas it increased as expected in Qassi-sø from 2008 to 2009. Usually low nutrient levels result in low plant production and high visibility (high Secchi depth).

Temperature

Due to the higher altitude and wind exposure, the lowest temperature is in Qassi-sø. A temporary thermocline was observed in Badesø during warm periods in July and August (Jensen and Rasch 2009), whereas temperature was almost constant throughout the water column in Qassi-sø during the summer months. The ice free period, and consequently also the productive period, is somewhat

Table 4.6 Mean values ± variance of water chemistry, physical data, Chlorophyll a *and morphometric data from Badesø and Qassi-sø during 2008 and 2009. TN: Total nitrogen, TP: Total phosphorus, SD: Secchi Depth, Chl.* a*: Chlorophyll* a.

	Badesø		Qassi-sø	
	2008	2009	2008	2009
TN ± var (mg l^{-1})	0.084±0.001	0.027±<0.001	0.390±0.45	0.022±<0.001
TP ± var (mg l^{-1})	0.005±<0.001	0.004±<0.001	0.016±<0.001	0.002±<0.001
SD ± var (m)	8.24±5.11	6.43±4.01	3.66±2.49	4.85±0.89
Chl a ± var (µg l^{-1})	0.43±0.03	0.52±0.14	0.17±0.02	0.58±0.11
Area (ha)	80		52	
Maximum depth (m)	32		26	

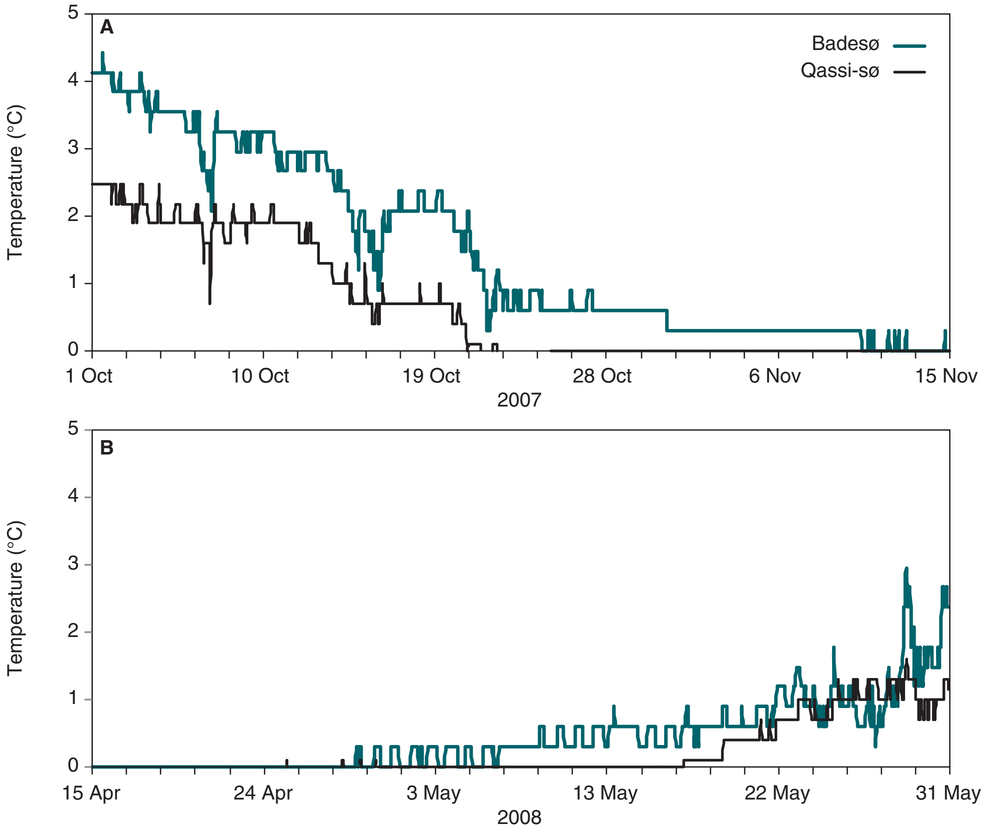


Figure 4.12 Hourly temperature measurements from Badesø and Qassi-sø during autumn 2007 (1 October-15 November, A) and spring 2008 (15 April-1 June, B).

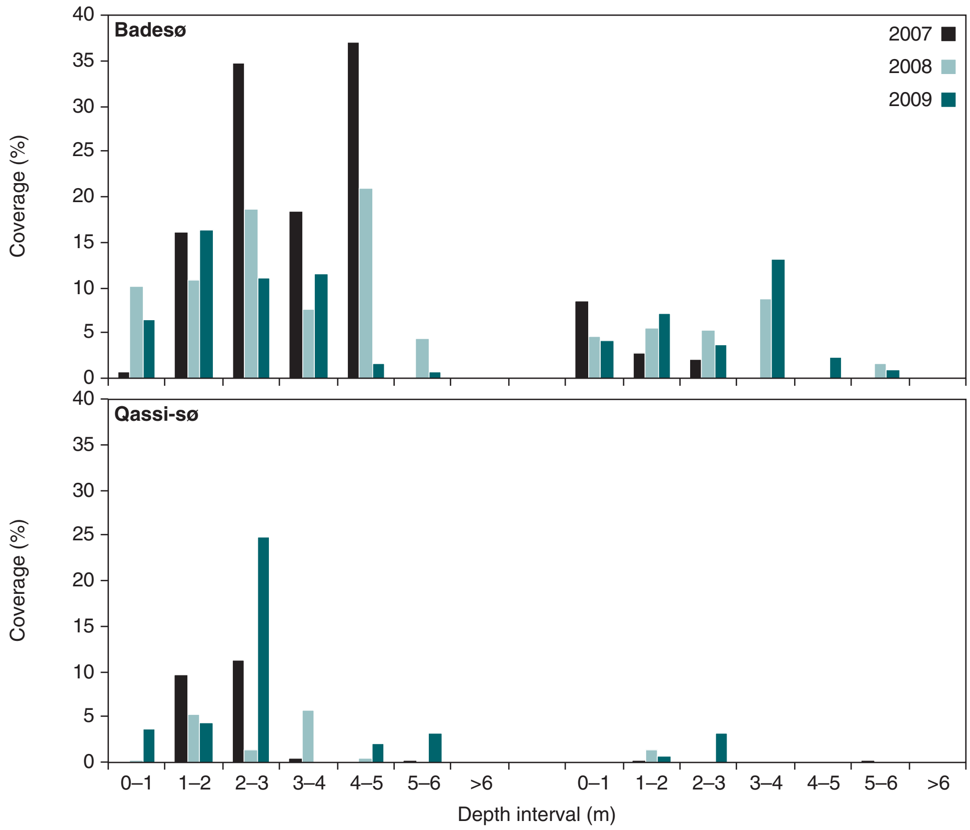
longer in Badesø than in Qassi-sø due to an earlier ice melt and a later ice cover. In 2007, ice cover occurred in Qassi-sø and Badesø on 23 October and 11 November, respectively. Ice melt occurred on 17 May and 1 May, respectively, giving a 35 days longer ice free period in Badesø than in Qassi-sø (figure 4.12). With global warming, we may expect the ice free period to expand as seen in the Zackenberg region (Klitgaard and Rasch 2008).

Vegetation

In 2007 to 2009, the submerged vegetation consisted of mosses and macrophytes (*Callitriche hamulata*). The depth limits of *C. hamulata* and the mosses were between 5 and 6 m in all three years (figure 4.13). In general, Badesø has more submerged vegetation than Qassi-sø. This is consistent with higher temperature and correspondingly higher productivity. In both lakes, mosses were less widely

The submerged vegetation in the two lakes is dominated by the water-starwort Callitriche hamulata. *Photo: Katrine Raundrup.*

Figure 4.13 Coverage of Callitriche hamulata *(left half of figure) and mosses (right half of figure) in one-meter depth intervals in Badesø and Qassi-sø during 2007 to 2009.*

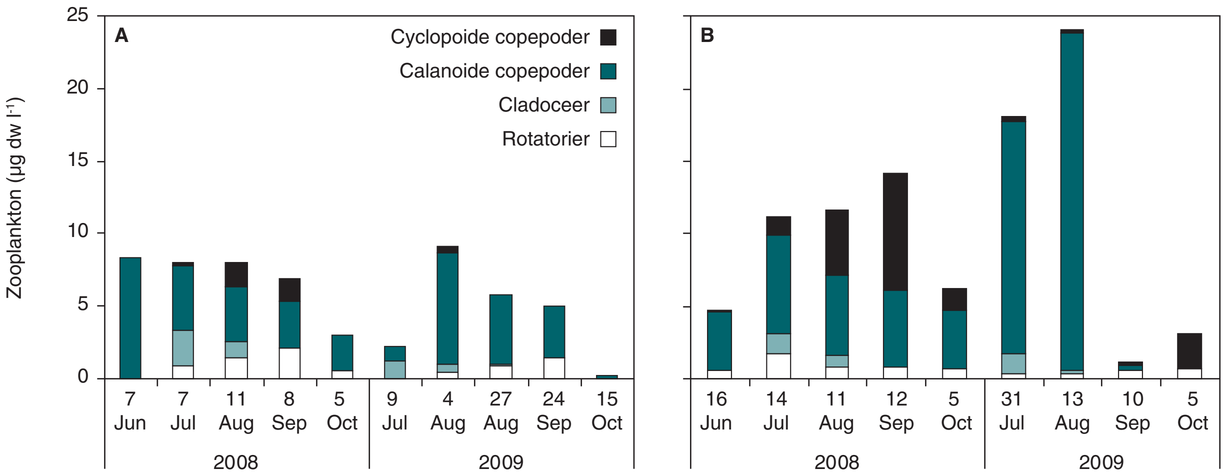


spread than *C. hamulata* and especially in Qassi-sø; mosses had a more patchy distribution along the lakeshore than Badesø. From 2007 to 2009, the cover of macrophytes decreased in the deeper parts (2-6 m depth) of Badesø. This may be due to the reduced clarity of the water (table 4.13).

Zooplankton

In Badesø, the total zooplankton biomass varied between 0.2 and 9.2 µg DW l^{-1} during the sampling periods in 2008 and 2009 (figure 4.14). It was dominated by copepods (nauplii, copepodits and adults are included in the figure), mainly calanoids (*Leptodiaptomus minutus*, 46-99 % of the total zooplankton biomass). Cyclopoids were of minor importance and only represented by copepodits *Cyclops* sp. In general, the cladocerans made up only a small part of the zooplankton biomass. The only exception was in July 2009, when cladocerans *Holopedium gibberum* were the most important group. In addition, the rotifers (dominated by the genera *Asplanchna*, *Collotheca*, *Conochilus* and *Polyarthra*) made up a smaller part of the zooplankton on most of the sampling dates. However, their abundance increased during the season in both years until September, followed by a large reduction in October.

Figure 4.14 Zooplankton biomass (µg DW l^{-1}) in Badesø (A) and Qassi-sø (B) in 2008 and 2009.



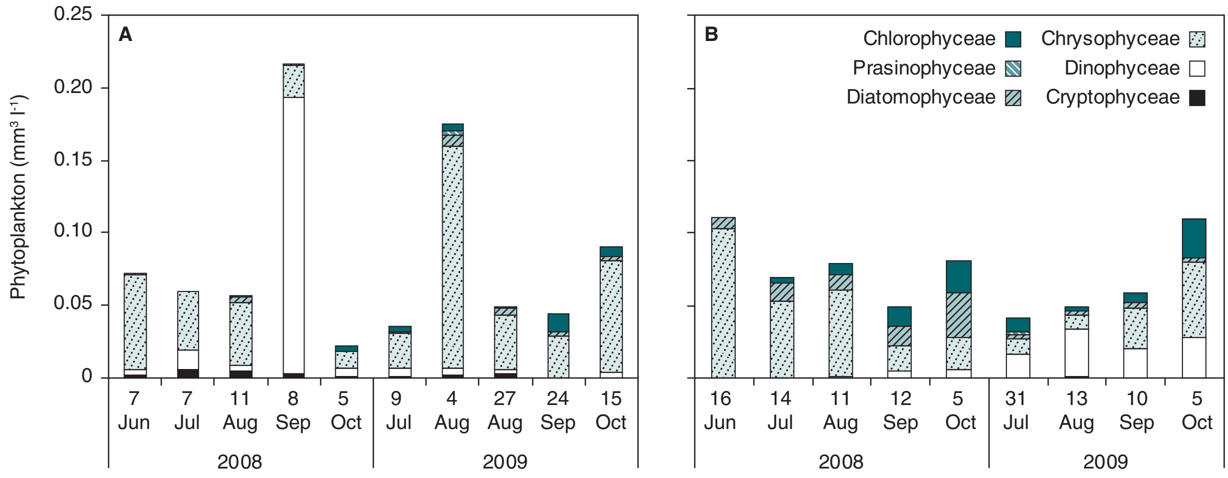


Figure 4.15 Phytoplankton biomass (mm³ l⁻¹) in Badesø (A) and Qassi-sø (B) in 2008 and 2009.

In Qassi-sø, the zooplankton biomass was, in general, higher than in Badesø (1.2-24 µg DW l^{-1}, figure 4.14). In contrast to Badesø, the cyclopoid copepods *Cyclops abyssorum* played an important role, at least in 2008, whereas in 2009 the calanoids (mainly *L. minutus* copepodits) dominated clearly. As in Badesø, cladocerans were less important (here represented by three species, *H. gibbberum*, *Daphnia pulex* and *Chydorus* sp.). The rotifer community are dominated by *Asplanchna* sp., *Collotheca* sp. and *Polyarthra* sp., and the biomass was in the same order of magnitude as in Badesø. The rotifer biomass was slightly smaller in 2009 than in 2008.

A common trait between the two lakes was a higher abundance of cyclopoid copepods in 2008 than in 2009, at least during the middle part of the season.

Phytoplankton

In Badesø, phytoplankton biomass ranged from 0.02-0.22 mm^3 l^{-1} and was dominated by Chrysophyceae (*Uroglena* spp. and *Chromolina* spp.) except during September 2008, with a peak dominated by dinophyceae (*Gymnodinium* spp.) (figure 4.15). In 2009, chlorophyceae played a slightly larger role than in 2008.

In Qassi-sø, the phytoplankton biomass ranged from 0.04-0.11 mm^3 l^{-1} (figure 4.15). As in Badesø, chrysophyceae (*Dinobryum* spp., *Ochromonas* spp. and *Chromulina* spp.) also played a significant role, especially in 2008. However, dinophyceae (*Gymnodinium* spp.) increased in abundance from August 2008 and made up an important part of the phytoplankton biomass in 2009. In addition, diatomophyceae (especially in 2008) and chlorophyceae were more abundant than in Badesø.

To illustrate the grazing capacity of zooplankton (copepods and cladocerans) on phytoplankton, the ratio between the two groups of organisms, expressed as µg C l^{-1}, is shown in figure 4.16. In general, the ratio is higher in Qassi-sø than in Badesø. This reflects the fish predation on the zooplankton in Badesø, which in turn becomes less effective grazers on the phytoplankton.

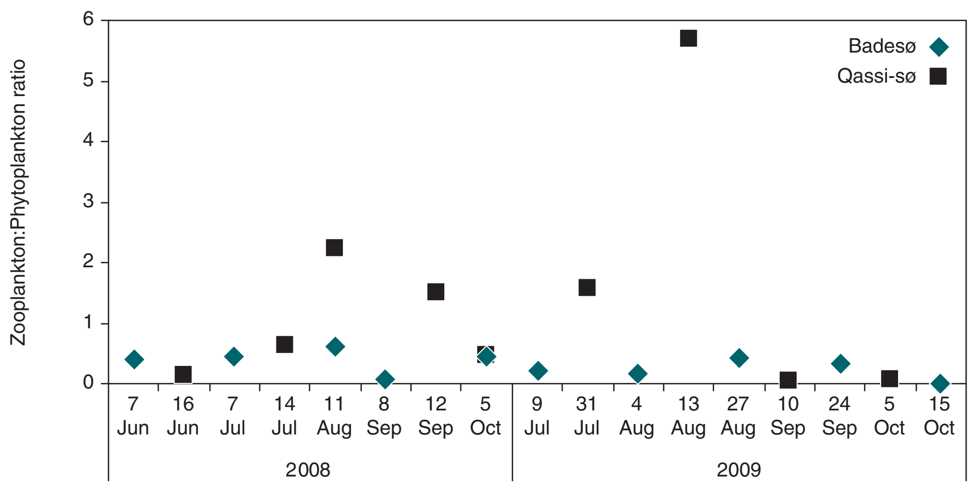


Figure 4.16 Ratio between zooplankton and phytoplankton (µg C l⁻¹) in 2008 and 2009.

5 NUUK BASIC

The MarineBasis programme

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This chapter presents results from the fourth year of the MarineBasis monitoring programme in Godthåbsfjord. The MarineBasis programme aims at establishing long time series of key parameters within physical, chemical and biological oceanography. Long time series are needed in marine environments for improving the understanding of seasonal and interannual variability and detecting possible effects of climatic changes. The programme includes monthly pelagic sampling at a 'Main Station' (64 °07'N, 51 °53'W) near Nuuk, an annual length section from Fyllas Banke to the inner part of the fjord and an annual cross section of the fjord in May (figure 5.1). The programme also includes benthic sampling at a 'Sediment Station' in Kobbefjord four times per year and annual monitoring of higher trophic levels of the marine ecosystem (i.e. seabirds and whales). In addition, sea ice conditions are monitored within the fjord system and in Baffin Bay using satellite imagery and a digital camera system. Methods are briefly described in this chapter. For more information please consult the MarineBasis Nuuk Manual (www.nuuk-basic.dk).

5.1 Sea ice

Daily AMSR-E satellite images (3-6 km resolution) of Baffin Bay showed maximum sea ice cover lasting until April / May, when the northern parts of the bay and areas west of Disko Island opened up (figure 5.2). Similar to previous years, minimum sea ice cover was observed in July / August with the entire west coast of Greenland as well as the northern and eastern parts of Baffin Bay becoming

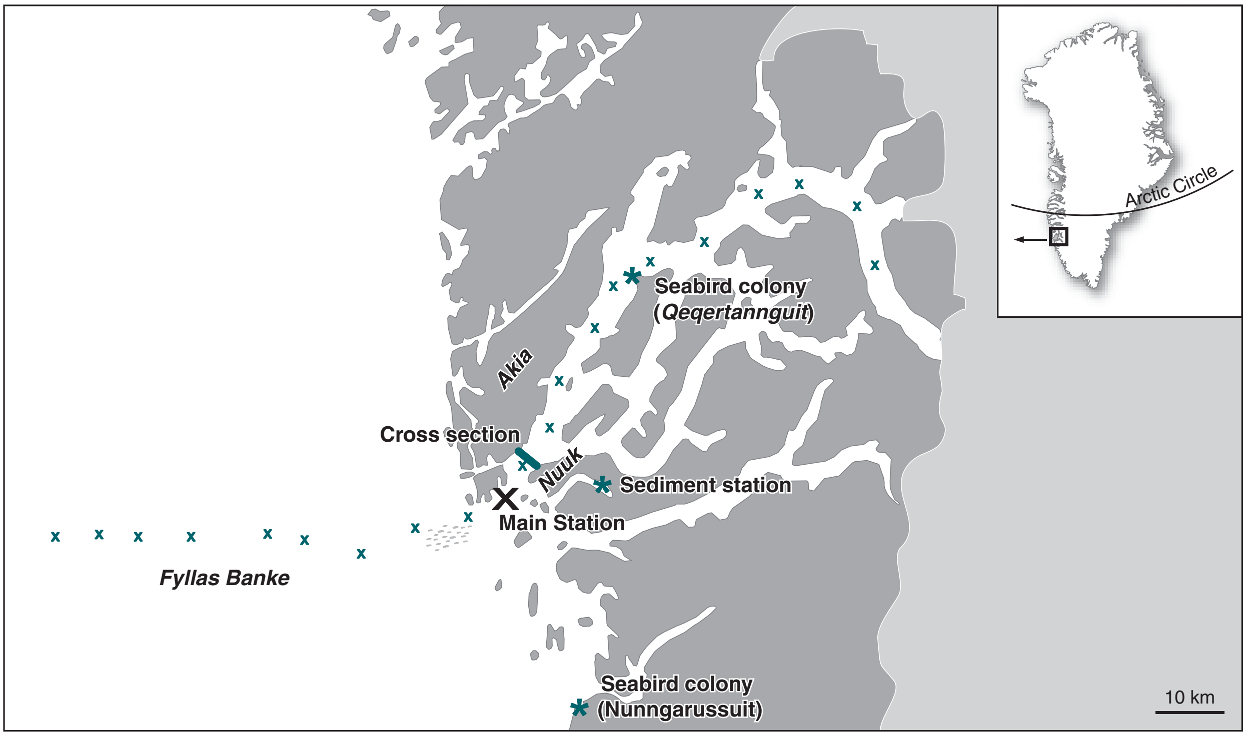


Figure 5.1 Map of sampling stations in and around the Godthåbsfjord system. X represent sampling stations along the hydrographical length section.

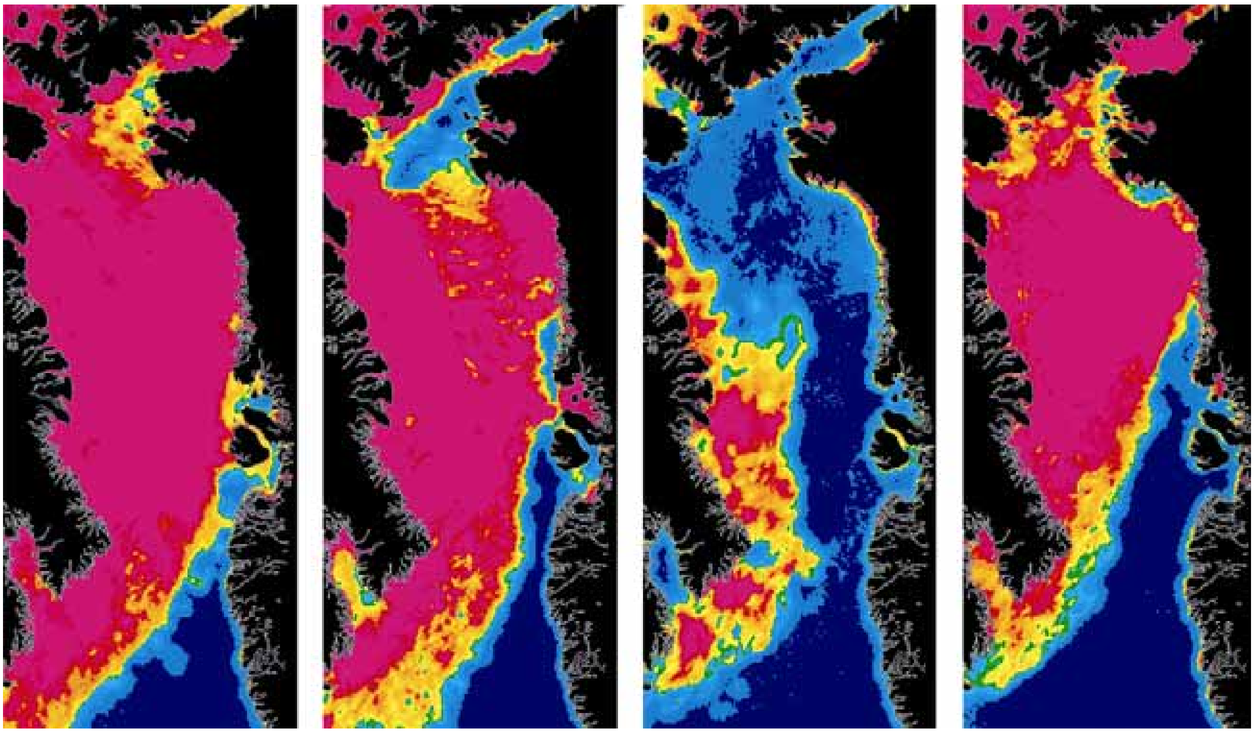


Figure 5.2 Satellite images (AQUA AMSR-E) shows sea ice extent in Baffin Bay during February, May, July and December 2009. Blue colour represents open water and yellow-red colours represent different sea ice conditions.

largely ice free. By December, sea ice again covered much of the northern and western parts of the bay.

Daily MODIS satellite images (250 m resolution) showed extensive sea ice cover of the inner part of Godthåbsfjord during winter 2008 / 09 (figure 5.3). While Kobbefjord also showed extensive sea ice cover, the rest of the fjord system remained largely ice free. Digital images taken every hour overlooking a section of the fjord near Nuuk only showed irregular bursts of glacial ice leaving the fjord as it has been observed during previous years (figure 5.4). In 2009, the digital camera system located at the Greenland Institute of Natural Resources was replaced by a system overlooking almost the same section of Godthåbsfjord, but from a higher altitude mounted on top of the mountain 'Lille Malene' (64 °11.23'N, 51 °38.31'W) near Nuuk.

Analyses of satellite data on sea ice cover are currently conducted as collaboration between Greenland Institute of Natural Resources, the Danish Meteorological Institute and Greenland Climate Research Centre (www.natur.gl). As a courtesy, daily satellite images covering Greenland are available at www.dmi.dk. Ongoing research at the Greenland Climate Research Centre and the Danish Meteorological Institute are aiming at improving the platforms for satellite imagery and remote sensing of the region.

5.2 Length and cross sections

Annual sampling along the Nuuk-Akia cross section (figure 5.1) in late-May included vertical profiles of hydrographical parameters including salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence using a SBE19+ CTD profiler. A similar pattern to previous years showed a

Figure 5.3 Satellite images (AQUA-MODIS) show sea ice conditions in Godthåbsfjord in March, July and October 2009.

Figure 5.4 Digital images overlooking a section of Godthåbsfjord showing open water in March (A) and two separate bursts of ice in October (B) and December (C) 2009.

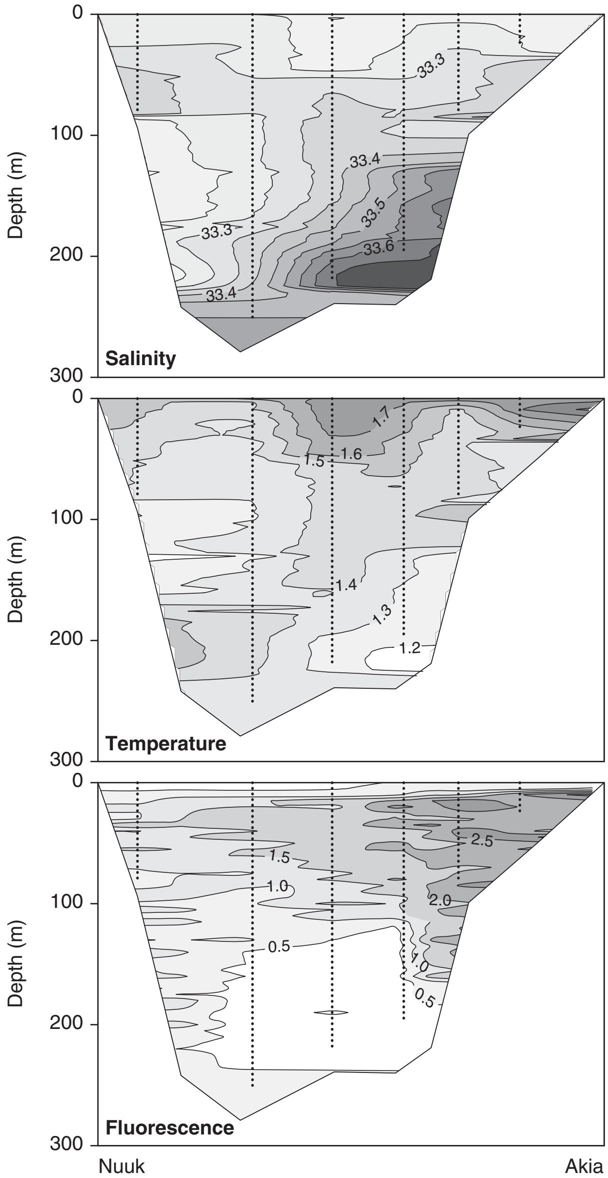


Figure 5.5 Salinity, temperature (°C) and fluorescence along the cross section from Nuuk to Akia in late-May 2009. Vertical dotted lines represent sampling stations and depths in increment.

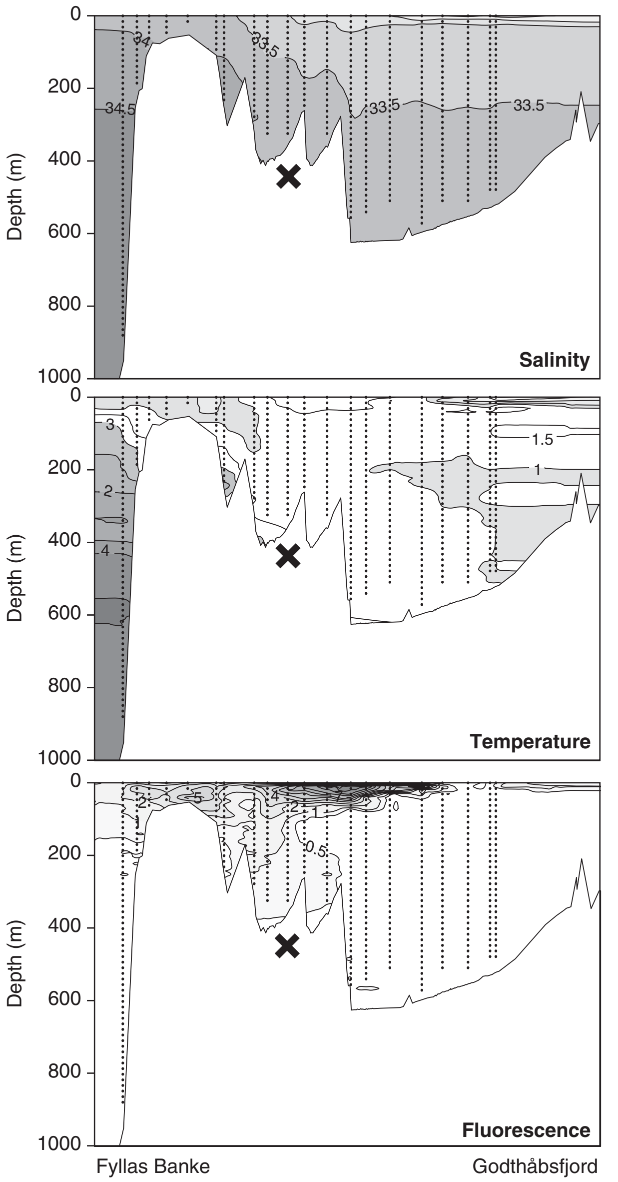


Figure 5.6 Salinity, temperature (°C) and fluorescence along the length section from Fyllas Banke to the inner part of Godthåbsfjord in mid-May 2009. Vertical dotted lines represent sampling stations and depths in increments. X marks the location of the 'Main Station'.

relatively fresh and warm surface layer towards Akia, with salinities down to 33.2 and temperatures up to 1.8 °C (figure 5.5). This surface layer depicted a weak seaward export of freshwater discharged from glacier and snow melt in the inner part of the fjord. Like in previous years, the highest phytoplankton biomass values were observed in this surface layer, as shown by fluorescence values up to 4.0 (approximately µg chlorophyll *a* l^{-1}). A deeper more saline and colder layer concentrated towards Akia was less pronounced than during previous years with salinities up to 33.7 and temperatures down to 1.2 °C.

The annual sampling along the approximately 200 km length section from Fyllas Banke to the inner part of the fjord was conducted in mid-May from 'M / S Masik Tender' (figure 5.1). As in previous years, the West Greenland current was observed flowing northward along the outside of Fyllas Banke depicting the highest salinities and temperatures recorded along the length section, i.e. up to 34.9 and 4.6 °C, respectively (figure 5.6). Another feature was the homogenous water mass protruding into the fjord as a subsurface layer with salinities of > 33.5 and temperatures around 1.0 °C, showing a deepwater renewal in progress. The fresher and warm-

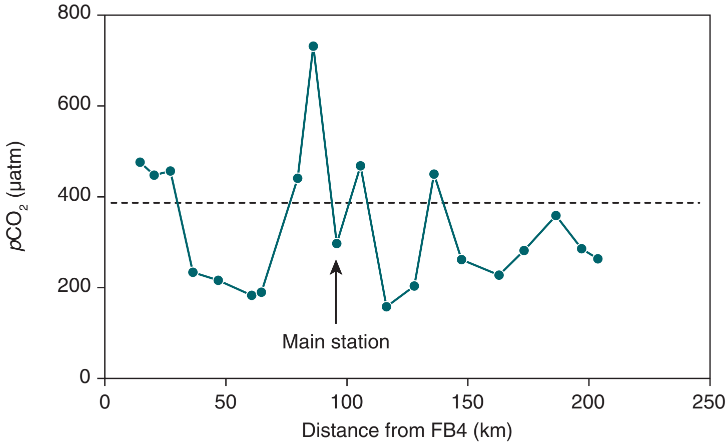


Figure 5.7 pCO_2 *(µatm) in surface water along the length section from Fyllas Banke (outermost station FB4, figure 5.1) to the inner part of Godthåbsfjord in mid-May 2009. Horizontal dotted line represents atmospheric content (387 µatm).*

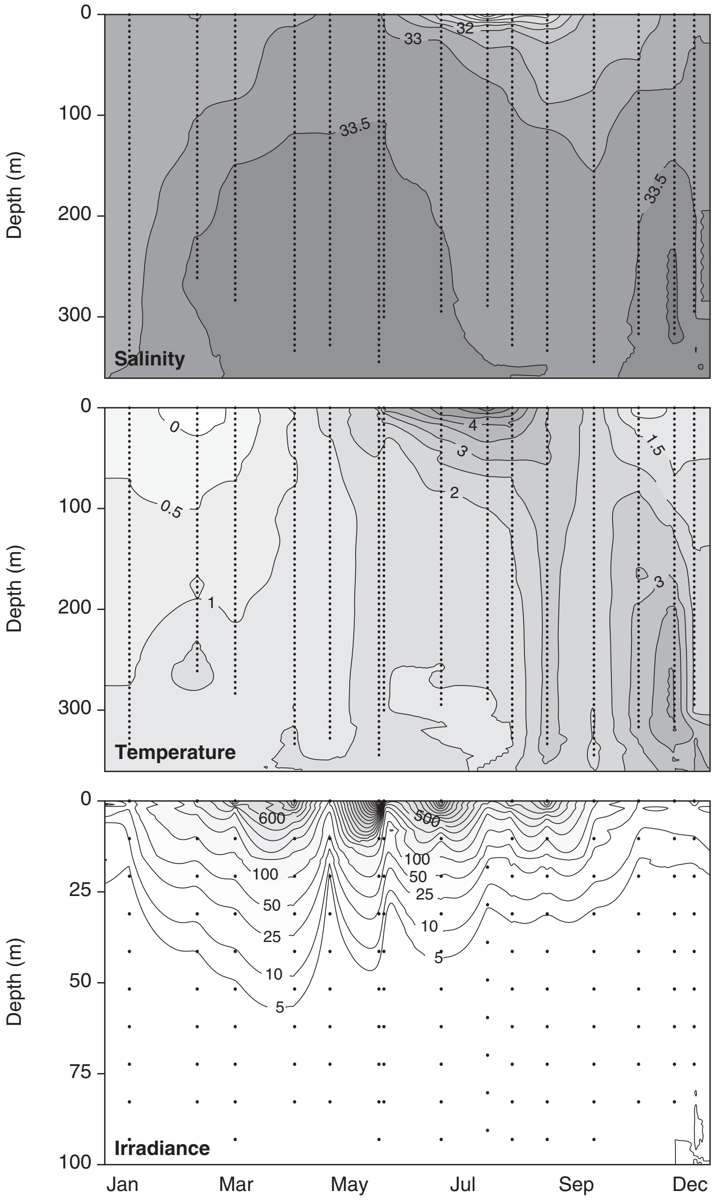


Figure 5.8 Annual variation in salinity, temperature (°C) and irradiance (PAR) at the 'Main Station' in 2009. Vertical dotted lines represent sampling days and depths in increments.

er surface layer formed by discharged melt water, as described for the cross section, can also be seen extending along the entire length of the fjord. This layer also shows some of the highest phytoplankton biomasses recorded along the length section with fluorescence values up to 12.2 (approximately µg chlorophyll *a* l^{-1}) in the outer part of the fjord. Elevated fluorescence values below the euphotic zone (> 50 m) at Fyllas Banke and the outer part of the fjord indicated a vertical mixing or subduction of plankton rich water to depth in this region.

The surface pCO_2 varied along the length section with the highest surface pCO_2 values encountered at the entrance of the fjord as observed in previous years (figure 5.7). At the Fyllas Banke, values were still low as compared with atmospheric levels (387 µatm). However, pCO_2 values outside the bank raised to levels above atmospheric levels as did several of the stations inside the fjord. Lowest values were recorded in the inner parts of the fjord, reaching a minimum of 220 µatm. The pCO_2 levels were very different from previous years (2005, 2006, 2007 and 2008). Thus, Godthåbsfjord was not as strong a CO_2 sink during May as observed in previous years.

5.3 Pelagic sampling

Abiotic and biotic pelagic parameters were sampled monthly at the 'Main Station' (GF3, 64 °07'N 51 °53'W, figure 5.1) near the entrance to Godthåbsfjord. This sampling programme included vertical profiles of salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence using a SBE19+ CTD profiler. Water samples were analyzed for concentrations of pigments (chlorophyll *a* and phaeopigments) and nutrients (NO_x, PO_4^{3-}, SiO_4 and NH_4^+) at 1, 5, 10, 15, 20, 30, 50, 100, 150, 250 and 300 m. In addition, dissolved inorganic carbon and total alkalinity were measured on water samples from 1, 5, 10, 20, 30 and 40 m, representing the euphotic zone.

Particulate primary production measurements were conducted using short-term (approximately 2 hours) free-drifting *in situ* C^{14} incubations corrected for *in situ* light conditions. The vertical sinking flux of material was measured using short-term (approximately 2 hours) free-drifting particle interceptor traps deployed at 65 m. We measured the total amount of particulate material in the traps, and analysed for pigments (chlorophyll *a* and phaeopigments) and particulate carbon and nitrogen in the collected material. The abundance and composition of phytoplankton and zooplankton was sampled using vertical hauls with 20 and 45 µm nets. Larger planktonic organisms, i.e. crab, shrimp and fish larvae, were sampled by oblique hauls using a 335 µm bongo net, this was also conducted along the length section in mid-May.

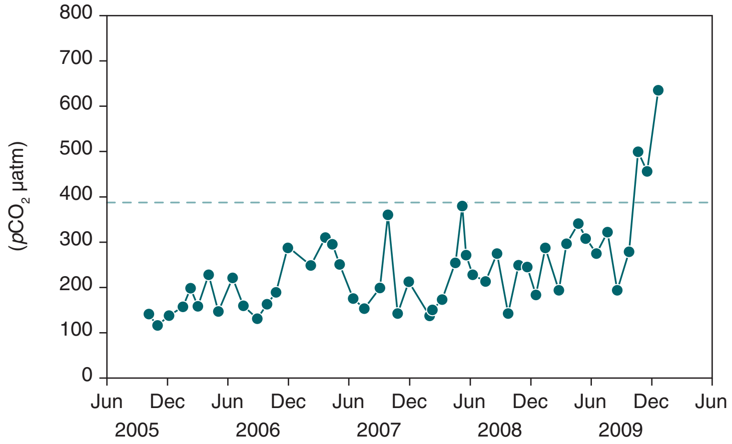


Figure 5.9 Annual variation in pCO_2 (µatm) in surface waters at the 'Main Station' from late 2005 to 2009.

Abiotic parameters

The overall annual trends in abiotic hydrographical conditions at the 'Main Station' resembled those observed in previous years (figure 5.8). Winter months showed increasing irradiance at depths, from January to April, as the seasonal incoming irradiance increased. The abrupt decrease in irradiance at depth in May was likely caused by a peak in phytoplankton biomass, as incoming irradiance was at an annual high during this particular sampling day. Variations in irradiance at depth during the rest of the year were likely a combination of the annual light cycle, suspended material in the water column (e.g. phytoplankton) and weather conditions affecting incoming irradiance. Similar to previous years, irradiance remained below 5 µmol photos m^{-2} s^{-1} at depths below 50 m, except during one sampling day in April.

Moderate salinity and temperature gradients were observed in the water column during winter with values ranging from 32.5 to 33.8 and –0.5 to 1.8 °C, respectively (figure 5.8). Similar to previous years, vertical mixing of the water column occurred in spring forming largely homogenous profiles during April and May. Summer heating of the fresher surface layer formed by the seaward export of melt water lead to a coinciding annual minimum salinity of 28.8 and maximum temperature of 5.9 °C. Autumn conditions resulted in a cooling of the surface waters and a less pronounced freshwater layer. At the same time, an inflow of deeper warm and saline coastal water resulted in subsurface temperatures reaching 4.0 °C in December.

Surface pCO_2 values from 2005 to 2009 vary from 125 to 650 µatm (figure 5.9). However, only three sampling dates from 2009 were above atmospheric content (387 µatm) in the time series. Average surface pCO_2 concentrations increase through the period investigated from 186 µatm in 2006, to 235 µatm in 2007, to 275 µatm in 2008 and to 340 µatm in 2009. Over the entire period, average pCO_2 values are below atmospheric concentration, indicating that Godthåbsfjord is a strong CO_2 sink. Due to inflow of pCO_2 rich water from outside the fjord during the autumn-winter 2009 Godthåbsfjord reduced its capacity to take up CO_2 in 2009.

Annual trends in nutrient concentrations in the water column were linked to seasonal phytoplankton production and vertical mixing of the water column. High nutrient levels were observed just prior to the spring phytoplankton bloom with maximum concentrations of 12.5, 1.0 and 6.2 µM for nitrate / nitrite, phosphate and silicate, respectively (figure 5.10). The onset of spring bloom in May lead to an abrupt decrease in nutrient levels, particularly in the productive surface layer with concentrations reaching annual minimums of 0.8, 0.1 and 0.8 µM for nitrate / nitrite, phosphate and silicate, respectively. Due to vertical mixing lowered nutrient levels were also observed at depth in May and June. Seasonal remineralisation and introduction of nutrient rich coastal water, combined with vertical mixing, lead to increasing nutrients levels during autumn and winter.

Biotic parameters

Phytoplankton biomass remained negligible prior to the onset of spring bloom, as illustrated by pigment concentrations in the water column (figure 5.11). Characteristic of the 'Main Station' the spring bloom resulted in annual peak values in pigments, reaching 11.8 and 2.4 µg l^{-1} for chlorophyll *a* and phaeopigments at 1 m in May, respectively. Although the spring

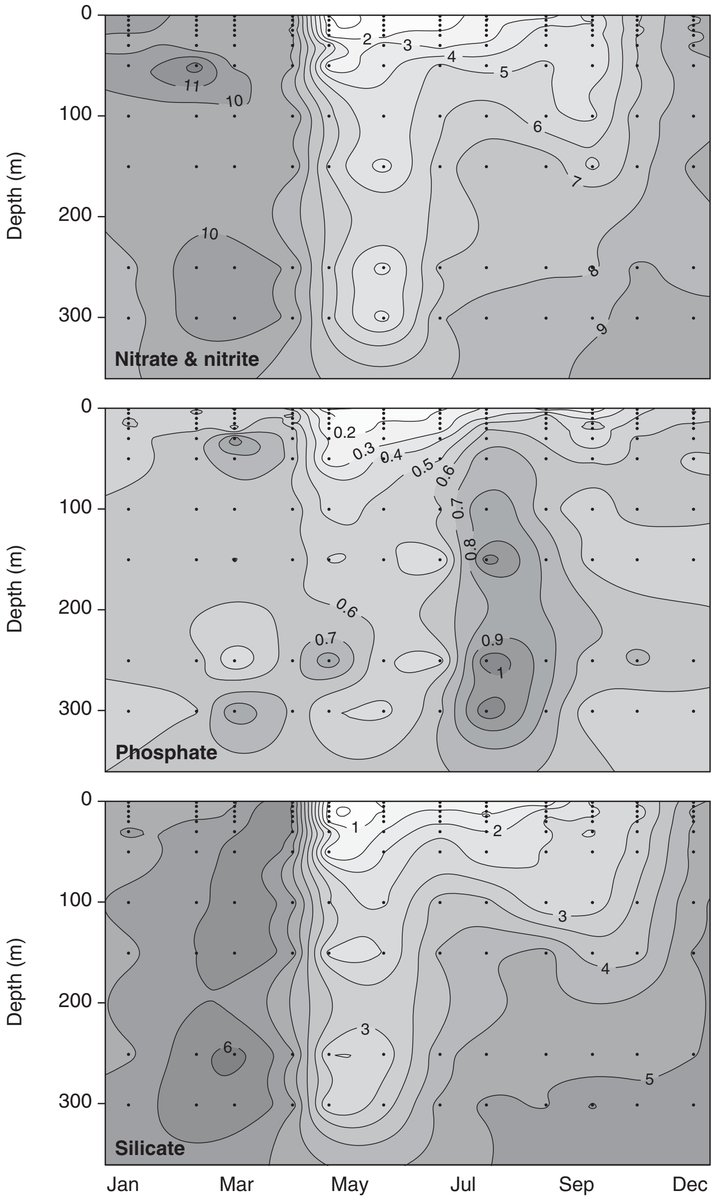


Figure 5.10 Annual variation in nitrate and nitrite (μM), phosphate (μM) and silicate (μM) concentrations at the 'Main Station' in 2009. Vertical dotted lines represent sampling days and depths.

bloom in May showed the highest primary production value of 421 mg C m^{-2} d^{-1} in 2009 (figure 5.11) it was considerably lower than previously observed spring bloom primary production values (ranging from 678 to 1284 mg C m^{-2} d^{-1} from 2006-08). Moreover, vertical mixing along with sinking flux of phytoplankton based material in spring lead to elevated pigment concentrations well below the euphotic zone (i.e. > 50 m). As seen during previous years, nutrient depletion during the spring bloom result in decreasing primary production values and pigment concentrations. Pelagic remineralisation of organic material and / or re-introduction of nutrients to the euphotic zone resulted in a minor secondary phytoplankton bloom of 190 mg C m^{-2} d^{-1} in August (figure 5.11); this also remained less pronounced than previously observed autumn blooms. Overall, the annual primary production was significantly lower than previously recorded estimates (76.0, 104, 91.1 and 38.2 mg C m^{-2} y^{-1} in 2006, 2007, 2008 and 2009, respectively). Hence, primary production at the 'Main Station' varies by a factor 2.7 within the current four-year time series.

The plankton community

Vertical net hauls from 0-60 m using a 20 μm net was used to sample phytoplankton species composition. A dominance of diatom species persisted throughout the entire year, but was more pronounced in spring (i.e. from March to May) when diatoms contributed > 99 % of the total phytoplankton assemblage (figure 5.12). The overall diatom dominance is consistent with previous years (i.e. 2006-08). However, the diatom dominance during the spring bloom in May differ from previous years where *Phaeocystis* (Haptophyceae) previously dominated. The single most important species during the phytoplankton bloom in May was the diatom *Fragilariopsis cylindrus* contributing 46.4 % of the total algal assemblage. Interestingly, the diatom species *Pauliella taeniata* dominated the phytoplankton community during pre-bloom conditions contributing 98.9 % of the total phytoplankton assemblage in March. Previously this species remained a minor component of the phytoplankton community (i.e. up to 2.6 % in March 2008).

Examples of other important single species, at specific times during the year, are the diatoms *Chaetoceros decipiens*, *C. debilis* and *C. curvisetus* (up to 77.1, 27.4 and 20.2 %, respectively), *Thalassionema nitzschioides* (up to 29.9 %) and the golden algae (i.e. Chrysophyta) *Dinobryon baltica* (up to 26.8 %).

Similar to previous years, the most important phytoplankton species integrated over the year were *Chaetoceros* spp. (42.4 %), *Thalassiosira* spp. (16.0 %) and *Fragilariopsis* spp. (4.2 %) (see table 5.1). However, *Pauliella taeniata* also came in among the most important species integrated over the year (8.4 %), due to its strong presence in March.

Vertical zooplankton net hauls were conducted from 0-100 m using a 45 μm WP2 net. Low copepod abundances were recorded throughout the year reaching a maximum of 19229 copepods and copepodites m^{-3} in September (figure 5.13), which is considerably lower than in pre-

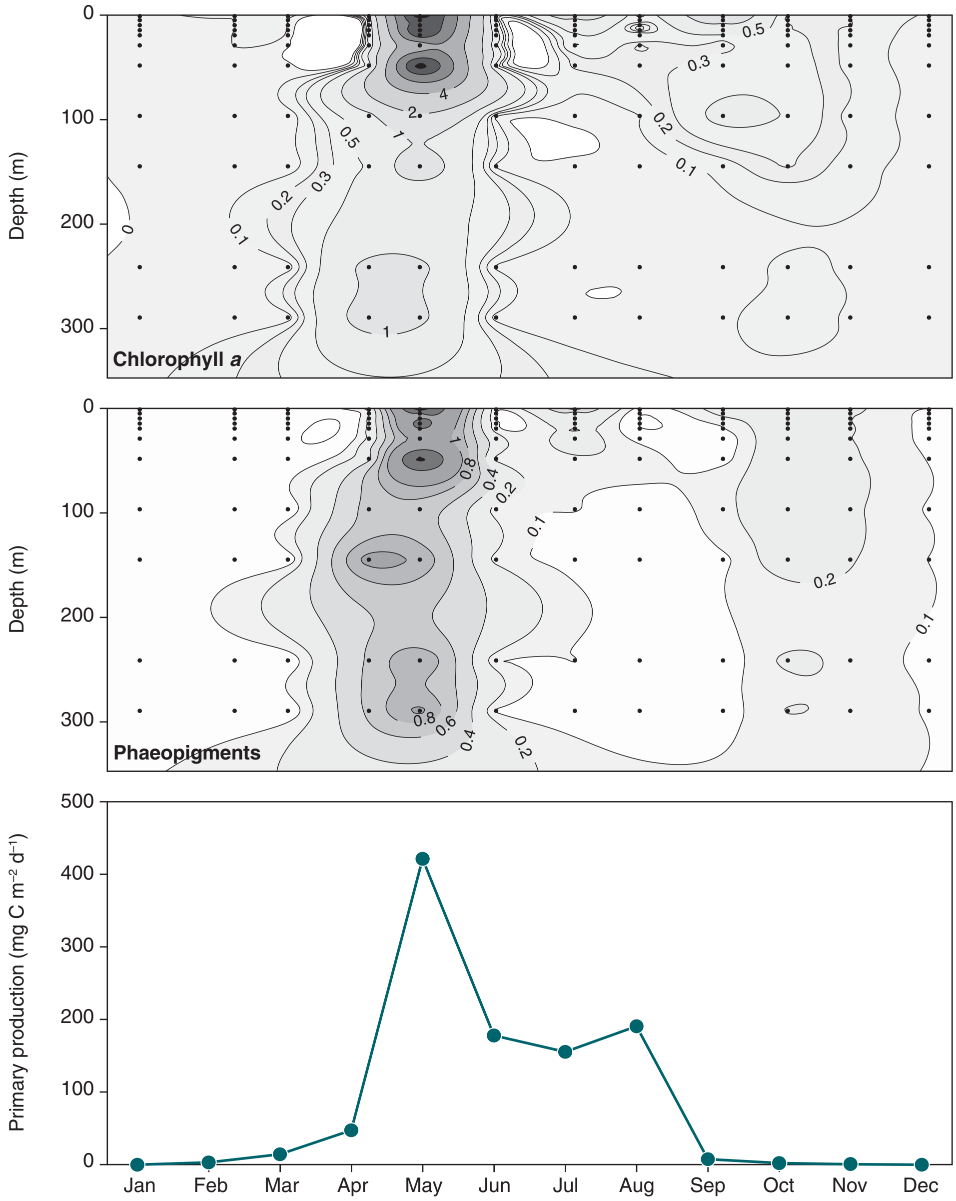


Figure 5.11 Annual variations in chlorophyll a *concentration (µg l^{-1}), phaeopigments concentration (µg l^{-1}) and primary production (mg C m^{-2} d^{-1}) at the 'Main Station' in 2009. Vertical dotted lines on chlorophyll a and phaeopigments plots represent sampling days and depths.*

vious years (36284-69882 copepods and copepodites m^{-3} during 2006-08). The same was true for copepod nauplii, reaching a maximum of 28392 nauplii m^{-3} in July. Nevertheless, the overall seasonal pattern of the copepod community resembled previous years with a peak in nauplii in July followed by a peak in copepods in September. Eggs were not counted in 2009 but will be included again in future.

Similar to previous years, the copepod community was dominated by *Microsetella* sp. throughout the year, except in October, contributing up to 88.0 % of the total copepod composition in August (figure 5.13). *Oithona* spp. dominated the copepod composition in October contributing 43.2 %. Other species contributing significantly to the species composition were *Microcalanus*, *Oncaea* and *Pseudocalanus* spp. contributing

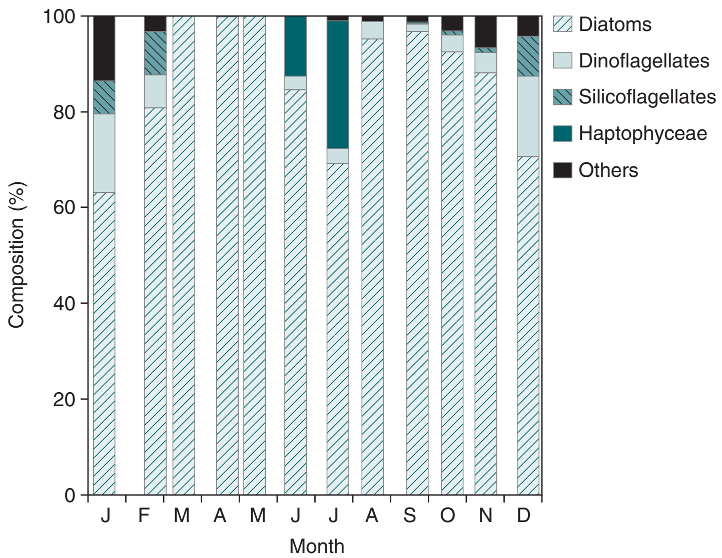


Figure 5.12 Seasonal variations in phytoplankton community composition (%) at the 'Main Station' in 2009.

Table 5.1 The ten most dominant phytoplankton species integrated over the year as their relative accumulated proportion of total cell counts (%) at the 'Main Station' in 2006-09.

2006		2007		2008*		2009	
Chaetoceros wighamii	30.5	*Chaetoceros* spp. (ex debilis)	20.1	*Thalassiosira* spp.	27.9	*Chaetoceros* spp.	42.4
Phaeocystis sp.	45.5	*Phaeocystis* sp.	36.3	*Phaeocystis* sp.	50.4	*Thalassiosira* spp.	58.4
Thalassiosira antarctica	53	*Thalassiosira* spp.	52.3	*Chaetoceros* spp.	62.1	*Pauliella taeniata*	66.8
Thalassionema nitzschioides	58.1	*Chaetoceros debilis*	65.5	*Fragilariopsis* spp.	70.0	*Fragilariopsis* spp.	71.0
Dictyocha speculum	62.7	*Thalassionema nitzschioides*	78.6	*Navicula* spp.	73.9	*Dinobryon baltica*	74.4
Pseudonitzschia cf seriata	66.2	*Fragilariopsis oceanica*	82.2	*Protoperidinium* spp.	77.5	*Centric diatoms undet.*	77.6
Thalassiosira nordenskioeldii	69.1	*Dictyocha speculum*	83.6	*Pseudonitzschia* spp.	80.5	*Protoperidinium* spp.	80.2
Nitzschia frigida	71.7	*Aulacoseira* sp.	84.9	*Podosira* spp.	83.2	*Dictyocha speculum*	82.4
Dinobrion balticum	74	*Cocconeis* spp.	86.1	*Leptocylindrus* spp.	85.7	*Leptocylindrus danicus*	83.8
Thalassiosira bioculata	76.1	*Ceratulina* sp.	87.0	*Peridenella catenata*	87.6	*Navicula* spp.	85.2

*From January to August

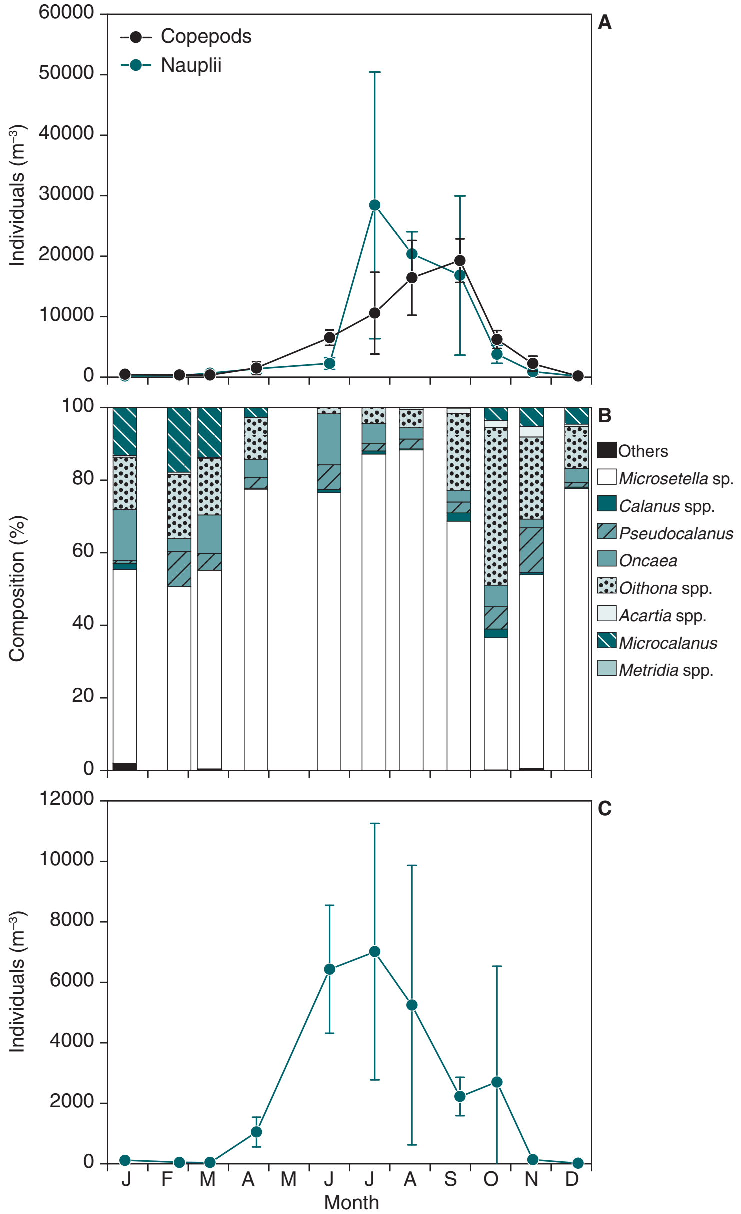


Figure 5.13 (A) Annual variation in abundance (individuals m^{-3}) of copepod nauplii and copepods (i.e. copepodites and adult stages), (B) copepod community composition (%) and (C) abundance of other zooplankton groups (individuals m^{-3}) at the 'Main Station' in 2009. Error bars represent standard deviation.

up to 18.1, 14.1 and 12.1 %, respectively.

In previous years, *Calanus* spp. has only been present in significant numbers during the spring bloom. Thus, *Calanus* spp. was expected to be present in May. However, this cannot be confirmed as zooplankton samples from May were unfortunately destroyed in transport. The highest confirmed contribution of *Calanus* spp. therefore remains 2.4 % in October.

The abundance of other zooplankton was also low in 2009 reaching a maximum of 7004 individuals m^{-3} in July (figure 5.13), compared to maximum values of >40000 individuals m^{-3} in 2006-08. Similar to previous years, Bivalvia and Cirripedia larvae peaked in spring / early summer (i.e. April / July; data from May is missing) while Gastropoda larvae, Rotifera and Foraminifera peaked in August / September

To assess fish larvae and shellfish at the 'Main Station', single oblique sampling with a bongo net (335 µm) was used each month during 2008 (except June) and 2009 (except October). Additional sampling with a double oblique bongo net (335 and 500 µm) were conducted along the length section from offshore Fyllas Banke to the inner fjord 2006 to 2009. Thirteen stations were sampled in May 2006, four stations in 2007 and 2008 and three stations in 2009.

At the main station (GF3), the highest concentration of fish larvae is usually found in spring (March-May, 2006-2008). In 2009, however, the highest concentration was found in summer / early autumn (July and September, figure 5.14a). This was caused by a decrease in abundance of sand eel *Ammodytes* sp. larvae in spring and a slight increase in abundance of capelin *Mallotus villosus* larvae in the early

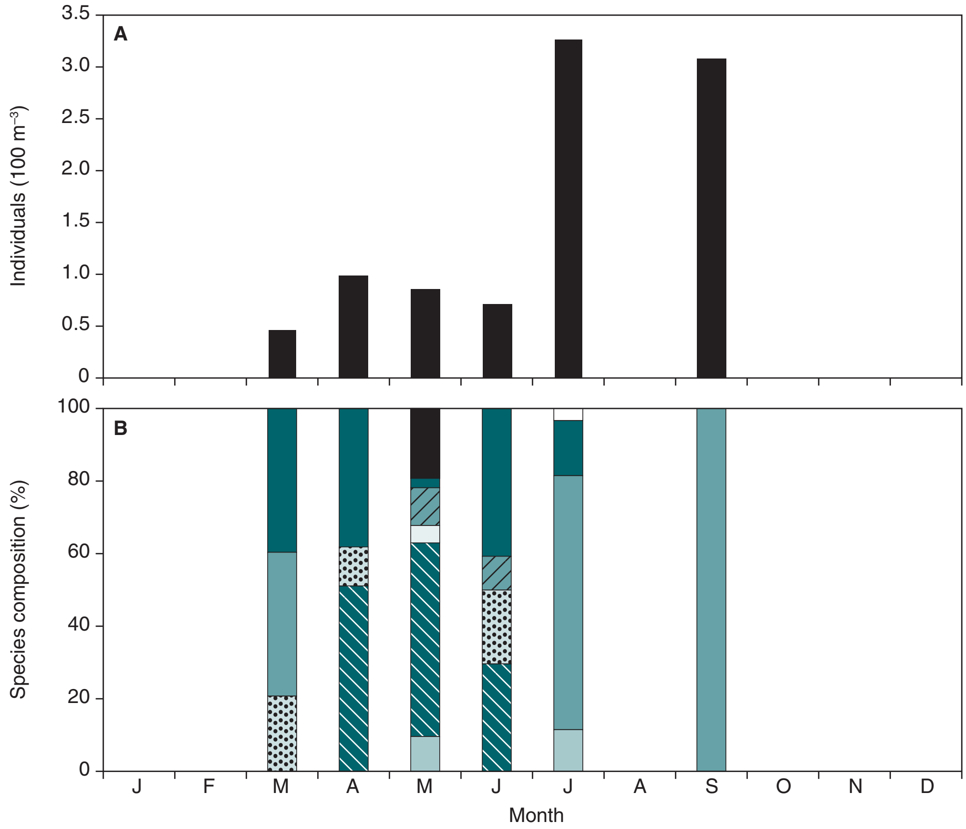


Figure 5.14 Annual variations in A) abundance (individuals 100 m^{-3}) and B) community composition (%) of fish larvae at the 'Main Station' in 2009. Samples were collected each month except August.

autumn in the 2009 samples. The abundance of sand eel larvae has gradually declined since the start of the monitoring programme in 2006. In March 2006, 14.7 individuals 100 m^{-3} were caught in the samples, whereas in March 2009, only 0.10 individuals 100m^{-3} were caught. In 2006-2008, sand eel larvae was the dominating species in spring at the main station, whereas in 2009 arctic shanny *Stichaeus punctatus* was the dominating species (figure 5.14b).

A temporal shift in species composition occurred during summer at the 'Main Station'. In 2009, arctic shanny was the dominating species in spring whereas capelin was dominating in late summer / early autumn (figure 5.14b). Cod larvae *Gadus morhua* were found in May and July.

The length section in the fjord in May shows the same pattern in fish larvae concentration and species composition as previous years. Highest concentration was found closer to the inlet of the fjord at the 'Main Station' (figure 5.15a). The concentration was however lower than previous years due to decreased abundance of sand eel larvae. Species composition also varied along the length section with fewer species in the samples deeper inside the fjord (figure 5.15b). Cod larvae were found both close to the inlet and in the mid-part of the fjord.

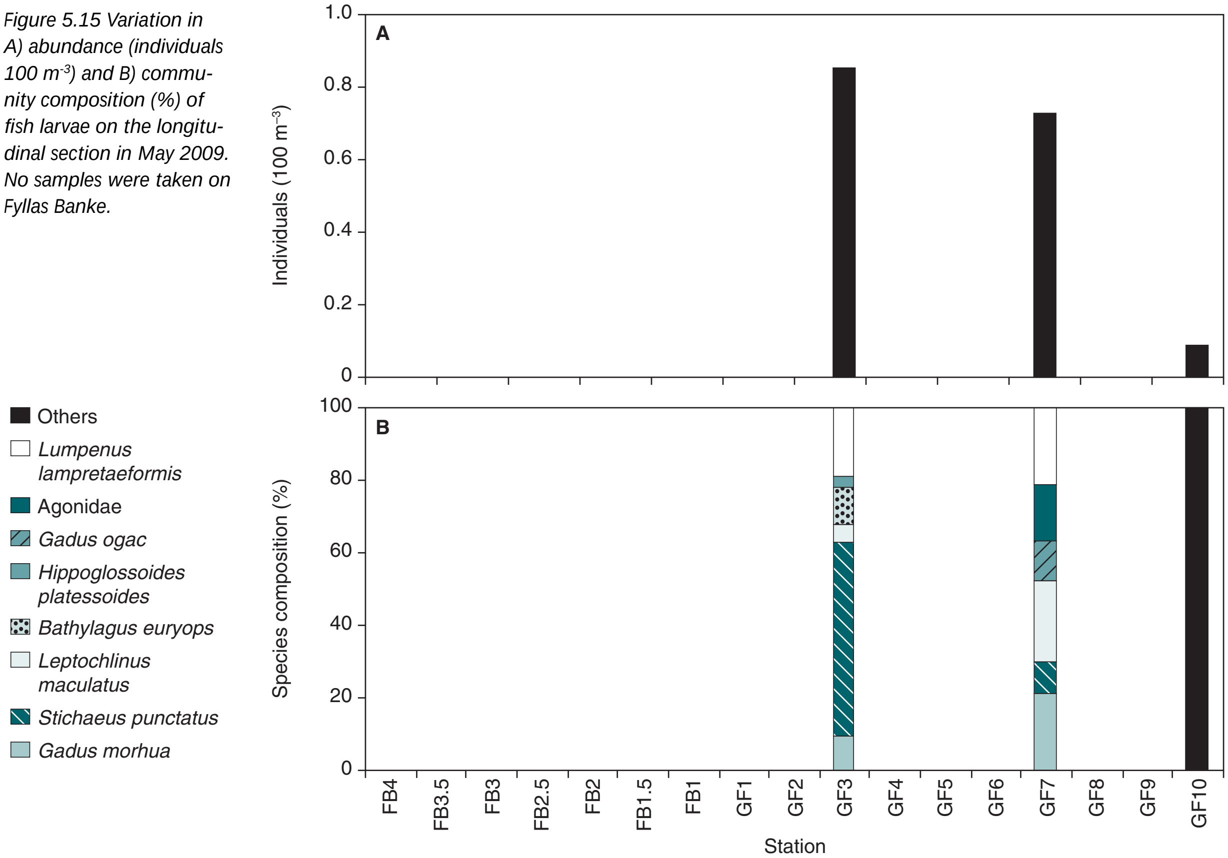
Fish larvae species composition seem to vary between years with most species found in 2008 (table 5.2).

At the main station (GF3) seasonal pattern in the abundance of shellfish

Table 5.2 Species list of fish larvae 2006-2009.

Species list	2006	2007	2008	2009
Gadus morhua	×	×	×	×
Stichaeus punctatus	×	×	×	×
Leptochlinus maculatus	×	×	×	×
Ammodytes sp.	×	×	×	×
Mallotus villosus		×	×	×
Aspidophoroides monopterygius	×	×	×	
Bathylagus euryops		×	×	×
Cyclothone sp.		×		
Liparis sp.		×		
Pholis sp.	×	×	×	
Reinhardtius hippoglossoides	×		×	
Myoxocephalus scorpius			×	
Hippoglossoides platessoides			×	×
Sebastes sp.			×	
Gadus ogac			×	×
Leptagonus decagonus				×
Agonidae				×
Lumpenus lampretaeformis				×
Total	**7**	**10**	**13**	**11**

Figure 5.15 Variation in A) abundance (individuals 100 m⁻³) and B) community composition (%) of fish larvae on the longitudinal section in May 2009. No samples were taken on Fyllas Banke.



(*Chionoecetes opilio, Hyas* sp. *Pandalus* sp.) showed similarities with 2008 (figure 5.16a and 16b). However, almost no larvae were observed in April 2008, though a high relatively abundance was observed in April 2009. Concentration of *Pandalus* sp. peaked in May and exceeded values compared to 2008 by almost an order of magnitude. Abundance of *C. opilio* was low compared to *Hyas* sp. in both 2008 and 2009. Larvae stage zoae I of *C. opilio* and *Hyas* sp. dominating samples in April to June whereas larvae stage zoae II were more prevalent in July. Low concentrations of megalope stage of *C. opilio* and *Hyas* sp. were observed in October 2009. Preliminary data indicate a temporal shift in species composition during 2009 – in May to August 2008 *Sagitta* sp., *Ctenophora* sp. and other Jellyfish were the more abundant species (figure 5.16c and 16d). In 2009 *Sagitta* sp. remained the single most abundant species, except for February, April and June. Another consistently abundant species was *Ctenophora* sp. (40 % in September) (figure 5.16e and 16f).

Along the length section concentration of crab and shrimp, larvae were highest in 2007 and were remarkably low in 2008 and 2009, where only few individuals were observed in the samples (data not shown).

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. and *Hyas* sp. were found in the samples from 2007-2009. In 2007 *Chionoecetes opilio* were observed at the offshore stations. In all years, all tree species were abundant at the 'Main Station' (GF3). At the outer fjord larvae of *C. opilio* and especially *Hyas* sp. were more abundant than shrimp larvae. *Hyas* sp. was dominant at the stations at the shallow bank.

Vertical sinking flux

Vertical sinking flux of total particulate material showed no clear seasonal trends, as observed in previous years, averaging 58.2 g m^{-2} d^{-1}. Even more so, little variability was observed throughout the year compared to previous years (coefficient of variation of 29.1 % for 2006, 30.9 % for 2007, 40.7 % for 2008 and 15.9 % for 2009, figure 5.17). The previously reported importance of lithogenic material from glaciers and melt rivers was again depicted in the low carbon content and high carbon to nitrogen ratio of the collected sinking ma-

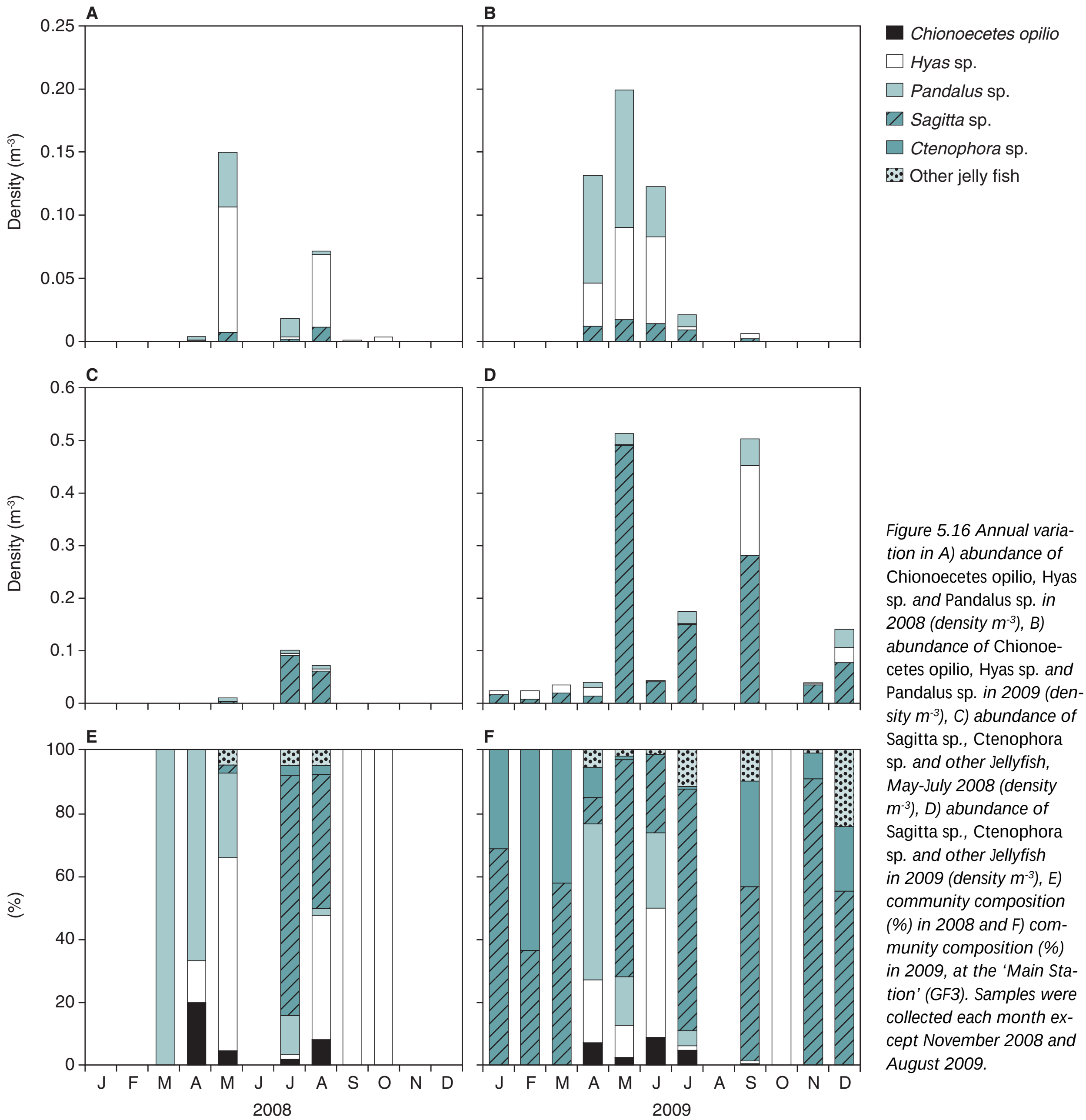


Figure 5.16 Annual variation in A) abundance of Chionoecetes opilio, Hyas sp. *and* Pandalus sp. *in 2008 (density m⁻³), B) abundance of* Chionoecetes opilio, Hyas sp. *and* Pandalus sp. *in 2009 (density m⁻³), C) abundance of* Sagitta sp., Ctenophora sp. *and other Jellyfish, May-July 2008 (density m⁻³), D) abundance of* Sagitta sp., Ctenophora sp. *and other Jellyfish in 2009 (density m⁻³), E) community composition (%) in 2008 and F) community composition (%) in 2009, at the 'Main Station' (GF3). Samples were collected each month except November 2008 and August 2009.*

terial (averaging 2.4 % and 10.5 mol:mol, respectively). Phytoplankton based material typically has a carbon to nitrogen ratio closer to the Redfield Ratio (6.6 mol:mol). Total particulate carbon sinking fluxes were slightly higher during spring than winter, likely due to sinking of phytoplankton material (figure 5.17). Moreover, two distinct peaks in total particulate carbon sinking fluxes in August and October is thought to be related to the release of material with a higher carbon content during draining of two glacial ice-dammed lakes in the inner part of the fjord. Sinking fluxes of phytoplankton based material, i.e. chlorophyll *a*, showed a clear seasonal pattern with a strong peak during the spring bloom reaching 20.4 mg m^{-2} d^{-1} (figure 5.17). Moreover, elevated chlorophyll *a* sinking fluxes was observed throughout summer and autumn in parallel with the seasonally elevated phytoplankton biomasses in the water column.

Although the estimated annual total particulate material sinking flux in 2009 was slightly lower than during previous years, it remained comparable in size (table 5.3). In contrast, the estimated annual sinking flux of total particulate carbon presently remains the highest on record, largely driven by the two peaks in carbon sinking fluxes in August and October (figure 5.17).

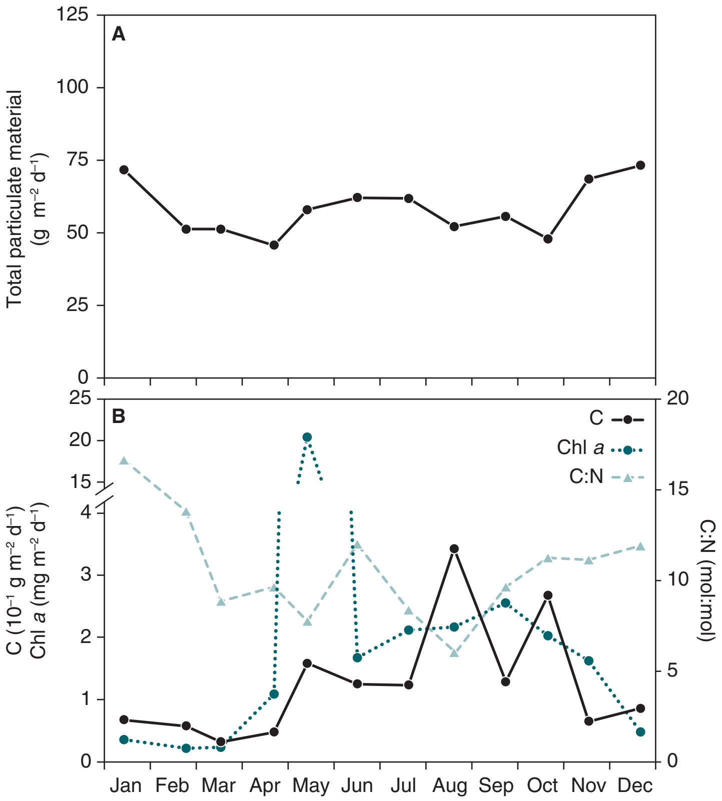


Figure 5.17 Annual variation in vertical sinking flux of A) total particulate material (g m^{-2} d^{-1}), B) total particulate carbon (10^{-1} g m^{-2} d^{-1}), chlorophyll a (mg m^{-2} d^{-1}) and carbon to nitrogen ratio (mol:mol) of the sinking particulate material collected at the 'Main Station' in 2009.

5.4 Sediments

Fresh organic matter on the sea bed either is consumed by organisms or is mineralized to reduced substances involving a number of different electron acceptors. At the sediment surface, oxygen is the key electron acceptor while sulphate is 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 four times during 2009 (February, May, August and November) at a depth of 125 m in Kobbefjord (64 °09.975'N, 51 °28.328'W). Oxygen fluxes were measured by closed core incubations and diffusive oxygen by microprofiling. In all sampling periods, oxygen was depleted within 1 cm of the sediment surface. Maximum consumption occurred in May when pelagic biological activity is high and sedimentation rate is likely to be high, consisting of high organic matter settling to the seafloor (figure 5.18). This is also reflected by higher bioturbation activity over that of diffusive oxygen uptake (TOU / DOU 1.62) suggesting faunal activity was responding to an input of fresh organic matter. 9.67 mmol m^{-2} d^{-1} was returned to the water column as dissolved inorganic carbon (DIC) (table 5.4). Oxygen consumption rates were similar for most periods during the year, while high bioturbation and mineralisation during May suggest a seasonal effect on oxygen dynamics in Kobbefjord.

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*, is monitored each year in May at the entrance of Kobbefjord (64°07.651'N, 51°38.587'W, 50-60 m depth). Physiological fitness is measured by using the ratio of gonad mass / total soft tissue mass to the mass of calcium carbonate shell. Individuals experiencing energetically favourable conditions can invest more energy into soft tissue growth and reproduction and therefore attain higher index values.

In 2009, specimens were collected 7 May. For sea urchins, both index values were comparable to 2008 values. For the scallops, a small but significant increase in the conditions index (Jensen and Rasch 2009) was observed (figure 5.19).

The time series are still too short for statistical analysis of correlations between physiological indices and environmental parameters. However, the *a priori* hypothesis is that food availability is a key parameter together with water temperature. During the winter, both species rely on stored energy. As the metabolic rate is dependent on temperature a higher temperature during the winter would increase the energetic demand resulting in lower low index values.

Table 5.3 Integrated annual vertical sinking flux of total particulate material and carbon at 65 m at the 'Main Station' in 2006-2009.

Depth	Parameter	2006	2007	2008	2009
65 m	Total particulate flux (×1000 g dry weight m^{-2} y^{-1})	21.4	24.9	20.2	19.3
	Carbon (g C m^{-2} y^{-1})	253.9	364.1	315.2	431.5

Table 5.4 Sediment-water oxygen, DIC and nutrient exchange, measured from intact sediment cores. Where DOU (diffusive oxygen uptake), TOU (total oxygen uptake) and DIC (dissolved inorganic carbon) all are in mmol m^{-2} d^{-1} ± standard error (SE) of the mean, n denotes number of samples. Positive values indicate release into the water column while negative values reflect uptake.

	Month								
Parameter	**February**		**May**		**August**		**November**		**n**
TOU	–4.35	±0.65	–11.90	±1.71	–4.77	±0.57	–3.82	±0.67	6
DOU	5.47	–	7.34	–	6.85	–	6.59	–	3
TOU/DOU	0.79	–	1.62	–	0.70	–	0.58	–	–
DIC	2.45	±1.33	9.67	±1.34	5.69	±0.69	2.01	±0.71	6
PO_4^{3-}	–0.07	±0.03	0.07	±0.01	–0.14	±0.02	0.02	±0.01	6
$NO_3^- + NO_2^-$	0.40	±0.06	0.65	±0.28	0.09	±0.10	0.11	±0.03	6
SiO_4	3.54	±0.53	2.20	±0.43	1.05	±0.13	0.69	±0.14	6

Benthic flora

The flora of the sea bottom can contribute significantly to the total primary production of shallow coastal waters (Gattuso et al. 2006) as opposed to oceanic systems where phytoplankton is the only type of primary producer. Even shallow coastal high arctic waters where sea ice covers the surface of the sea most of the year may have a significant benthic production (Rysgaard and Glud 2007, Gomez et al. 2009). This is for example the case in Kobbefjord, Nuuk, where a belt of macroalgae extends to maximum depths of about 40 m (Juul-Pedersen et al. 2009).

Large brown kelps often form a conspicuous part of the macroalgal community in temperate and arctic areas (Mann 1973, Rysgaard and Glud 2007, Juul-Pedersen et al. 2009). The genus *Laminaria* and related species produce an annual blade. Annual blade growth reflects the growth conditions of the preceding year with respect to e.g. light availability and thus sea ice cover and therefore selected as a relevant monitoring variable. In higher latitudes, the annual growth of sugar tangle, *Saccharina latissima*, can be estimated based on a single sampling in late summer, since the new blades are separated clearly from the old blades by constrictions, which may remain for 1-2 years (Lund 1951, Dunton 1985, Borum et al. 2002). At lower latitudes, however, the blades are turned over at faster rates. At Nuuk, for example *L. longicruris*, which shares many morphological characteristics with *S. latissima*, may lack the extremity of the new blade by the end of summer. Here, blade length therefore reflects minimum annual growth (Juul-Pedersen et al. 2009).

Laminaria longicruris was collected by diver at 5-6 m depth in the outer southern

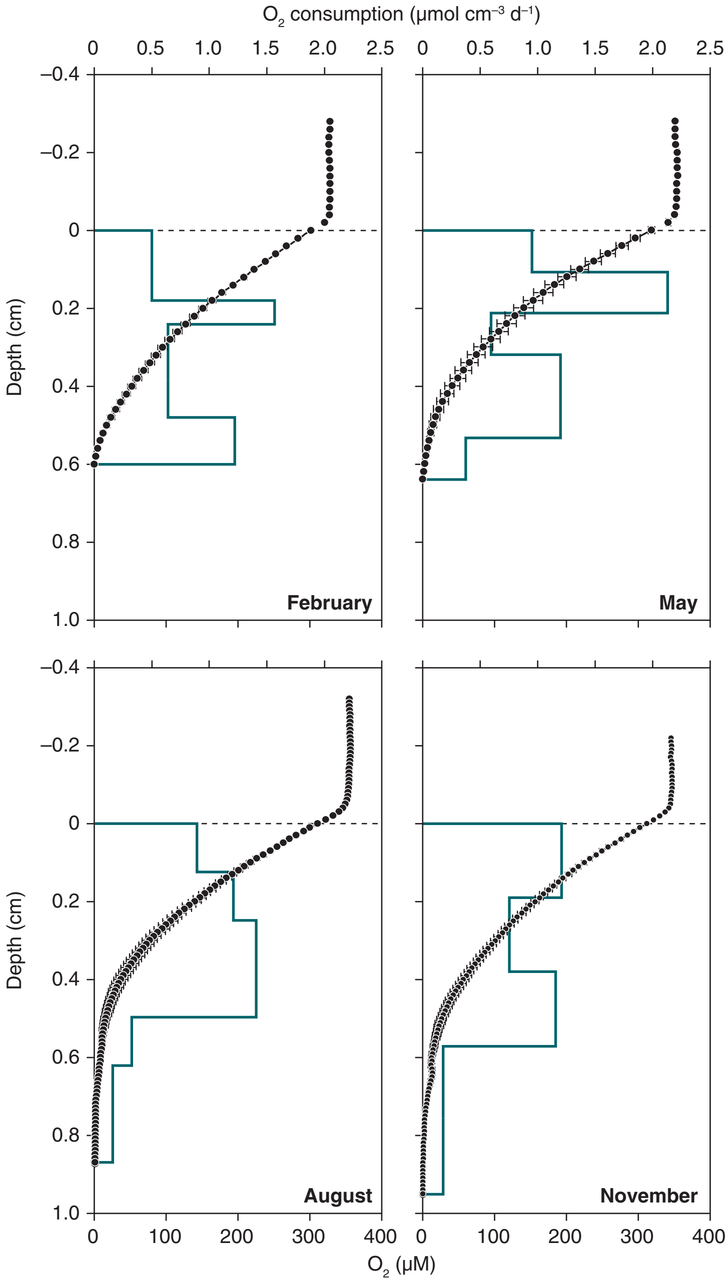


Figure 5.18 Vertical concentration profiles of oxygen (closed dots) and modelled consumption rates (solid line) from microelectrode profiles with sediment depth for each of the four sampling periods. Error bars represent standard error of the mean.

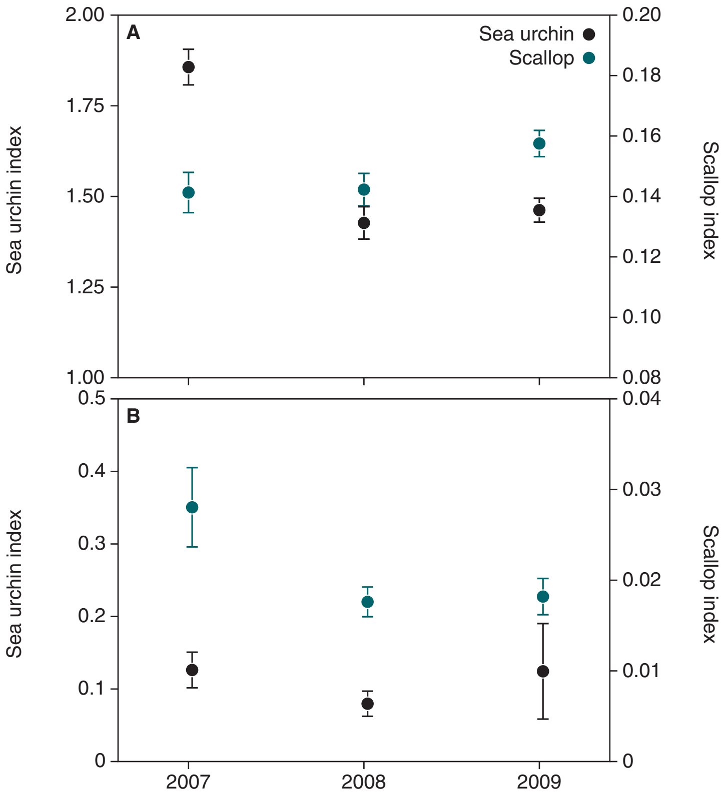


Figure 5.19 A) Condition index for the sea urchin Strongylocentrotus droebachiensis *and the scallop* Chlamys islandica *collected in May at the 50-60 m depth in Kobbefjord (mean ± 95% CI). B) Gonad index for the same two species.*

part of Kobbefjord. A total of 41 specimens were collected at a protected site (64°08.408'N, 51°35.158'W) where sea ice forms in winter, and 57 specimens at an exposed site (64°07.908'N, 51°37.074'W) with less sea ice.

The size structure of the algae followed similar patterns at both sites. Blade length increased as a linear function of stipe length (figure 5.20a), and stipe width increased as a saturating function of stipe length (figure 5.20b). Blade width increased as a saturating function of blade length (figure 5.20c), and blade biomass increased as a linear function of blade length (figure 5.20d).

Reproductive tissue, visible as dark patches of sori, was never found in blades shorter that 1 m, but was frequently observed in blades of 1.5 m and longer (figure 5.21). Therefore, those plants are considered mature.

The size of mature individuals (blades >1.5 m) was comparable at the two sampling sites: Blade lengths 203 and 201 cm, biomasses 191 and 177 g DW (figure 5.22, left panels) and carbon contents 67 and 63 g (data not shown) at the protected and the exposed site, respectively. Over the

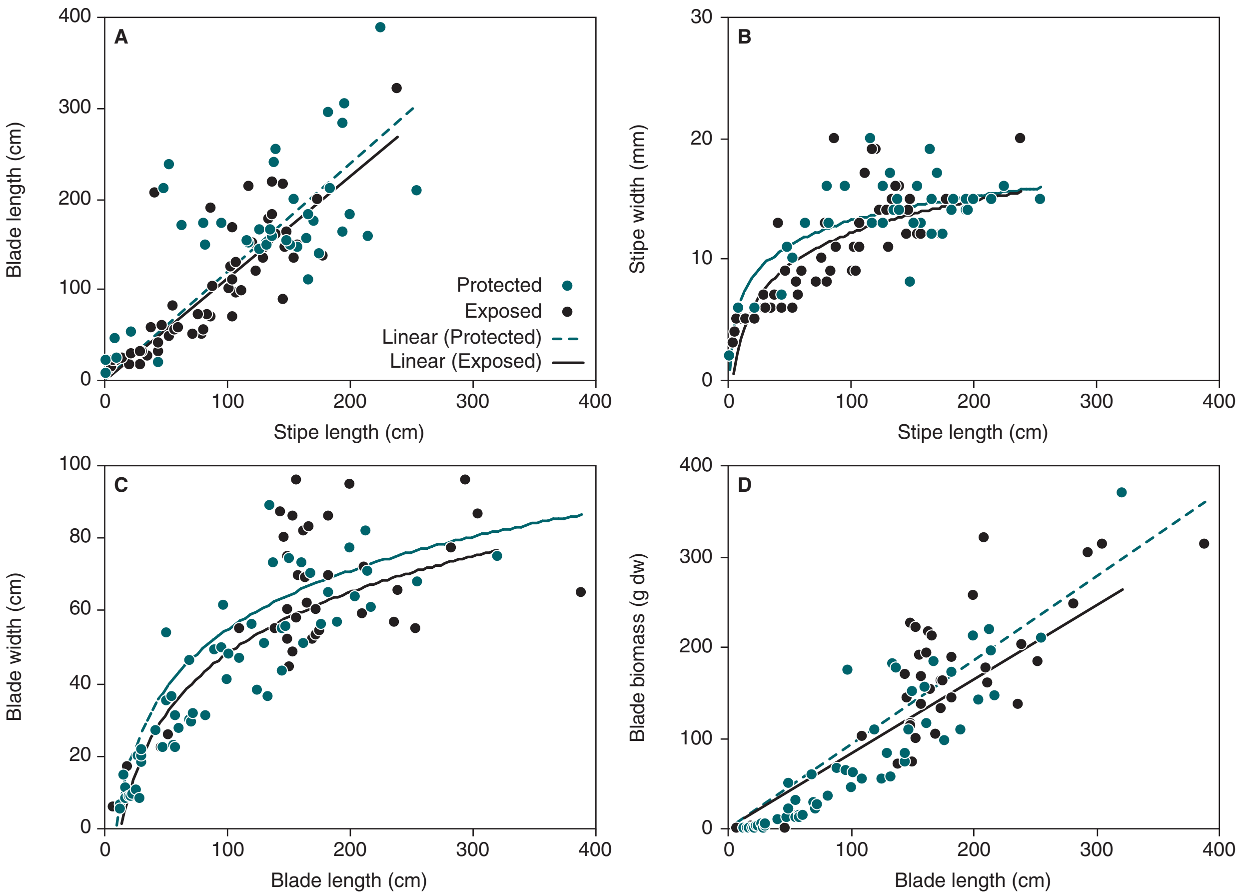


Figure 5.20 Size structures of populations of Laminaria longicruris *collected at a protected and an exposed site in Kobbefjord in August 2009.*

period 2007-2009, the blades had similar length but showed a tendency of larger biomass (figure 5.22a+b). In Kobbefjord, the lower degree of sea ice cover at the exposed site relative to the protected site did not result in longer blades of mature individuals as expected. However, the annual growth of *Laminaria* in Kobbefjord is large relative to that in Young Sund, NE Greenland, where sea ice covers the fjord 9-10 months of the year (Borum et al. 2002).

Nitrogen content and C / N-ratio of the algae were also similar at the two sites in 2009 but varied considerably between years (figure 5.22c+d). The nitrogen content reflects the balance between demand and supply. During winter when the supply is high and the demand is low, nitrogen reserves are built up, while they are drained during summer, when the demand is high and the supply is low. Release of spores may exert an extra drain on the N reserves in late summer. Nitrogen concentrations are therefore likely to reach a minimum by the end of summer. Carbon concentrations, by contrast, are likely to be highest during this period, as carbohydrates are built up by photosynthesis during the summer. These mechanisms may explain the generally lower N content and higher C / N-ratio in the September sampling of 2007 relative to the August samplings of 2008 and 2009. The differences in the levels nitrogen and C / N between August samplings of 2008 and 2009 reflect additional year-to-year variation in supply and demand of N and of carbon storage (figure 5.22c+d).

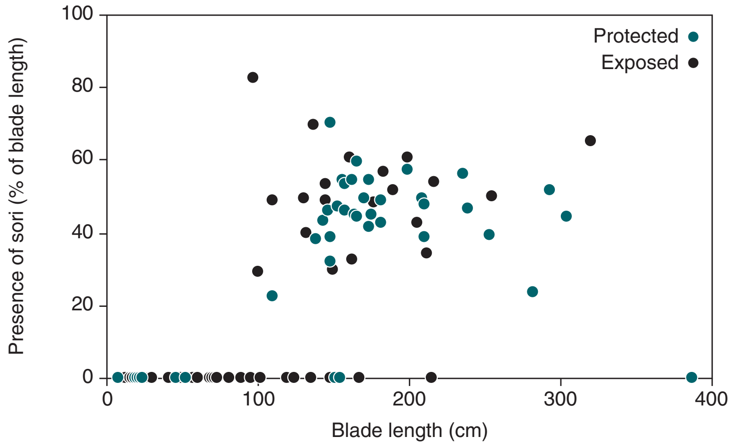


Figure 5.21 Presence of sori, visible as dark spots at the surface of the blades of Laminaria longicruris, *collected at a protected and an exposed site in Kobbefjord in August 2009, respectively. Data are shown as a function of blade length.*

5.6 Seabirds

Two major seabird colonies near Nuuk are included in the MarineBasis programme. Additional seabird colonies in

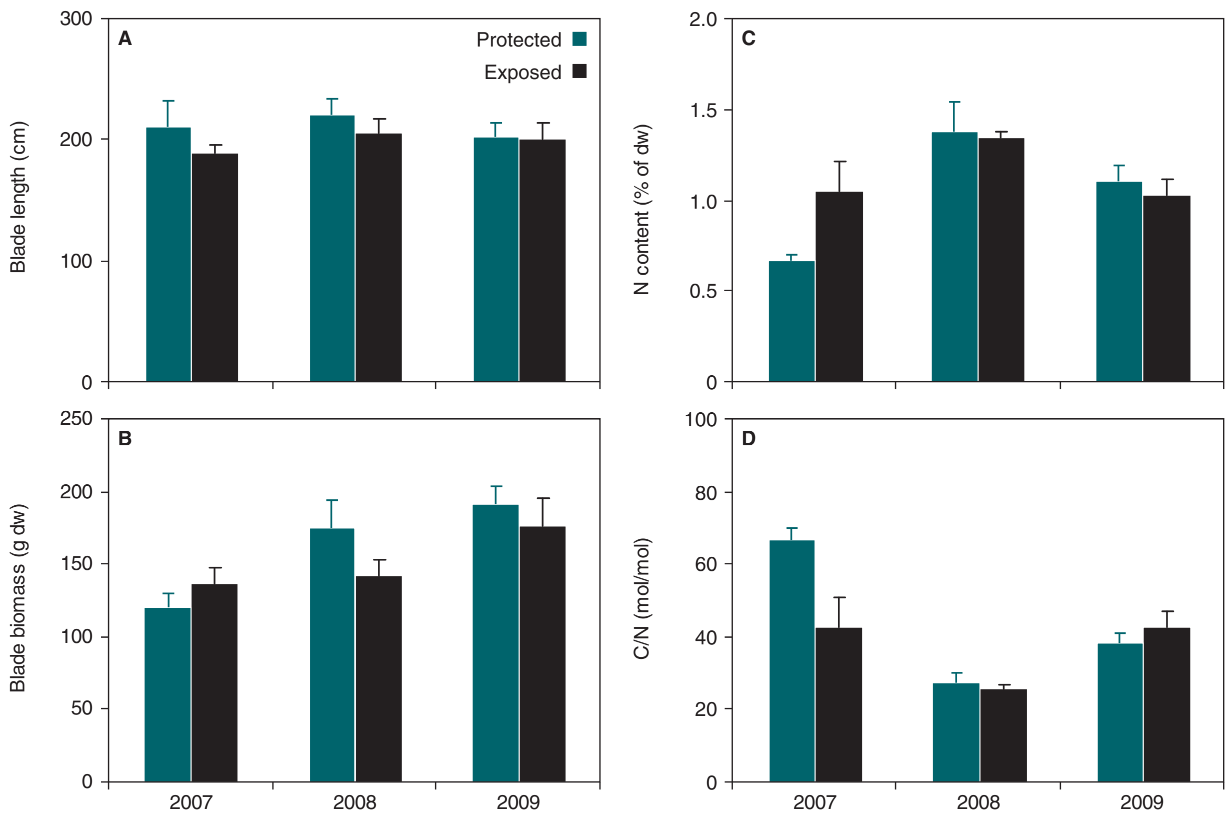


Figure 5.22 Length (A), biomass (B), nitrogen content (C) and C/N ratio (D) of blades of mature Laminaria longicruris *with blade lengths larger than 1.5 m collected at a protected and an exposed site in Kobbefjord 19 September 2007, 13 August 2008 and 14 August 2009.*

the Nuuk area have been visited since 2007. Amongst them, the kittiwake *Rissa tridactyla* colonies of the Nuuk fjord (five in total) were surveyed 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 at Aarhus University. (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, which holds the largest diversity of breeding seabirds in the Nuuk District. Especially surface feeders such as gulls (Laridae), kittiwake and arctic tern *Sterna paradisaea* are well represented at the site (table 5.5). Counts of the entire island were conducted on 4 June (early in the incubating period) using direct counts of Apparently Occupied Nests (AON) or territorial behaviour as a criterion of breeding pairs. The steep cliff in the middle of the southeast facing side of the island (kittiwake and Iceland gull *Larus glaucoides*) 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 from land.

Other birds observed 4 June (not considered breeding or not systematically censured) included one common gull *Larus canus*, one male mallard duck *Anas platyrhynchos*, eight (four pairs) long-tailed ducks *Clangula hyemalis*, two northern wheatear *Oenanthe oenanthe*, three pairs of ptarmigan *Lagopus mutus*, one Lapland bunting *Calcarius lapponicus* and several snow buntings *Plectrophenax nivialis*. Red-breasted merganser *Mergus serrator* and purple sandpiper *Calidris maritima* were not observed in 2009.

The arctic tern colony appeared to be in an early state with only one nest with one egg, 15 birds nearby and 135 birds on the water near the island. The colony was not revisited this year.

Kittiwakes, Iceland gulls and arctic terns appeared to be more numerous than in 2008. However, the number of Iceland gull is still lower than in 2006 and 2007. The number of great black-backed gull *Larus marinus* is lower than during all previous years. The numbers of the other bird species are similar to former counts (table 5.5).

Qeqertannguit is influenced by legal egg harvesting (great black-backed gull and glaucous gull *L. hyperboreus* prior to 31 May) and illegal egg harvesting (after 31 May). Illegal egg harvesting from protected species (e.g. Iceland gull, black-backed gull *L. fuscus*, herring gull *L. argentatus*) has been reported several times since the start of the monitoring programme.

Nunngarussuit (colony code: 63010)

Nunngarussuit is located approximately 40 km south of Nuuk (figure 5.1). The north facing cliff wall of the small island holds the only colony of guillemots *Uria*

Table 5.5 Breeding seabirds (pairs (P), individuals (I) or adults on nests (AON)) at Qeqertannguit since 2006.

Year	2009		2008		2007		2006	
Species	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**
Black-legged kittiwake (*Rissa tridactyla*)	55	AON	20	AON	45	AON	45	AON
Iceland gull SE side (*Larus glaucoides*)	40	AON	33	AON	82	AON	118	AON
Iceland gull NV side (*Larus glaucoides*)	19	AON	12	AON		AON*	–	AON
Great black-backed gull (*L. marinus*)	24	P	44	P	38	P	46	P
Lesser black-backed gull (*L. fuscus*)	21	I	25	I	11	P	10	P
Glaucous gull (*L. hyperboreus*)	5	P	13	P	14	P	10	P
Herring gull (*L. argentatus*)	1	P	2	P	1	I	-	P
Arctic tern (*Sterna paradisaea*)	150	I	0	I	150	I	150-220	I
Arctic skua (*Stercorarius parasiticus*)	2	P	2	P	2	P	2	P
Black guillemot (*Cepphus grylle*)	637	I	689	I	562	I	615	I
Red-throated diver (*Gavia stellata*)	1	P	1	P	1	I **	1	P
Red-breasted merganser (*Mergus serrator*)	0	P	3	P	4	P	observed	

*These birds are included in number for SE birds
**Seen at the coast, but the lake was dry and no nest visible

Table 5.6 Breeding seabirds (individuals = I) at Nunngarussuit since 2006.

Year	2009	2008	2007	2006	Unit
Species	No.	No.	No.	No.	
Guillemot unspecified			–	694	I
Brünnich's guillemot (*Uria lomvia*)	475	388	705	–	I
Common guillemot (*U. aalge*)	47	36	87	–	I
Guillemots on the water	–	450	450	2-300	I
Glaucous gull	12	14	14	20	I
Great black-backed gull	5	2	5	5	I
Northern fulmar (*Fulmarus glacialis*)	11	17	13	23	I

sp. in Nuuk District (the colony includes both Brünnich's *Uria lomvia* and common guillemot *U. aalge*. These alcids are deep divers preying on fish and large zooplankton. Both direct and photo counts of birds present on the cliff wall were conducted from the sea (boat) on 6 July (table 5.6). The number of guillemots on the water was not possible to estimate due to turbulent sea (sea state 3). The number of guillemots (including both common and Brünnich's guillemot) on the cliff in 2009 (table 5.6) was higher than in 2008 but still lower for both than in 2007 (table 5.6).

In order to address the proportion of the boreal distributed common guillemot versus the arctic Brünnich's guillemot in the colony, an analysis of digital photographs was carried out. This is interesting in the context of climate change where the proportion of common guillemot could be expected to increase in a warmer climate. Of 508 guillemots identified to species, 9 % were common guillemots.

Other seabird observations near Nunngarussuit

Simiutat (63013) on 6 July: Due to the sea state only one of the Simiutat islands were visited and it was only possible to state the presence and not the number of puffins *Fratercula arctica* and razorbill *Alca torda*. Numbers of breeding individuals were four glaucous gulls, 15 great black-backed gulls and two lesser black-backed gulls. Nonbreeders found was 60 great cormorants *Phalacrocarox carbo*, 15 harlequin ducks *Histrionicus histrionicus*, about 35 common eiders *Somateria mollissima* and six king eiders *Somateria spectabilis*.

Qarajat qeqertaat (63019) on 7 July. This site consists of two islands:

West Island: 38 nests of common eider were found (15 empty, four of them showed signs of predation, average of 3.0 eggs in the remaining, no chicks found). Number of apparently breeding individuals were: 10 great black-backed gulls, six lesser black-backed gulls, two glaucous gulls, two herring gulls, three arctic skuas (two dark and one light morph) and 255 black guillemots. All were potential breeders. No breeding arctic terns were found.

East Island: 13 nests of common eider found (six empty, none with chicks, average of 2.9 eggs in nests with eggs), a nest of purple sandpiper with two eggs and one nest of red-breasted merganser with eight eggs and 230 black guillemots. Ninety common eiders were counted on the water around both islands. No breeding arctic terns were observed on any of the islands and both islands showed signs of predation of gulls, guillemots (birds and eggs) and eider eggs.

Other kittiwake colonies in the Nuuk fjord (see the Seabird Database for details)

Innaarsunnguaq (64015): 435 pairs of Iceland gull, 12 pairs of kittiwake and 27 razorbills (29 May).

Kangiusaq (64018): 284 pairs of kittiwake (29 May) and 261 pairs (522 individuals) of Iceland gull (5 June).

Alleruusat (64022): 164 pairs of kittiwake and 80 pairs of Iceland gull. 22 great cormorants observed but not breeding (6 June).

Innajuattoq (64019): 458 pairs of kittiwake, 1553 individuals of Iceland gulls and seven AON of great cormorant.

5.7 Marine mammals

West Greenland is a summer feeding ground for humpback whales (Pomilla and Rosenbaum 2005). Most of them stay on the off-shore banks, but some visit the

Figure 5.23 Photo identification pictures of the same whale (WG_00005) photographed in A) 2007 and again in B) 2009. The Greenland Institute of Natural Resources (GINR) archive.

fjords and bays to feed on zooplankton and capelin, *Mallotus villosus* (Heide-Jørgensen and Laidre 2007). In the Nuuk Basis monitoring programme we aim to estimate the number of humpback whales feeding in the fjord each summer and the turnover of whales during a season in order to understand how much they eat and how these top predators affect the Godthåbsfjord ecosystem.

In the previous years, we have used two different methods i.e. landbased theodolite surveys and photo-identification. The relative few sightings, despite the large effort, and the movement patterns of the whales observed from land, make abundance estimates hard to accomplish from these data. Based on this experience, we have decided to change the monitoring programme to focus only on photo-identification and with time, when the dataset is large enough, use mark-recapture analysis to estimate the number of humpback whales in Godthåbsfjord.

Photo-identification is a technique used to identify individual animals from 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-identification 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 tall contalns individual colour patterns, which are different in a way comparable to human fingerprints (figure 5.23).

Photo-identification 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 public also kindly contributed with photos. 209 ID-photos were collected through 2007 to 2009, with 20 individuals identified in 2007, 20 individuals identified in 2008 and 15 individuals identified in 2009. Of the 32 individuals identified in 2007-08, a total of seven (21 %) were re-identified in 2009. Eight new individuals were identified in 2009. In 2008, we had a 40 % re-identification rate. However, with the data from 2009, this has been halved, and it seems like fewer animals re-enter the fjords from year to year (than was expected based on last year's data). However, this variability from year to year is most likely the effect of a very small sample size as we are only on our third year of monitoring still. It is therefore too early to give any conclusive estimates yet.

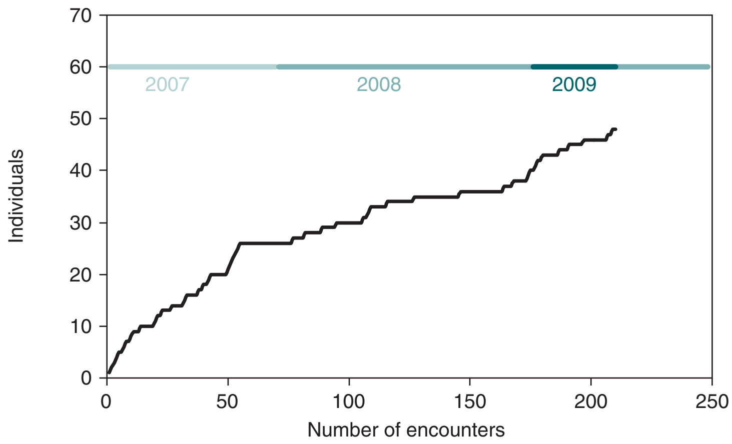


Figure 5.24 A discovery curve showing the number of new individuals identified for each encounter accumulated through 2007-2009.

The 'population' of humpback whales in Godthåbsfjord is an open population. Animals move in and out the fjord during the season. This is also obvious from the detection curve, where new animals keep being added to the 'population' of photographed animals (figure 5.24). This has to be taken into account when modelling the number of animals using Godthåbsfjord, and to run the mark-recapture model we therefore need more years of data collection.

6 RESEARCH PROJECTS

6.1 Linking ice sheet thinning and changing climate, FreshLink

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

The FreshLink programme is a consortium of Greenlandic / Danish institutions and a number of international partners. The project aims at doing research on the thinning of the Greenland Ice Sheet margin, which 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 SW Greenland, i.e. 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 spring 2008, 2009 was used to collect data, while the last year 2010 will be used for data analysis and paper writing.

The first long time series of the surface freshwater layers properties such as pressure, temperature and salinity was recovered in 2009 for the period June 2008 to October 2009. The mean depth of the instrument (SBE37SMP, 'MicroCat') was 2.69 m covering the depth range 0 m to 5.63 m. During the same period mean salinity was found to 26.71 and mean temperature to 1.59 °C, covering the range 4.53 to 33.05 and –1.73 °C to 11.2 °C, respectively. Maximum in temperature and minimum salinity were observed in August. Minimum in temperature was found in December, whereas maximum in salinity was found in May. The MicroCat was located in a depth where important information on surface stratification was obtained.

Figure 6.1 One of the emptied ice-dammed lakes, Ujaragtôq (the lake with many stones), notice the person in the foreground. Photo: Thomas Juul-Pedersen.

In July 2009, the first time series of continuous current profiles were recovered from the entrance of the 'Icefjord'. The mooring had broken loose from its anchor, due to a defect stainless steel shackle. Fortunately, it was equipped with a satellite beacon to tell its unexpected surfacing. Beside its sudden appearance, the mooring returned high quality data for the period February to July 2009. This period was characterized by a 'steady' inflow in a bottom near layer with current directions becoming more fluctuating higher in the water column.

Another unexpected event happened early September 2009 when a number of ice-dammed lakes drained. The event was first observed and reported by local hunters. In a short period, an estimated volume approximately 1.5 km^3 of freshwater was released to the inner parts of the Godthåbsfjord system (figure 6.1). For more information, see www.freshlink.natur.gl.

6.2 FreshNor; the freshwater budget of the Nordic Seas

Søren Rysgaard and John Mortensen

The freshwater cycle has a central role in global atmospheric circulation, controls the global energy cycle (through the release of latent heat) as well as the carbon, 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 evaporation. 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 model simulations for the Arctic region, and for the Nordic countries in climate change scenarios. This work aims at improving existing atmospheric regional climate models (RCMs) for the Nordic regions as well as for the Arctic. 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 has been funded by the Nordic Council of Ministers' Arctic Co-operation Programme. The last meeting took place in Nuuk in August 2009 in connection with Nuuk Climate Days 2009 (figure 6.2). Here the FreshNor workshop joint with the AGU International Workshop on Changes of the Greenland Cryosphere. For more information, see http://freshnor.dmi.dk/afb2009/ and http://conferences.dtu.dk/conferenceDisplay.py?confId=22.

Figure 6.2 The Nuuk Climate Days 2009 ended with an excursion to the inner part of Kobbefjord, sponsored by Greenland Climate Research Centre, Greenland Institute of Natural Resources. Photo: Winnie Martinsen.

6.3 Copepods feeding in a glacial marine environment – effects of suspended sediments

Kristine Engel Arendt, Jörg Dutch, Sigrún Huld Jónasdóttir, Signe Jung-Madsen, Eva Friis Møller and Torkel Gissel Nielsen

The first length section in the MarineBasis Nuuk programme revealed huge differences in plankton community structure and biomasses between the offshore areas and the Godthåbsfjord system. The offshore area was dominated by *Calanus finmarchicus* in high biomasses, whereas biomasses in the fjord were much lower and dominated by *Pseudocalanus minutus* and *Metridia longa*. Analysis of the plankton community structure suggests a separation of the offshore system and the fjord system. It was therefore suggested that the physical gradients, the West Greenland Current and the run-off from the Greenland Ice Sheet determine differences in plankton community structure.

The aim of this study was to investigate the species specific tolerance to natural conditions of suspended sediments in a glacial marine environment. Such information would illuminate the present influence of runoff to the system and would be valuable to predict consequences for the fjord ecosystem under the present conditions of accelerating melting of the Greenland Ice Sheet.

In the laboratory filtration, egg- and fecal pellet production were measured for three copepod species *C. finmarchicus*, *P. minutus* and *M. longa*, when feeding on the diatom *Thalassiosira weissflogii* at 300 µg C l^{-1} at seven silt concentrations ranging from 0-100 mg silt l^{-1}.

Filtration rate (F, ml individual^{-1} d^{-1}) of *C. finmarchicus* and *P. minutus* decreased with increasing sediment concentration, whereas no significant effect in F was seen for *Metridia longa*. There was no significant difference in fecal pellet production for *C. finmarchicus* or *M. longa*, but there was a significant difference in fecal pellet production for *P. minutus* feeding at the tested silt concentrations. Volume of fecal pellets increased with increased silt concentration for *C. finmarchicus* and *M. longa*, whereas there was no general trend for *P. minutus.* All tree species ingested silt and clay particles which can clearly been seen in the fecal pellets (figure 6.3). The EPR of *C. finmarchicus* decreased from 35.3 ± 9.3 eggs fem^{-1} day^{-1} at 0 mg sediment l^{-1} to 0.3 ± 3.0 eggs fem^{-1} day^{-1} for incubations with 100 mg silt l^{-1}. Egg production rate (EPR) for *M. longa* was low and *P. minutus* were caring eggs at all tested sediment concentrations.

The study shows that *C. finmarchicus* and *P. minutus* are sensitive to high concentrations of suspended sediments, whereas *M. longa* is a tolerant species. Ingested sediment particles take up space in the gut that may be occupied by nutritious food, and therefore it has a negative effect on the nutrition of the copepod. Species-specific tolerance to high silt concentrations could be important in determining the copepod community structure along glacial melt water influenced fjords like Godthåbsfjord.

Kommisionen for Videnskabelige Undersøgelser i Grønland (KVUG), Greenland Institute of Natural Resources, Technical University of Denmark and The Danish Agency financed the project for Science, Technology and Innovation (FNU). The project is affiliated with the International Polar Year (IPY).

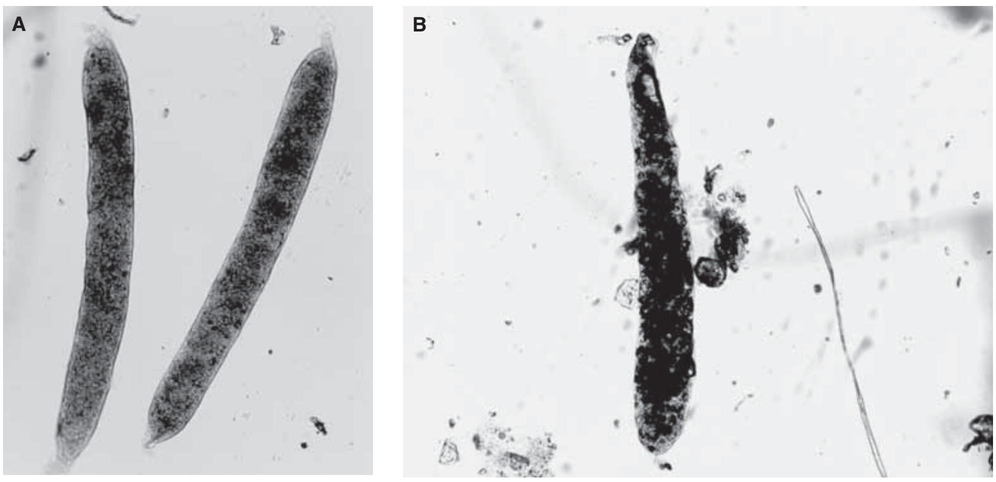


Figure 6.3 Fecal pellets of Calanus finmarchicus *A) when feeding without suspended sediments and B) feeding with suspended sediments.*

6.4 Dynamics of autotrophic and heterotrophic activity in sub-arctic first-year sea ice

Dorte Haubjerg Søgaard, Morten Kristensen, Søren Rysgaard, Ronnie N. Glud, Per Juel Hansen and Karen Marie Hilligsøe

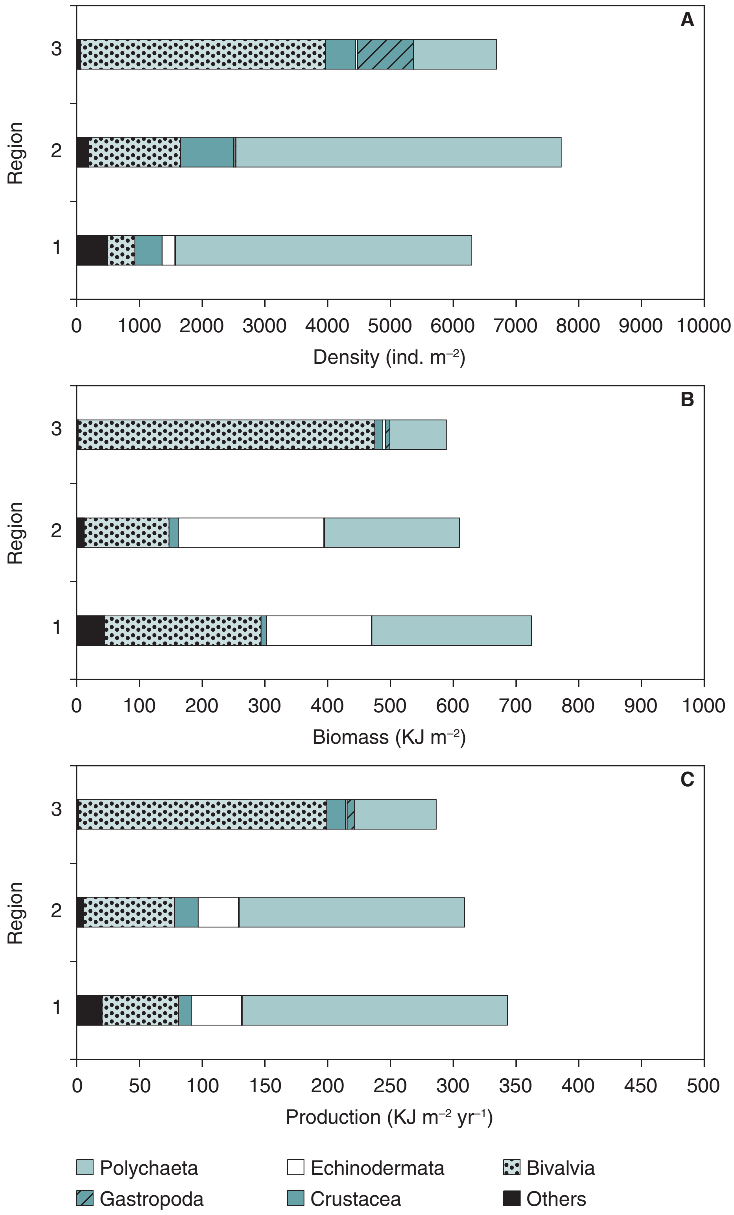
In this study, an attempt was made to describe the dynamics of autotrophic and heterotrophic activity in sub-arctic first-year sea ice. In 2008, we studied the autotrophic and heterotrophic activities in a sub-arctic sea ice (Malene Bight, SW Greenland) by two different approaches: 1) Standard incubation techniques ($H^{14}CO_3^-$ and [^{3}H]thymidine incubation) on sea ice cores brought to the laboratory, and 2) Cores incubated *in situ* in plastic bags with subsequent melting and measurements of changes in total O_2 concentrations. The standard incubations showed that the annual succession followed a distinctive pattern, with a low, almost balancing heterotrophic and autotrophic activity during February and March. This period was followed by an algal bloom in late March and April, leading to a net-autotrophic community. During February and March, the oxygen level in the bag incubations remained constant, validating the low, balanced heterotrophic and autotrophic activity. As the autotrophic activity exceeded the heterotrophic activity in late March and April, it resulted in a significant net oxygen accumulation in the bag incubations. Light availability was the major factor regulating sea ice algal production and high light attenuation coefficients in snow and sea ice cover led to low primary production (<1.5 mg C m^{-2} d^{-1}) prior to snow and sea ice melt. Later in the season, snow melt increased the light availability, which resulted in higher sea ice algal biomass and a peak in primary productivity (12.60 mg C m^{-2} d^{-1}) leading to a net-autotrophic community. The results suggests that the sub-arctic first-year sea ice is a highly dynamic environment in which interactions between the physical, chemical and biological properties of the ice determine the dynamics of the autotrophic and heterotrophic activity.

6.5 Evidence for strong trophic coupling between macrozoobenthos and wintering eiders in Nipisat Sound, SW Greenland

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

We monitored the number of wintering eiders (*Somateria* spp.) during the winters of 2008-10 in a shallow inlet, Nipisat Sound, a key wintering habitat in the Godthåbsfjord system, SW Greenland. Moreover, the macrobenthic species abundance and biomass were studied in the spring of 2008, and annual production was estimated by an empirical model including environmental characteristics, fauna composition and indi-

Figure 6.4 Contributions of different taxonomic groups to A) abundance, B) biomass, and C) annual production of the macrobenthic community in Nipisat Sound, a key wintering habitat for eiders.



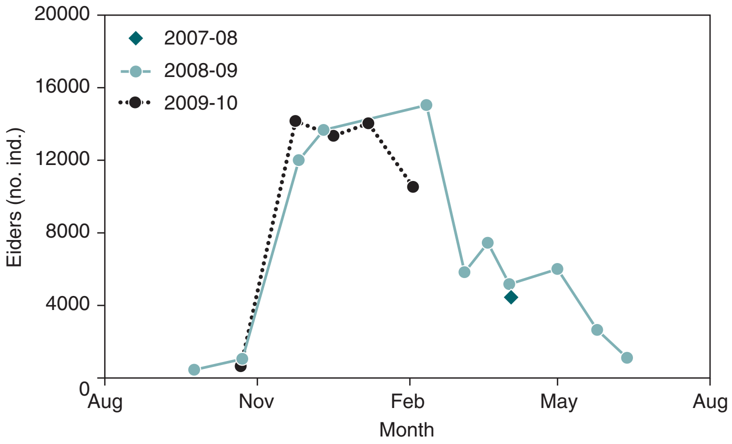


*Figure 6.5 Graph showing the seasonal development in the number of wintering eiders (*Somateria spp.*) in Nipisat Sound during three different winters from spring 2008 to spring 2010.*

vidual biomass. From species abundances, we identified three distinct macrobenthic communities, corresponding to sheltered, semi-exposed and exposed areas of the inlet. However, even if species composition differed significantly on a spatial scale, total abundance and biomass were rather similar between regions (figure 6.4). Hence, the average macrozoobenthic abundance and biomass in Nipisat Sound were 6912 individuals m^{-2} and 28.4 g ash free dry mass (AFDM) m^{-2}, respectively. Annual production was estimated at 13.9 AFDM y^{-1}. Converted to energy this corresponded to a biomass of 647 KJ m^{-2} and a production of 317 KJ m^{-2} y^{-1}, respectively. We observed a distinct wintering season for eiders lasting from late October through May. Eider abundance peaked at 12-15000 individuals in midwinter with an average of approximately 8000 individuals throughout the winter in the area covering 17 km^2 (figure 6.5). In combination with estimates of the energetic requirements of eiders, we estimated that wintering eiders required 16 to 30 % of the expected autumn biomass and 50 to 90 % of the total annual production of macrobenthos. Thus, eiders probably have a strong impact on the macrobenthic community structure. The diet of eiders wintering in Nipisat Sound a few years earlier did not directly reflect the macrobenthic species composition as observed in the spring of 2008. Hence, we suggest that eiders are likely to switch between different feeding strategies or food sources either during a wintering period and / or from one year to the next as adaptations to variations in macrobenthic community structure in order to be able to cover the costs of living. We assume that the predictability of profitable food resources on arrival just before midwinter is important for eiders wintering in Nipisat Sound.

6.6 Oxygen turn-over; from pelagic-micropellets to complex benthic surfaces

Ronnie N. Glud, Paul Batty, Peter Berg, Martin E. Blicher, Eva Friis Møller, Anni Glud, Andrew Hume, Kunuk Lennert, Torkel Gissel Nielsen, Kam Tang and Søren Rysgaard

The current research project consists of two coordinated sub-projects:

Pelagic microniches

In deeper waters most of the organic carbon reaches the sea bed in the form of agglutinated packages so-called ‘marine aggregates’. In the Arctic where a significant fraction of the primary production is grazed of by copepods (Rysgaard et al. 1999), fecal pellets and carcasses represent important components of such aggregates. As the material sinks towards the sea bed, a considerable fraction is degraded by aerobic bacteria. However, intense metabolic activity could lead to transient anoxic microniches inside fecal pellets and copepod carcasses that thereby could host a potential for denitrification and anammox converting nutrients into dinitrogen gas, i.e. a potential, unresolved nutrient sink in the marine environment.

Microsensor measurements inside fixed, living and actively feeding copepods documented that while the outer parts of the hind-gut only was O_2 depleted, the inner hind-gut and the mid-gut were completely anoxic. Released fecal pellets were placed on a small gaze covered plateau ensuring good water circulation during the measurements, and microprofiles showed that the pellet quickly became oxic all to the centre, independent of species and diet. However, after a lag phase the fecal pellets gradually became more and more O_2 depleted, presumably as bacteria abundance and metabolic activity inside the pellets increased. However, the pellets did never become completely anoxic but reached low saturation levels of 15-25 % when surrounded by in 100 % air saturated water. When the ambient O_2 concentration was lowered, the pellets did go anoxic, suggesting that under some conditions sinking pellets could host anoxic micro patches.

Whereas conditions in the fecal pellets are complex, measurements clearly documen-ted that sinking, carcasses were completely anoxic. The microsensor work was complemented by incubations of pellets and copepod carcasses in rotating, gastight glass-ampoules enriched with ^{15}N labelled nitrate. These showed that carcasses hosted denitrification even when incubated in fully air-saturated water, an activity that increased with declining O_2 levels in the ambient water. In contrast, fecal pellets only showed denitrification activity at very low ambient O_2 concentrations.

These results are preliminary. Exact rates have to be calculated and identification of the microbial communities under different conditions is still in progress. However, previous work has shown that a significant proportion of copepods in the environment actually are dead (10-20 % of the population is common, Tang et al. 2006). Our current work suggest that such aggregates host denitrification potential along with fecal pellets sinking through O_2 depleted water columns.

Oxygen eddy correlations measurements across complex benthic substrates

The benthic O_2 exchange represents a key measure for assessing the benthic carbon turn-over (Glud 2008). Traditionally this has been quantified by enclosed sediment incubations or calculated from porewater microprofiles. Recently a new approach, the eddy-correlation technique, has been introduced to the aquatic environment (Berg et al. 2003). From simultaneous recordings of variations in the vertical flow velocity and the O_2 concentrations, the O_2 exchange rates can be quantified non-invasively integrating the activity of many square meters of sea bed (Berg et al. 2007 and 2009). Another advantage of this approach is, that it can be used across benthic surfaces like consolidated sand, rocks, cliffs and stones, where chamber insertion or microsensor profiles are impossible. In fact such substrates are cha-ra-cteristic for many arctic and sub-arctic coastlines. During summer 2009, we conducted a number of eddy-correlation measurements at typical, shallow water substrates in Kobbefjord and Godthåbsfjord (water depths 6 to 17 m).

At the only soft-bottom station, the eddy-correlation value exceeded the microsensor and chamber derived exchange rates by 50 and 25 %, respectively. Measured exchange rates showed a gradual increase as larger sediment areas are assessed – simply because they had better encompass effects of macro- and mega-fauna. Measurements at rocks, cliffs and stones, showed surprisingly high carbon turn-over rates with intense primary production during daytime and high O_2 consumption rates at night time.

The first direct *in situ* measurements of the O_2 production and consumption in such environments show that they are highly active and may play an important quantitative role in the carbon cycling of the Godthåbsfjord system, and presumably in arctic and sub-arctic fjords in general. The work is still in progress.

6.7 Arctic Tipping Points

Dorte Krause-Jensen

Arctic Tipping Points (ATP) is a large-scale integrating project funded by the EU 7th Framework Programme. The projected is coordinated by Paul Wassman, University of Tromsø, Norway. The project has participants from research institutions in Norway, Spain, Greenland, Denmark, England, France, Poland, Portugal and Russia.

The project aims to identify the elements of the Arctic marine ecosystem likely to show abrupt changes in response to climate change and to identify the levels of the corresponding climate drivers inducing regime shifts in those tipping elements.

Possible tipping points will be identified through various types of data collection and analyses. Time series of data on important species will be analysed to reveal possible historical shifts in the marine ecosystem. Controlled experiments will test the effect of warming on various components of the marine ecosystem across the full spectrum of projected warming scenarios. In addition, studies along natural climatic gradients will identify spatial differences in the ecosystems, which may help explain future shifts in arctic ecosystem structure and function because of global warming.

In addition, state-of-the-art oceanographic, ecological, fisheries, and economic models will determine the effect of crossing the possible thresholds for the arctic marine ecosystems, and the associated risks and opportunities for economic activities dependent on the marine ecosystem of the European Arctic. For more information about the project, visit the home page: http://www.eu-atp.org/.

In the summer of 2009, part of the field work and laboratory experiments of the ATP-project were conducted at the Greenland Institute of Natural Resources, Nuuk, with the aim of identifying the effects of warming on the benthic vegetation. These studies were coordinated with the monitoring of marine vegetation under the Nuuk Basic programme.

6.8 Mercury (Hg) transport from the terrestrial to the marine environment

Frank F. Rigét, Mikkel P. Tamstorf, Martin M. Larsen, Gert Asmund and Karl Martin Iversen

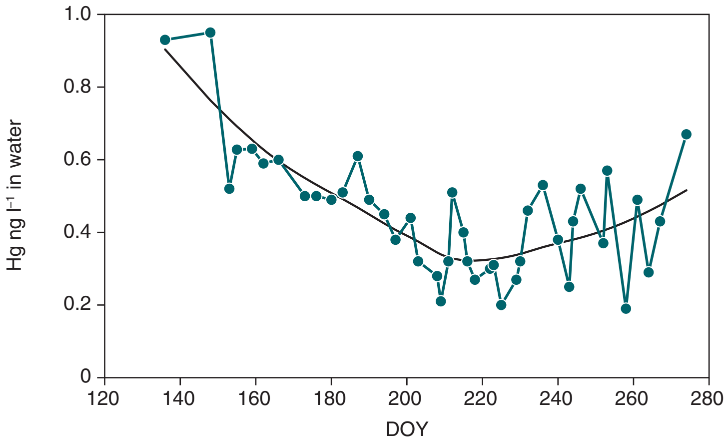
In 2009, a project was initiated with the objective of estimating the amount of total mercury (Hg) that is transported to the coastal areas from the Kobbefjord drainage basin and trying to identify the most important input sources of this transport. It is uncertain how the influence of a warming climate will affect the Hg pathways although it may be expected that changes will happen. Increasing or changing precipitation patterns may influence the Hg deposition from the atmosphere. Similarly, increasing temperatures will likely influence the process of methylation of inorganic Hg to methyl-Hg (Macdonald et al. 2003), which is much more bioavailable and will enter into the food web.

During the period from 28 May to 1 October fourty-five water samples (250 ml) were collected from the Kobbefjord River. As there is no visible sediment in the water the samples were not filtered.

The treatment of the water samples and measurements of Hg follows the procedure of adding a BrCl solution to oxidise the Hg species to Hg^{2+}. The surplus of oxidant is removed by hydroxyl / ammonium, after which Hg^{2+} is reduced by a $SnCl_2$ solution and the released Hg (g) is driven by Argon air current on a gold trap. A burnout is performed on the gold trap and Hg (g) is released and measured by atom-fluorescence on a PSA analytical Millennium Merlin System. Detection limit based on the variation of blind samples is typically 0.1-0.2 ng l^{-1}.

Figure 6.6 shows the Hg concentrations in river water throughout the season. The black line represents the loess (local polynomial regression) smoother line. In general, there is a large day to day variation. When all chemical and physical parameters for the river water are available, it may be possible to explain parts of this day-to-day variation. In the beginning of the season Hg concentrations are highest. Thereafter it decline until about 19 July (DOY 200) which is the period of snow smelt. There may be a small tendency to increasing Hg concentrations in the last part of the season. One hypothesis is that the high levels in the beginning of the season represent atmospheric Hg deposition on the snow surface during the winter season, and that the decreasing levels represent decreasing relative amount of melted snow in the river. However, this thesis has to be tested in the years to come.

Figure 6.6 Hg concentrations in river water during the period 28 May to 1 October. Black line represents loess (local polynomial regression) smoother line.



7 Disturbances in the study area

Peter Aastrup

The study area at Kobbefjord is situated approximately 20 km southeast 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 boat at the bottom of the fjord – no landing.
- Visits by boats at the bottom of the fjord – the persons take a short walk inland and returns within a few hours or less.
- Visits by boats at 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 in 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 hydropower plant in Buksefjord runs through the area.

In 2009, there were only few interactions between 'visitors' in the study area and the different setups and the camp. Once during the season, while unattended, somebody broke into the research hut and food, personal belongings and a tent were stolen.

At several occasions, foxes have been eating wires connecting temperature probes with data loggers (TinyTags) in the ITEX-plots. They have physically moved TinyTags, moved pittfall traps mainly in the Art4 plot, dug up several litterbags with buried material in the Mart5, and dug holes in the ground at the very edge of Sil4.

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.

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 (mainly Mondays, Tuesdays and Thursdays). In the beginning of the season, the base camp was used temporarily by 2-10 persons. The base-camp consisted of two to four sleeping tents and a kitchen tent. By the end of the season, the new research hut was taken in use. For further information, please consult Chapter 8.

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 CO_2-flux measuring plots.

A fire in the vegetation on a hillside along the fjord approximately 5.5 km northwest of the research hut was observed 31 August. Due to the wind, the smoke blew towards the monitoring area on a few occasions, but with help from Nuuk Fire Department, the fire died out within a few days.

In conclusion, it is estimated that the third years' monitoring activities in Kobbefjord only had minor impact on the vegetation and terrain.

8 Logistics

Henrik Philipsen

In 2009, Greenland Institute of Natural Resources took care of the logistics related to Nuuk Basic in Kobbefjord.

The 2009 field season in Kobbefjord was from 14 January to 16 December. During this period 34 scientists and logisticians spend approximately 242 'man-days' and 79 'man-days', respectively, in the study area.

During spring, several attempts to reach the study area in the bottom of Kobbefjord by boat were made, but due to thick sea ice, this was not possible. The Danish Navy Wessel 'Einar Mikkelsen' broke two canals in the ice in Kobbefjord 24 May but unfortunately, Greenland Institute of Natural Resources' boat, 'Aage V. Jensen II Nuuk', was not able to push its way through the broken ice. Finally, 2 June, it was possible to go to Kobbefjord by boat and 8 June the first group of scientists, logisticians and construction workers arrived to the study area in the bottom of Kobbefjord.

Greenland Institute of Natural Resources carried out transportation of staff, construction workers and scientists from Nuuk to the study area in Kobbefjord with the boats 'Aage V. Jensen II Nuuk' and 'Erisaalik'. The total number of days with boat transport related to Nuuk Basic was 137 (55 days by BioBasis, GeoBasis and ClimateBasis, 43 days by logisticians and construction workers, 39 days by MarineBasis on investigations in Kobbefjord and Godthåbsfjord). The two boats, financed by Aage V. Jensen Charity Foundation, proved to be very efficient for their purpose.

In 2009, scientists were accommodated in the field in smaller tents with a bigger kitchen tent until August. Afterwards, the 55 m² research hut was taken into use.

Water for drinking and other purposes were taken from the nearby river. Electrical power was provided by a portable 5 kW diesel generator and by two 2 kW gasoline generators. The 5 kW diesel generator provided power for 10 hours in 2009 before having a vital breakdown. Instead the two 2 kW gasoline generators supplied power for the rest of the field season.

Communication to / from Nuuk was made by Iridium satellite telephones, while local communication within the study area was by portable VHF-radios.

Aage V. Jensens Charity Foundation has financed two huts for Nuuk Basic at Kobbefjord, i.e. a 55 m² research hut with laboratory and accommodation facilities and an 8 m² hut for a generator. From 8 June to 12 October 2009 construction workers spend in total 136 'man-days' to finish the construction of the two huts.

The research hut has a ramp for ski-doos, a terrace facing the fjord and an 11 m² storage below the living room. The inside of the building consists of a living room, a bathroom, a laboratory and an entrance. Only minor work need to be done in 2010, before the construction and furnishing of the two huts are completed.

The generator hut was moved 100 m from the east to the west side of the research hut. A new foundation was made and the old foundation is now used as a rack for left-over materials.

In June and July 2009, drainage canals for melt- and rainwater were made in bedrock and soil underneath and along the research hut.

On 17 June 2009, an AS 350 helicopter made three slings from Nuuk to Kobbefjord with furniture and a 1200 litre water tank for the new house.

On 5 September, building materials were sailed by the boat 'Masik' with one barge from Nuuk to Kobbefjord. In Kobbefjord, an AS 350 helicopter made 14 slings with materials to the building site. The generator hut was at this day taken apart, and the helicopter made three slings to move the hut to its new site. The broken generator was slinged to the barge and returned to Nuuk before being shipped to Italy for repair.

Fuel consumption for generators was 15 litres of diesel and 200 litres of gasoline. Gas used for cooking and heating totalled four 11 kg bottles.

350 kg non-burnable garbage from the construction was removed by ship and send to Nuuk. Burnable garbage was burned during mid-August and mid-September on the site. Household garbage was also returned to Nuuk during summer.

On 25 July, somebody broke into the research hut. A window frame had minor damage and a tent, some personal gear, food and tools were stolen.

The research area in Kobbefjord was during 2009 visited by several honourable guests:

9 June: Chairman Leif Skov and director Vagn Forring visited the site together with other board members from Aage V. Jensen Charity Foundation.

17 June: Klaus Nygaard and Fernando Ugarte, Greenland Institute of Natural Resources; Søren Rysgaard, Greenland Climate Research Centre; Morten Skovgaard Olsen and Frederik Schmidt, Danish Energy Agency; Mikael Petersen, Mette Frost, Pernille Møller, Lone Nukaaraq Møller and Najaraq Paniula, Government of Greenland.

26 August: Niels Skov from Aage V. Jensen Charity Foundation.

28 August: 43 participants in Nuuk Climate Days together with several journalists.

In Nuuk, the Nuuk Basic scientists were accommodated in the annex of Greenland Institute of Natural Resources, with a total of 200 bed nights.

9 Personnel and visitors

Compiled by Thomas Juul-Pedersen

Scientists

Kristine Engel Arendt, Greenland Institute of Natural Resources, Greenland
Dirk van As, Geological Survey of Denmark and Greenland, Denmark
Paul Batty, Greenland Institute of Natural Resources, Greenland
Jørgen Bendtsen, National Environmental Research Institute, Aarhus University, Denmark
Martin E. Blicher, Greenland Institute of Natural Resources, Greenland
Tenna K. Boye, Greenland Institute of Natural Resources, Greenland
Carl Egede Bøggild, University Centre in Svalbard (UNIS), Norway
Peter Bondo Christensen, National Environmental Research Institute, Aarhus University, Denmark
Tage Dalsgaard, National Environmental Research Institute, Aarhus University, Denmark
Jörg Dutz, Danish Technical University, DTU Aqua, Denmark
Parnuna Egede, Greenland Institute of Natural Resources, Greenland
Carsten Egevang, Greenland Institute of Natural Resources, Greenland
Bradley Eyre, Centre for Coastal Biogeochemistry, Southern Cross University, Australia
Tom Fenchel, Marine Biological Laboratory, University of Copenhagen, Denmark
Mads C. Forchhammer, National Environmental Research Institute, Aarhus University, Denmark
Rene Forsberg, Danish Technical University, DTU Space, Denmark
Ronnie N. Glud, Scottish Association of Marine Sciences, Oban, Scotland
Sergio R. Halpern, Institute for Advanced Studies, Mallorca, Spain
Susanne Hanson, Danish Technical University, DTU Space, Denmark
Rasmus Hedeholm, Greenland Institute of Natural Resources, Greenland
Lars Heilmann, Greenland Institute of Natural Resources, Greenland
Jens Hesselberg-Christensen, Danish Meteorological Institute, Denmark
Randi Schjøtt Huusgaard, Marine Biological Laboratory, University of Copenhagen, Denmark
Hannes Höffer, Danish Technical University, DTU Aqua, Denmark
Karl Martin Iversen, Asiaq – Greenland Survey, Greenland
Sigrun Jonasdottir, Danish Technical University, DTU Aqua, Denmark
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John Mortensen, Greenland Institute of Natural Resources, Greenland
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Rasmus Nygaard, Greenland Institute of Natural Resources, Greenland
Josephine Nymand, Greenland Institute of Natural Resources, Greenland
Niels Nørgaard-Pedersen, Geological Survey of Denmark and Greenland, Denmark
Birgit Olesen, Institute of Biology, Aarhus University, Denmark.

Dorte Pedersen, Asiaq – Greenland Survey, Greenland
Morten Rasch, National Environmental Research Institute, Aarhus University, Denmark
Lars Maltha Rasmussen, Greenland Institute of Natural Resources, Greenland
Anja Retzel, Greenland Institute of Natural Resources, Greenland
Mads Ribergaard, Danish Meteorological Institute, Denmark
Bert Rudels, Finnish Institute of Marine Research, Finland
Søren Rysgaard, Greenland Institute of Natural Resources, Greenland
Mikael K. Sejr, National Environmental Research Institute, Aarhus University, Denmark
Malene Simon, Greenland Institute of Natural Resources, Greenland
Martin Stendel, Danish Meteorological Institute, Denmark
Dorte Søgaard, Greenland Institute of Natural Resources, Greenland
Kam Tang, Virginia Institute of Marine Science, USA
Kisser Thorsøe, Asiaq – Greenland Survey, Greenland
Martin Truffer, Geophysical Institute, University of Alaska, USA
Monica Trümper, University Centre in Svalbard (UNIS), Norway
Katrine Worsaae, Marine Biological Laboratory, University of Copenhagen, Denmark

10 Publications

Compiled by Lillian Magelund Jensen

Scientific papers

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12 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