NERO

NUUK ECOLOGICAL RESEARCH OPERATIONS

4th Annual Report 2010

Aarhus University

DCE – Danish Centre for Environment and Energy

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Back cover photo: Karl Martin Iversen and Nanna Kandrup making discharge measurements at the hydrometric station at the outlet of Badesø, April 2010. Photo: Lillian Magelund Jensen

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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:
Department of Bioscience, 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 participating institutions

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Summary for policy makers

Morten Rasch and Lillian Magelund Jensen

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The establishment of research infrastructure for Nuuk Basic was finalised early in 2010. The infrastructure now includes a hut with accommodation, storage and laboratory facilities in Kobbefjord and a number of boats for transportation between Nuuk and the field sites in Kobbefjord and Godthåbsfjord. Aage V. Jensen Charity Foundation has generously provided all infrastructures.

A number of different research projects is already using data provided by the Nuuk Basic programme. In 2010, means were funded from funding sources outside the programme to several research projects cooperating with and making use of data from the monitoring programme. Among these projects, more substantial funding were given to a Canada Excellence Research Chair (CERC) in Arctic Geomicrobiology and Climate Change at the University of Manitoba led by professor Søren Rysgaard from Greenland Climate Research Centre and a new Nordic Centre of Excellence, DEFROST, led by professor Torben Røjle Christensen from Lund University.

During 2010, the Nuuk Basic programme had a turnover of approximately 5.8 mill. DKK.

Josephine Nymand (Greenland Institute of Natural Resources, Nuuk) briefs the ministers, Charlotte Sahl-Madsen (Minister for Science, Technology and Innovation, Denmark) and Mimi Karlsen (Minister for Culture, Education, Research and Church Affairs, Greenland), about the Nuuk Basic programme at their visit to Kobbefjord, August 2010. Photo: Peter Bondo Christensen.

Executive Summary

Mark Andrew Pernosky, Birger Ulf Hansen, Peter Aastrup, Thomas Juul-Pedersen, Lillian Magelund Jensen and Morten Rasch

Introduction

The year 2010 was the fourth year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was the second year with complete annual time series for all sub-programmes.

ClimateBasis

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

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

The mean annual air temperature in 2010 was 3.4 °C, which is the highest annual air temperature measured in Kobbefjord since the start of the programme. In addition, the frost free period lasted longer than in previous years with the first day with a mean air temperature above freezing occurring 16 days earlier than in 2008/2009 and the last day with a mean air temperature above freezing occurring 31 days later than in 2007-2009.

In Kobbefjord, measurement 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 2010 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 fall before the river freezes.

In 2009, a final Q/h-relation was established, incorporating discharge measurements over nearly the entire recorded water level. For H2, H3, H4 and H5 there still is a lack of discharge measurements at high water levels to establish reliable Q/h-relations.

For H1, which is placed at the main river in Kobbefjord, the total discharge during the hydrological year 2009/2010 was 22.9 million m^3. The peak discharge in 2010 was recorded 30 August and was caused by a rain event.

GeoBasis

The 2010 season was the third full season for the GeoBasis programme with a field season from May to late October.

2010 was the warmest year registered since the air temperature measurements were initiated in 1866 in Nuuk. In 2010, the annual mean air temperature reached 2.6 °C and was thereby the 12th year within the total time series with an annual mean air temperature above 0 °C. The second warmest year in the time series was 1941 with an annual mean air temperature of 0.8 °C. In 2010, the monthly mean air temperatures in May, August, September, November and December were the highest measured during the period 1866-2010, which makes it a historically warm year.

The 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 melt on the lakes was approximately one month earlier than in 2009. Due to logistical problems, only one snow survey was carried out in mid-April in co-operation with the ClimateBasis programme. Snow depth varied from 18 cm to 20 cm at the three soil microclimate stations and was 77 cm lower than in 2009.

The micrometeorological stations in Kobbefjord confirmed the warm climate in 2010 with a mean monthly air temperature of 11.3 °C at SoilFen in August compared to 8.7 °C in 2009 and only 7.4 °C in August 2008. Even at M500 (500 m a.s.l.) the mean monthly air temperature in August was 9.0 °C in 2010 compared to 7.1 °C in 2009 and 5.4 °C in 2008.

At the three automatic soil stations in the area; SoilFen, SoilEmp and SoilEmpSa the soil inter-annual variations in 2010 were quite similar to those documented in 2009 although the warmer climate in 2010 caused an average soil temperature of 3.3 °C compared to only 2.8 °C in 2009.

In 2010, 61 water samples were collected from late April to mid-October, which is the longest field season since the initiation of the GeoBasis monitoring programme in Kobbefjord. *In situ* measurements of river water temperature, conductivity and pH were conducted along with the water sampling. The river water temperature varies through the season 2010 with a minimum temperature of 1.7 °C measured 28 April and with a maximum temperature of 15.8 °C measured 19 July. The conductivity shows a significant decrease within the snow-melting period (April-May) to a level of 18 ± 1.5 µSc m^{-1}, while pH shows a constant level of 6.8 ± 0.4 from April to October 2010.

The temporal methane (CH_4) flux pattern in 2010 was similar to the pattern observed in the two previous years 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). During autumn, the methane flux continued to decrease consistently in September and October. The peak summer emissions in 2010 were 4 mg CH_4 m^{-2} h^{-1}, which was low, compared to 8 mg CH_4 m^{-2} h^{-1} in 2009 and 5 mg CH_4 m^{-2} h^{-1} in 2008.

The temporal variation in daily net exchange of CO_2 began 14 May and continued until 11 October. The period with net CO_2 uptake in 2010 lasted until 18 August, which was two days later than in 2008 and nine days earlier than in 2009. During this period, the fen accumulated 65.5 g C m^{-2}, which is 50 % higher than in 2009. The estimated net uptake period was approximately 81 days in 2010 or 42 % longer than in 2009, and the maximum daily uptake reached 3.14 g C m^{-2} d^{-1} compared to 1.48 g C m^{-2} d^{-1} in 2009.

In the 2010 season, the programme has been completed and major repairs have been carried out. The third full year has provided valuable learning to ensure improvements of the monitoring in the following years. All methods and sampling procedures are now described in details in the manual 'GeoBasis – Guidelines and sampling procedures for the geographical monitoring programme of Nuuk Basic', which can be downloaded from the website (www.nuuk-basic.dk)

BioBasis

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

The year 2010 had a very early melt off. A preliminary review of data related to flowering and plant reproductive phenology indicate that 2010 was characterised by early flowering.

The general pattern is that greening of vegetation as measured by Normalised Difference Vegetation Index (NDVI) starts as soon as the snow has melted in the beginning of June with a peak in greenness during mid-summer (20 July-5 August) followed by a gradual decrease in greenness until the frost sets in during autumn. There are exceptions to this pattern: In snow patches, greening increases through the complete growing season, and *Loiseleuria procumbens*, *Silene acaulis*, and *Empetrum nigrum* plots have more or less constant greenness through the complete snow free season. Monitoring of *Salix glauca* and *Eriophorum angustifolium* is especially useful for studying the greening process through the season while monitoring of the evergreen *Empetrum* plots and the *Silene* and *Loiseleuria* plots with sparse vegetation cover are most relevant for monitoring at a longer time perspective.

Measurements of the land-atmosphere exchange of CO_2 (using the closed chamber technique), soil temperature, soil moisture and phenology of *S. glauca* have been conducted weekly during June-September since 2008. All plots generally functioned as sinks for atmospheric CO_2 at the time of measurements, as NEE was generally negative. In May, September and October, net ecosystem exchange (NEE) fluxes were close to zero. Similar to both 2008 and 2009, the net CO_2 uptake was generally higher in C plots compared with T and S plots. The ecosystem respiration showed a constant pattern of higher emissions in T plots compared with other treatments, which can be explained by warmer and drier conditions leading to increased respiration rates.

Permanent plots for studying lichens, bryophytes, and fungi (basidiomycetes) were established in the monitoring area in 2010.

All four arthropod pitfall-trap stations established in 2007 and two window trap stations established in 2010, were open during the 2010 season. The material is stored in 70 % ethanol at Aarhus University. Sorting follows a scheme giving time series as quickly as possible.

Three samplings of microarthropods in Kobbefjord took place in the beginning of June, August and September, respectively. Each sampling consists of two sampling occasions one week apart. The collected microarthropod data enables an identification of key community species.

The most common bird species were snow bunting and Lapland bunting with approximately 45 territories all together. Several territories of northern wheatear were observed and twice the number of redpolls compared to 2009. This indicates that the different species indeed have a slightly different timing of territorial behaviour. Although the total amount of singing males differs between the two surveys, the distribution between the species is approximately the same. As this year had an early melt off, we may have been a little late with the survey. Lake ecology is studied in two lakes: Badesø (with fish) and Qassi-sø (without fish). Nutrient levels are generally low in the two lakes. When comparing water temperature data logged at 2 m depth in Badesø in 2008 and 2010, a clear difference emerges. In 2010, warming started earlier and the lakes were generally warmer throughout spring and early summer than in 2008. This led to early ice melt (ice free 20 May) and a prolonged growing season. Nutrient levels are generally very low in both lakes, but particularly total nitrogen (TN) is very variable, ranging from 0.04 to 0.14 mg l^{-1} in Badesø and from 0.03 to 0.15 mg l^{-1} in Qassi-sø. Chlorophyll *a* varied notably between the years of sampling, but compared to more nutrient rich lakes the variation remains within a very narrow range due to the low nutrient levels. Over the three year period chlorophyll *a* concentration increased in both Badesø and Qassi-sø.

MarineBasis

The MarineBasis programme is running on its fifth year. Parameters are presented of sea ice conditions, physiochemical oceanography and biological studies of microscopic organisms up to the highest trophic levels. The continuous monitoring of this system will go beyond just providing a better understanding of high latitude marine systems and making it possible to observe and identify effects of climatic change in these regions.

Satellite imagery showed a seasonal pattern of sea ice coverage in Baffin Bay, which was comparable to previous years. Sea ice retreated northward in spring leaving no significant ice by mid-summer, before ice started building up again from the north during autumn. Inside Godthåbsfjord, less sea ice was observed than during most previous years, only the innermost parts of the fjord appear to have experienced sea ice coverage visible to satellite. Glacial ice and sea ice was exported from the fjord in seasonal bursts as it has been observed previously, but in 2010 glacial ice from Narssap Sermia flowed unhindered out of the fjord as no sea ice was observed in front of the glacier. Thus, more icebergs reached Nuuk and flowed out of the fjord as compared to previous years.

Vertical profiles of the water column showed a warm inflow of deep coastal water during winter followed by some of the highest temperatures and lowest salinities recorded in the surface waters during summer over the past five years. This surface layer also revealed high phytoplankton biomasses in summer leading to the second highest primary production peak measured since 2005. In contrast, the spring phytoplankton bloom appears to have been less pronounced than generally observed, which led to a more moderate decrease in nutrient levels in spring than usual. Nevertheless, nutrient exhaustion in the surface layer did subsequently take place during summer production. High pCO_2 values (i.e. above atmospheric concentrations) observed during the latter part of 2009 continued into January 2010, producing the single highest recorded value during the programme. Aside from another smaller peak, pCO_2 values during spring were generally lower than the year before, thus indicating that the fjord had regained some of its CO_2 uptake capacity.

Phytoplankton showed a seasonal succession resembling the pattern observed in all years but 2009, with diatoms dominating community abundances throughout the year except during the spring bloom. Hence, *Phaeocystis* sp. was the most abundant algal species during spring bloom in all years, except in 2009 when they remained entirely absent. Copepods peaked a month earlier than generally observed, which coincided with the highest copepod nauplii abundance recorded during the programme. *Microsetella* sp. still dominated the copepod abundance in all but one month, when *Microcalanus* was most abundant. The large *Calanus* spp. was only present in significant numbers during the spring bloom. Other zooplankton than copepods also peaked during the summer production in July. Fish larvae showed highest abundances during spring in 2006-08, while they peaked during summer in 2009-10 due to a decrease in sand eel and an increase in capelin. Cod larvae were observed during spring and summer. Overall, the abundance of fish larvae has decreased since the start of the programme (i.e. 2006).

A length section from outside the fjord (Fyllas Banke) to the inner part of the fjord showed the highest fish larvae concentration at the entrance of the fjord (i.e. 'Main station') along with decreasing species diversity in the inner part of the fjord, as observed in previous years. Shellfish larvae were present from spring to summer and sand crab (*Hyas* sp.) and shrimp larvae (*Pandalus* sp.) showed almost twice the abundance as in 2008-09. Jellyfish were observed during winter and early spring while comb jellies (ctenophores) were present only from summer. While the length section showed crab and shrimp larvae to be present at all stations, abundances varied between stations along the length section and showed a significant inter-annual variation.

Sinking fluxes of particulate material followed the seasonal patterns in the pelagic production. Isotopic composition of the sinking material indicated a stronger terrestrial signal in autumn, likely to be caused by the higher discharge of freshwater. Total carbon sinking flux integrated over the year was comparable to the values estimated in previous years. A large part of the organic material that reaches the sediments is consumed and mineralized, partly to be returned to the water column as nutrients. Maximum oxygen consumption coincided with the summer peak in pelagic production and elevated temperatures, which is in contrast to most previous years where consumption peaked during the higher spring production.

The energetic status of one species of sea urchin and scallop is estimated using a condition index and gonad index. Scallops showed the highest gonad index in 2007 and 2010 and sea urchins in 2007 and 2009. Conditions indexes also vary significantly between years; scallops showed higher values in 2007 and sea urchins in 2009 and 2010. Inter-annual differences between species may be due to different spawning times and feeding strategies.

Monitoring of the large macroalgae species *Laminaria longicruris* (i.e. benthic flora) showed some of the highest recorded blade length and biomasses since 2007. Macroalgae sampling at two sites with different exposure, i.e. protected and exposed to sea ice in most years, does not show a consistent difference in growth rates. The time series rather do however reflect variation around an established average blade length and biomass.

Two major seabird colonies near Nuuk have been monitored since 2007, while other colonies in the area have been included later. One of the major colonies (Qeqertannguit) showed numbers of breeding kittiwakes, Iceland gulls and black-backed gull similar to previous years. This colony experiences egg harvesting. In 2007, no representative seabird counts were obtained from the Brünnich's guillemot colony (Nunngarussuit). Surveys of Qegertannguit and four other colonies in the area seem to indicate movement of the kittiwakes and Iceland gull between the different colonies and that the four other colonies may likely prove important in the monitoring programme.

A photo-identification programme of humpback whales is used to estimate the minimum number of individuals entering Godthåbsfjord (i.e. out of the estimated 3000 humpback whales annually feeding in West Greenland waters). Since 2007, 52 different individuals have been identified, with 12 new individuals identified in 2010. Hence, the population is considered an open population where individuals move in and out during different seasons and years. While the re-sight rate of individuals from one year to the next is rather high, the re-sight rate of individuals in all four years is lower. Moreover, individual humpback whales repeatedly revisiting Godthåbsfjord seem to have a longer annual residence time within the fjord.

Research projects

In 2010, five different research projects were carried out in cooperation with Nuuk Ecological Research Operations. The research projects focused on different biological topics in the limnic and terrestrial compartment of the ecosystem. The research projects are presented in Chapter 6.

1 Introduction

Morten Rasch and Lillian Magelund Jensen

The year 2010 was the fourth year of operation of the fully implemented Nuuk Basic program-me (including both a terrestrial and a marine component), and it was the second year with complete annual time series for all sub-programmes.

The 2010 field season in Kobbefjord started 7 January and continued until 16 December. During this period 36 scientists spend approximately 360 'man-days' in the study area.

1.1 The research hut at Kobbefjord

The research hut at Kobbefjord was taken into use during August 2009, and only minor work needed to be carried out before the construction and furnishing was completed. This work was carried out in 2010. The 55 m^2 hut, which was generously funded by Aage V. Jensen Charity Foundation, includes excellent field facilities for accommodation, storage and preliminary laboratory analyses.

1.2 Funding

Nuuk Basic is funded by the Danish Energy Agency and the Environmental Protection Agency with contributions from Greenland Institute of Natural Resources, Asiaq – Greenland Survey, Department of Bioscience at Aarhus University and University of Copenhagen. Aage V. Jensen Charity Foundation has generously provided most of the necessary research infrastructure, including boats, research hut, office and accommodation facilities at Greenland Institute of Natural Resources.

1.3 Greenland Institute of Natural Resources and Greenland Climate Research Centre

In May 2010, professor Søren Rysgaard (head of the Greenland Climate Research Centre at Greenland Institute of Natural Resources), became Canada Excellence Research Chair (CERC) in Arctic Geomicrobiology and Climate Change at the University of Manitoba. Søren Rysgaard will hold this position in parallel with his current position as director of the Greenland Climate Research Centre. This will allow for a more intense cooperation between the Greenlandic and Canadian polar research communities. The project is strongly connected with the activities within Nuuk Basic.

Late in 2010, Aarhus University launched the idea of establishing an Arctic Centre at the University. Detailed plans for the structure of the centre were still not in place by the end of 2010, but it is a wish from Aarhus University to establish a close cooperation between the centre, the University of Manitoba and the Greenland Climate Research Centre.

In June 2010, professor Torben Røjle Christensen from Lund University received funding for establishment of a new Nordic Centre of Excellence called DEFROST. The overall objective of DEFROST is to improve our understanding of how the carbon exchange with the cryosphere (permafrost, snow and sea ice) is affected by climate change. Focus is on key cryospheric components such as land, freshwater and ocean systems; components that individually have substantial potential for changing ecosystem-climate feedback mechanisms. The project is strongly connected with the activities within Nuuk Basic.

In August 2010, the Minister for Science, Technology and Innovation, Charlotte Sahl-Madsen (Denmark) and the Minister for Culture, Education, Research and Church Affairs, Mimi Karlsen (Greenland) paid a visit to the Greenland Institute of Natural Resources and the Greenland Climate Research Centre. Following the visit to the Institute, the Ministers and their entourage visited Kobbefjord where a presentation was given of the monitoring programme 'Nuuk Basic'. The Ministers also had the opportunity to speak with students associated with the programme and to visit the new research hut, which came into use in August 2009.

1.4 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 stations) to coordinate their activities. Both projects received funding through the EU 7th Framework Programme in 2010, and will be launched in the beginning of 2011. A major component of the project is a Transnational Access programme allowing each of the participating stations (in Greenland there are four research stations participating in INTERACT) to fund the stay of foreign EU-scientists at the research stations.

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.

1.5 Further information

Further information about the Nuuk Ecological Research Operations (NERO) programme is collected in previous annual reports (Jensen and Rasch 2007, 2008 and 2009). Much more information is available on the NERO website: www.nuuk-basic.dk including manuals for the different monitoring programmes, a database holding data from the monitoring, up-to-date weather information, a NERO bibliography and a collection of public outreach papers in PDF-format.

The NERO programme's address is:

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2 NUUK BASIC

The ClimateBasis Programme

Mark Andrew Pernosky

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) monitor all physical parameters necessary to describe the variations in climate and hydrology.

Location of the different stations can be seen in figure 2.1. ClimateBasis is operated by Asiaq – Greenland Survey.

2.1 Meteorological data

In 2010, the climate stations in Kobbefjord were visited once by Asiaq technicians and six times by other Asiaq personnel. The maintenance of the stations included reference tests of important parameters, and replacement of the following sensors at both stations: RVI, PAR, Net Radiation (Lite) and the four component net radiometer (CNR1). A full description of the climate stations are given in Jensen and Rasch 2008.

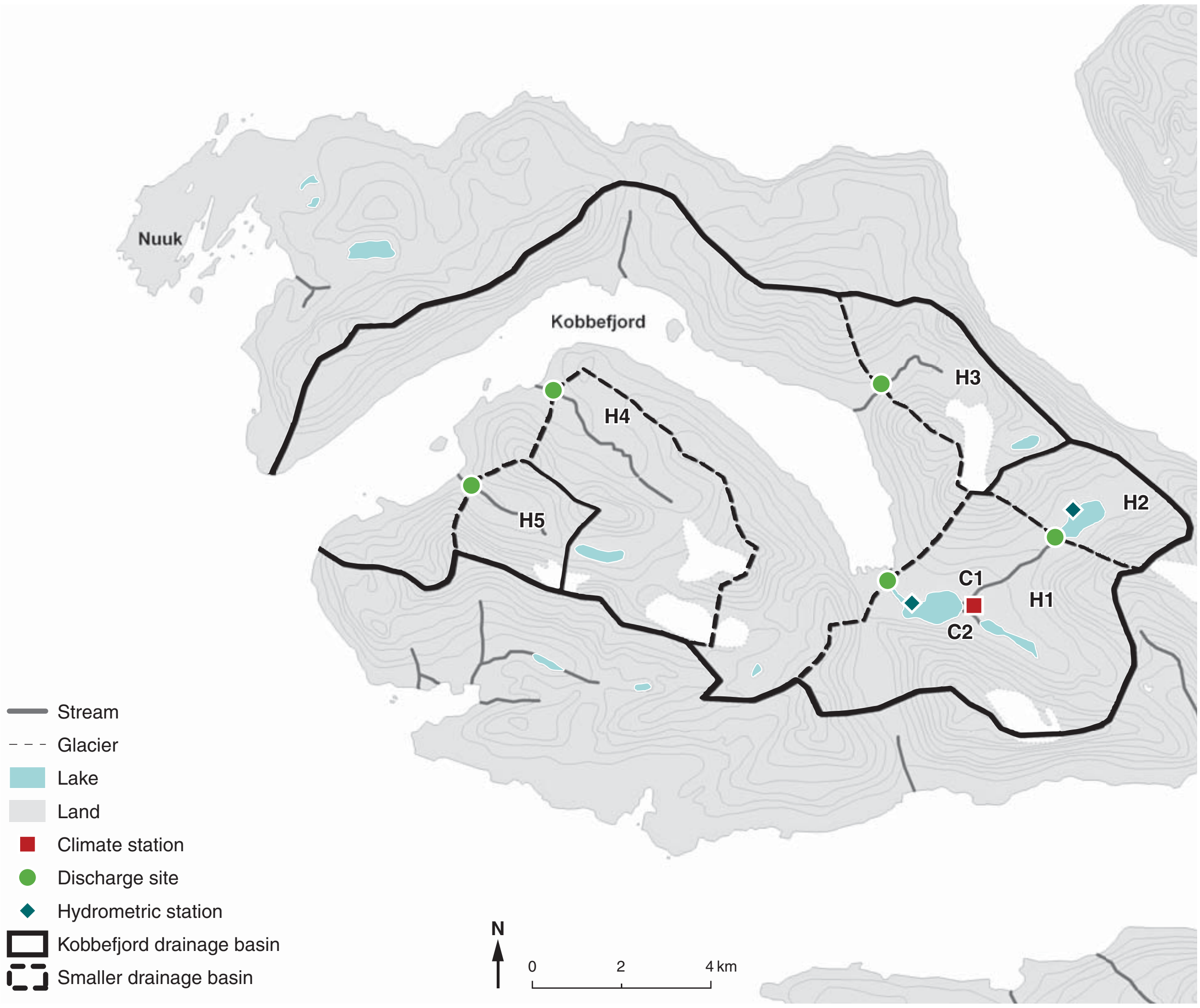

Figure 2.1 Location of the climate (C1, C2), hydrometric (H1, H2) and diver stations (H3, H4, H5) in Kobbefjord together with the drainage basins of Kobbefjord and the drainage basin for the hydrometric stations and the diver stations.

During 2010, further work was made to facilitate automatic data retrieval from Nuuk. The system could not be made operational during 2010. It is planned that the system will become operational in August 2011, which will directly improve the data resilience for all connected stations (C1, C2, H1 and some stations run by GeoBasis).

During the quality control of the meteorological data, it was discovered that the air temperatures measured at both climate stations were 0.8 °C too low according to seven reference tests since the beginning of the programme and according to a comparison with the hydrometric station H1. Data has been corrected back to 2007 and therefore the air temperatures reported here will differ from the ones reported in previous years. The corrected data has been sent to the Nuuk Basic database at Aarhus University, Department of Bioscience.

Meteorological data 2010

This annual report describes the third full year of data for all climate parameters and refers to data collected in the period from 1 January to 31 December 2010. Figure 2.2 gives an overview of selected meteorological parameters in 2010.

The annual mean of recorded air temperatures in 2010 was 3.4 °C, table 2.1. The coldest month was March with an average temperature of -4.5 °C and minimum temperature as low as -17.4 °C. The warm-

Figure 2.2 Variation of selected climate parameters in 2010. 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.

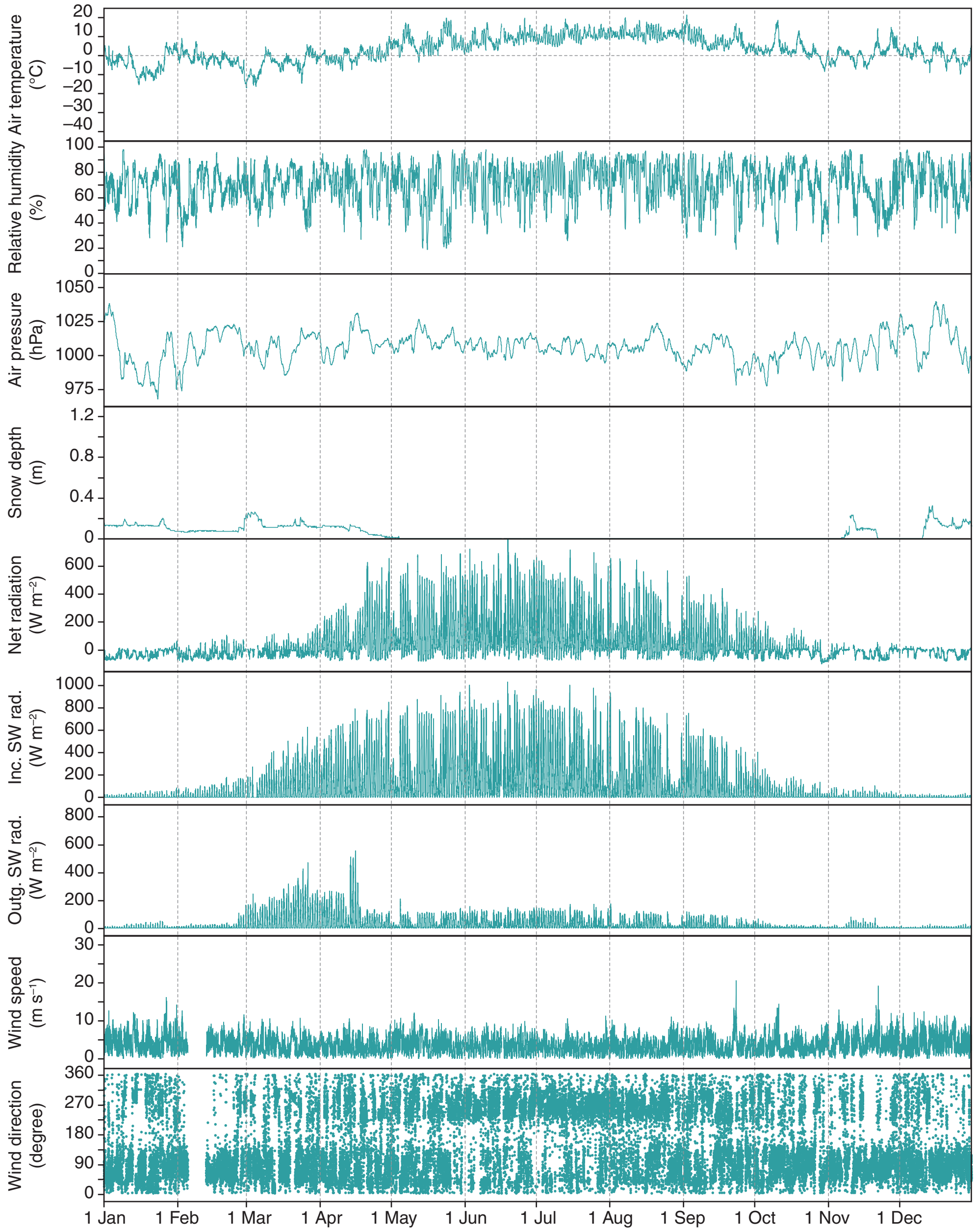

Table 2.1 Monthly and annual mean values of selected climate parameters for 2010. For 2010 also mean relative humidity, snow depth, annual mean temperature, mean air pressure, accumulated precipitation and mean wind speed.

Month 2010	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	69	0.125	-3.8	999	61.5	4.2	16.0	NE
February	66	0.074	-1.6	1010	39.8	–	–	–
March	69	0.147	-4.5	1005	56.7	3.4	10.6	NE
April	73	0.083	-0.1	1010	33.8	3.2	10.5	NE
May	66	0.001	7.1	1011	94.7	3.7	12.0	NE
June	71	–	8.7	1008	55.2	3.4	9.8	W
July	76	–	10.7	1005	18.2	3.0	11.2	W
August	77	–	11.7	1008	241.0	3.1	10.9	WSW
September	71	–	7.8	1001	41.1	3.4	20.5	NE
October	69	–	2.9	1001	25.6	3.2	14.3	NE
November	67	0.048	1.2	1006	101.3	4.1	19.1	ENE
December	73	0.107	0.5	1013	136.3	4.1	12.3	E
2010	71	–	3.4	1006	905.1	3.5	–	–

est month was August with temperatures averaging 11.7 °C. However, the maximum temperature occurred on 2 September measuring 22.3 °C. Compared with the climate normal for Nuuk (1961-90), the recorded temperatures in Kobbefjord during 2010 were above normal for the entire year (Cappelen et al. 2001).

The general weather pattern from January to March 2010 was characterized by long periods with NE winds and generally warm, unstable temperatures ranging from -17 °C to 9 °C. Occasional storms brought stronger winds from the WNW and precipitation. Although every day in February measured a minimum temperature below 0 °C, only 11 days measured a maximum temperature below 0 °C and only 1 day measured a minimum temperature below -10 °C. After a period of nearly nine days in the end of January and beginning of February with temperatures above 0 °C, the snow pack at the climate stations was reduced to a mere six cm. Due to little precipitation throughout the month of February, snow levels did not rise above eight cm until the end of the month. In general, 2010 had little snow cover as compared to previous years. The average temperature in March was 7.2 °C warmer than in March 2009, table 2.2.

Spring came early to Kobbefjord and the last day with a mean air temperature below the freezing point was recorded on 28 April, which is on average 16 days earlier than in 2008 and 2009. The dominant wind continued to come from NE during April and May and precipitation increased in May with 94.7 mm as opposed to only 33.8 mm in April. In May, the average temperature was 6.8 °C warmer than in May 2009.

In June, the dominant wind direction changed to a westerly wind. This continued throughout July and changed slightly to come out of the WSW during August. Air pressure remained high and stable throughout the entire summer. Although the mean air temperatures were above

Table 2.2 Comparison of monthly mean air temperatures 2007 to 2010 (italic text represents months with incomplete coverage).

Month	Air temperature (°C)			
	2007	2008	2009	2010
January	–	–12.0	–5.4	–3.8
February	–	–13.3	–6.1	–1.6
March	–	–8.3	–11.7	–4.5
April	–	–0.9	–3.2	–0.1
May	*0.6*	3.9	0.3	7.1
June	*5.3*	7.9	6.4	8.8
July	*10.8*	10.9	10.6	10.7
August	10.6	8.7	9.3	11.7
September	4.0	4.4	3.8	7.8
October	–0.5	0.0	–0.6	2.9
November	–3.5	–1.7	–7.9	1.2
December	–8.7	–7.8	–2.8	0.5
Year	–	-0.7	-0.6	3.4

average and higher than in previous years during the winter and spring months, summer temperatures remained close to normal. In fact, since 2007 the average temperature in July has not varied more than 0.3 °C, table 2.2. As in 2009, June and July were characterized by stable weather conditions with little precipitation, a high frequency of clear sky conditions and diurnal variations in wind speed, temperature, and relative humidity.

The warmest month of the year was August instead of July, as it had been for the past three years. Most of the summer had been relatively dry, but that changed in August with a total precipitation of 241 mm occurring during four events. In September, the dominant wind direction turned back to NE. A passing low pressure system during the end of September brought along precipitation followed by wind speeds up to 20 m s^{-1} and tempe-ratures up to 17 °C. Although this event brought the strongest winds of the year, the temperature increase was not as impressive as a spell with temperatures up to 19.2 °C 10 October, followed by a temperature drop to 3 °C 11 October, with temperatures falling as quickly as 6.5 °C per hour. These types of events caused by low pressure systems are common during the autumn months. However, from October to December there was only one occurrence with mean wind speeds above 15 m s^{-1}, compared with six in 2008 and three in 2009. Throughout November and December, the dominant wind direction changed slowly from NE to E.

The first day in the autumn of 2010 with a mean daily temperature below 0 °C occurred on 28 October, which is on average 31 days later than during the period of 2007-2009. Snow was first recorded at the climate stations on 6 November but was gone again on 21 November due to warm temperatures and rain. Snow did not return until 10 December, which was also the start of the permanent snow cover at the climate stations.

The levels of selected radiation parameters are displayed in table 2.3. The vegetation underneath the radiation masts greened much sooner than during 2009, with the first daily Normalised Differential Vegetation Index (NDVI) value above 0.2 occurring 23 April 2010, as opposed to 5 June in 2009. The maximum greenness was measured in August with a NDVI value of 0.36. The period with positive month mean net radiation was April to September, which is a month longer than in both 2008 and 2009.

2.2 River water discharge

Hydrometric stations

In 2010, hydrological measurements were carried out at five sites 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.

Table 2.3 Monthly mean values of selected radiation parameters in 2010.

Month 2010	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	0.00	0.66	4.6	3.0	250	284	–31.6	11.6	0.2
February	0.04	0.29	17.5	5.5	249	294	–32.4	44.0	0.9
March	–0.09	0.79	69.5	53.3	256	283	–9.6	165	3.9
April	0.04	0.35	170	58.1	270	313	73.3	379	12.0
May	0.25	0.13	204	30.2	298	351	120	457	19.8
June	0.31	0.14	211	31.9	319	368	130	468	25.8
July	0.34	0.15	211	33.7	327	384	120	468	23.3
August	0.36	0.14	140	21.8	338	376	79.0	309	14.3
September	0.30	0.14	93.3	14.9	305	349	34.6	204	7.2
October	0.22	0.14	22.5	3.5	283	317	–14.9	53.1	1.8
November	0.14	0.46	6.3	3.7	281	306	–22.0	15.9	0.3
December	0.08	0.69	1.8	1.3	288	304	–16.4	4.7	0.1

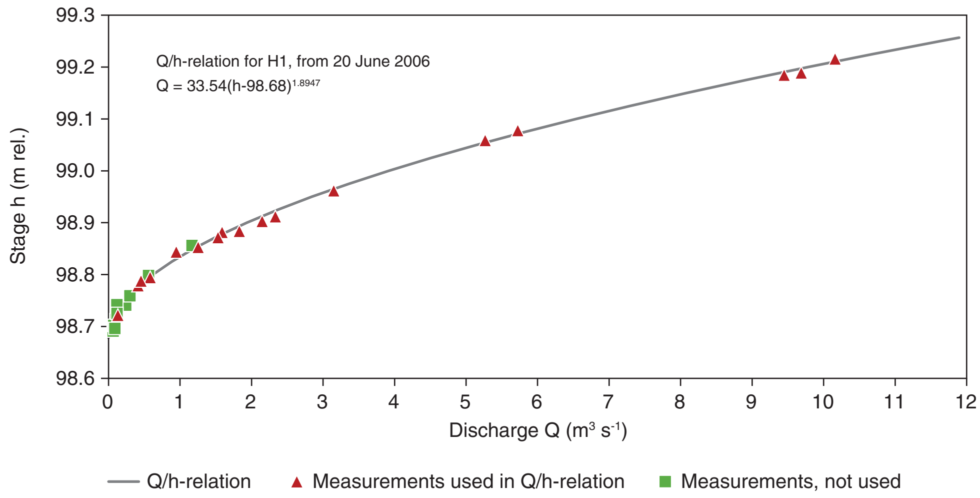

Figure 2.3 Discharge - water level relation curve (Q/h-relation) at the hydrometric station H1. The coefficient of correlation (R^2) for the curve is 0.998.

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 2008 and 2009.

Q/h-relation

Manual discharge measurements have been carried out at station H1, H3, H4 and H5 (respectively 6, 8, 10 and 5 times) during 2010. The purpose is to establish 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 not enough discharge measurements have been made, especially at high water levels, to produce reliable Q/h-relations. Therefore, data from these stations are not presented.

In 2009, a new Q/h-relation was calculated based upon 17 discharge measurements, figure 2.3. For further description of the Q/h-relation, see Jensen and Rasch 2010. All of the discharge measurements made during ice free conditions in 2010 are in good accordance with the Q/h-relation.

By the end of 2010, 12 discharge measurements have been carried out while the outlet was affected by ice and/or snow. These measurements are not included in the Q/h-relation. However, it has been observed that the Q/h-relation estimates discharge during conditions with ice and snow very well, except during heavy thaw and rain events. As a result, the Q/h-relation has been used during the winter months to estimate discharge. While these results are considered a good estimate, they still should be used with care.

River water discharge at H1

Figure 2.4 shows data from 2010. In 2010, the period with ice/snow free conditions at the outlet was approximately from 20 April to 11 November, and again from 21 November to 10 December. Discharges calculated beyond this period are estimated.

The total discharge from H1 during the hydrological year 2009/2010 was 22.9 million m^3, which is 42 % lower than in 2008/2009 and 30 % lower than in 2007/2008. The total discharge corresponds to a runoff of 739 mm when assuming that the drainage basin covers 31 km^2. The majority of the snow pack melted and drained through the river during the first 15 days of May. June and July were relatively dry months with little variation in discharge. Due to a very wet August, two high peaks occurred during the month with the peak discharge recorded 30 August and caused by a rain event. Due to a warm autumn, discharge levels did not drop significantly below 0.5 m^3 s^{-1} until 1 November. Discharge steadily dropped to 0.2 m^3 s^{-1} by 20 November. On 21 November, water levels began rising again due to warm temperatures and rainfall that completely melted the snow pack in low lying areas. This caused discharge to peak at 4.4 m^3 s^{-1} on 3 December. As colder temperatures returned to Kobbefjord around 6 December, discharge levels steadily decreased to 0.4 m^3 s^{-1}.

A comparison of discharge with precipitation has been made for the hydrologi-

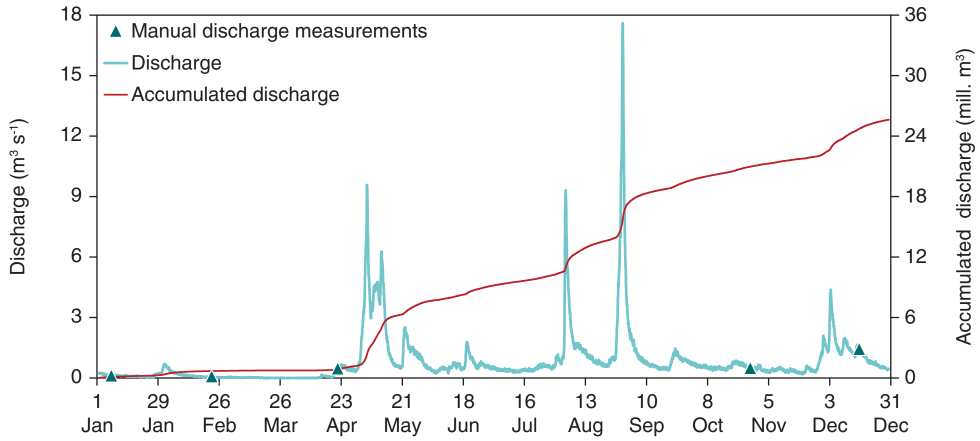

Figure 2.4 River water discharge at H1 during 2010.

cal year 2009/2010. The precipitation at the meteorological stations, C1 and C2, was 832 mm while the runoff from H1 equalled 739 mm. There can be many reasons for the difference between precipitation and runoff. Although the Q/h-relation provides estimates of runoff during ice and snow conditions, there remains uncertainty. Other factors to take into consideration are difficulties in measuring precipitation (the technical aspect and geographic distribution), glacial runoff and evaporation.

In addition, there is a need for more knowledge of the hydrological processes in Kobbefjord. In 2011, it is hoped that hydrological modelling of the catchments in Kobbefjord (using the new digital elevation model) will provide more insight into winter discharges at the different measuring sites.

Karl Martin Iversen making discharge measurements at the hydrometric station at the outlet of Badesø, April 2010. Photo: Lillian Magelund Jensen.

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 2010 operated by the Department of Geography and Geology, University of Copenhagen, in collaboration with the Department for Arctic Environment, National Environmental Research Institute, Aarhus University. In 2010, GeoBasis was funded by 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 October with some year-round measurements from automated stations.

The 2010 season is the third full season for the GeoBasis programme. In 2007, the field programme was initiated during a three-week intensive field campaign in August in which most of the equipment was installed. Methods and sampling procedures are described in detail in the manual 'GeoBasis - Guidelines and sampling procedures for the geographical monitoring programme of Nuuk Basic', which can be downloaded from (www.nuuk-basic.dk/news/geobasis_manual/)

Data collected by the Danish Meteorological Institute shows that 2010 is the warmest year registered since air temperature mea-surements were initiated in 1866 in Nuuk. In 2010, the annual mean air temperature reached 2.6 °C and is thereby the 12th year within the total time series with an annual mean air temperature above 0 °C. The second warmest year in the time series is 1941 with an annual mean air temperature of 0.8 °C (Carstensen and Jørgensen, 2011). In figure 3.1, the monthly minimum, mean and maximum air temperature for the period 1866-2010 measured at Nuuk are compared with the monthly mean air temperatures for 2010. During the period, 2010 had the maximum monthly mean air temperature in May, August, September, November and December. This makes 2010 a historically warm year.

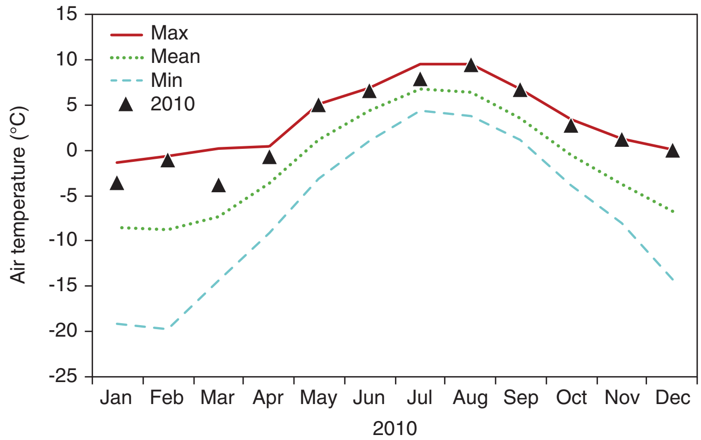


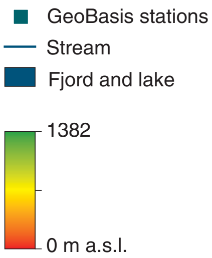
Figure 3.1 The monthly minimum, mean and maximum air temperature for the period 1866-2010 measured at Nuuk (lines solid and dashed) and monthly mean air temperature for 2010 (points) (Carstensen and Jørgensen, 2011).

3.1 Snow and ice

Snow cover extent

The first three 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. In September 2009, the last two snow monitoring cameras K5 and K6 were installed. Both cameras were installed at position N64 °9'06.25'' W51 °20'46.47'' 770 m a.s.l. (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 with 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



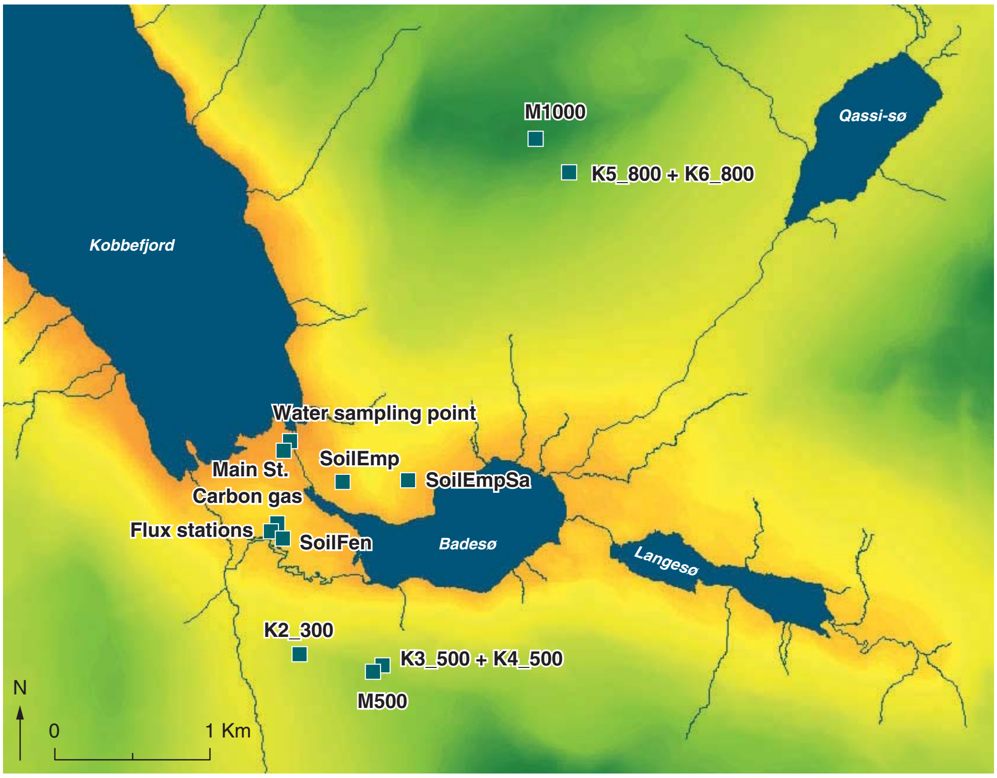


Figure 3.2 Location of GeoBasis stations in Kobbefjord. The base map is created from new elevation and feature data.

data unsuitable for mapping purposes. A new updated and more user-friendly algorithm for snow cover monitoring has been developed in MatLab, so it is now possible, for each melting season, to construct snow cover depletion curves for user specified regions of interest (ROI) based on 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 cause a smaller snow accumulation and an earlier snow melt with 50 % of the snow cover melted on DOY 122 (2 May) in 2008. A more extensive snowfall during winter and spring 2008/2009 caused a delay in the snow melt, so 50 % snow cover was first reached 23 days later in 2009. The depletion curves for ROI 300 in 2010 (figure 3.3) indicates a snow melt very similar to 2008 – only delayed four days, and the snow cover at ROI 300 was entirely melted 10 May. The ROI's at 200 and 250 m a.s.l. are facing to the north, which causes a leeward accumulation of snow and a later snow melt due to a shade effect from the surrounding mountains. On 14 May most of the area was covered with a very shallow snow cover, which delayed the snow melt with 2-3 days.

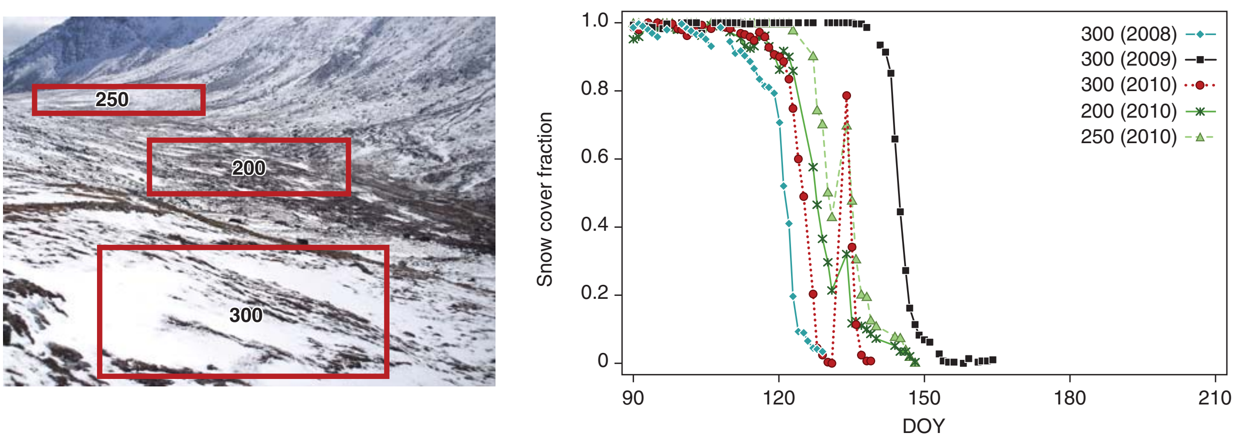


Figure 3.3 Snow cover depletion for three regions of interest 200, 250 and 300 m a.s.l. has been analysed using a new snow cover algorithm. The regions are specified on the image to the left, and the depletion curves for each region are shown in the diagram to the right. DOY= day of year. For ROI 300 the snow depletions for all three years are also shown and the image to the left show the area 14 May after a minor snowfall had occurred.

Table 3.1 Snow pit depth, average density, snow depth, average snow temperature and average water equivalent at the three soil stations (SoilFen, SoilEmp and SoilEmpSa) measured 15 and 16 April 2010. No snow pit was dug at SoilEmpSa.

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 (A1)	15	339	2–20–40	7	–0.3	51
Soil *Empetrum Salix* (B1)	n.a.	n.a.	7–19–68	13	n.a.	n.a.
Soil *Empetrum* (C1)	10	366	6–17–65	14	n.a.	37

Snow cover

In 2010, the snow cover survey for Kobbefjord was carried out 15 and 16 April 2010. It describes snow depths and densities at the three GeoBasis soil microclimate stations SoilFen, SoilEmp and SoilEmpSa using ground penetrating radar (GPR) and manual stake measurements (figure 3.4). During the winter 2009-2010 there was generally very little snow around sea level due to frequent thaw events. Due to low snow volume in April it was not possible to use GPR neither at SoilEmp nor at SoilEmpSa for the snow cover survey. Instead, the snow depths were measured with manual stake measurements every 5 meters for the two stations in the sections 1-2, 1-3, 1-4 and 1-5 (figure 3.4). For SoilFen the GPR was used to measure snow depth and to determine ice layer thickness and peat layer thickness. In order to document the properties of the snowpack; snow pits were dug at SoilFen in point A1 and at SoilEmp in point C1 (figure 3.4). The examination of the snowpack included temperature profiling, density measurements and texture description. Table 3.1 summarises the snow depth, density and temperature results from the three stations. No snow pit was dug at SoilEmpSa due to thin snow layer. Snow temperature, density and water equivalent are therefore not available for SoilEmpSa in 2010. The texture of the snow profile at SoilEmp is characterized as homogenous coarse grained snow. For SoilFen, the 15 cm profile was characterized by three horizons, i.e. the top 5 cm as fresh snow, in depth 5-10 cm as slush and below depth of 10 cm as ice. When comparing the snow cover survey 2010 with the snow cover survey 2009, carried out on the exact same dates (i.e.15 and 16 April), it is concluded that the average snow depth in 2010 was 77 cm lower at the three locations than in 2009. At SoilEmp and SoilFen, the average density was 17 % higher than at the same time in 2009 (Hansen et al. 2010).

Ice cover

The period with ice cover on the lakes in the Kobbefjord drainage basin was generally shorter in the winter 2009/2010 than in the previous winters (table 3.2). The break-up of the ice cover on the lakes was approximately one month earlier than in 2009.

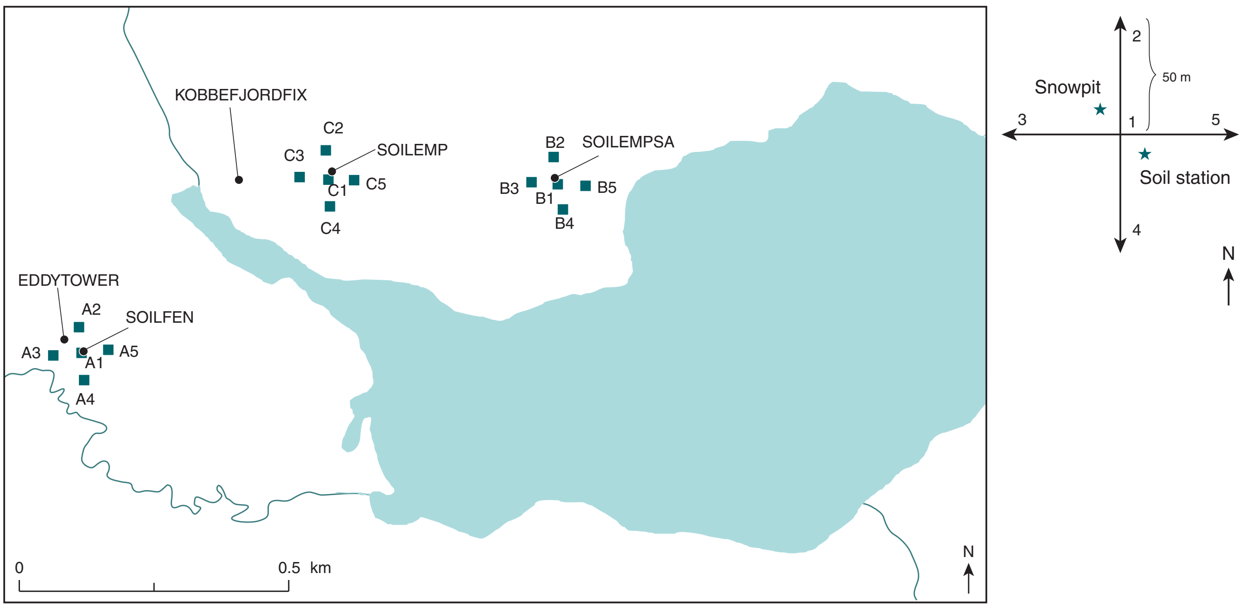


Figure 3.4 Map showing the three snow survey sites. The figure on the right outlines the strategy at each site.

*Table 3.2 Visually estimated dates for perennial formation of ice cover and dates for break-up of ice cover on selected lakes within the Kobbefjord drainage basin and on Kobbefjord in 2009 and 2010. Data for Langesø is missing for the field season 2009/2010. *Due to low cloud cover, it was not possible to estimate the exact date for break-up of the ice cover on Kobbefjord in 2010.*

	Break-up	Formation	Break-up
Badesø	13 June 2009	1 November 2009	14 May 2010
Langesø	11 June 2009	–	–
Qassi-sø	22 June 2009	10 October 2009	24 May 2010
Kobbefjord	4 June 2009	12 February 2010	Between 15 Feb and 6 March 2010*

An ice cover developed along the shore-line of Kobbefjord in mid-February 2010 but melted within the following two weeks. Thereafter, the fjord remained ice free for the rest of the winter and spring. An ice cover formed three weeks earlier on Qassi-sø (250 m a.s.l.) than on Badesø (30 m a.s.l.). The ice cover on Qassi-sø broke up ten days later than on Badesø. The difference in the period with ice cover on the two lakes is due to the difference in elevation.

Micrometeorology

Table 3.3 reports the monthly mean air temperature, relative humidity, surface temperature and soil temperature measured at SoilFen during the field season 2010. Since measurements began in 2007, 2010 was the year with the highest monthly mean air temperatures measured at the SoilFen station. Figure 3.5 shows a comparison between the monthly mean air temperatures in 2010 and the maximum and the minimum monthly mean air temperatures from SoilFen in 2007-2010. Note that data for November and December 2010 are not yet available and therefore not included. The unusual high monthly mean air temperatures are not caused by local factors within the drainage basin of Kobbefjord (figure 3.1).

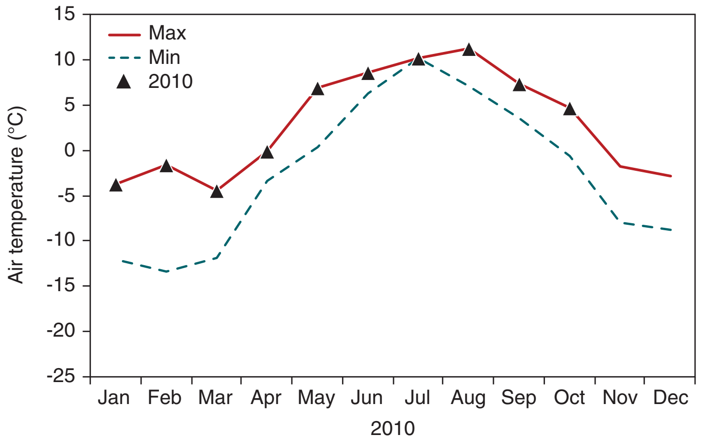


Figure 3.5 Monthly mean air temperatures in 2010. Max and Min are maximum and minimum monthly mean air temperatures from 2007-2010. Data from November and December 2010 are not yet available and therefore not included in this figure.

For 2007-2010, the minimum monthly mean air temperature is –13.5 °C measured at SoilFen in February 2008, while the maximum is 11.3 °C measured in August 2010 (table 3.3).

For the micrometeorological station M500, monthly mean air temperature, relative humidity, surface temperature and shortwave irradiance are presented in table 3.4. For 500 m a.s.l., the pattern of higher monthly mean air temperature for 2010 is confirmed. In general, the monthly mean air temperatures for 2010 are higher than in 2008 and 2009 except for June and July in which the highest monthly mean air temperatures were registered in 2008. Note that the monthly mean incoming shortwave irradiance for May-August 2010 was lower than in the same months in 2008 and 2009.

3.2 Soil

Physical soil properties

The results of selected parameters for the soil stations SoilFen, SoilEmp and SoilEmpSa are presented in tables 3.3, 3.5 and 3.6. The difference in soil properties between the three locations, which were detected in 2009, is also seen in the data collected in 2010 (i.e. higher winter soil temperatures at SoilFen than at SoilEmp and SoilEmpSa). The results of the measured soil water content show markedly lower values for the well-drained soil at SoilEmp than at SoilEmpSa. The monthly mean soil moisture was 13 % at SoilEmp and 35 % at SoilEmpSa during the field season 2010. The monthly mean soil temperature in depth –1 cm (surface temperature) measured at SoilEmp in April-October in 2010 are higher than in 2009 which corresponds with the higher monthly mean air temperatures measured at SoilFen in 2010.

Table 3.3 Air temperature, relative humidity, surface temperature and soil temperature at five depths (1 cm, 10 cm, 30 cm, 50 cm and 75 cm) from the SoilFen station in the fen area, from August 2007 to October 2010.

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)
2007								
August	7.6	84.1	7.6	9.0	9.8	10.1	8.6	7.4
September	3.8	70.1	1.9	3.4	4.3	5.3	5.9	5.8
October	–0.5	64.6	–4.8	–0.6	0.2	1.1	2.3	2.8
November	–3.5	74.2	–7.1	–0.3	–0.2	0.4	1.2	1.7
December	–8.9	71.8	–13.1	–0.2	–0.2	3.0	0.9	1.3
2008								
January	–12.1	73.2	–16.0	–0.3	–0.1	0.3	0.8	1.2
February	–13.5	73.1	–15.7	–0.3	–0.1	0.2	0.7	1.0
March	–8.8	75.0	–11.5	–0.3	–0.1	0.2	0.7	1.0
April	–	–	–	–	–	–	–	–
May	–	–	–	–	–	–	–	–
June	–	–	–	–	–	–	–	–
July	–	–	–	–	–	–	–	–
August	7.4	76.6	7.6	9.3	9.2	8.6	8.4	7.6
September	4.1	77.8	3.9	4.7	5.2	5.9	6.0	6.0
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
2010								
January	–3.8	71.1	–7.0	–1.9	–1.0	0.5	0.7	1.1
February	–1.6	67.7	–5.4	–3.2	–2.3	0.1	0.3	0.8
March	–4.5	69.8	–7.9	–2.2	–1.8	–0.2	0.1	0.5
April	–0.1	74.1	–3.0	–0.5	–0.5	–0.1	0.1	0.4
May	6.9	68.8	6.9	6.2	2.3	0.0	0.1	0.4
June	8.6	73.6	10.7	10.9	7.8	1.0	0.8	0.7
July	10.2	78.2	12.6	13.8	12.1	7.9	6.9	5.5
August	11.3	79.8	11.7	12.6	11.9	9.7	9.0	7.9
September	7.4	73.4	6.5	7.3	7.7	7.7	7.6	7.2
October	4.7	68.8	2.4	2.5	3.3	4.7	5.0	5.3

Table 3.4 Air temperature, relative humidity, surface temperature and shortwave irradiance measured at the M500 station from January 2008 to September 2010. (Data from October to December are not yet retrieved).

Month-year	Air temp. 2.5 m (°C)	Rel. Hum. 2.5 m (%)	Surface temp. 0 m (°C)	Shortwave irradiance 2.5 m (W m^{-2})
2008				
January	–14.3	78.5	–16.3	6.7
February	–15.6	78.1	–17.3	30.3
March	–10.7	83.5	–12.3	77.2
April	–2.4	67.2	–4.6	172.5
May	2.4	73.2	3.5	237.0
June	5.9	72.1	8.7	295.1
July	8.9	64.3	10.5	253.7
August	5.4	80.1	6.3	157.7
September	0.1	90.0	–0.7	74.0
October	–3.2	77.6	–6.2	38.2
November	–5.0	91.4	–6.2	8.5
December	–10.8	82.2	–13.0	3.3
2009				
January	–7.7	72.0	–11.4	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	220.8
July	8.8	67.8	11.0	287.7
August	7.1	74.2	7.7	188.5
September	–0.2	84.4	–1.2	82.8
October	–3.6	74.9	–6.4	44.6
November	–9.2	75.1	–12.2	11.8
December	–3.8	57.5	–9.3	3.3
2010				
January	–5.5	73.8	–9.1	5.9
February	–2.7	65.4	–7.5	29.6
March	–6.7	73.1	–9.6	80.4
April	–2.9	79.9	–5.4	170.4
May	4.6	71.3	3.8	205.6
June	5.7	79.9	7.9	211.4
July	8.5	76.3	11.2	217.8
August	9.0	81.3	8.8	132.6
September	5.6	70.9	3.2	92.7

Soil water

Ninety soil water samples were collected from the soil water stations at SoilEmp and SoilFen during the period 27 May-4 October 2010. pH, temperature and conductivity measurements were carried out on the samples at the research hut in Kobbefjord. In August 2010, laboratory equipment was installed in the research hut, which further enabled analyses of soil water alkalinity. The results of soil water chemistry analyses will be reported in the 2011 Annual Report.

Table 3.5 Soil temperature and soil moisture at four depths measured at SoilEmp from January 2009 to October 2010.

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 (%)
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	7.4	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
2010								
January	–5.2	–5.1	–4.9	–3.9	1	8	2	2
February	–5.3	–5.1	–5.0	–4.1	1	8	1	2
March	–4.5	–4.4	–4.4	–3.9	1	8	1	2
April	–0.6	–0.8	–0.8	–0.8	6	16	10	8
May	6.4	5.6	5.1	3.8	19	42	34	31
June	10.1	9.4	9.0	7.7	5	35	8	5
July	12.4	11.8	11.4	10.4	4	28	5	4
August	11.6	11.3	11.2	10.6	11	37	15	15
September	7.0	7.3	7.4	7.6	9	38	14	11
October	2.8	3.2	3.4	4.0	6	37	6	5

River water

In 2010, 61 water samples were collected from the end of April to mid-October, which is the longest field season since the initiation of the GeoBasis monitoring programme in Kobbefjord. *In situ* measurements of river water temperature, conductivity and pH were carried out along with the water sampling. The measured values are presented in figure 3.6. The river water temperature varies through the 2010 season as it did during the 2009 season (Hansen et al. 2010) with a minimum temperature of 1.7 °C measured 28 April and a maximum temperature of 15.8 °C measured 19 July 2010. The conductivity shows a significant decrease within the snow melting period (April-May) to a level of

Figure 3.6 River water temperature (A), conductivity (B) and pH (C) measured in Kobbefjord River at the water sampling point near the research hut in 2010.

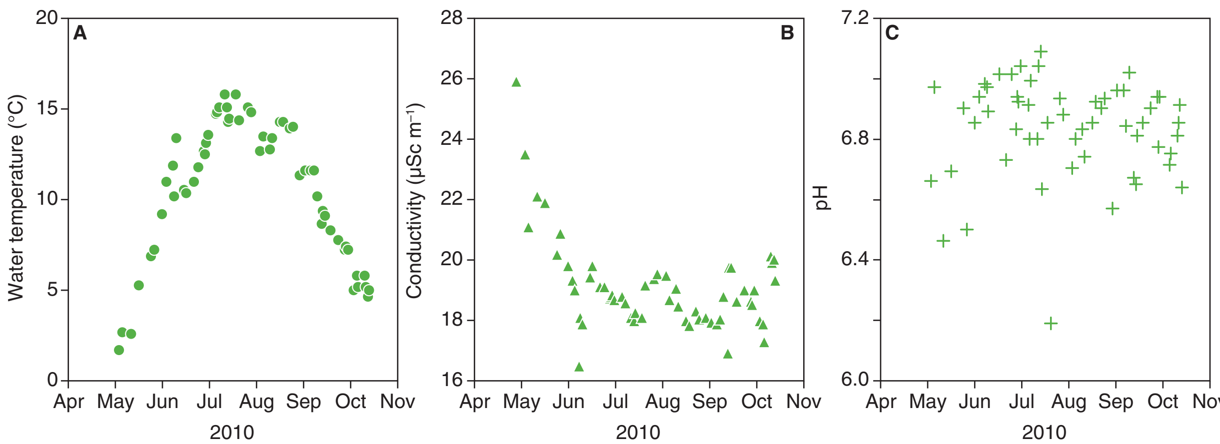


Table 3.6 Soil temperature and soil moisture at four depths measured at SoilEmpSa from January 2009 to October 2010.

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 (%)
2009								
January	–	–	–0.3	0.2	37	27	41	38
February	–	–	–1.1	–0.3	15	13	33	32
March	–	–	–1.4	–0.7	13	12	12	25
April	–	–	–0.4	–0.2	15	13	13	14
May	–	–	0.0	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	–	–	10.2	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	0.0	0.3	52	37	41	42
December	–0.7	–0.2	–0.4	–0.1	28	21	38	35
2010								
January	–1.7	–1.0	–1.4	–0.5	23	14	19	34
February	–2.6	–1.8	–2.2	–1.3	21	13	12	22
March	–1.9	–1.7	–1.8	–1.4	20	12	11	12
April	–0.2	–0.3	–0.3	–0.3	26	15	12	13
May	3.1	1.3	1.7	1.0	59	47	26	17
June	8.3	6.0	6.8	5.5	60	46	47	46
July	11.4	9.7	10.6	9.2	56	32	42	38
August	11.0	10.2	10.4	10.1	59	49	44	45
September	7.6	7.7	7.6	7.7	60	49	46	49
October	3.8	4.6	4.1	4.9	58	37	44	45

18 ± 1.5 µSc m^{-1}. From the beginning of June and through the rest of the field season, the conductivity shows no significant trend. pH shows a constant level of 6.8 ± 0.4 from April to October 2010.

3.3 Vegetation

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

Satellite imagery

Acquisition of satellite imagery for a specific date can be difficult since the satellite have to pass on the given day under cloud free conditions. Therefore, the satellite companies allow only for ordering of imagery from a given minimum period (e.g. three weeks) and not a specific date. When the conditions of cloud free acquisition are met, the first time during this period, the task is done and no further acquisitions performed. In 2010, the conditions for a successful acquisition were met on 10 July i.e. a week earlier than the images from 2008 and 2009 and around three weeks earlier than the time of maximum growth (see section 4.1). The reasons for inter-annual differences between greenness are therefore difficult to access although a comparison will give an indication. A QuickBird multispectral image with 2.4 m resolution was acquired and georectification performed. Dark subtraction was carried out as the atmospheric correction but without topographic correction.

Normalised Difference Vegetation Index (NDVI) has been calculated on the imagery from 10 July 2010. An NDVI image covering the main part of the monitoring area is shown in figure 3.7.

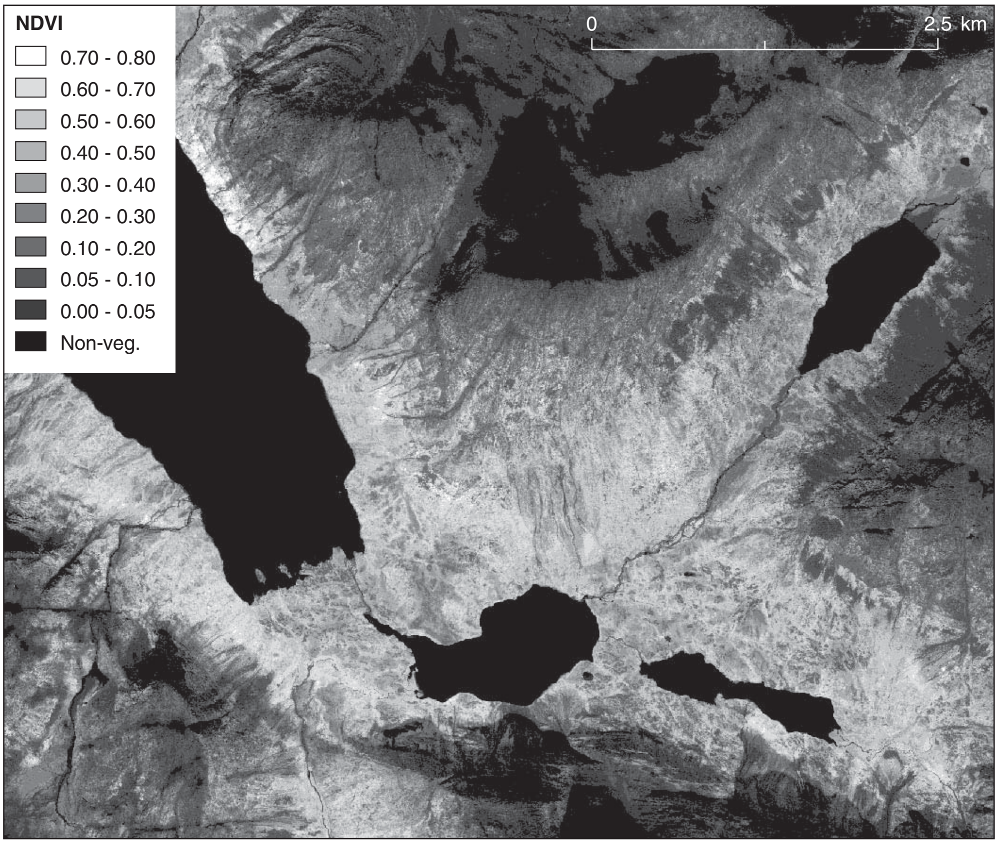


Figure 3.7 Normalised Difference Vegetation Index (NDVI) based on QuickBird imagery from 10 July 2010. Data are dark subtracted as atmospheric correction and lack the topographic correction.

The areas on the imagery represent five different vegetation types from the area: fell field, open mixed heath, *Empetrum* dominated heath, fen and copse.

Figure 3.8 shows the difference in NDVI for the five vegetation types in 2008, 2009 and 2010 (Notice that images are not topographically corrected and that date of acquisition is outside the maximum greenness peak). The fell field areas had a much higher NDVI in 2010 than in previous years, though direct comparison is difficult due to the different dates of the images.

3.4 Carbon gas fluxes

Carbon gas fluxes are monitored on plot and landscape scale in a 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 (see figure 3.11) was installed in August 2007 (Tamstorf et al. 2009). In 2010, the system was operated from 14 May until 11 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 (figure 3.9) is primarily

Figure 3.8 NDVI for the five vegetation types from 17 July 2008 and 2009, and 10 July 2010. Notice that changes between greenness are due not only to phenology differences between years but also seasonal phenology as the image is acquired approximately 2 weeks before the maximum greenness and on different dates.

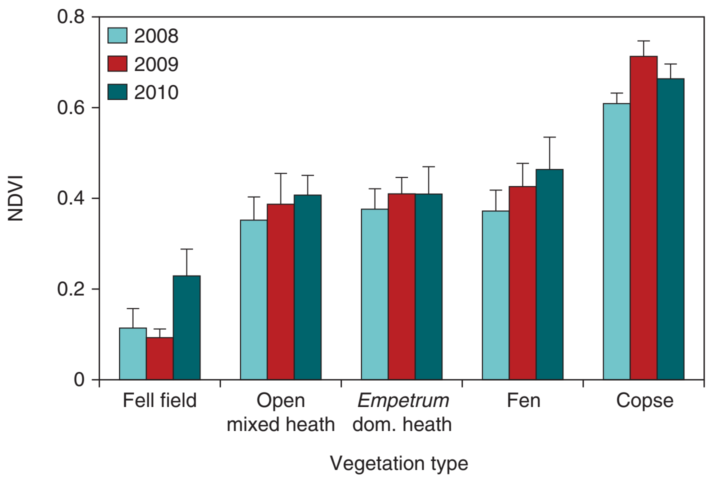
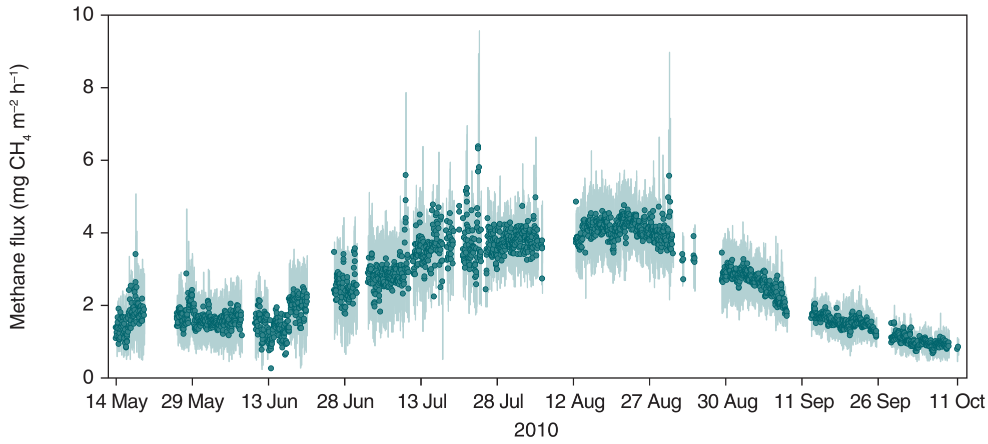


Figure 3.9 Methane (CH_4) emissions from the fen during 2010.



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, by which CH_4 is an end product.

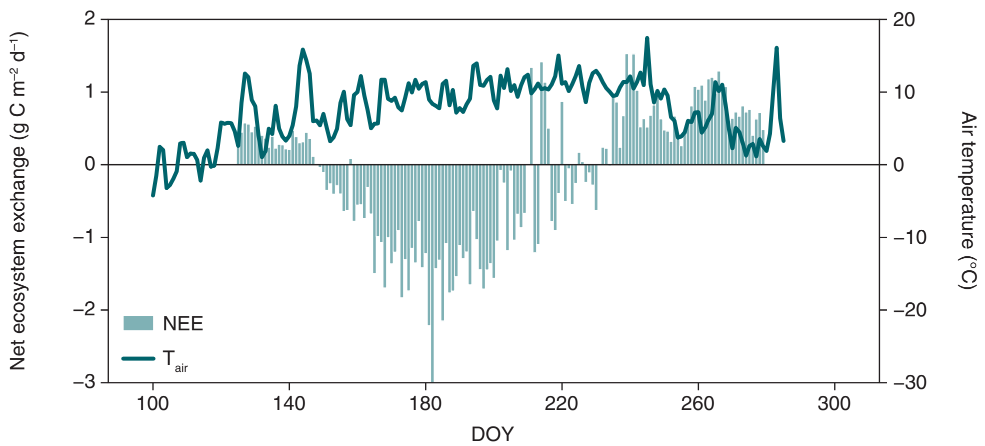
In 2010, measurements started earlier than in previous years, allowing monitoring of CH_4 emissions before onset of the growing season. During May, fluxes were fairly constant ranging 1-3 mg CH_4 m^{-2} h^{-1}. The observed overall temporal CH_4 flux pattern in 2010 was similar to the patterns observed in 2008 and 2009; i.e. low shoulder season emissions and a dome-shaped peak with a maximum in July. Peak summer emissions, approximately 4 mg CH_4 m^{-2} h^{-1}, were lower than those observed in 2009 but in the same range as those observed in 2008. The peak summer CH_4 emissions from the fen in Kobbefjord are comparable to the emissions in a fen in Zackenberg, NE Greenland.

Eddy covariance measurements

In order to describe 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). Raw data from the eddy covariance systems were calculated using the software package EdiRe (Robert Clement, University of Edinburgh). For more details on the flux calculation procedures see Hansen et al. 2010.

The temporal variation in the mean diurnal net ecosystem exchange of CO_2 (NEE) and air temperature during 2010 for the fen site is shown in figure 3.10, and various variables are summarised in table 3.7. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants, plant respiration and microbial decomposition. The

Figure 3.10 Diurnal net ecosystem exchange (NEE) and air temperature (T_{air}) measured in the fen in 2010.



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; fluxes directed from the surface to the atmosphere are positive, whereas fluxes directed from the atmosphere to the surface are negative.

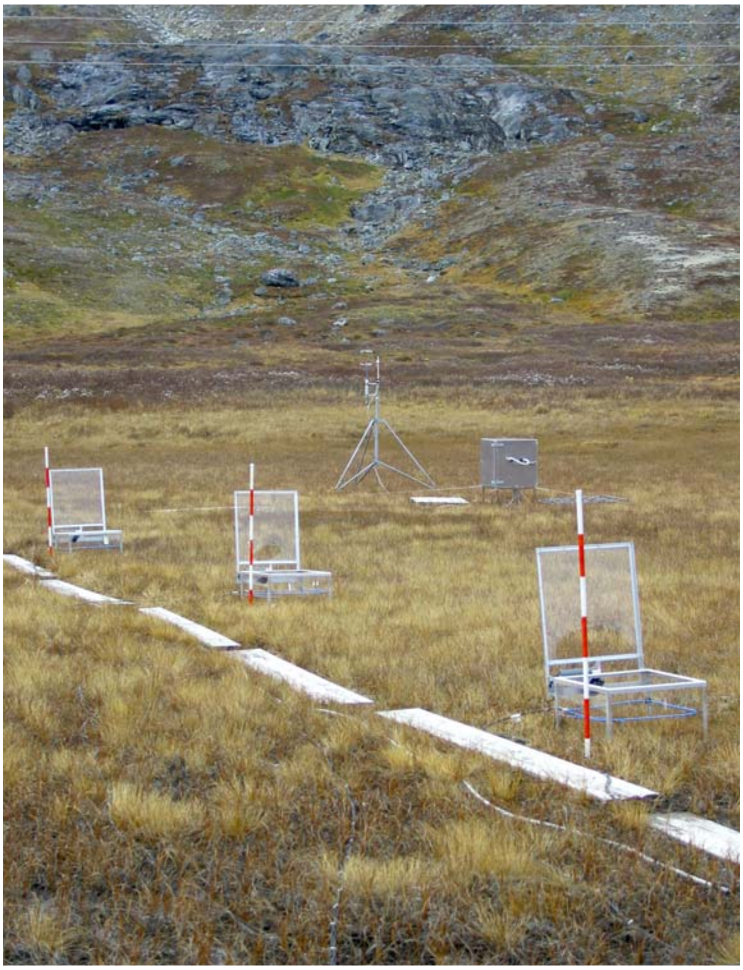
Eddy covariance measurements of the CO_2 and H_2O exchange in the fen were initiated 4 May and lasted until 9 October. During this period, 5% of data were lost due to malfunction, maintenance and calibration. Early in the season, before plants began photosynthesising, small CO_2 emissions were measured. Maximum spring diurnal emission was measured 7 May, amounting to 0.57 g C m^{-2} d^{-1}. As the vegetation developed, the photosynthetic uptake of CO_2 started, and 29 May the fen ecosystem switched from being a net source to a net sink of atmospheric CO_2. This is the earliest onset of net uptake period measured so far.

The period with net CO_2 uptake in 2010 lasted until 18 August (table 3.7), which was in between 2008 (16 August) and 2009 (27 August). During this period, the fen accumulated –65.4 g C m^{-2}, and the maximum daily accumulation rate amounted to –3.1 g C m^{-2} (measured 1 July). These are the highest accumulation rates measured so far, likely associated with the early snow melt and onset of growing season period. By 18 August, respiration processes exceeded the fading photosynthesis, and the ecosystem returned to a net source of atmospheric CO_2. In the beginning of this period, 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 27 August (1.53 g C m^{-2} d^{-1}). During the entire measuring period (158 days), the total CO_2 accumulation amounted to –20.9 g C m^{-2}.

Table 3.7 Summary of the measuring periods and CO_2 exchanges for 2008-2010 at the fen site. Please note that the measuring period varies from year to year.

Year	2008	2009	2010
Measurements start	5 Jun	15 May	4 May
Measurements end	29 Oct	31 Oct	9 Oct
Start of net uptake period	–	1 Jul	29 May
End of net uptake period	16 Aug	27 Aug	18 Aug
NEE for measuring period (g C m^{-2})	–45.5	–14.0	–20.9
NEE for net uptake period (g C m^{-2})	–	–42.5	–65.4
Max. daily accumulation (g C m^{-2} d^{-1})	–2.27	–1.48	–3.14

Figure 3.11 Eddy covariance mast and automatic chambers for measurement of GHG exchange in the Kobbefjord area. Photo: Morten Rasch.



4 NUUK BASIC

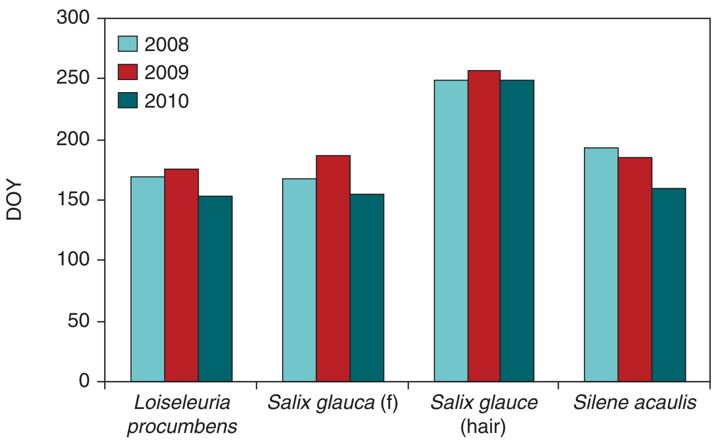
The BioBasis programme

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

This chapter presents the results of the fourth year of the BioBasis monitoring programme at Nuuk. The chapter gives an overview of the activities and presents some examples of the results. The programme aims at providing long-term data series on biotic variables from the Kobbefjord area. 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 National Environmental Research Institute, Aarhus University, in cooperation with the Greenland Institute of Natural Resources. BioBasis is funded by the 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 chapter, which do not necessarily reflect the position of the Environmental Protection Agency.

*Figure 4.1 Mean value day of year (DOY) of 50% flowers for each of the species (*Loiseleuria procumbens, Salix glauca, *and* Silene acaulis*) in the plant reproductive phenology plots for 2008, 2009 and 2010. Also included are the senescent flowers in* Salix glauca.



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. The first visit to the plots in 2010 was 28 April. Snow melt was very early and some of the plots were already free of snow. In addition, at this occasion, many of the plots were heavily impacted by larvae of the noctuid moth, *Eurois occulta*.

Loiseleuria procumbens budding and flowering in 2010 occurred earlier than seen in previous years. The time for 50% flowering occurred up to three weeks earlier than in 2009 (figure 4.1), while the time for peak flowering occurred more than one month earlier this year compared to 2009, which so far was the year with the latest flowering (figure 4.2A). The sequence of flowering by plot was the same as in previous years with plot Loi4 being the earliest followed by plot Loi1, Loi2, and Loi3.

Flowering in *Silene acaulis* peaked around 9 June (figure 4.2B), at the same time as we expect that the number of *Euroris occulta* larvae peaked. The true peak would probably have been later if the moths had not been there. The time of 50% flowering in Sil4 was approximately two weeks earlier in 2010 than in 2009 and approximately one week earlier than in 2008 (figure 4.1). This plot was the one with least signs of larvae attack at the time of flowering. We were not able to record counts of 50% flowers in plot Sil1, Sil2 and Sil3 because a high proportion of the buds were eaten just before flowering. The date of 50% flowers seems to have been between

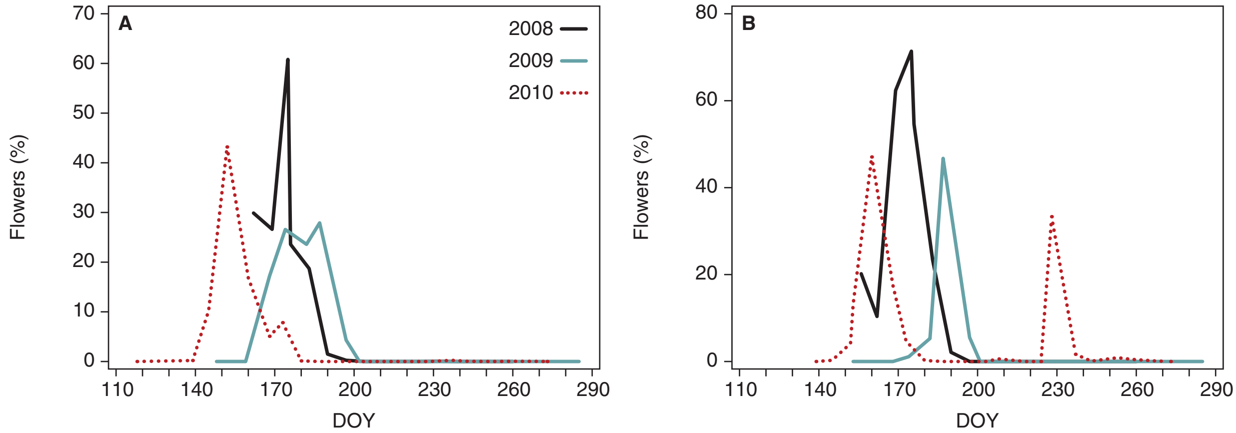


Figure 4.2 The progression in phenology shown as the percentage of flowers by day of year (DOY) in 2008, 2009 and 2010. A: Loiseleuria procumbens *B:* Silene acaulis. *Percentages have been averaged over plots.*
Erratum: Figure 4.2A in NERO 3rd Annual Report (Jensen and Rasch 2010) is not correct. Data has now been recalculated and is shown correctly in the present report.

2 June and 8 June. It seems that there was a high degree of synchrony among the plots in 2010 as was also the case in 2009. We did see new buds later in the season but only few of these reached flowering.

The phenological progression in female flowers in *Salix glauca* occurred almost three weeks earlier in 2010 than in 2009 (Sal2 and Sal3) (figure 4.3A and B), while the progression of formation of hairs was only 10 to 15 days earlier (figure 4.1). It seems that the timing of 'hairing' takes place within a relatively short period of time by the end of September, independent of the timing of flowering. In all three years, the female flowering has exhibited a similar pattern with a steep rise in flowering followed by a long period of 50 to 90 days with a constantly high proportion of flowers. In plot Sal1, we recorded almost no buds or flowers because leaves and buds were eaten by the noctuid larvae *E. occulta*. The plants suffered severely until the beginning of August when new green leaves appeared. We did not record any new buds or flowers.

Phenology of *Salix glauca* in CO_2-flux plots

In 2010, *Salix glauca* produced female flowers in only eight CO_2-flux plots. In all but one plot *Salix glauca* specimens produced less than 10 female buds. Most buds were produced in Temperature manipulated plot 3 (3T), but most flowers were produced in the Short Growing season plot 2 (2SG). In 2010, only this plot and the Long Growing season plot 2 (2LG) produced flowers with hairs indicating that most of the flowers in the other plots did not produce mature seeds, were eaten, or fell off before reaching maturity. Figure 4.4 shows an example of the phenology in a CO_2-flux plot (4C).

Total flowering

Total counts of flowers were only carried out in the *Eriophorum angustifolium* plots, and in *Loiseleuria* plot number 4. Due to the larvae outbreak of *Eurois occulta* most of the buds and flowers in the remaining plots were eaten before total counts could be made.

The flowering of *Eriophorum* was at the same level as during the two previous years. However, plot 4 had much more

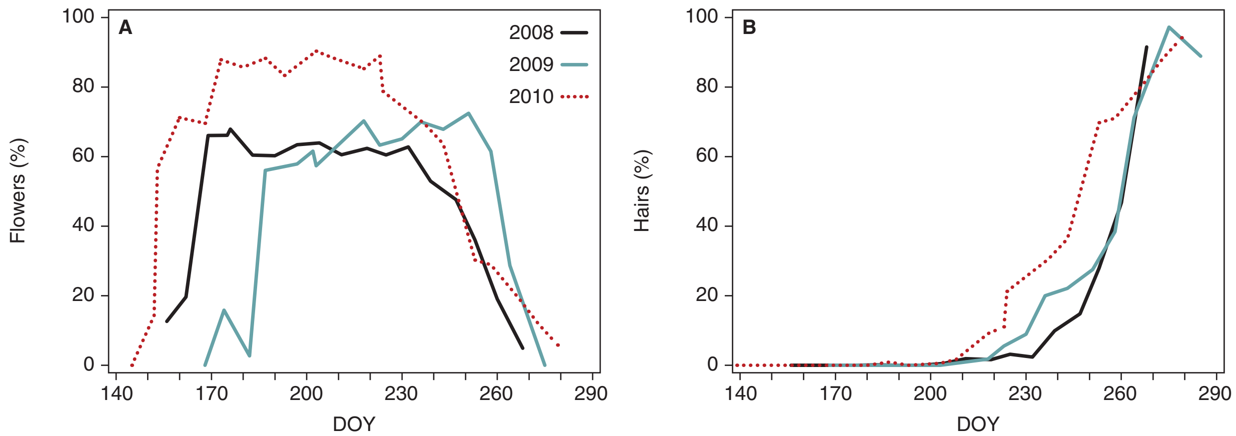


Figure 4.3 Salix glauca *flowers (A) and senescent flowers (B) in 2008, 2009 and 2010 averaged over all plots.*

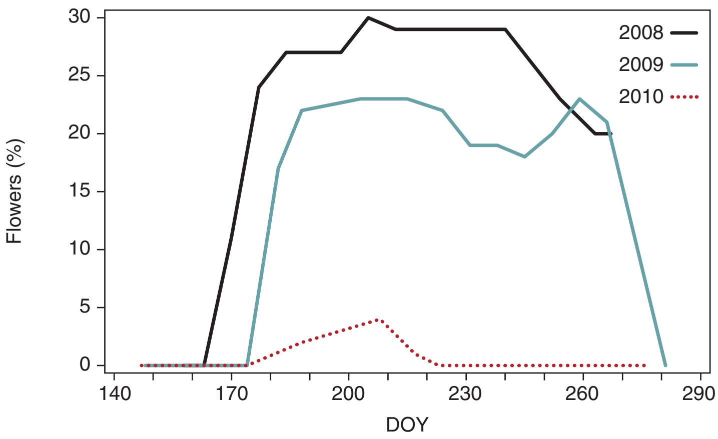


Figure 4.4 Salix glauca *flowers in the CO_2-flux control plot 4C in 2008, 2009 and 2010.*

flowers than the other plots. *Loiseleuria* plot 4 had less than a fourth of the number of flowers counted in 2009, probably due to the larval outbreak.

Summing up reproductive plant phenology

The year 2010 had a very early melt-off of snow. A preliminary review of data related to flowering and plant reproductive phenology indicate that 2010 was characterised by:

- Early flowering
- Two budding events in *Loiseleuria procumbens* and *Silene acaulis*
- A high impact of noctuid moth, *Eurois occulta*
- Low seed production compared to the two previous years as a consequence of many buds and flowers being eaten by the noctuid moth, *Eurois occulta* larvae.

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).

NDVI in *Empetrum nigrum* and plant phenology plots

As in the two previous years, vegetation greening followed three different patterns depending on the species monitored. The evergreen *E. nigrum* (figure 4.5A) has no clear peak time of greenness. Plot 4, however, had a weak indication of a peak in all three years; this may be because of the presence of *Salix glauca* and *Vaccinium uliginosum* in this plot. *Eriophorum angustifolium* (figure 4.5B) and *Salix glauca* (figure

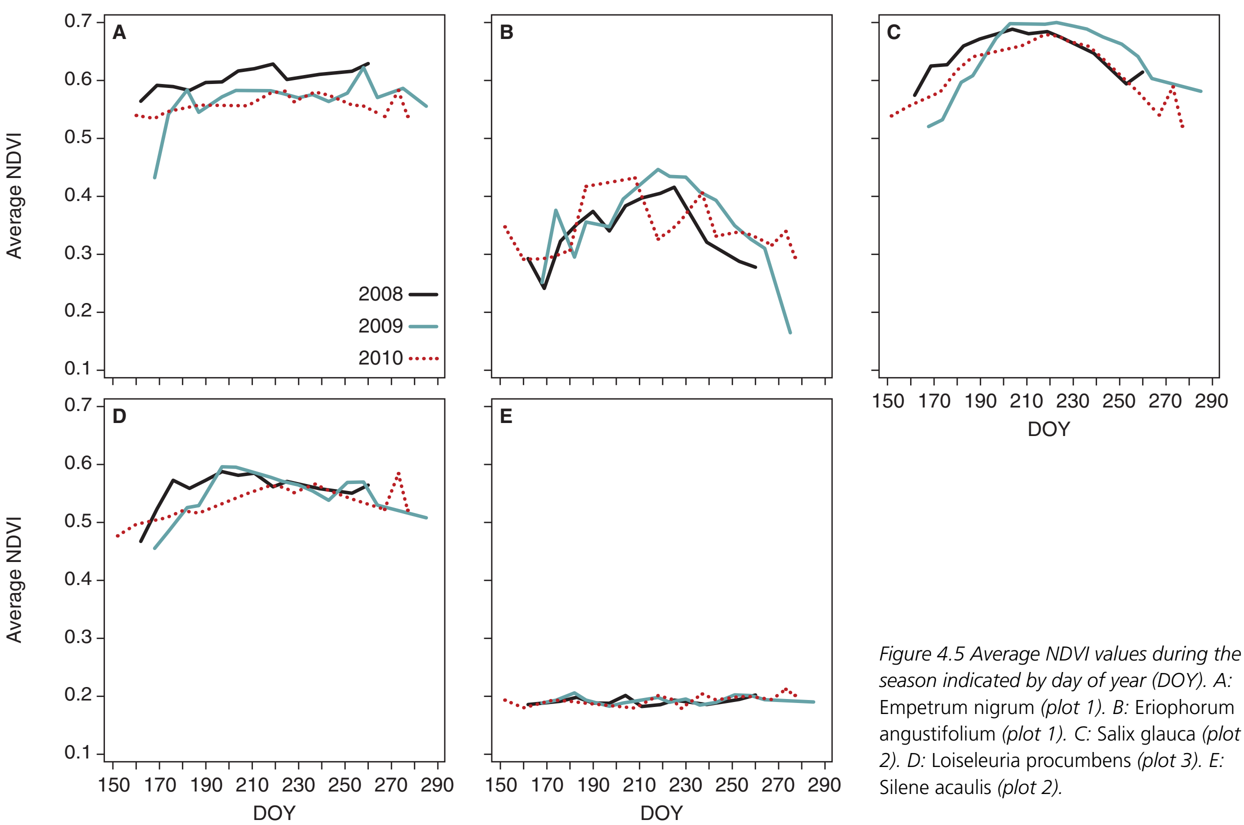


Figure 4.5 Average NDVI values during the season indicated by day of year (DOY). A: Empetrum nigrum *(plot 1). B:* Eriophorum angustifolium *(plot 1). C:* Salix glauca *(plot 2). D:* Loiseleuria procumbens *(plot 3). E:* Silene acaulis *(plot 2).*

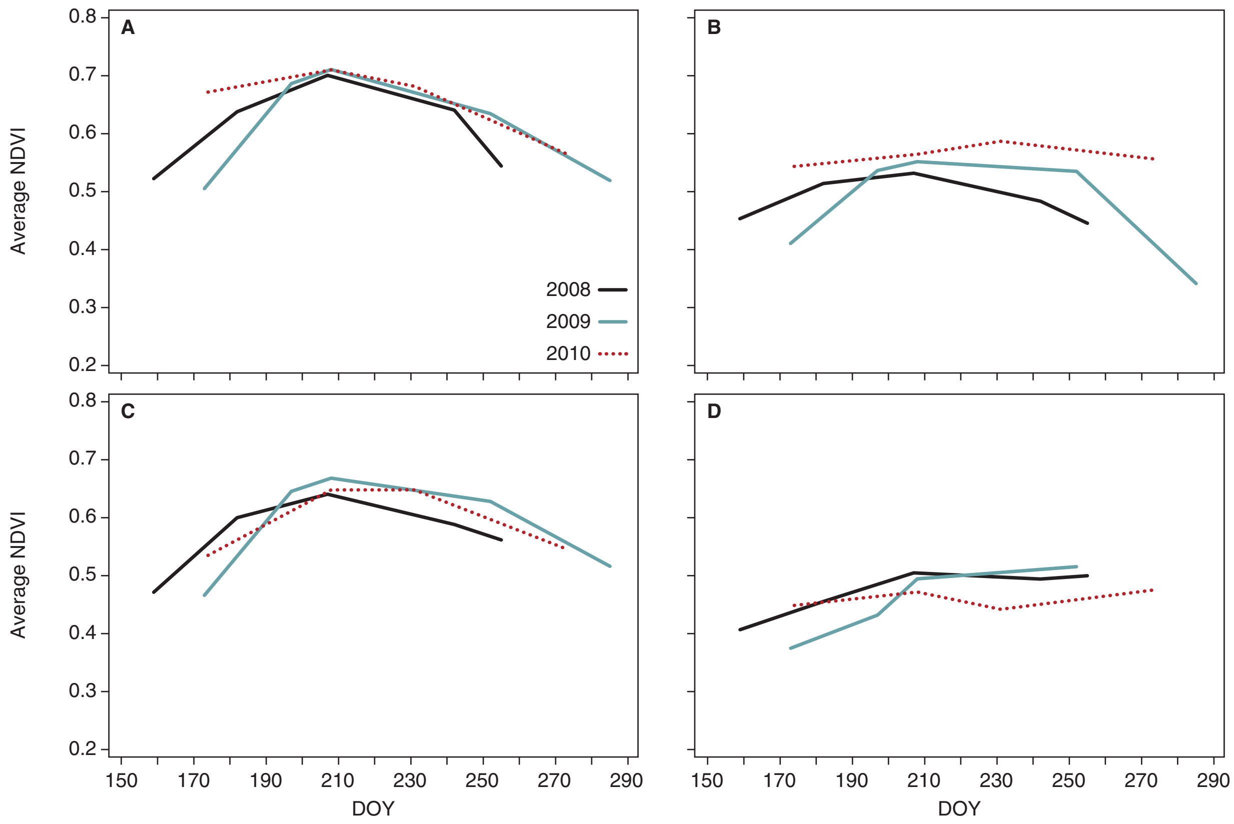


Figure 4.6 NDVI measurements along the NERO line represented for four vegetation types in 2008, 2009 and 2010. A: Copse. B: Fen. C: Dwarf shrub heath. D: Snow patch vegetation. For location of the different vegetation types please see Jensen and Rasch 2010.

4.5C) exhibited more or less bell-shaped greening curves, except for plot Sal1, which to some degree fluctuated, probably because of the loss of leaves due to the *E. occulta* larvae. *Loiseleuria procumbens* plots have sparse vegetation, and greening only showed weak time dependence (figure 4.5D). One plot had a weak bell shaped curvature (Loi3). *Silene acaulis* plots gave the lowest NDVI-values through all seasons independent of day of year (figure 4.5E).

NDVI along the NERO line

The NERO line (Bay et al. 2008) 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 shows 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 similar or slightly later greening in 2010 compared to 2008 and 2009.

Summing up – vegetation greening

After only three 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 midsummer (20 July-5 August) followed by a gradual decrease in greenness until the frost sets in during autumn. There are exceptions to this pattern:

- In snow patches greening increases through the complete growing season.
- *Loiseleuria procumbens*, *Silene acaulis*, and *Empetrum nigrum* plots have more or less constant greenness through the whole snow free season.

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

Carbon dioxide exchange

In 2008, a manipulation experiment was initiated with five different treatments, each with six replicates. The experiment is located

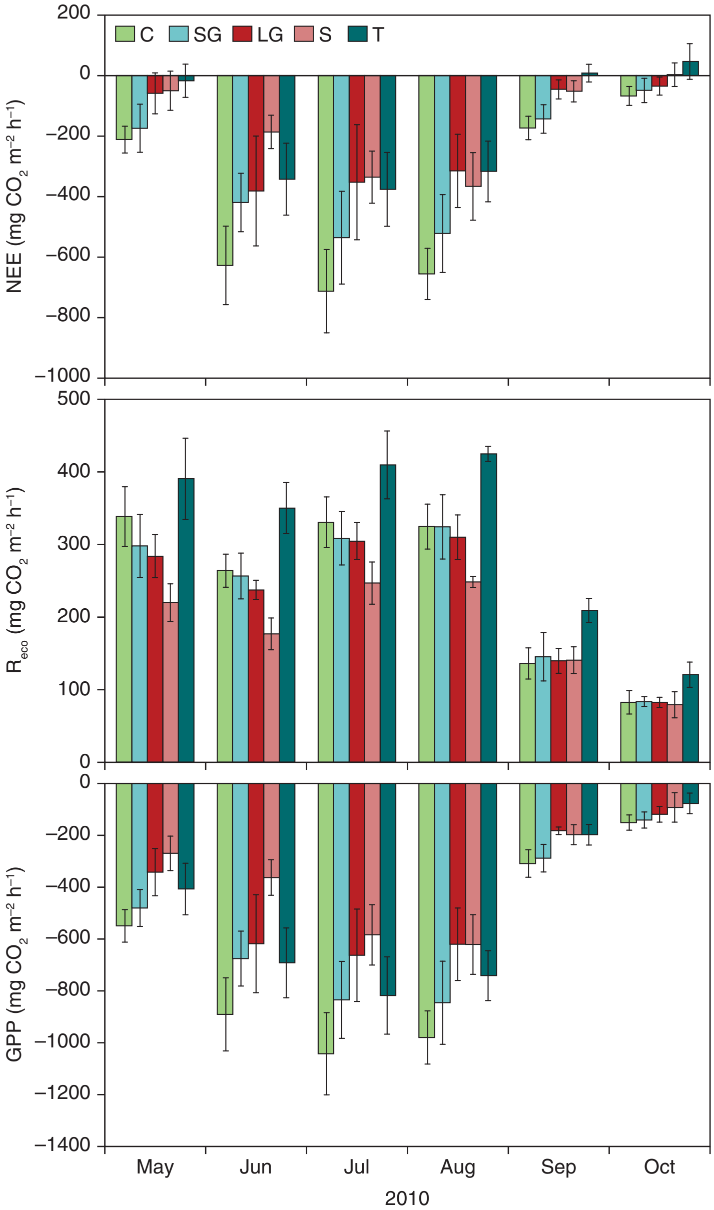


Figure 4.7 Monthly means of net ecosystem exchange (NEE: upper panel), ecosystem respiration (R_{eco}: middle panel) and gross primary production (GPP: lower panel) in 2008, 2009 and 2010 in the manipulation experiment plots. Error bars refer to standard error in spatial variability (six replicates). Negative fluxes indicate CO_2 uptake by the ecosystem, while positive fluxes indicate CO_2 release to the atmosphere.

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 have conducted measurements of land-atmosphere exchange of CO_2 using the closed chamber technique, soil temperature, soil moisture and phenology of *Salix glauca* approximately weekly during June-October in each year. The net ecosystem exchange (NEE) was measured with a transparent chamber while the ecosystem respiration (R_{eco}) was measured with a darkened chamber. The SG and LG treatments have not been applied in 2008-2010, so results from these plots can be considered as controls.

The first CO_2 flux measurement day in 2010 was 25 May (the area was snow free early this year). Until the last measurement day (11 October), CO_2 fluxes were measured in all plots on 18 occasions. All plots generally functioned as sinks for atmospheric CO_2 at the time of measurements, as NEE was generally negative (figure 4.7). In May, September and October, NEE fluxes were close to zero. Similar to both 2008 and 2009, the net CO_2 uptake was generally higher in C plots compared with T and S plots. The ecosystem respiration showed a constant pattern of higher emissions in T plots compared with other treatments, which can be explained by warmer and drier conditions leading to increased respiration rates. The highest rates of gross primary production (GPP: difference between NEE and R_{eco}) were generally observed in C plots, while especially S plots showed lower GPP rates compared with other treatments. As photosynthesis is driven by solar radiation, shading decreases GPP and build-up of biomass.

These results are in general similar to those obtained in 2008 and 2009.

UV-B exclusion plots

Measurements of chlorophyll fluorescence as a measure of plant stress were carried out in Kobbefjord in 2010. The impact of ambient UV-B radiation on the vegetation is studied in a mesic dwarf shrub heath dominated by *Empetrum nigrum* and with *Betula nana* and *Vaccinium uliginosum* as subdominant species. The experimental UV-B set-up reduces the UV-B influx by approximately 60 % (Mylar film) and this is compared to a control film (Teflon), which is UV-B and PAR neutral, and an open control. The exclusion plots were set up by the end of May, and besides periods with spells of strong winds the treatments were maintained until the mid to end of August.

The ambient UV-B radiation on fluorescence parameters were monitored on *Vaccinium* and *Betula*. The total performance index (PI_{total}, integrating responses of antenna, reaction centre, electron transport and end acceptor dependent parameters) meaning an indicator of a samples viability, were sensitive to UV-B exclusion in both *Betula* and *Vaccinium*. The average PI_{total} was improved by around 8 % in *Vaccinium* and around 14 % in *Betula* when reduced UV-B was compared to near ambient UV-B (table 4.1). The PI_{total} was significantly decreased 27 July but not 6 August in *Betula* (figure 4.8). In *Vaccinium* the PI_{total} were improved 27 July, but not 29 July and 6 August when UV-B was reduced compared to near ambient UV-B (figure 4.8).

Permanent lichen plots

At the end of June 2010, 13 permanent lichen monitoring plots were established in Kobbefjord by Eric Steen Hansen, Natural History Museum of Denmark, University of Copenhagen. The aim of the study was to establish permanent plots for long-term monitoring of lichen communities. The monitoring plots were established in close connection to the NERO Line. Each plot consists of 10 replicate plots perpendicular to the NERO Line 2 m apart. Each replicate was analysed with Raunkjær vegetation analyses. Additionally 22 permanent lichen plots were established, 12 epilithic lichens and 10 epigaeic lichens, in order to follow the increase or decrease of growth in these specific lichens. The total number of lichens species recorded is 114, which is less than the 160 species recorded for the surroundings of Nuuk. One reason may be that the comparatively short time spent in the area did not allow for all interesting lichen sites to be thoroughly investigated.

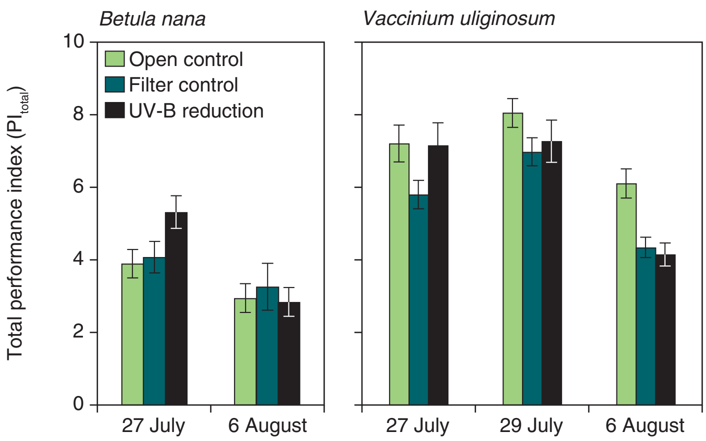


Figure 4.8 Seasonal variations in total performance index for Betula nana *and* Vaccinium uliginosum. *The values are mean ± standard error for Open control (no filter) Filter control (transparent filter, Teflon) and UV-reduction (UV-B absorbing filter, (Mylar).* B. nana *was measured only twice while* V. uliginosum *was measured three times.*

Permanent bryophyte plots

At the end of August 2010 seven permanent bryophyte monitoring plots were established in Kobbefjord by Kristian Hassel and Tommy Prestø, Norwegian University of Science and Technology, Museum of Natural History and Archaeology, Trondheim, Norway. The aim of the study was to establish permanent plots for long term monitoring of bryophyte communities. The monitoring plots were established 3-5 m northeast of the NERO Line. Each plot consists of five replicates plots 5 m apart along a straight line parallel to the NERO Line. Each of the replicate

Table 4.1 The chlorophyll fluorescence parameters were analyzed with the OJIP test approach (Strasser et al. 2004). The parameters: The ratio of PSII reaction centre's (RC) and absorbance flux, [RC/ABS]. The maximum quantum yield, [$\phi Po = FV/FM$)] which corresponds to the efficiency an absorbed photon will be trapped by PSII RC leading to QA reduction. The fraction of electrons transported beyond QA-per exiton trapped by the open reaction PSII RC, [$\psi Eo = ETo/TRo$]. The efficiency with which an electron can move from the reduced intersystem electron acceptors to the PSI end acceptors, [$\delta Ro = REo/ETo$]. The performance index [$PIabs = (RC/ABS) \times [\phi Po/(1-\phi Po)] \times [\psi Eo/(1-\psi Eo)] \times [\delta Ro/(1-\delta Ro)]$]. The total performance index integrating the responses of antenna, reaction centre, electron transport and end acceptor dependent parameters [$PI_{total} = (RC/ABS) \times [\phi Po/(1-\phi Po)] \times [\psi Eo/(1-\psi Eo)] \times [\delta Ro/(1-\delta Ro)]$]. The presented values are the seasonal mean ± standard error for open control (No filter), Filter Control (near ambient UV-B, Transparent filter, Teflon), UV-B reduction (UV-B absorbing filter, Mylar). Analysis of variance included effects of block, campaign (C), treatment (T) and the interaction CxT and the P-values for treatment are given. Tukey test different letters indicate differences between means tested with the test, ($p < 0.05$).

2010	Parameter	C	F	B	P-value
Betula nana	F_V/F_M	0.77±0.007^{B}	0.768±0.007^{B}	0.79±0.006^{A}	0.008
	RC/ABS	0.589±0.011^{AB}	0.571±0.013^{B}	0.62±0.017^{A}	0.0127
	ET_0/TR_0	0.512±0.011^{A}	0.472±0.012^{B}	0.52±0.013^{A}	0.0014
	RE_0/ET_0	0.583±0.008^{A}	0.617±0.014^{A}	0.58±0.014^{A}	0.0395
	PI_{abs}	2.47±0.21^{B}	2.08±0.15^{B}	3.04±0.27^{A}	0.0003
	PI_{total}	3.42±0.28^{B}	3.61±0.29^{AB}	4.2±0.35^{A}	0.0747
Vaccinium uliginosum	F_V/F_M	0.82±0.004^{A}	0.815±0.004^{A}	0.817±0.003^{A}	0.5494
	RC/ABS	0.617±0.008^{A}	0.581±0.007^{B}	0.607±0.008^{A}	0.0002
	ET_0/TR_0	0.673±0.004^{A}	0.642±0.006^{B}	0.652±0.006^{B}	0.0001
	RE_0/ET_0	0.53±0.005^{A}	0.531±0.004^{A}	0.522±0.005^{A}	0.0012
	PI_{abs}	6.17±0.21^{A}	4.96±0.18^{C}	5.49±0.23^{B}	0.0001
	PI_{total}	7.06±0.27^{A}	5.7±0.24^{B}	6.18±0.34^{B}	0.0001

plots were pin point analysed using a frame of 70 cm × 70 cm with 100 pins. Each species hit by the pin through the vegetation layer were monitored. Lichens were recorded as a functional group as were graminoids, herbs, woody plants, detritus and club mosses. Additionally, a free search within the plots as well as between the plots, were undertaken to register presence of additional species, as the pin point method tends to miss rare species.

The collection is currently being examined, but so far, 215 taxa of bryophytes have been identified.

Permanent basidiomycetes plots

In mid-August 2009, twenty-four permanent basidiomycetes monitoring plots were established in Kobbefjord by Thorbjørn Borgen, Botanical Museum, University of Copenhagen, Denmark. The aim of the study was to establish permanent plots for long-term monitoring of basidiomycetes communities. The monitoring plots were established next to and parallel with the NERO Line. Each plot consists of a square measuring between 3 m² and 10 m². Each plot was intensively surveyed for fungi. The collection is currently being examined but so far 78 species of basidiomycetes have been identified. As the season of 2009 was very dry and hence not optimal for fungi growth, the potential number of common taxa is expected to be higher. About 40 additional taxa are occurring in neighbouring areas (Nuuk, Paamiut, Sisimiut).

4.2 Arthropods

In Kobbefjord, all four pitfall trap stations established in 2007 and two window trap stations (each with two trap) established in 2010 were open during the 2010 season. Sampling procedures follows the manual 'Conceptual design and sampling procedures of the biological programme of Nuuk Basic' (Aastrup et al. 2009). Part of the samples are being sorted by Department of Terrestrial Ecology, National Environmental Research Institute, Aarhus University, Denmark. The material is stored in 70 % ethanol at Aarhus University.

Window traps

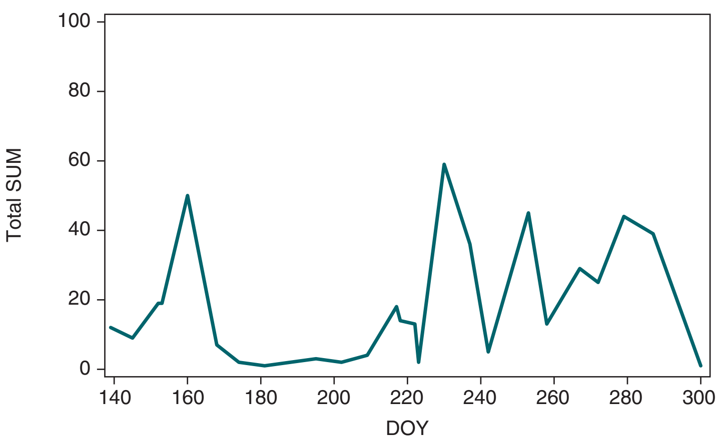
This was our first season with window traps. We established two traps each with two trapping chambers at two different locations: At Art2 named Wart1 and Wart2 on 12 May, and at Art3 named Wart3 and WArt4 on 14 May. They worked continuously until the end of the season (beginning of October).

Pitfall traps

All pitfall traps were established on 12 or 14 May. They all worked continuously until the end of October when their liquid began to freeze.

This year we had an outbreak of insect larvae and especially of larvae of *Euroris occulta*. The largest number of larvae was present in the beginning of June (figure 4.9). Later in the season (at the end of August) we saw two other peaks of larvae other than *E. occulta*. The samples have not all been sorted yet, but the work is ongoing at Aarhus University. The outbreaks of larvae have been known to occur every now and then. In 2010, it was reported from several places along the west coast of Greenland, more pronounced in the inland areas than in the coastal areas.

Figure 4.9 Total number of larvae in the arthropod samples through the season 2010.



Microarthropods

The three samplings for microarthropods in Kobbefjord took place in the beginning of June, August and September, respectively. Each sampling consists of two sampling occasions one week apart. The soil cores are extracted at Greenland Institute of Natural Resources immediately after sampling, and the extracted microarthropods are stored in 70 % ethanol. After the last sampling, the specimens are shipped to Aarhus University.

The population data structure as revealed by principal component analysis (PCA) of the correlation matrix of log(x+1) transformed population abundances is shown in figure 4.10.

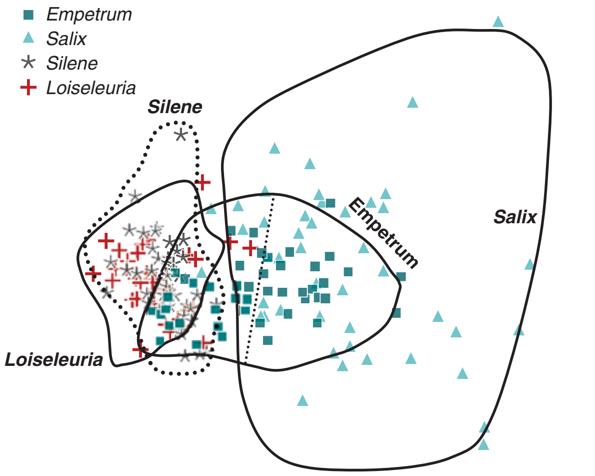


Figure 4.10 PCA plot of the correlation matrix of log-transformed microarthropod community samples. Each soil core sample is represented by a symbol. Lines are drawn around clusters comprising the microarthropod samples within the plant communities. The broken line through the Empetrum *cluster divides the cluster into the two sampling plots that were both assigned to the* Empetrum *plant habitat type.*

Table 4.2 Mean abundances (× 1000 individuals m^{-2}) of mites, at order level, and collembolans, at species level. Microarthropods are the sum of mites and collembolans. Shaded areas: habitat characterising key species S: Collembolan species richness; H' = −∑ pi $\log_2$ pi, where pi is the proportion of species in the sample to total collembolans; E: H/$\log_2$ n, where n is number of collembolan species.

	Salix	*Empetrum*	*Silene*	*Loiseleuria*
S, species richness	19	12	9	11
H', diversity index	2.8	2.7	1.2	2.1
E, evenness	0.7	0.7	0.4	0.6
Microarthropods	108	114	127	152
Acari	80.3	89	115	137
Collembola	27.8	24.8	11.8	15.1
Tullbergiinae[1]	6.2	2.6	8.5	4.7
Tetracanthella arctica	1.5	6.2	0.2	4.9
Willemia sp.[2]	4.6	1.3	2.3	3.7
Isotomiella minor	7.4	2.3	0.1	0.07
Folsomia quadrioculata	2.2	6		0.6
Folsomia sensibilis[3]	1	4.6	0.1	0.1
Desoria olivacea	2.3	0.8		
Micranurida pygmaea	0.02	0.6	0.4	0.9
Juvenile *H. claviger*	0.6	0.2	0.1	
Parisotoma notabilis	0.46	0.02		
Desoria tolya	0.36		0.01	
Onychiurinae[4]	0.18	0.01		
Lepidocyrtus violaceus	0.04			0.12
Lepidocyrtus cyaneus	0.01		0.04	
Juvenile *Isotomidae*[5]	0.03	0.01		
Arrhopalites principalis	0.03			
Sminthuridae[6]	0.025			
Isotoma anglicana	0.017			
Fimetaria coeruleogrisea				0.01
Pseudanurophorus binoculatus				0.01
Megalothorax minimus	0.01			
Actinedida	40.4	41.2	67.5	74.7
Oribatida	33.9	45.5	46.9	59.9
Gamasida	3.9	2.1	0.2	1.1
Acaridida	0.03	0.09		0.02

[1]Include *Mesaphorura tenuisensillata, M. jirii, M. macrochaeta, Karlstejnia norvegica*
[2]*W. anophtalma* and *W. scandinavica*
[3]Includes other folsomids
[4]Presumably dominated by *Oligaphorura ursi* but also include other Onychiurinae
[5]*Isotoma multisetis* or *Isotoma anglicana*
[6]A. principalis juveniles, *Sminthurinus schotti* and unidentified *Sminthurides* juveniles

The first two principal components reflect the difference between the four plant communities. *Isotomiella minor*, *Folsomia quadrioculata*, *Folsomia sensibilis* and *Desoria olivacea* contributes to the first principal component (PC) axis and are common in *Salix* and *Empetrum* plots but rare in *Silene* and *Loiseleuria* plots as was also observed in 2009.

Therefore, the first PC axis is a habitat axis ordering the plant habitats from *Loiseleuria-Silene*, *Empetrum* Mart2, *Empetrum* Mart1, over *Salix* MArt3 to *Salix* MArt4. The *Empetrum* MArt2 plot has much more *Tetracanthella arctica* than MArt1 plot.

The second PC axis divides the *Salix* and *Empetrum* plots according to the dominant euedaphic Tullbergiinae and *Willemia* sp., which contributed to this axis. Hence, *Salix* MArt3 plot has more of these collembolans compared to Mart4 plot. Although it can still be questioned whether the two plots within the same habitat type are sufficiently similar to be treated together, the four habitats still fall naturally into large groups.

Phenology

The collembolan that attained the highest observed abundance, *T. arctica*, (table 4.2) had an exponential population growth during the season, which was significant in 2009 but not in 2010. In both years of sampling the abundance of *D. olivacea* increased during the first two months, while the common *F. quadrioculata* in *Empetrum* and *Salix*, MArt4 plot, did not show any phenological trends. *Folsomia sensibilis* had a mid-summer minimum in both years, which in 2009 could be explained by summer drought. However, in 2010 another mechanism must have been the cause. *I. minor* declined significantly during the season in both *Salix* and *Empetrum* plots, where it otherwise was most abundant.

Climatic trends

Hitherto 2010 was the warmest and wettest season (May-August) since the beginning of the monitoring programme in 2007. The 2009 season was the driest and coldest season. We compared the two years by running an ANOVA of log+1 transformed population numbers. For most of the species we found no dramatic changes except for *Loiseleuria* plots MArt8 and MArt7 where the Tullbergiinae and *Willemis* sp., respectively, were much lower in 2009 than in 2010. The eudaphic life-form is expected to be more vulnerable to drought, as they do not possess visible traits that protects against drought. In the *Silene* MArt6 plot and *Salix* MArt3 plot a similar phenomenon was observed for Tullbergiinae.

Future perspective

The collected microarthropod data are now of a quality that enables an identification of key community species. As the sampling has been limited to the top 5.5 cm of the soil and førne (litter) layer some euedaphic species, i.e. collembolans living in the top of the soil and true soil dwellers, may not be represented in the dataset, which then calls for an additional sampling covering the complete vertical soil profile. The *Salix* and *Empetrum* heath habitats harvest the most diverse communities and the largest biomass compared to the *Silene* and *Loiseleuria* habitats. The last two habitats have a low primary productivity and a sandy soil with a comparably low humus content, so we find small microarthropods adapted to these conditions and with a growth potential when conditions become favourable, i.e. Tullbergiinae, *Willemia* sp. and Actinedid mites. To gain further insight into the soil ecosystem processes of the Kobbefjord area we suggest characterizing the food web structure using natural abundance of stable isotopes. For future soil food web modelling the information about the role of species and functional guilds in processing soil organic matter and plant debris is crucial. By using stable isotope δ signatures of ^{13}C and ^{15}N, we can identify relationships between the composition and structure of the soil community and the ecosystem processes to which they contribute, like organic matter decomposition, the emission of CO_2, and the mineralisation of nutrients. So future ecosystem modelling would then be able to calculate the process rates as carried out by soil organisms and their role in provisioning stability of ecosystem processes. When employing δ signatures to map the trophic structures, we can detect changes in the food web structure over time as an additional indicator of ecological change. As such, trophic changes is related to the actual functioning of the organisms and they may prove to be more valuable than tracking ecosystem changes through population dynamics.

4.3 Birds

Survey for breeding passerines

The survey for breeding birds took place 1 June and 15 June following the same procedure and transects as in previous years. The transects crosses 14 waypoints, and at each waypoint five minutes is spent making observations. Birds observed within a distance of up to 300 m from the transect were mapped on field maps. Individuals of snow bunting (*Plectrophenax nivalis*) Lapland bunting (*Calcarius laponicus*) and northern wheatear (*Oenanthe oenanthe*) were sexed and singing activities recorded. Based on singing and the number of males, the numbers of territories of snow bunting and Lapland bunting were estimated (table 4.3). Redpolls (*Carduelis flammea*) were not sexed.

The most common species were snow bunting and Lapland bunting with approximately 45 territories all together. Several territories of northern wheatear were observed and also twice the number of redpolls compared to 2009. This indicates that the different species indeed have a slightly different timing of territorial behaviour. In 2009 there was more consistency between the two surveys compared to 2010; this may be explained by the longer period between the surveys in 2010. Although the total amount of singing males differs, the distribution between the species is approximately the same. As this

Table 4.3 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.

	2009		2010	
Date	**2 June**	**8 June**	**1 June**	**15 June**
Snow bunting ♂	29	21	15	9
Lapland bunting ♂	17	19	29	15
Wheatear ♂	1	1	8	4
Redpoll individuals	2	5	9	5

year had an early melt-off, we may have been a little late with the survey.

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 a following five minute period was used for counting the birds. In 2010 the first observation was 17 May and the last was 6 October, so this year we had the longest period of bird counting.

Lapland bunting

As in the last two years Lapland buntings were observed at most points during the entire season except in the beginning and at the end. We observed more birds in 2010 than the previous years, but we also conducted more censuses. Knowing that there were outbreaks of insect larvae (see previous section), this may have increased the survival and number of successful breeding attempts. Most of the Lapland buntings were observed in the fjord area with the highest number in the middle of the season (end of June) (figure 4.11).

Snow bunting

Snow bunting was the most numerous of all passerines with the highest numbers in the beginning and at the end of the season. Especially in mid-September we found a high number of snow bunting at the fjord and more inland.

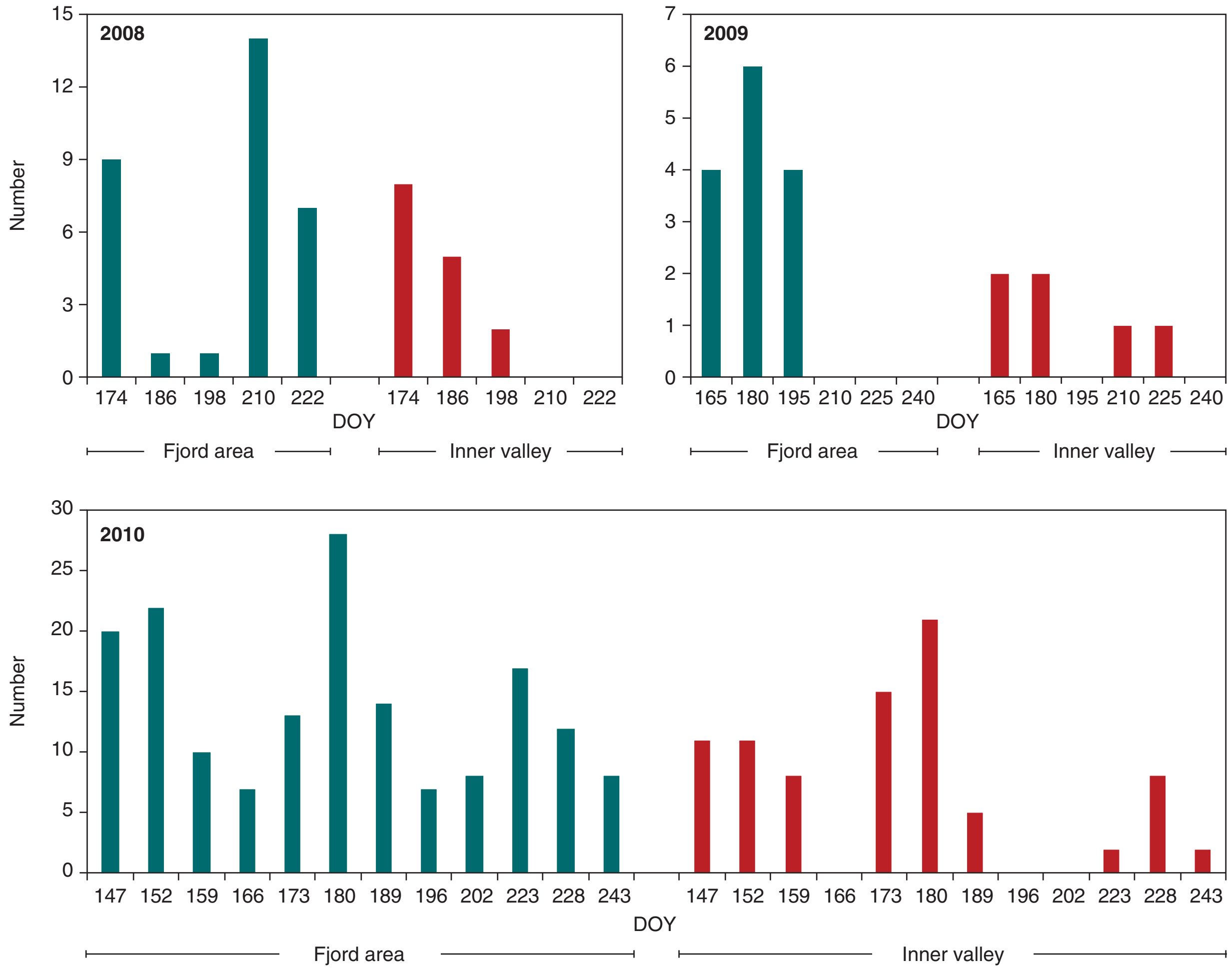
Redpoll

In contrast to previous years we saw redpolls during the entire season except from September. In addition, they were seen both in the fjord area and in the inner valley. The last observation was 4 October when one group of approximately 20 individuals were clearly on migration.

Northern wheatear

The number of northern wheatear was the highest ever recorded. We have observations from the beginning of the season until the end of August. The observations are distributed throughout the entire census area, and both males and females were observed. However, by the end of the season the number of individuals in groups tended to be higher than in the beginning of the season.

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, 2009 and 2010.



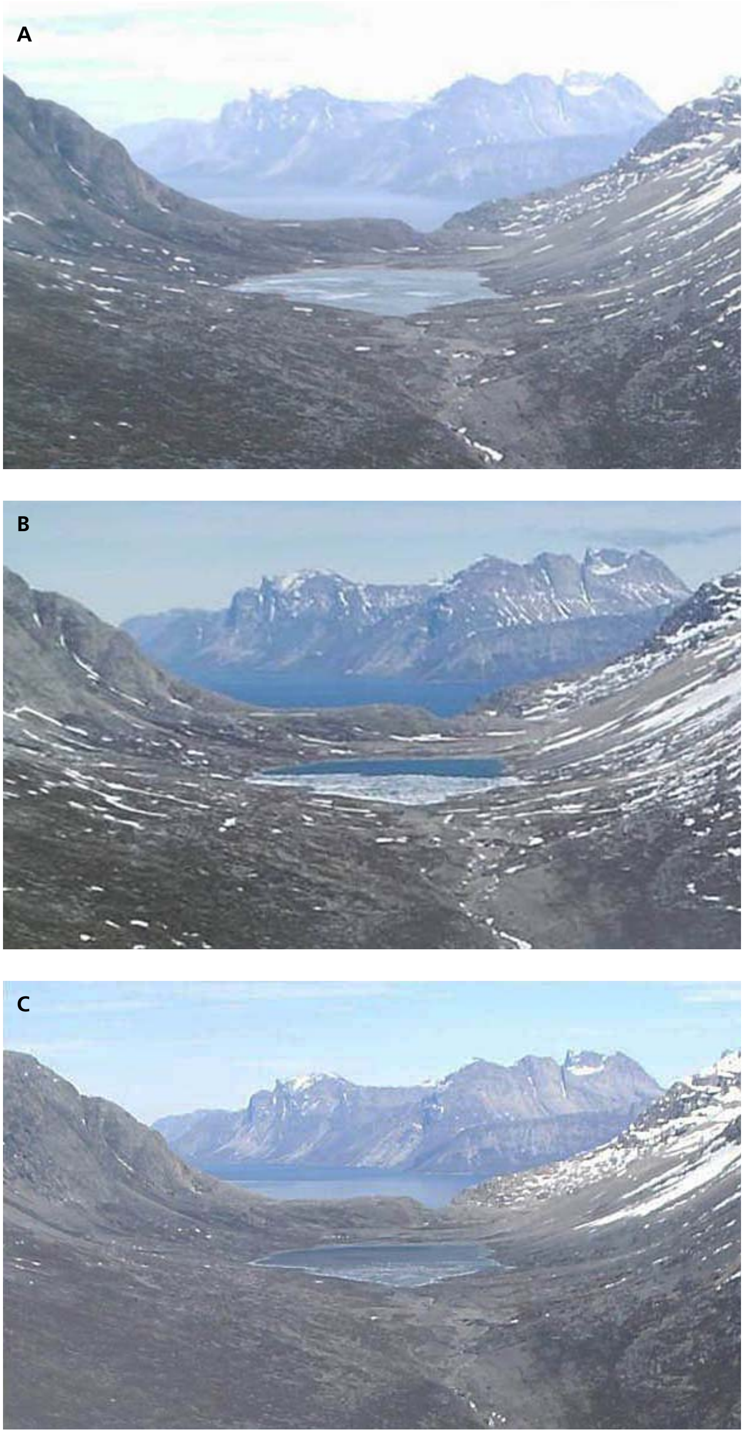


Figure 4.12 50 % ice cover in Qassi-sø 10 June 2008 (A), 22 June 2009 (B), and 24 May 2010 (C). The lake was ice free 12 June in 2008, 28 June in 2009 and 20 May 2010. Photo: GeoBasis programme.

4.4 Mammals

We did not see any mammals in the Kobbefjord area except for Arctic fox. During the late winter and early spring we heard Arctic fox barking at several visits to Badesø but otherwise they were rarely seen.

On 1 June a presumed rabies infected fox attacked and bit our boatman. The fox was shot and delivered to the authorities for examination, and it was confirmed that it was infected with rabies.

4.5 Lakes

The BioBasis programme monitors two of four lakes in the catchment area of Kobbefjord, Badesø and Qassi-sø. They are both deep lakes with a maximum depth of 33 and 26 m, respectively. Badesø is the downstream lake situated at an altitude of 50 m a.s.l. and has an area of 80 ha. Qassi-sø is situated upstream of Badesø at an altitude of approximately 250 m a.s.l. and has an area of 52 ha. Badesø contains fish (Arctic char and sticklebacks), while Qassi-sø is without fish.

A full data set from the BioBasis programme is now available for the three year period 2008-2010. Submerged macrophytes data are available from 2007-2010, and hourly/daily water temperature data from 2008 and 2010. Fish and macroinvertebrates have been sampled once, in 2008.

Temperature

The altitude difference between the two lakes causes a temperature difference, and the length of the ice free period consequently varies. In 2007, the ice free period was 35 days longer in Badesø than in Qassi-sø (Jensen and Rasch 2010). In addition, within the lake inter-annual variations occurred in the ice free/ice covered periods depending on climatic conditions. The daily overview photos of the Kobbefjord catchment area illustrate the development (figure 4.12). In 2008, Qassi-sø was 50 % ice covered and ice free 10 and 12 June, respectively. In 2009 the corresponding dates were 22 and 28 June, respectively. In 2010 the corresponding dates were 24 and 31 May, respectively. From 2008 to 2009 the ice free period has shortened with 12-16 days, while from 2009 to 2010 it was prolonged by almost one month. A similar pattern was observed in Badesø (figure 4.13).

The temperature data logged in the lakes provide similar information but also add to our knowledge on the primary production capacity in the systems. The production is not only dependent on light availability and the duration of the ice free period but is also positively correlated with temperature. When comparing water temperature data logged at 2 m depth in Badesø during the period 15 April to 14 June in 2008 and 2010, a clear difference between the years emerges (figure 4.14). In 2010, warming started earlier and the lakes were generally warmer throughout spring and early summer than in spring 2008. This led to an early ice melt (ice free 20 May), a prolonged growth season and a potentially higher primary production during the growth season, either in the water phase as phytoplankton or as epiphyton at the sediment surface in areas where light reaches the bottom.

Nutrients

Nutrient levels are generally very low in both lakes, but particularly total nitrogen (TN) is very variable, ranging from 0.04 to 0.14 mg TN l^{-1} in Badesø and from 0.03 to 0.15 mg TN l^{-1} in Qassi-sø. In addition, total phosphorous (TP) varied widely, in particular in 2008, ranging between 0.002 and 0.008 mg l^{-1} in Badesø, and 0.001 and 0.025 mg l^{-1} in Qassi-sø (figure 4.15A and B). A comparison of between-year summer concentrations shows that TN and TP were lower in 2009 compared to 2008 and 2010. Spring 2009 was cold and primary production started later, which may have influenced the TN and TP concentrations. However, only a slightly lower phytoplankton biomass was recorded in Badesø in 2009 (figure 4.19).

Chlorophyll *a* and suspended matter

Chlorophyll is correlated to nutrient levels and the chlorophyll *a* levels of the two lakes are consequently low (figure 4.16). Chlorophyll varied notably between the years of sampling, but compared to more nutrient rich lakes, the variation remains within a very narrow range due to the low nutrient levels. Over the three year period chlorophyll concentrations increased in both Badesø and Qassi-sø (figure 4.16). In correspondence with this the Secchi depth decreased, this being particularly pronounced in Badesø where the Secchi depth decreased from 8.2 m to 5.4 m (figure 4.17). In Qassi-sø we did not find the same reduction in Secchi depth, probably because Secchi depth in Qassi-sø is affected by silt rather than chlorophyll. Increasing chlorophyll levels and decreasing Secchi depth are typical signs of increasing eutrophication and are an expected outcome of temperature increase. It must be borne in mind, though, that our data concerns only a three year period and the results may therefore be coincidental. Future results will help clarify this.

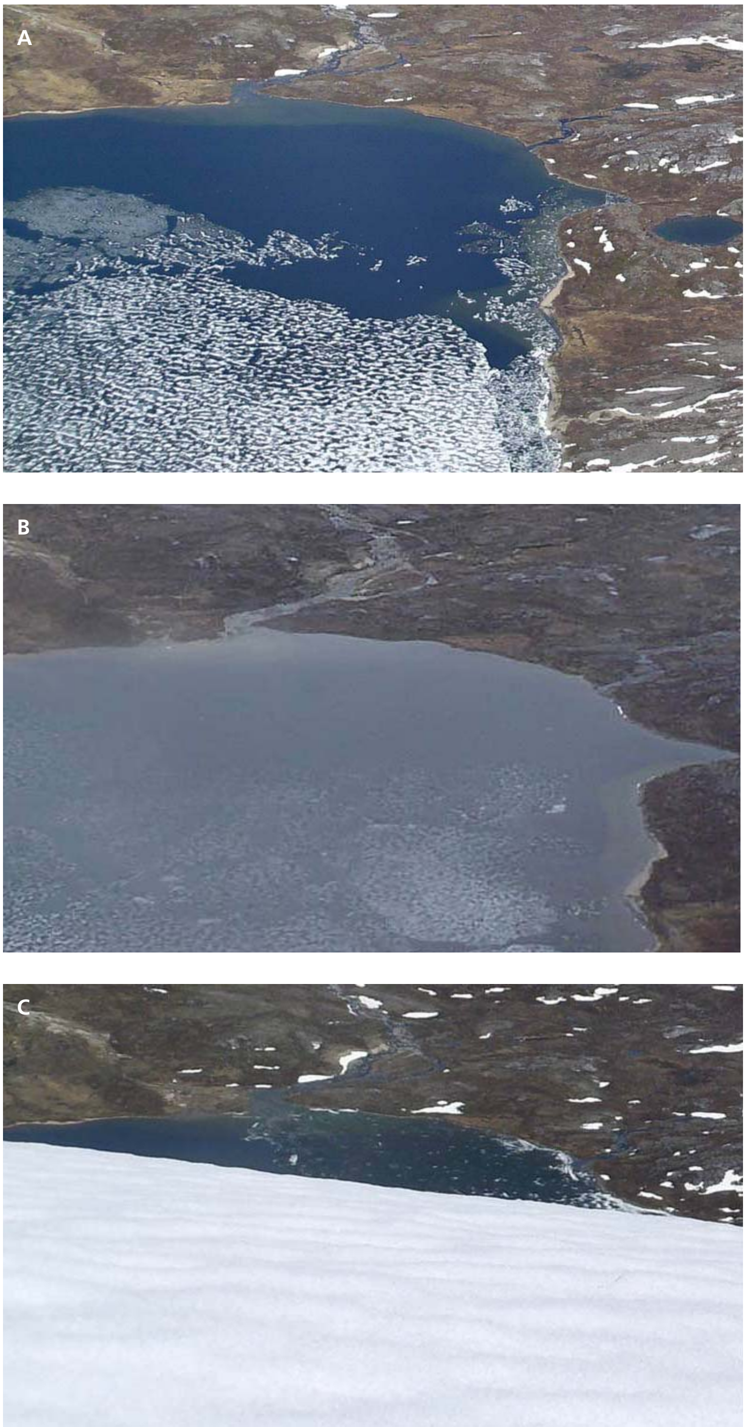
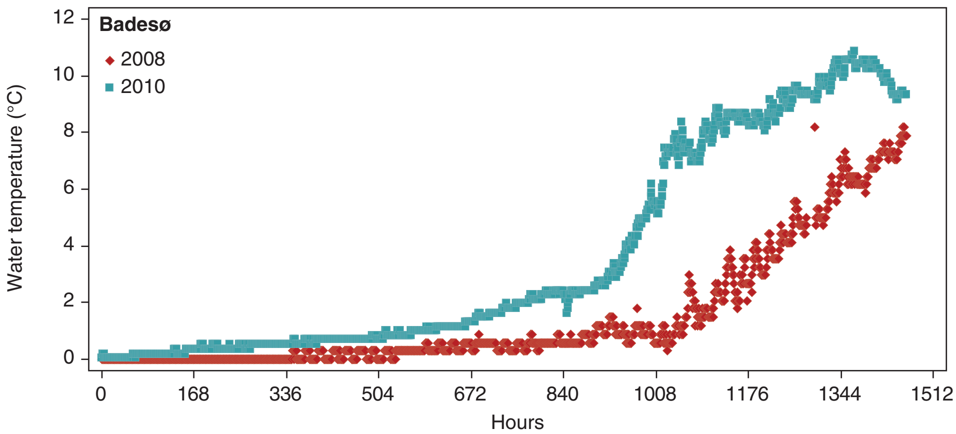


Figure 4.13 50 % ice cover in Badesø 1 June 2008 (A), 12 June 2009 (B), and 19 May 2010 (C). The lake was ice free 3 June 2008, 15 June 2009 and 20 May 2010. The snow cover was thicker in the winter 08/09 compared to 07/08 and 09/10, as illustrated by the snow fan in front of the camera in June 2009. Photo: GeoBasis programme.

Suspended matter includes organic and inorganic matter such as silt and clay derived from snow melt and eroded material during periods with high runoff due to, for instance, heavy rain. The close correlation between silt and Secchi depth was illustrated in Qassi-sø in September 2010 (figure 4.18), after several days of exceptionally heavy rain. This led to an extreme runoff and transport of silt into the lake, resulting in an very low Secchi depth of 0.5 m (figure 4.17).

Figure 4.14 Hourly water temperature measurements at 2 m depth in Badesø during spring 2008 and 2010 (from 1 am 15 April to 11 pm 14 June, both years). One week is 168 hours.



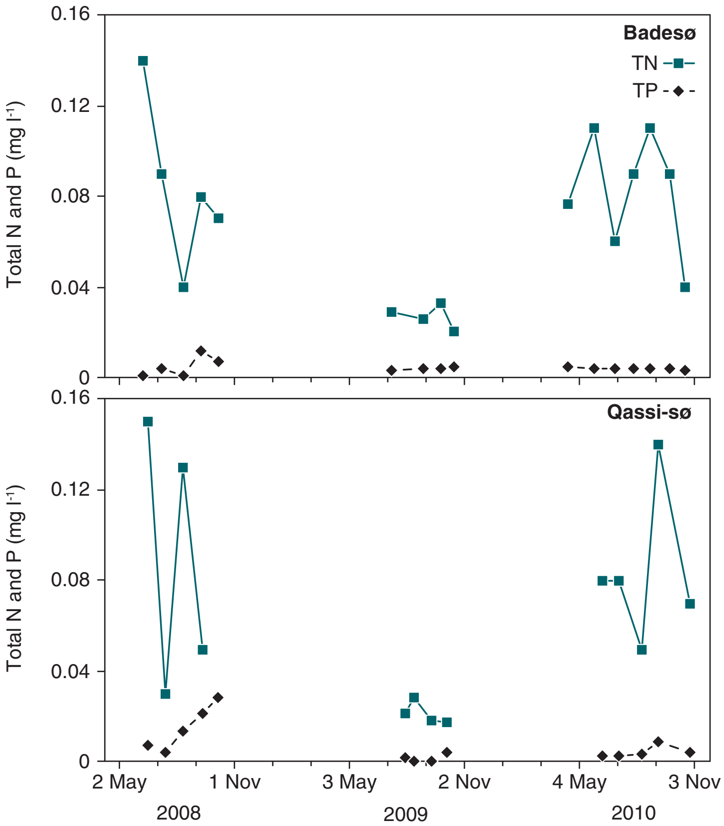


Figure 4.15 Total nitrogen (TN) and total phosphorus (TP) concentrations during summer 2008-2010 in Badesø and Qassi-sø.

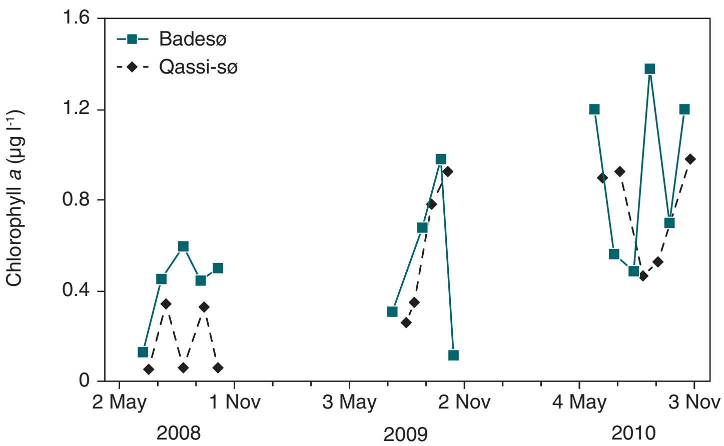


Figure 4.16 Chlorophyll a concentrations during summer 2008-2010 in Badesø (solid line) and Qassi-sø (broken line).

Phytoplankton

In both lakes the phytoplankton biomass was completely dominated by chrysophytes and dinophytes, species typical of oligotrophic systems. The chrysophytes did not dominate the entire year, but only from ice break up until mid-July, then dinophytes typically took over or constituted at least 50 % of the biomass. From late summer diatoms contributed significantly to the biomass in Qassi-sø, but chlorophytes were important too. The low nutrient levels in 2009 are not reflected in the phytoplankton biomass. A possible explanation is P-limitation, as known from marine waters. This theory is supported by the increasing phytoplankton biomass during autumns 2008 and 2009 in Qassi-sø, where the TP concentration rose as well (figure 4.19).

Phytoplankton sampling was conducted following ice break in spring. This explains the abrupt appearances in figure 4.19. However, in 2010 the first samplings in Badesø were obtained in April before ice break, showing a modest phytoplankton biomass and therefore, presumably, negligible primary production under the ice. Phytoplankton production due to light attenuation through the ice could have been hypostasised, but this is not supported by the results. On the other hand, the 2010 results from Badesø show a very fast appearance of algae following the ice break, illustrating the growth potential in spring when light conditions are optimized and nutrients have accumulated during the winter period.

Vegetation

As in previous years, the submerged macrophytes community was clearly dominated by water starwort (*Callitriche hamulata*) and secondarily by mosses (figure 4.20). In 2010, macrophyte coverage reached its highest level in Badesø compared to the previous three years, and its second highest level in Qassi-sø. In four of six 1 m depth zones of Badesø, *C. hamulata* increased in coverage. In contrast, there was a decrease in the coverage of mosses. We do not know if mosses compete with *C. hamulata*, but when *C. hamulata* expand, mosses will invariably decline. The increase in *C. hamulata* coverage can be a response to an earlier and warmer spring in 2010 compared to 2009, improving primary production conditions in 2010.

Figure 4.21 depicts the maximum depth limit of *C. hamulata* and mosses. In both lakes there were a significant increase in the depth limit during the monitoring period, but especially the mosses expanded extraordinarily fast towards deeper water. A depth expansion is very positive in eutrophic waters; whether a depth expansion is positive or negative in oligotrophic, clear and cold water lakes is more uncertain, however, the expansion may be due to a prolonged temperature dependent growing season. If so, the expansion is induced by climatic changes and thus negative.

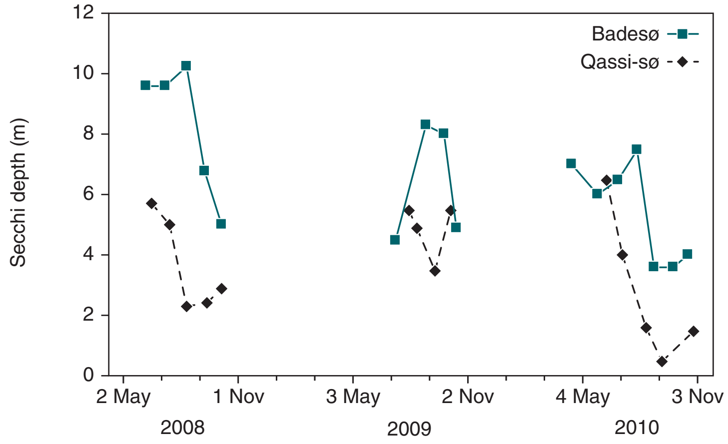


Figure 4.17 Secchi depths during summer 2008-2010 in Badesø (solid line) and Qassi-sø (broken line).

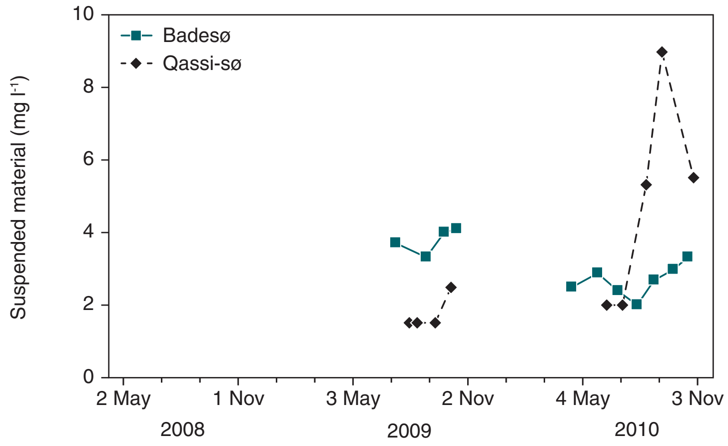


Figure 4.18 Suspended matter during summer 2009-2010 in Badesø (solid line) and Qassi-sø (broken line). No data from 2008.

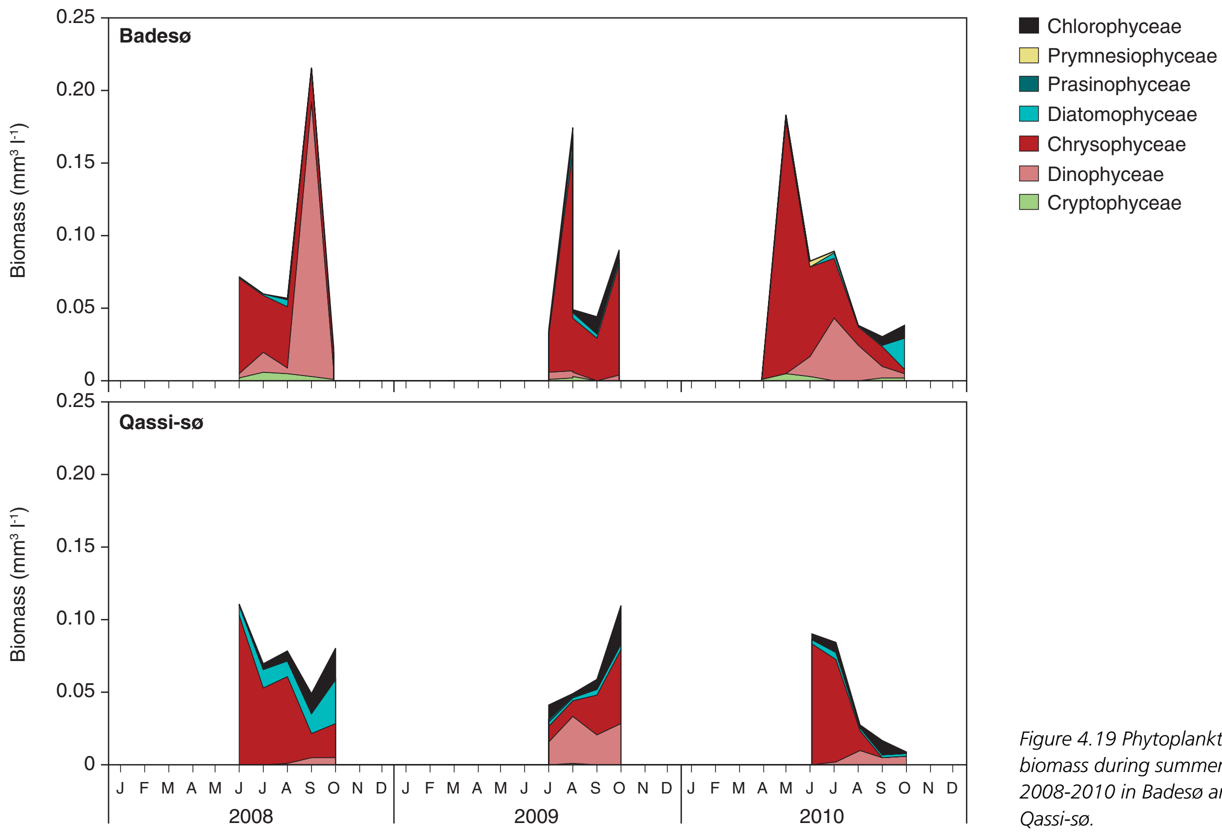


Figure 4.19 Phytoplankton biomass during summers 2008-2010 in Badesø and Qassi-sø.

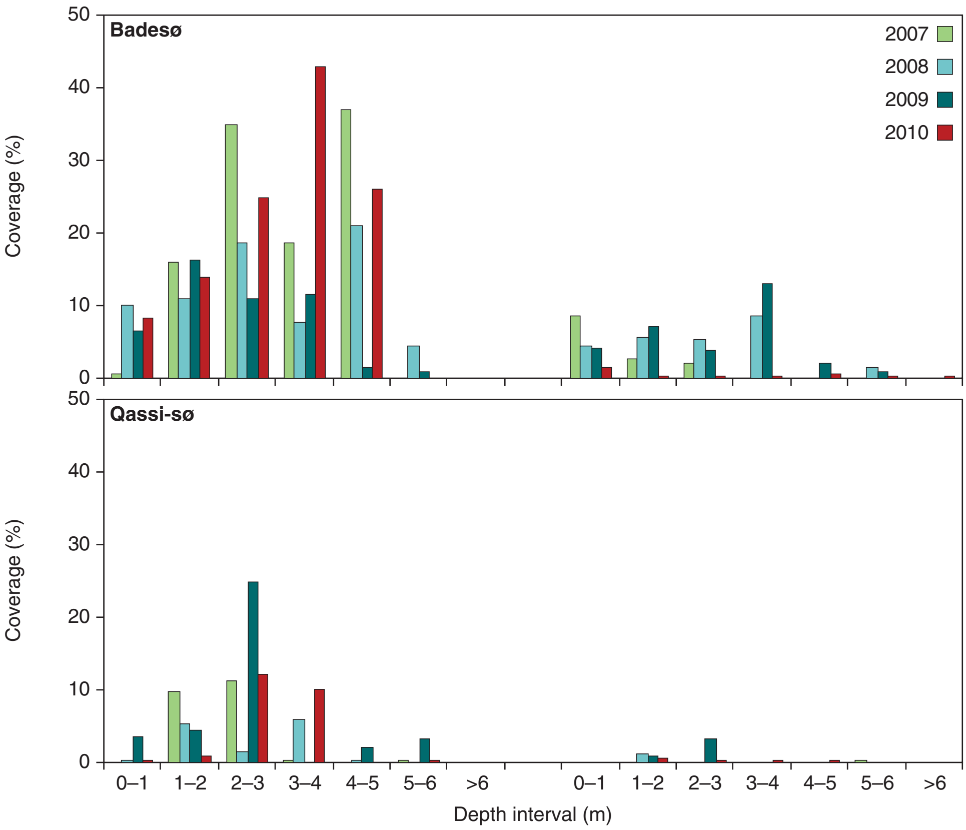


*Figure 4.20 Macrophyte coverage at 1 m depth intervals down to 6 m from 2007-2010 in Badesø and Qassi-sø. Water starwort (*Callitriche hamulata*) is shown to the left and mosses to the right. Macrophyte coverage is measured once every year in August.*

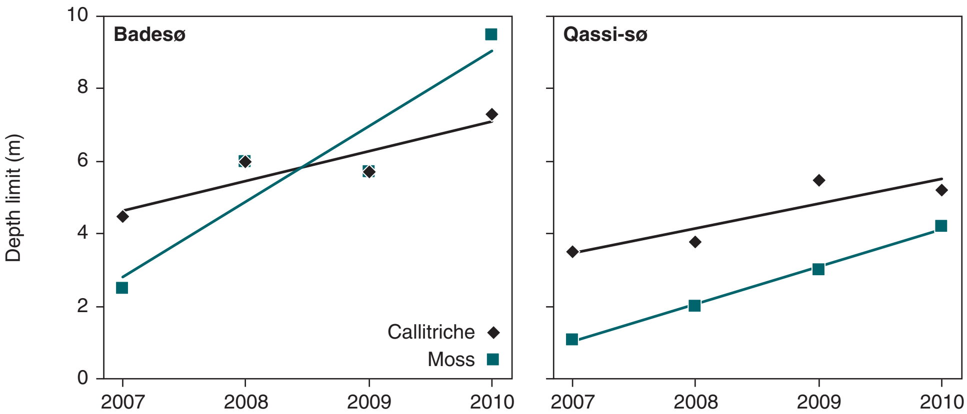


Figure 4.21 Maximum macrophyte depth limits in Badesø and Qassi-sø from 2007-2010. Linear regression lines are shown.

In view of the reduced Secchi depth during the monitoring period, a reduced macrophytes depth limit would have been expected. However, the depth limit has not reached the potential maximum depth limit at the given Secchi depth yet (maximum depth limit = 0.07 + 1.83 × Secchi Depth, see Jensen et al. 1996). Consequently, it can be concluded that factors other than Secchi depth control the depth limit in these clear water lakes.

5 NUUK BASIC

The MarineBasis programme

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The following chapter presents results from 2010, the fifth year of the MarineBasis monitoring programme in Godthåbsfjord. The programme aims at establishing long-time series of key parameters within physical, chemical and biological oceanography, along with organisms on higher trophic levels. In order to get a better understanding of the marine ecosystems in arctic regions, particularly on seasonal and inter-annual variability, demands consistent time series. Long-time series are even more important for improving the ability to separate out natural variability in order to detect possible effects of climatic changes. Monthly pelagic sampling is carried out at a 'Main Station' (64°07'N, 51°53'W) near the entrance to the Godthåbsfjord system. In addition, an annual length section is carried out from Fyllas Banke to the inner part of the fjord along with an annual cross section of the fjord, both during May (figure 5.1). The programme also includes benthic sampling four times per year at a 'Sediment Station' in Kobbefjord. The annual monitoring efforts also comprise a sub-programme on benthic flora and fauna as well as observations on seabirds and whales. Finally, sea ice conditions within the fjord system and Baffin Bay are monitored using satellite imagery and digital camera systems (Godthåbsfjord only). Methods are briefly described throughout the chapter. For more details please consult the MarineBasis Nuuk Manual (www.nuuk-basic.dk).

5.1 Sea ice

Sea ice conditions in Baffin Bay are monitored daily using AMSR-E satellite images (3-6 km resolution, figure 5.2). Similar to previous years, sea ice covered much of the

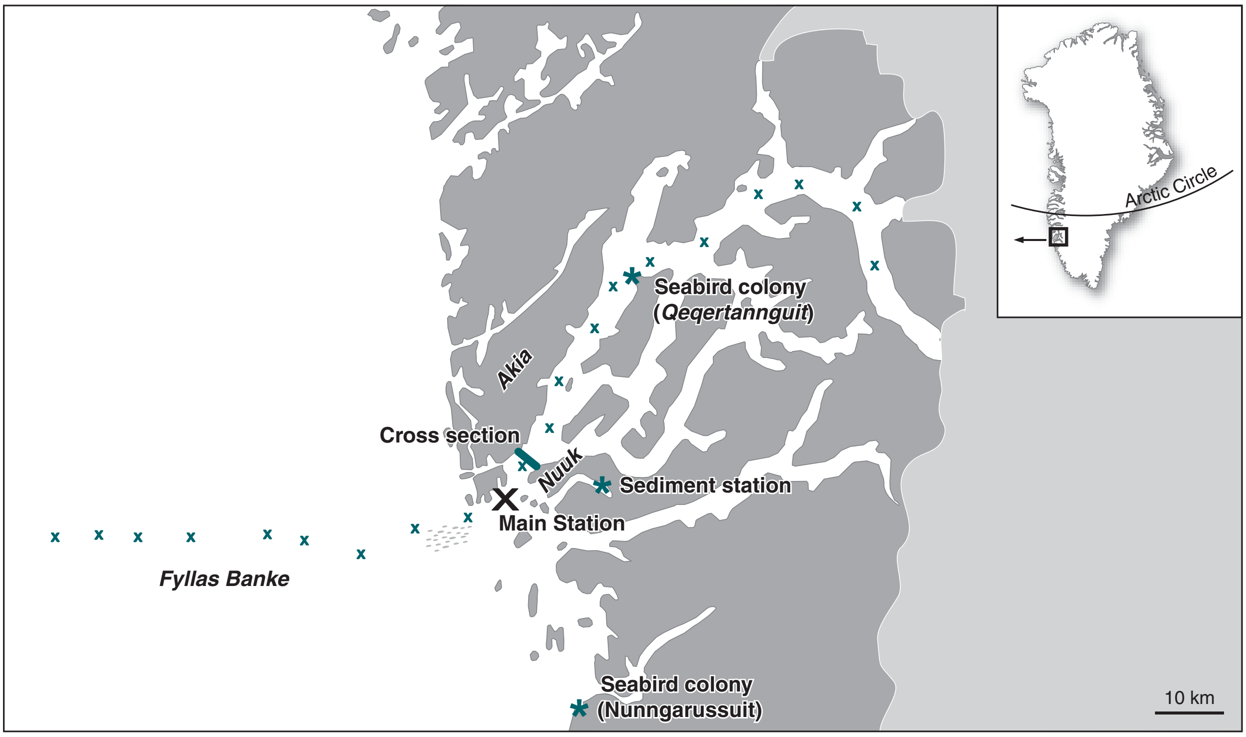


Figure 5.1 Map of sampling stations in and around the Godthåbsfjord system. X represent sampling stations along the hydrographical length section.

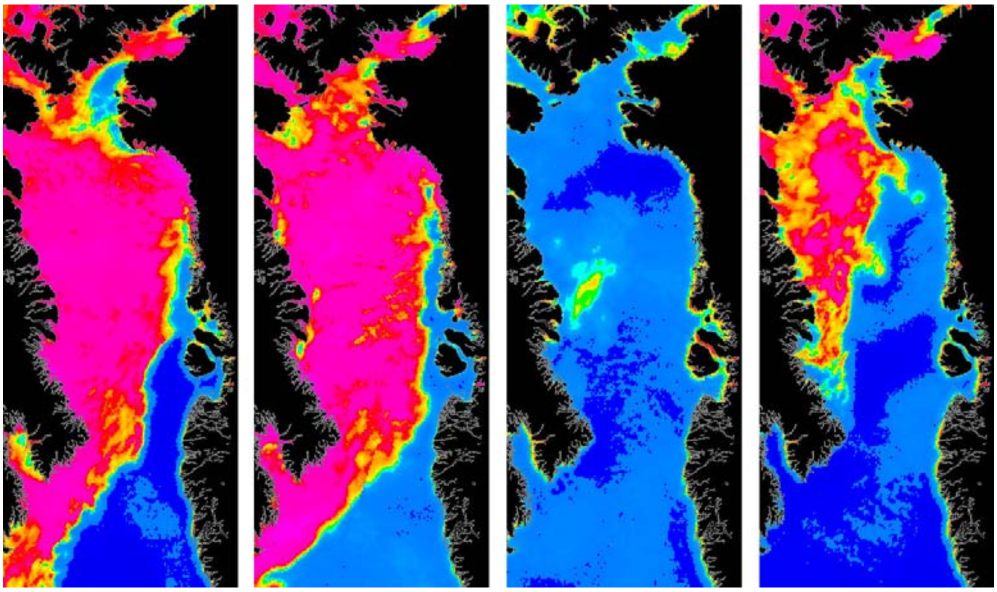


Figure 5.2 Satellite images (AQUA AMSR-E) showing sea ice extent in Baffin Bay in February, May, August and December 2010.Blue colour represents open water and pink and yellow colours represent different sea ice conditions.

bay until April/May when it retreated from the south, reaching a summer minimum coverage (i.e. open water) by July/August. Sea ice started building-up again from the north in September, covering the north-western part of the bay by December.

Daily MODIS satellite images (250 m resolution, figure 5.3) showed a modest sea ice cover in the inner part of Godthåbsfjord and smaller fjord branches, considerably less than was observed during the previous winter (i.e. 2008/2009). Sea ice in Kobbefjord was also limited to the innermost part of the fjord. Analyses of satellite data on sea ice coverage are currently conducted in collaboration between Greenland Institute of Natural Resources, the Danish Meteorological Institute and Greenland Climate Re-

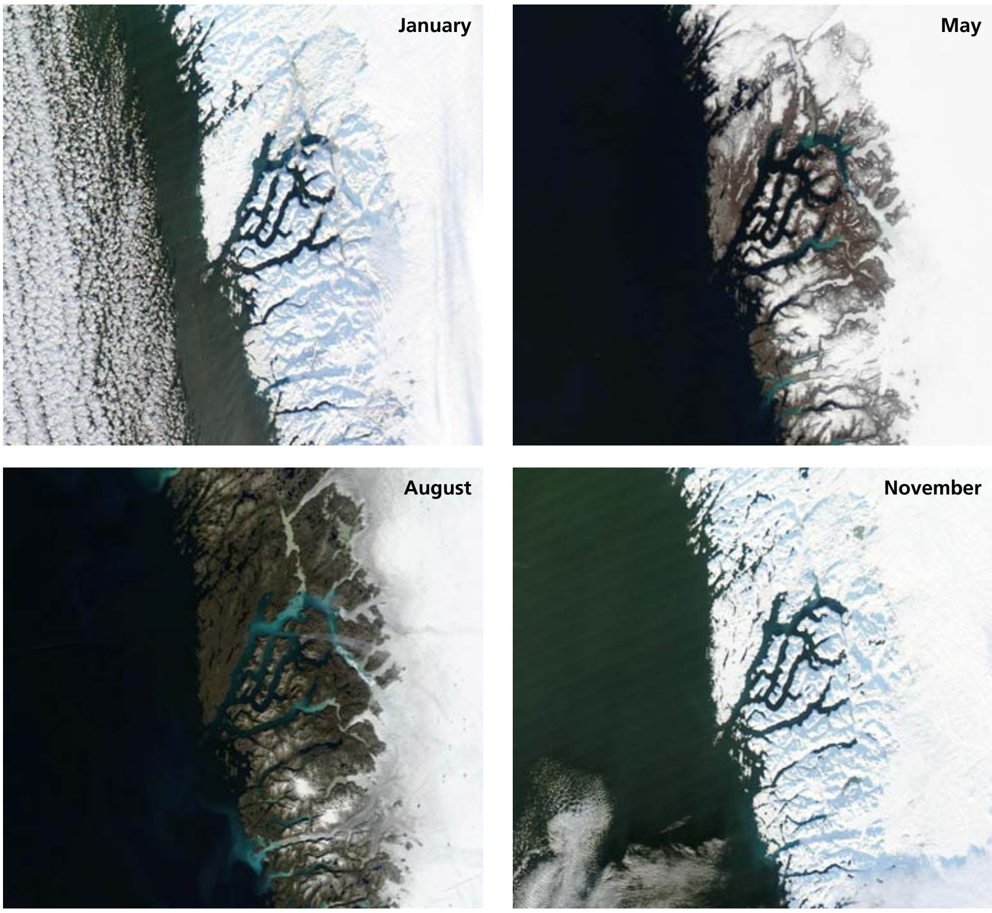


Figure 5.3 Satellite images (AQUA-MODIS) showing sea ice conditions in Godthåbsfjord during January, May, August and November 2010.

Figure 5.4 Digital images from Godthåbsfjord showing open water in October (A) and a burst of glacial ice in December 2010 (B).

search Centre. As a courtesy, daily satellite images covering Greenland are available on www.dmi.dk. Ongoing research at the Greenland Climate Research Centre and the Danish Meteorological Institute is attempting to improve satellite imagery and remote sensing data for the region. Digital images are recorded every hour overlooking a section of Godthåbsfjord near Nuuk (figure 5.4). Major parts of the Godthåbsfjord system remain largely free of ice, only experiencing periodic bursts of sea ice and glacial ice being exported out of the fjord, as it is recorded on the presented digital images. However, in 2010, glacial ice from one of the glaciers within the fjord (Narssap Sermia) could flow unhindered out of the fjord as no sea ice was observed in front of the glacier. Thus more icebergs reached Nuuk and were exported out of the fjord as compared to previous years.

5.2 Length and cross sections

A cross section of Godthåbsfjord, i.e. from Nuuk to Akia (figure 5.1), was sampled in late-May using a SBE19+ CTD profiler measuring salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence. Vertical profiles of salinity, temperature and fluorescence

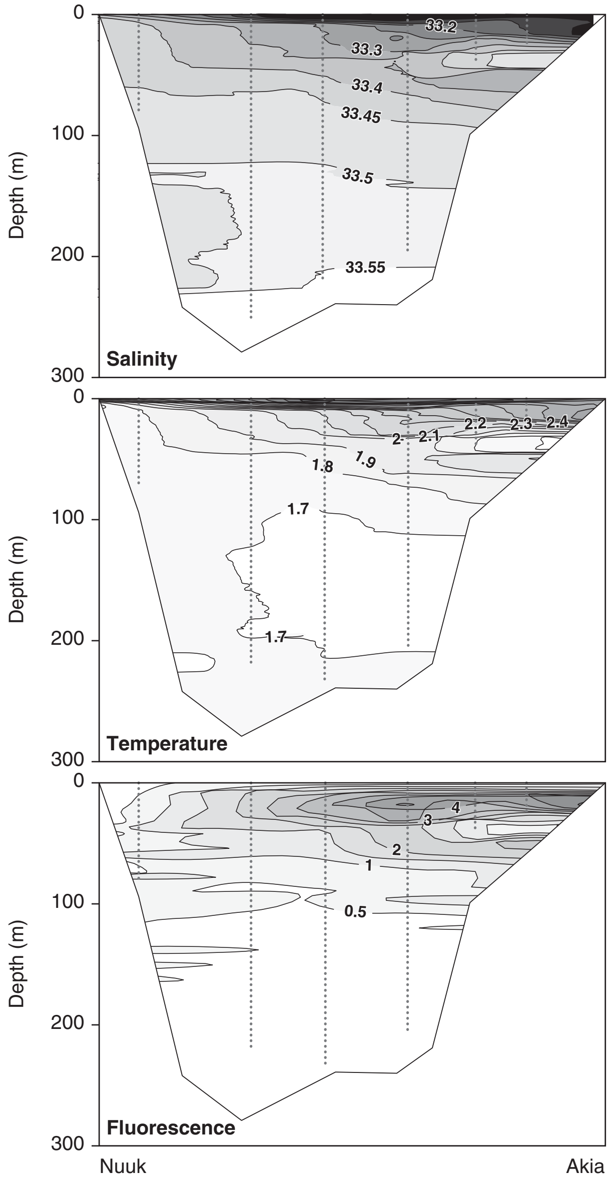


Figure 5.5 Salinity, temperature (°C) and fluorescence along the cross section from Nuuk to Akia in late-May 2010. Vertical dotted lines represent sampling stations and depths in increments.

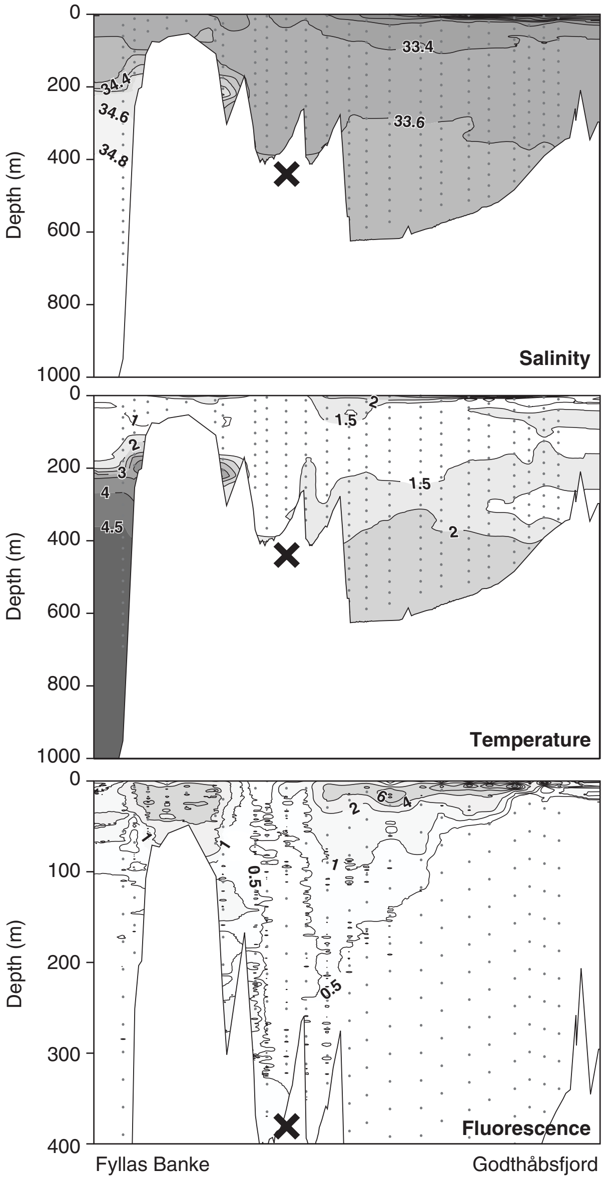


Figure 5.6 Salinity, temperature (°C) and fluorescence along the length section from Fyllas Banke to the inner part of Godthåbsfjord in early-May 2010. Vertical dotted lines represent sampling stations and depths in increments. X marks the location of the 'Main Station'.

along the section showed a flow of warmer and fresher surface water out of the fjord along the Akia side (figure 5.5), as it has been observed in previous years. The surface layer depicted minimum salinities (down to 33.0) and maximum temperatures (up to 3.4 °C) which have not been equalled since sampling of the cross section in May 2006. Solar heating of this fresher surface layer created a rather strong pycnocline with fluorescence values reaching 5.0 (approximately µg chlorophyll *a* l^{-1}, fluorescence is a proxy for phytoplankton concentrations).

Annual sampling along a length section from Fyllas Banke to the inner part of the fjord (approximately 200 km) was conducted in early-May onboard 'R/V Adolf Jensen' (figure 5.1). Hydrographical profiling using a SBE19+ CTD profiler revealed warm saline water at depth on the outside of Fyllas Banke, while rather homogenous temperatures and salinities were observed across Fyllas Banke and into the fjord as a subsurface layer (figure 5.6). Above this subsurface layer was the seaward flowing fresher water, and below the subsurface layer was water with higher temperatures and salinities. The surface layer showed the highest phytoplankton concentrations, i.e. fluorescence, while elevated values were also observed at depth around the sill at the entrance to Godthåbsfjord due to tidal mixing.

Surface pCO_2 along the length transect remained below the atmospheric concentration (i.e. 387 µatm, figure 5.7), except at two station near the entrance to the fjord where outgassing seemed to have occurred. Decreasing values of pCO_2 into the fjord, except at the innermost station(s), reached a minimum pCO_2 of 103.1 µatm. Thus, the fjord appear to have been a stronger CO_2 sink than in 2009, when higher pCO_2 values were recorded at most stations in the fjord.

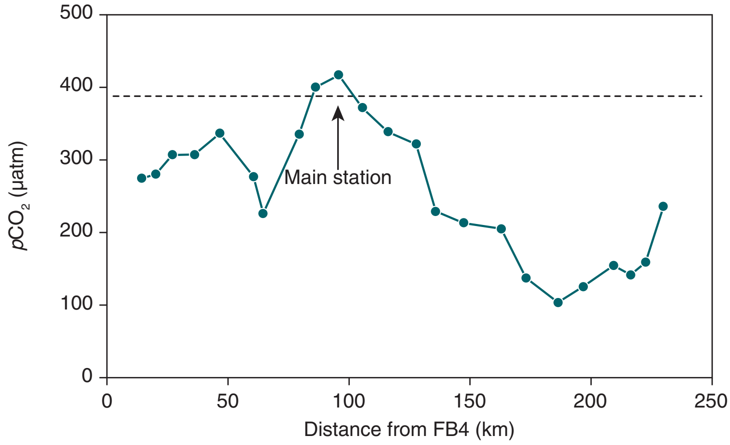


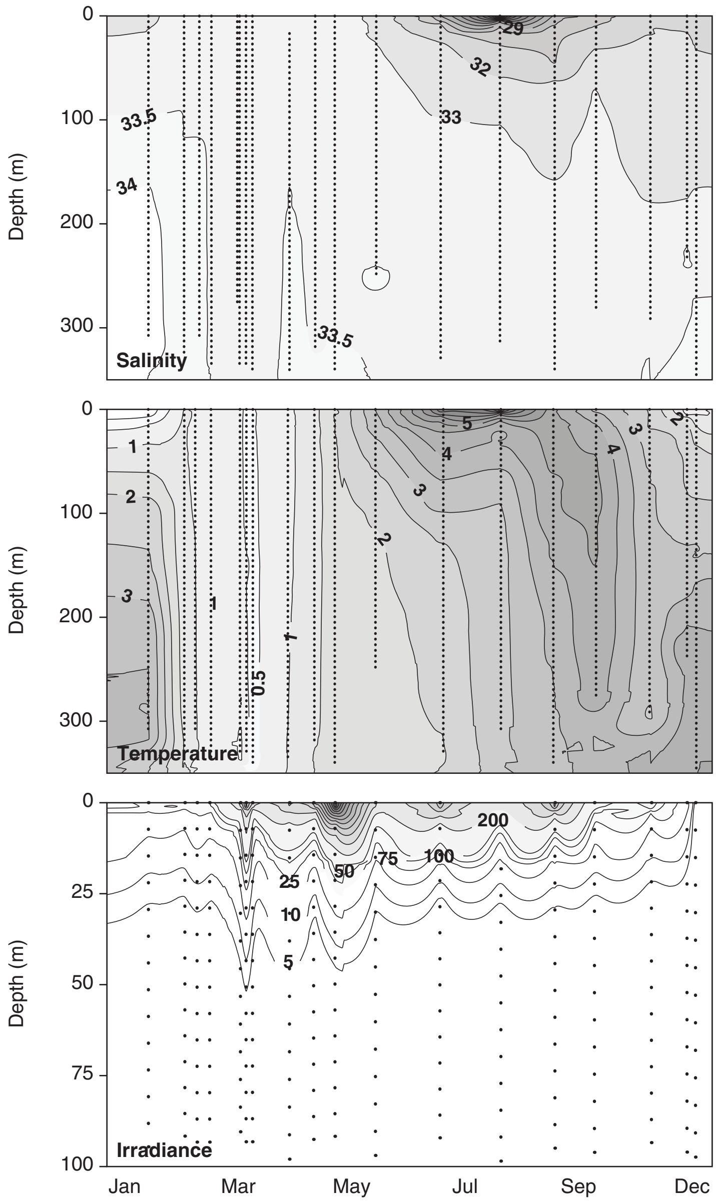
Figure 5.7 pCO_2 *(µatm) in surface waters along the length section from Fyllas Banke (outermost station FB4, figure 5.1) to the inner part of Godthåbsfjord in early-May 2010. Horizontal dotted line represents atmospheric content (387 µatm).*

5.3 Pelagic sampling

Monthly sampling was conducted at the 'Main Station' (GF3, 64°07'N 51°53'W, figure 5.1) at the entrance to Godthåbsfjord. This sampling programme of abiotic and biotic parameters 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 h) free-drifting *in situ* C14 incubations corrected for *in situ* light conditions. The vertical sinking flux of material was measured using short-term (approximately 2 h) free-drifting particle interceptor traps deployed at 65 m. We measured the total amount of particulate material in the traps, and measured 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, respectively. Larger planktonic organisms, i.e. crabs, shrimps and fish larvae, were sampled by oblique hauls using a 335 µm bongo nets. This was also conducted along the length section in early-May.

Figure 5.8 Annual variation in salinity, temperature (°C) and irradiance (PAR) at the 'Main Station' in 2010. Vertical dotted lines represent sampling days and depths in increments.



Abiotic parameters

Hydrographical conditions at the 'Main Station' in the beginning of the year resembled conditions in previous years.

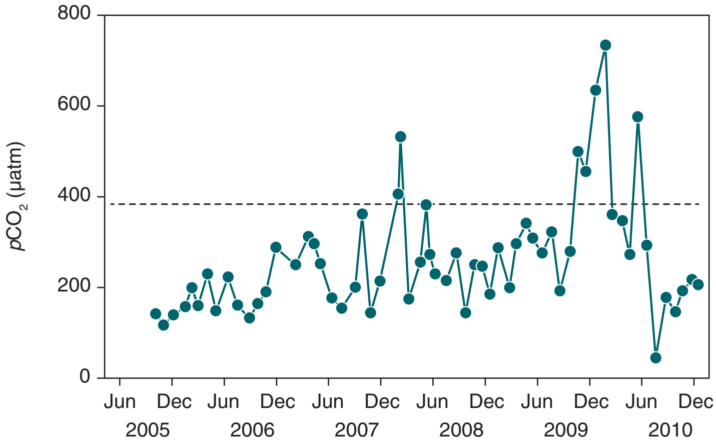
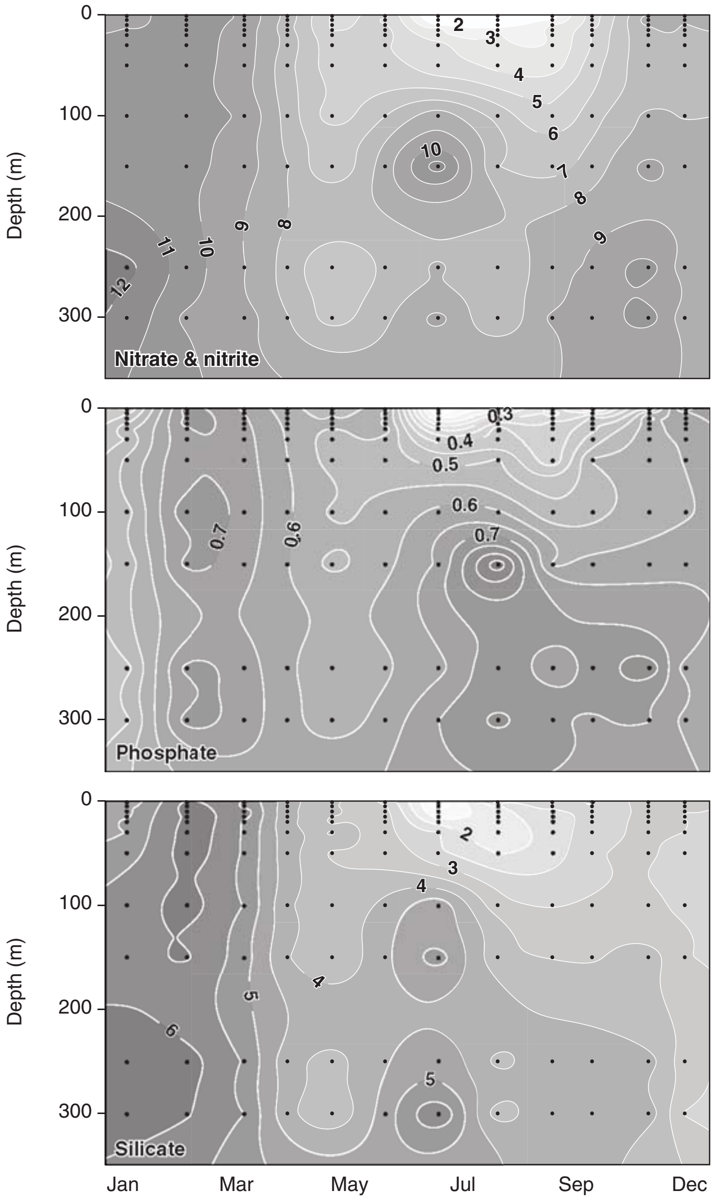


Figure 5.9 Annual variation in pCO_2 *(µatm) in the surface water at the 'Main Station' from late 2005 to 2010. Horizontal dotted line represents atmospheric content (387 µatm).*

Figure 5.10 Annual variation in nitrate and nitrite (µM), phosphate (µM) and silicate (µM) concentrations at the 'Main Station' in 2010. Vertical dotted lines represent sampling days and depths.



Winter, both early and late 2010, was characterised by a moderate stratification of the water column with warmer more saline water towards the bottom likely representing an inflow of coastal water (salinities and temperatures up to 34.3 and 3.5 °C, respectively, figure 5.8). Vertical mixing of the water column followed during spring creating homogenous conditions throughout the entire water column with salinities just above 33 and temperatures below 1 °C. Solar heating of surface waters combined with outflow of melt water stratified the water column during summer producing a surface layer with the lowest salinities (down to 18.5) and highest temperatures (up to 8.3) recorded during the run of the programme. This pycnocline weakened during autumn, and only a moderate stratification persisted during winter, as mentioned above. The light regime of the upper water column varied due to seasonal variations in incoming irradiance and absorption by suspended material in the water (e.g. phytoplankton). Irradiance remained below 5 µmol photos m^{-2} s^{-1} at depths below 50 m, as it has been reported in previous years.

The high pCO_2 values reported in late 2009, i.e. above the atmospheric concentration, continued into January 2010 reaching a new maximum recorded value (734 µatm, figure 5.9). Afterwards values generally decreased until autumn, except for a peak in May. During autumn, surface pCO_2 values reached a stable level well below the atmospheric concentration, which lasted for the rest of the year. Average recorded surface pCO_2 in 2010 (297 µatm) signified a decrease from the high 2009 average (340 µatm), while still remaining above the levels in previous years (186-275 µatm from 2006 to 2008, respectively). Thus, it appears that the inflow of CO_2 rich coastal water persisted into early 2010, but during the rest of the year, Godthåbsfjord regained much of its CO_2 uptake capacity.

Inflow of coastal water in early 2010 introduced high nutrient levels, particularly in deeper waters (maximum 12.3, 0.5 and 6.2 µM for nitrate/nitrite, phosphate and silicate, respectively, figure 5.10). High nutrient levels persisted throughout the water column until the onset of the phytoplankton bloom in summer (July/August), although a moderate decrease was observed from May. The summer bloom resulted in depleted nutrient levels in the

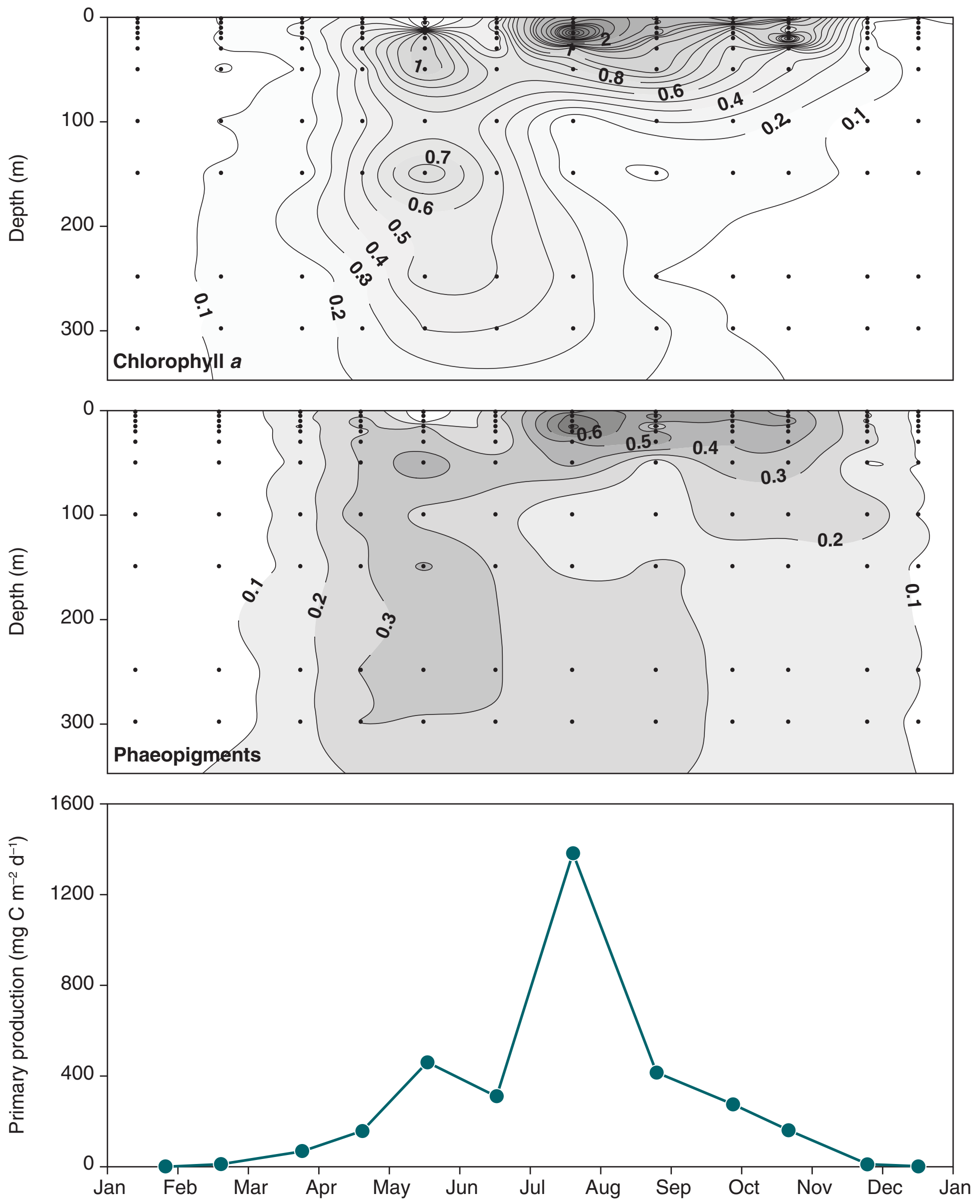


Figure 5.11 Annual variation in chlorophyll a concentration (µg l^{-1}), phaeopigments concentration (µg l^{-1}) and primary production (mg C m^{-2} d^{-1}) at the 'Main Station' in 2010. Vertical dotted lines on chlorophyll a and phaeopigments plots represent sampling days and depths.

upper part of the water column (minimum of 0.06, 0.06 and 0.8 µM for nitrate/nitrite, phosphate and silicate, respectively). A break-down of the stratification in autumn likely combined with benthic/pelagic re-mineralisation and introduction of nutrient rich coastal water resulted in re-established nutrient levels.

Biotic parameters

The phytoplankton biomass, i.e. chlorophyll *a* concentrations, remained low during winter months when light was limited (figure 5.11). Increased light conditions in spring brought on a phytoplankton bloom with increasing chlorophyll *a* concentrations. Vertical mixing at the 'Main Station' in spring resulted in elevated concentrations at depth. The following stratification of the water column, due to freshwater outflow and solar heating, maintained the bulk phytoplankton biomass within the euphotic zone (upper 50 m), resulting in peak pigment concentrations in July (chlorophyll *a* and phaeopigments 3.5 and 0.8 µg l^{-1}, respectively). While the spring bloom in May was depicted in the primary production, the highest production value of 1382 mg C m^{-2} d^{-1} was recorded in July during the time of high surface temperature and low salinity. This production value is the second highest recorded since the programme was initiated in late 2005; the highest value was during May 2009 (1551 mg C m^{-2} d^{-1}). Please note that previously reported seasonal primary production values from 2009 (Juul-Pedersen et al. 2009) was underestimated due to an error in irradiance values used for light correction (also, annual values were presented as mg

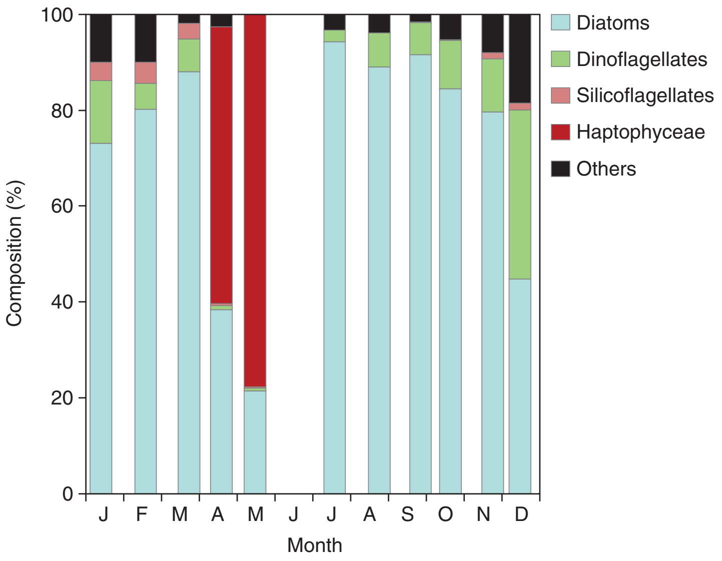


Figure 5.12 Seasonal variation in phytoplankton community composition (%) at the 'Main Station' during 2010.

C m^{-2} y^{-1} while they should have been in g C m^{-2} y^{-1}). Hence, the annual integrated primary production in 2010 (106 g C m^{-2} y^{-1}) was the highest recorded during the run of the programme (76.0, 104, 91.1 and 99.7 g C m^{-2} y^{-1} in 2006, 2007, 2008 and 2009, respectively).

The plankton community

Vertical net hauls (20 µm) from 0-60 m was used to sample for phytoplankton species composition. The phytoplankton community showed the characteristic pattern with diatoms dominating throughout the year, except during the spring bloom when *Phaeocystis* sp. (Haptophyceae) was the major constituent (figure 5.12). Only 2009 differed from this general seasonal species succession, as *Phaeocystis* sp. remained absent all through the year. In contrast, the higher percent contributions of dinoflagellates and other phytoplankton species during mid-winter in 2010 are consistent with 2009. Overall, more than half of the phytoplankton community integrated over 2010 consisted of the three algae groups *Chaetoceros* spp., *Phaeocystis* sp. and *Thalassiosira* spp. (table 5.1), as it was observed prior to 2009 (i.e. 2006-08).

Vertical zooplankton net hauls (45 µm WP2 net) were conducted from 0-100 m. The copepod abundance peaked about a month earlier than in previous years (47000 individuals m^{-3} during July, figure 5.13), but with a peak value comparable to previous years (19000-70000 individuals m^{-3} during 2006-2009). In contrast, the peak copepod nauplii abundance in July (117995 individuals m^{-3}) was by far the highest concentration recorded during the five years of sampling (28000-63000 individuals m^{-3} during 2006-2009), possibly linked to high temperatures. While previous years showed a month separation between the peak in nauplii and copepods there was no separation between the two groups in 2010.

The copepod community was again in 2010 dominated by *Microsetella* sp., except

Table 5.1 Ten most dominant phytoplankton species integrated over the year as their relative accumulated proportion of total cell counts (%) at the 'Main Station' in 2006-2010.

2006		2007		2008*		2009		2010	
Chaetoceros wighamii	30.5	*Chaetoceros* spp. (ex debilis)	20.1	*Thalassiosira* spp.	27.9	*Chaetoceros* spp.	42.4	*Chaetoceros* spp.	37.2
Phaeocystis sp.	45.5	*Phaeocystis* sp.	36.3	*Phaeocystis* sp.	50.4	*Thalassiosira* spp.	58.4	*Phaeocystis* sp.	51.0
Thalassiosira antarctica	53	*Thalassiosira* spp.	52.3	*Chaetoceros* spp.	62.1	*Pauliella taeniata*	66.8	*Thalassiosira* spp.	61.4
Thalassionema nitzschioides	58.1	*Chaetoceros debilis*	65.5	*Fragilariopsis* spp.	70.0	*Fragilariopsis* spp.	71.0	Centric diatoms undet.	66.8
Dictyocha speculum	62.7	*Thalassionema nitzschioides*	78.6	*Navicula* spp.	73.9	*Dinobryon baltica*	74.4	*Protoperidinium* spp.	70.8
Pseudonitzschia cf *seriata*	66.2	*Fragilariopsis oceanica*	82.2	*Protoperidinium* spp.	77.5	Centric diatoms undet.	77.6	*Leptocylindrus danicus*	72.8
Thalassiosira nordenskioeldii	69.1	*Dictyocha speculum*	83.6	*Pseudonitzschia* spp.	80.5	*Protoperidinium* spp.	80.2	*Stenosomella* spp.	74.6
Nitzschia frigida	71.7	*Aulacoseira* sp.	84.9	*Podosira* spp.	83.2	*Dictyocha speculum*	82.4	*Alexandrium* sp.	76.1
Dinobrion balticum	74	*Cocconeis* spp.	86.1	*Leptocylindrus* spp.	85.7	*Leptocylindrus danicus*	83.8	*Skeletonema* sp.	77.6
Thalassiosira bioculata	76.1	*Ceratulina* sp.	87.0	*Peridenella catenata*	87.6	*Navicula* spp.	85.2	*Dictyocha speculum*	78.9

*From January to August

during February when *Microcalanus* comprised more (45.5 vs. 39.4%, respectively; figure 5.13). The only other species contributing significantly to the copepod composition was *Oithona* spp. (up to 22.6%) and *Pseudocalanus* spp. (up to 17%), while *Calanus* spp. only contributed up to 8.5% of the total copepod abundance. Similar to previous years, *Calanus* spp. was mainly present during the spring bloom in May. However, it is important to keep in mind that the specific species contribution to the copepod community biomass will differ from the abundance, as significant size differences occur between these species.

The peak abundance of other zooplankton (36729 individuals m^{-3}) coincided with the maximum copepod abundance in July. While the seasonal succession observed for Bivalvia larvae (i.e. spring) and Gastropoda larvae and rotifera (i.e. summer) resembled previous years, Bivalvia larvae peaked later (i.e. summer) than generally observed. Moreover, foraminifera were almost absent throughout the year.

To assess shellfish as well as fish larvae at the 'Main Station' (GF3), single oblique sampling with a bongo net (335 µm) was used each month during 2008 (except June), 2009 (except October) and 2010. Additional samplings with a double oblique bongo net (335 and 500 µm) were conducted along a length section from offshore Fyllas Banke to the inner part of the fjord during May 2006-2010. Thirteen stations were sampled in May 2006, four stations in 2007 and 2008, three stations in 2009 and five stations in 2010.

At the 'Main Station' (GF3), the highest concentration of fish larvae were usually found in spring (March-May, 2006-2008). In 2009 and 2010, however, the highest concentration was found in summer (July; figure 5.14A). This was caused by a decrease in abundance of sand eel (*Ammodytes* sp.) larvae in spring and an increase in the abundance of capelin (*Mallotus villosus*) larvae in summer in the 2009 and 2010 samples.

Overall, the total abundance of fish larvae (individuals 100 m^{-3}) has declined since the beginning of the programme in 2006. This is caused by gradually declining sand eel larvae abundance. In March 2006, 14.7 individuals 100 m^{-3} were caught in the samples, whereas in March 2010 only 0.003 individuals 100 m^{-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. However, in 2010 sand eel larvae was again the dominating species during spring at the 'Main station' (figure 5.14B), but at the lowest abundance (individuals m^{-3}) since 2006.

A temporal shift in species composition occurs during summer at the 'Main Station'. In 2009 and 2010, sand eel was the dominating species in spring whereas capelin was dominating in late summer/early fall (figure 5.14B). Cod larvae (*Gadus morhua*) were found in May, June and July and were the dominating species in June.

In May, the length section in the fjord shows the same pattern in fish larvae concentrations and species composition as previous years. Highest concentrations were found closer to the head of the fjord at

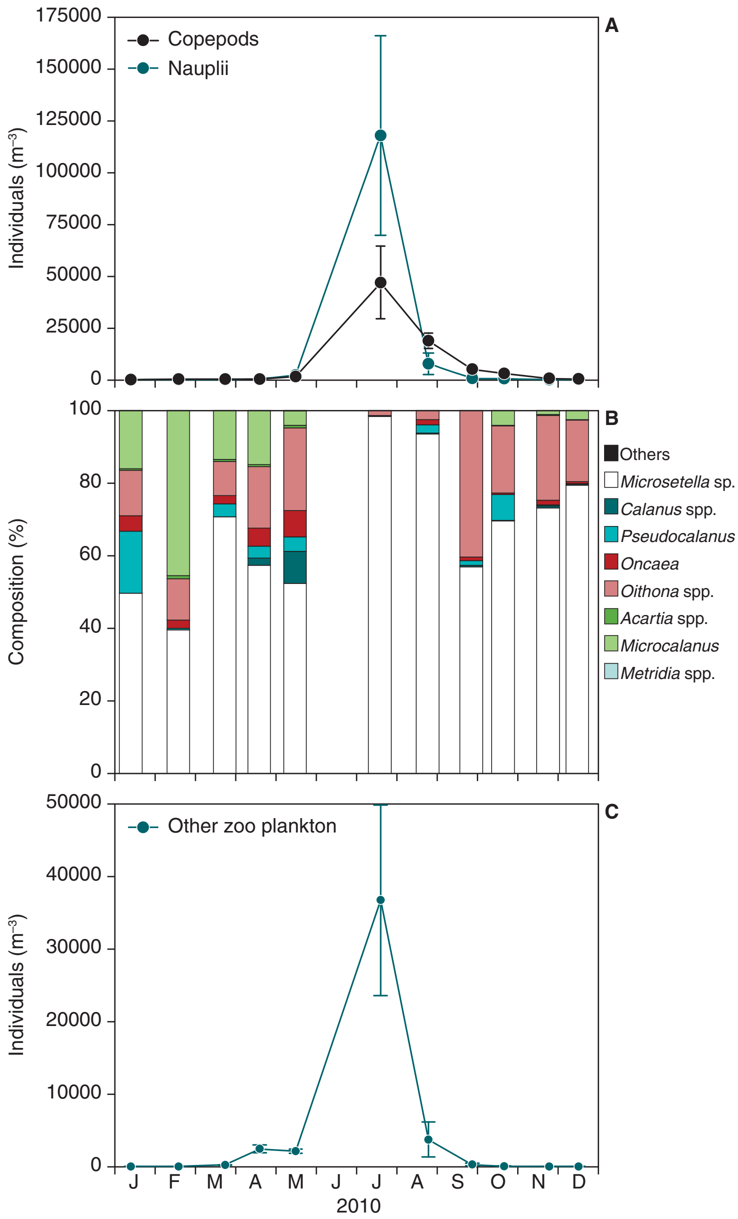
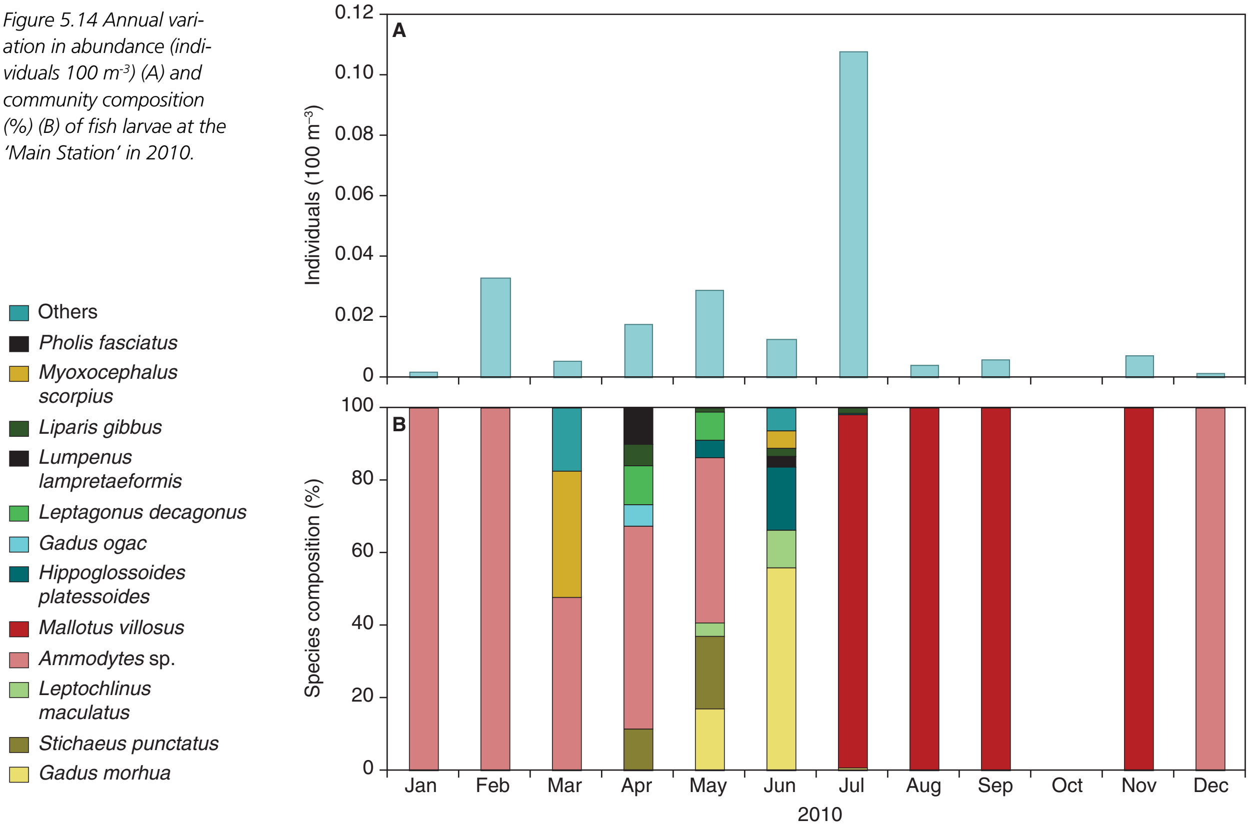


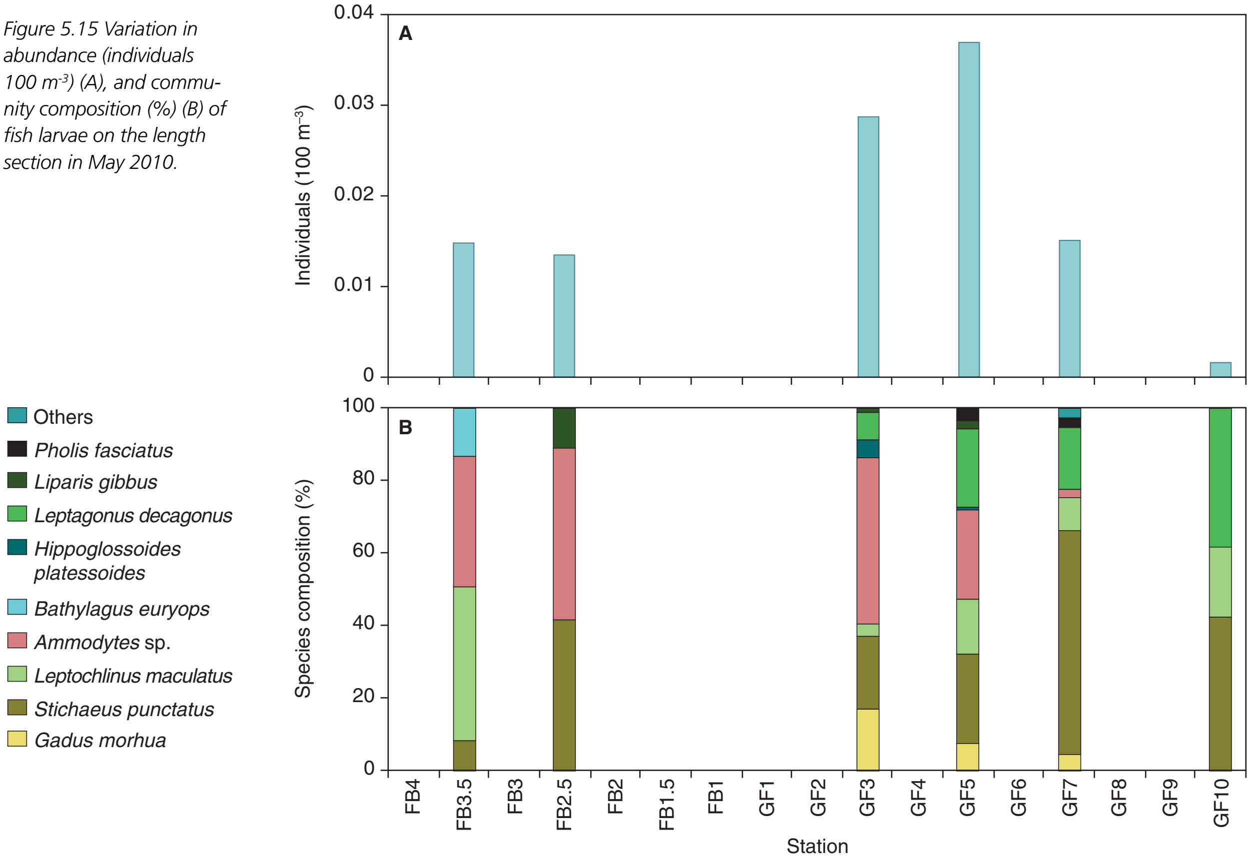
Figure 5.13 Annual variation in abundance (individuals m^{-3}) of copepod nauplii and copepods (i.e. copepodites and adult stages) (A), copepod community composition (%) (B) and abundance of other zooplankton groups (individuals m^{-3}) (C) at the 'Main Station' in 2010. Error bars represent standard deviation.

Figure 5.14 Annual variation in abundance (individuals 100 m^{-3}) (A) and community composition (%) (B) of fish larvae at the 'Main Station' in 2010.



the 'Main Station' (figure 5.15A), although lower than previous years due to decreased abundance of sand eel larvae. Species composition also varied on 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 middle part of the fjord.

Figure 5.15 Variation in abundance (individuals 100 m^{-3}) (A), and community composition (%) (B) of fish larvae on the length section in May 2010.



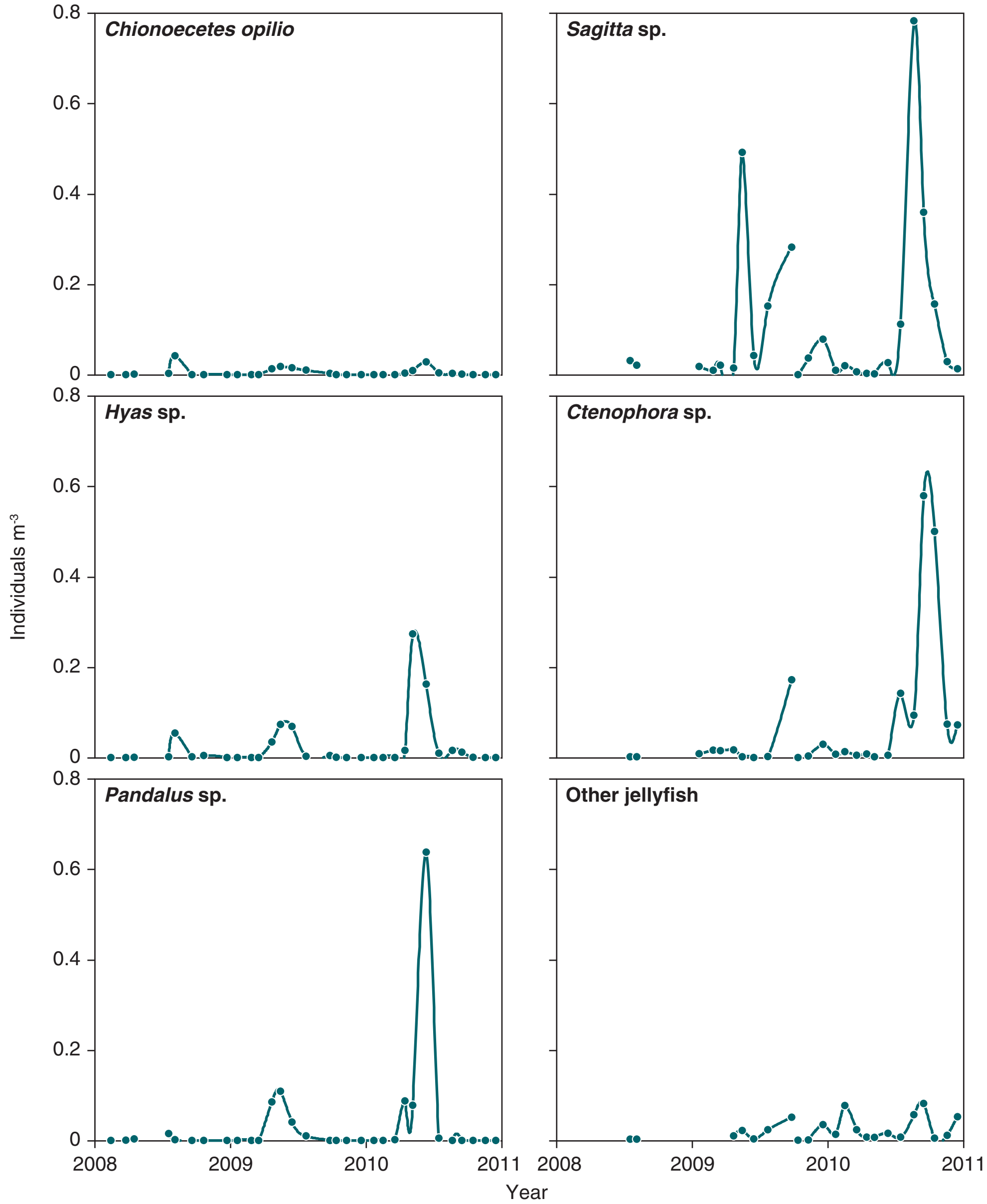


Figure 5.16 Annual variation in abundance of Chionoecetes opilio, Hyas *sp.,* Pandalus *sp.,* Sagitta *sp.,* Ctenophora *sp. and other jellyfish from 2008 to 2010 at the 'Main Station' (GF3). Samples were collected each month except November 2008 and August 2009.*

Fish larvae species composition seems to vary between years with most species found in 2008 and 2010 (table 5.2).

At the 'Main Station' (GF3), seasonal patterns in the abundance of shellfish (*Chionoecetes opilio*, *Hyas* sp., *Pandalus* sp.) show similarities over the past three years (figure 5.16). All three species of decapods were present in samples from April to August. Abundance of *Chionoecetes opilio* (snow crab) and *Hyas* sp. (sand crab) peaked in May, respectively, in 2009 and 2010, whereas *Pandalus* sp. (shrimp) peaked in June 2010, i.e. one month delayed compared to the two previous years. Density of *Hyas* sp. and *Pandalus* sp. exceeded previous values from 2008 and 2009 almost twofold. Larvae stage zoae I of *C. opilio* and *Hyas* sp. dominated samples from April to June, whereas larvae stage zoae II were more abundant in July. Low concentrations of megalope stage of *C. opilio* and *Hyas* sp. were observed in October. Throughout the time series, abundance of *C. opilio* has been low compared to *Hyas* sp. and *Pandalus* sp.

Community composition at the 'Main Station' (GF3) varies between years. In 2009, the ratio of *Sagitta* sp. (arrow worm) was relative higher from May to July compared with 2008 and 2010 (figure 5.17) and *Sagitta* sp. remained the single most abundant species, except for February, April and June. Another consistently abundant species was *Ctenophora* sp. (comb jelly), comprising 40 % in September. In contrast, jellyfish dominated samples in 2010 from January to March, while *Ctenophores* dominated in July and from September and onwards. *Sagitta* sp. was recorded in considerably lower numbers than during the previous years.

Table 5.2 Species list of fish larvae 2006-2010.

Species list	2006	2007	2008	2009	2010
Gadus morhua	×	×	×	×	×
Stichaeus punctatus	×	×	×	×	×
Leptochlinus maculatus	×	×	×	×	×
Ammodytes sp.	×	×	×	×	×
Mallotus villosus		×	×	×	×
Aspidophoroides monopterygius	×	×	×		
Bathylagus euryops		×	×	×	×
Cyclothone sp.		×			
Liparis sp.		×			
Liparis gibbus					×
Pholis sp.	×	×	×		
Pholis fasciatus					×
Reinhardtius hippoglossoides	×		×		
Myoxocephalus scorpius			×		×
Hippoglossoides platessoides			×	×	×
Sebastes sp.			×		
Gadus ogac			×	×	×
Leptagonus decagonus				×	×
Agonidae				×	
Lumpenus lampretaeformis				×	×
Total	**7**	**10**	**13**	**11**	**13**

Along the length transect from Fyllas Banke (offshore) to the inner part of the fjord (GF10) highest concentrations of sand crab larvae (*Hyas* sp.) were recorded at the offshore station FB2.5 in 2006 and 2010 (figure 5.18). Both crab and shrimp larvae are to be found at almost all stations along the length transect, with variations in density among species and between stations. Highest numbers of individuals (individuals m^{-3}) were observed in 2006 followed by a sharp decline in 2007 to 2009. Nevertheless, crab and shrimp larvae increased significantly in 2010.

Along the length transect, the community composition differed not only between stations but also between years (figure 5.19). At station GF10, located in the inner part of the fjord, larvae of *Ctenophores*, jellyfish and *Sagitta* sp. dominated the samples in 2009, whereas *Ctenophora* sp. were absent in 2010 which instead was dominated by *Sagitta* sp. with occurrence of shrimp and crab (*Hyas* sp.) larvae. *Sagitta* sp. dominated at GF3 ('Main Station') in 2009, but was negligible at GF3 and only recorded in a low numbers at GF7 in 2010. The abundance of *Pandalus* sp. and *Hyas* sp. were considerably higher in 2010 compared to previous years. At the outer fjord, larvae of *C. opilio* and especially *Hyas* spp. were more abundant than shrimp larvae, and *Hyas* spp. was dominant at the shallower parts of the bank.

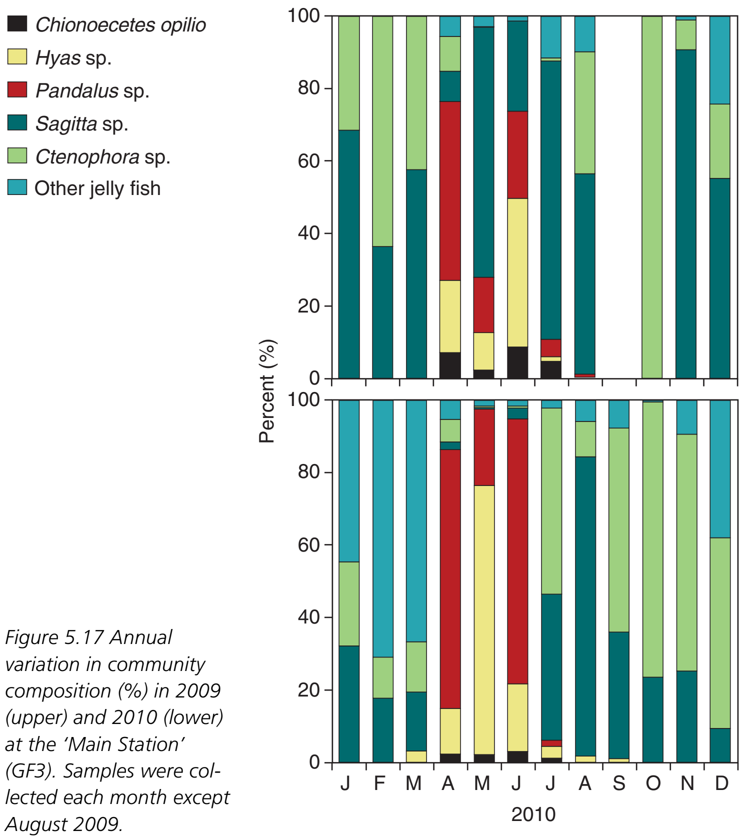


Figure 5.17 Annual variation in community composition (%) in 2009 (upper) and 2010 (lower) at the 'Main Station' (GF3). Samples were collected each month except August 2009.

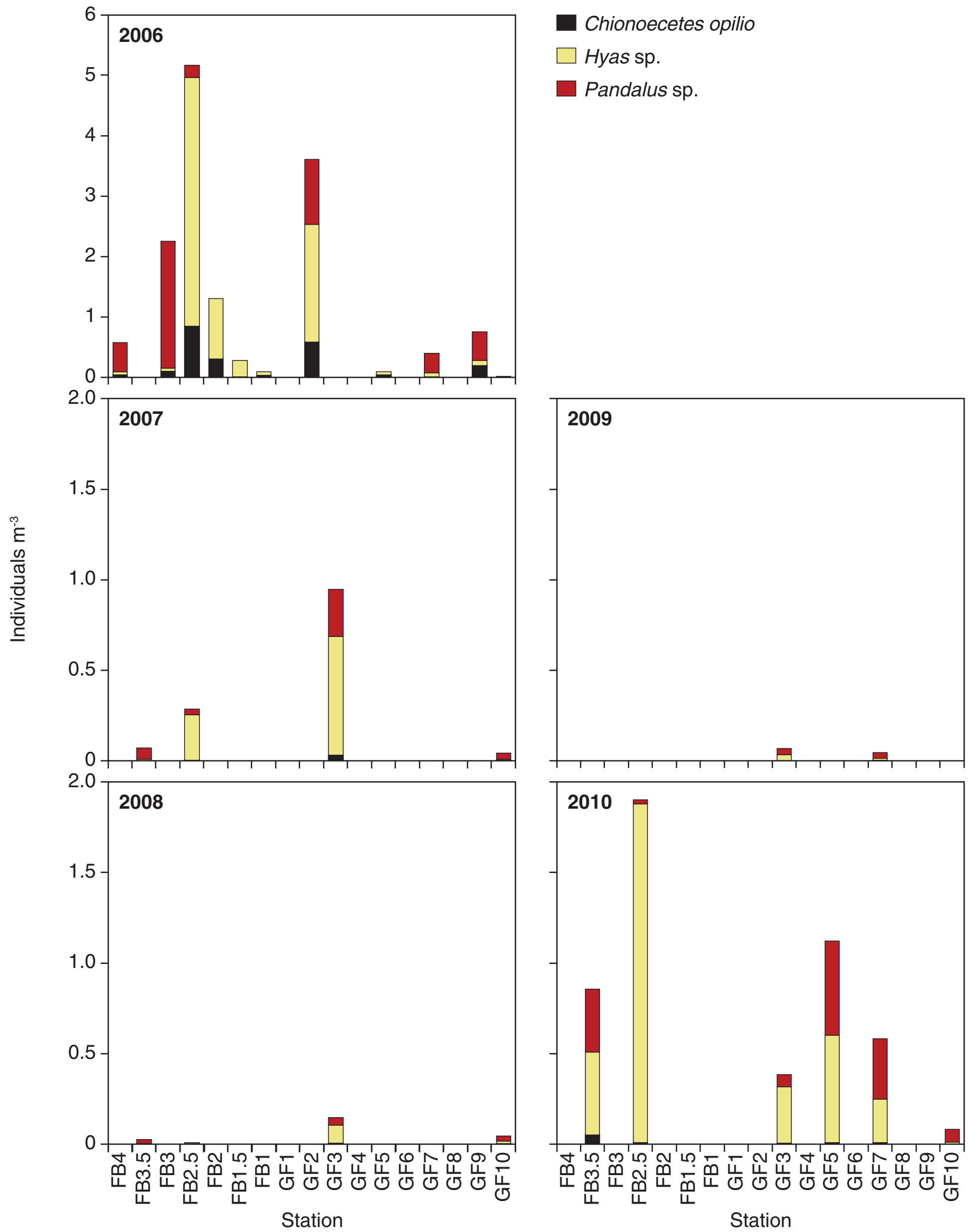


Figure 5.18 Annually variation in abundance (individuals m⁻³) of crab and shrimp larvae along the length section from Fyllas Banke (offshore) to the inner part of Godthåbsfjord conducted in May 2006 to 2010. In 2009, no sampling was carried out at Fyllas Banke.

Vertical sinking flux

Vertical sinking flux of particulate material was measured using monthly deployments of free-drifting short-term (approximately 2 h) sediment traps collecting material sinking from the euphotic zone (deployed at 65 m). Low sinking fluxes of both total particulate carbon (TPC) and chlorophyll *a* (Chl *a*) were observed in winter and spring, i.e. until April, when an increase occurred during the developing spring phytoplankton production (figure 5.20). The peak Chl *a* sinking flux (7.4 mg m^{-2} d^{-1}) in May corresponds with the rather moderate spring bloom previously described, while Chl *a* fluxes related to the higher summer bloom may have been missed due to the lack of data from August. The C:N ratio of the material collected during spring and summer (between 7.4 and 8.4 mol:mol from May to August) also indicates a strong phytoplankton based carbon component, i.e. close to the Redfield ratio (6:6 mol:mol) typical of fresh algal cells. This is further supported by the $\delta^{13}C$ and $\delta^{15}N$ values during this productive period. Variable Chl *a* sinking fluxes during spring and summer are contrasted by a moderate decrease in TPC sinking fluxes. The abrupt decline in $\delta^{13}C$ values during September was likely caused by a higher input of terrestrial material during discharge and seaward export of melt water. The annually integrated TPC sinking flux (351.2 g C m^{-2} y^{-1}) was comparable to previously reported values (between 253.9 and 431.5 g C m^{-2} y^{-1} from 2006-09). Sinking fluxes of total material (data not presented) may likely have been overestimated in

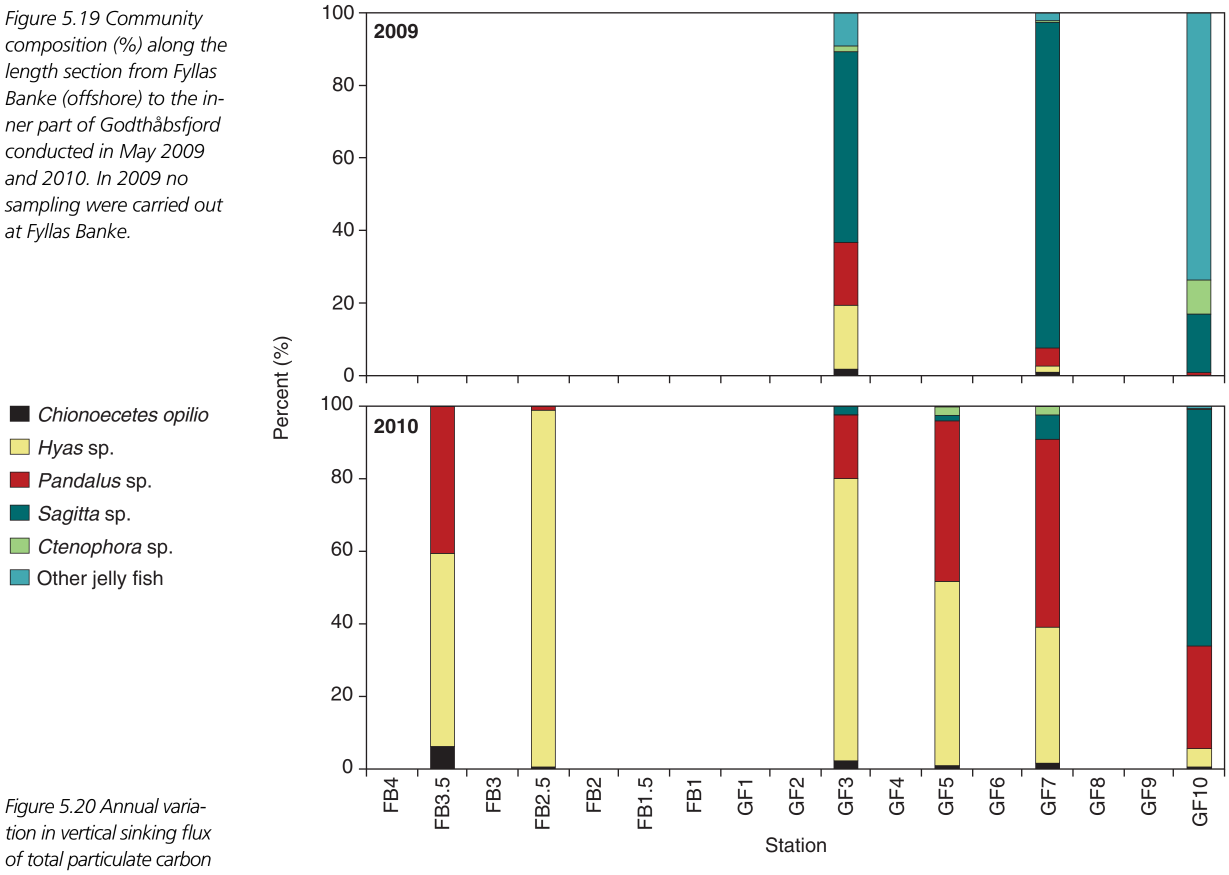
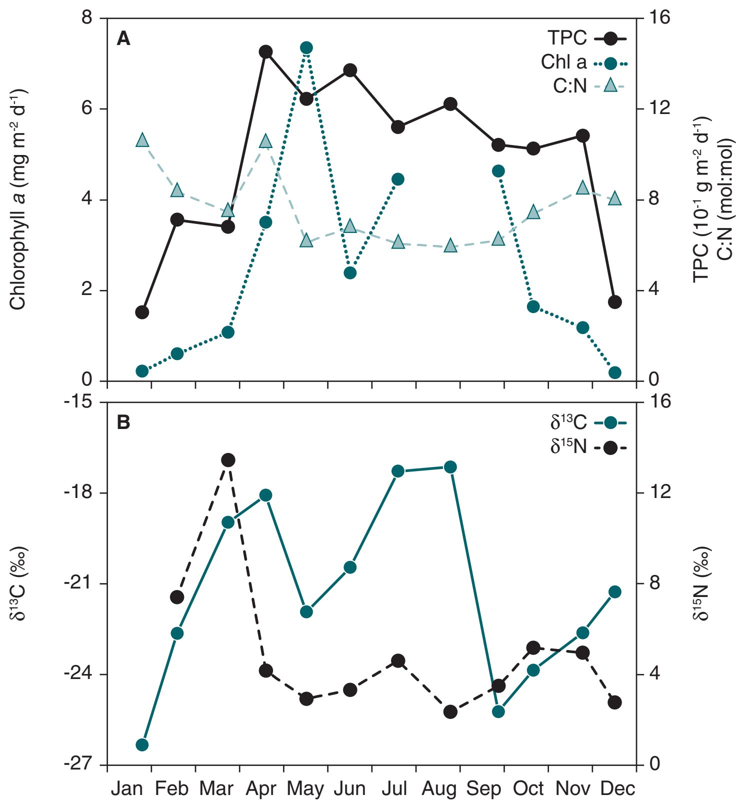


Figure 5.19 Community composition (%) along the length section from Fyllas Banke (offshore) to the inner part of Godthåbsfjord conducted in May 2009 and 2010. In 2009 no sampling were carried out at Fyllas Banke.

Figure 5.20 Annual variation in vertical sinking flux of total particulate carbon (10^{-1} g m^{-2} d^{-1}), chlorophyll a (mg m^{-2} d^{-1}) and the carbon to nitrogen ratio (mol:mol) (A), δ^{13}C (‰) and δ^{15}N (‰) of the sinking particulate material (B) collected at the 'Main Station' in 2010.



previous years due to excess salt on filter weights. The method has been corrected from late 2010, and a salt correction experiment suggests that also the previously reported average annual carbon fraction of total material (1.3-2.3% of total material from 2006-2009) may have been about an order of magnitude too low (estimated 15.4% of total material in 2010).

5.4 Sediments

Arrival of fresh organic matter to the sea bed is either consumed by organisms or is mineralised 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 re-mineralisation may be estimated by measuring the flux of oxygen into the sediment.

Intact sediment cores were recovered four times during 2010 (February, May, August and November) at a depth of 125 m in Kobbefjord ('Sediment Station' 64°09.975'N, 51°28.328'W; figure 5.1). Oxygen fluxes were measured by closed core incubations, while diffusive oxygen was measured by micro profiling. In all sampling periods oxygen was depleted within 1 cm of the sediment surface (figure 5.21). Maximum consumption occurred in

August, just after the summer bloom when sinking fluxes of algal material most likely was high (Chl *a* sinking flux from August is missing). Return of dissolved inorganic carbon (DIC) to the water column remained rather constant throughout the year (table 5.3). Oxygen consumption rates were highest during summer and autumn/winter (>1 µmol cm^{-3} d^{-1} in August and November) compared to winter/spring (<1 µmol cm^{-3} d^{-1} in February and May). Overall, seasonal differences seem to indicate highest benthic activity in summer and autumn, possibly due to the high organic input and elevated temperatures observed also at depth, which is in contrast to previous years with more acti-vity in spring.

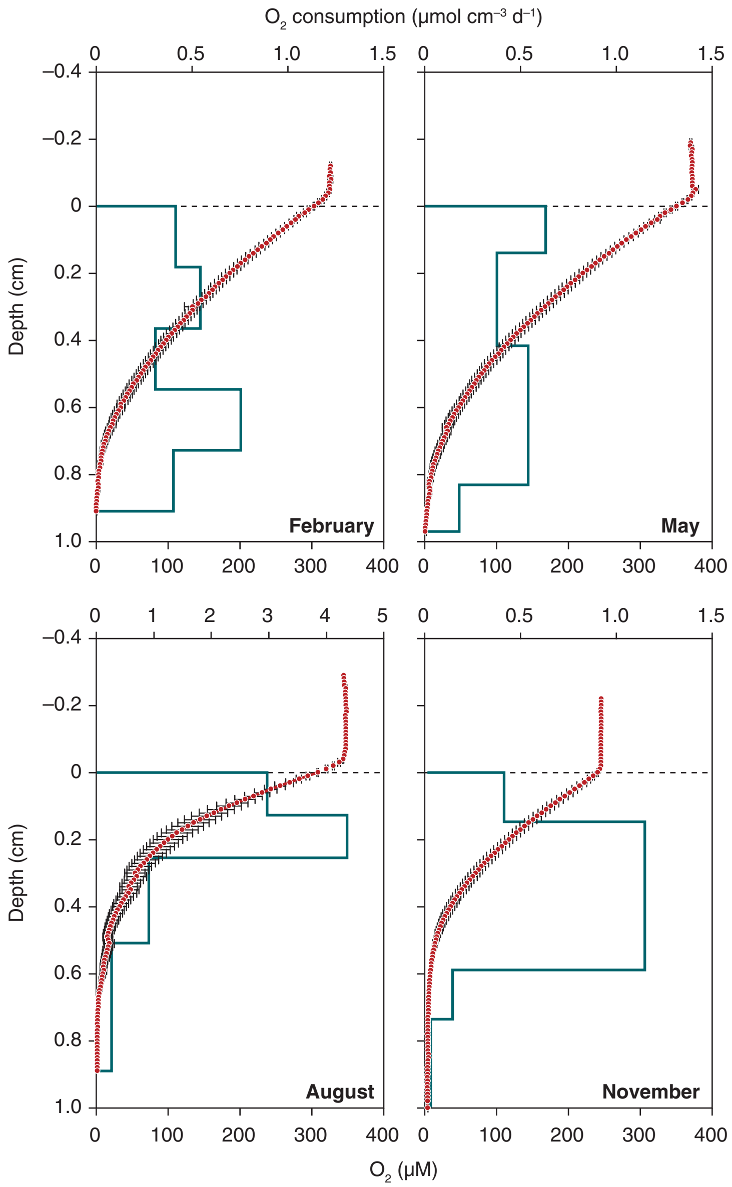


Figure 5.21 Vertical concentration profiles of oxygen (closed dots) and modelled consumption rates (solid line) from micro electrode profiles with sediment depth for each of the four sampling periods. Error bars represent standard error of the mean.

5.5 Benthic fauna and flora

Benthic fauna

The fauna found on the bottom of Greenland fjords are important components of the marine food web. On average they are estimated to consume approximately 20 % of the primary production (Blicher et al. 2009). Benthic fauna are also the preferred prey for predators such as walruses and eiders (Born et al. 2003, Merkel et al. 2007). Moreover, specific species such as sea urchins may actively influence the structure of the ecosystem through intense grazing of macro algae and subsequent formation of 'sea urchin barrens'. Finally, the benthic community consists of very high species richness with frequent observation of more than 100 species m^{-2} in outer part of fjords (Sejr et al. 2010).

In Kobbefjord, the sea urchin *Strongylocentrotus droebachiensis* and the scallop *Chlamys islandica* are found in large quantities in the shallow parts of the fjord (10-75 m) where they constitute the majority of the biomass (Blicher et al. 2009). Annual shell growth rates have been determined for both species. Additionally, a seasonal study looking at the growth dynamics of the different soft tissues of *C. islandica* produced a growth model indicating a negative influence of temperature (Blicher et al. 2010). Thus, a future warming of the upper water column can be expected to increase the metabolic cost with potential negative effects on the energy available for growth and reproduction.

Since 2007, the energetic status of the two species has been surveyed in May at a

Table 5.3 Sediment-water exchange rates of O_2 (TOU), NO_3^- + NO_2^-, PO_4^{3-} and SiO_4 measured in intact sediment cores, diffusive oxygen uptake by the sediment (DOU) and the ratios of DOU to TOU. n denotes the number of sediment cores. Positive values for NO_3 + NO_2^-, PO_4^{3-} and SiO_4 represent a release from the sediment to the water column, while positive values for TOU and DOU represent an uptake into the sediment. All rates are in mmol m^{-2} d^{-1}. SE denotes the standard error of the mean.

	Month								
Parameter	February		May		August		November		n
TOU	8.89	±1.35	6.32	±0.89	4.06	±1.03	5.73	±1.93	6
DOU	4.40	–	4.60	–	12.40	–	5.42	–	3
TOU/DOU	2.02	–	1.37	–	–	–	1.06	–	–
DIC	4.39	±0.70	5.70	±0.83	4.75	±1.20	4.35	±32	6
PO_4^{3-}	0.08	±0.16	0.12	±0.01	–0.25	±0.05	–	–	6
NO_3^- + NO_2^-	0.17	±0.04	0.25	±0.04	–	–	–	–	6
SiO_4	1.03	±0.17	1.11	±0.16	4.30	±0.89	1.79	±0.50	6

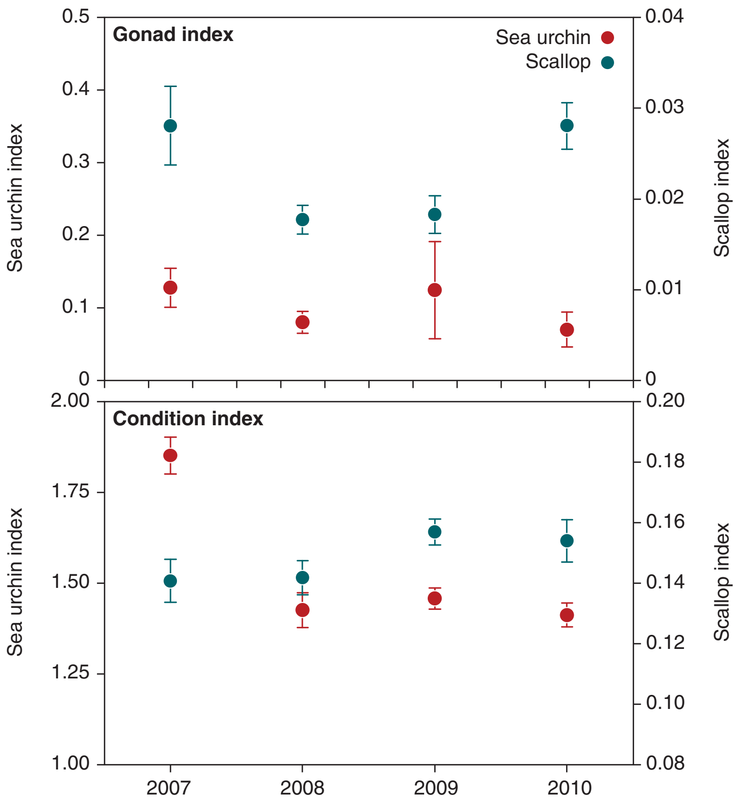
sampling station in the outer part of Kobbefjord (64°07.651'N, 51°38.587'W; depth: 55 m). Two indices are calculated for each species: a condition index and a gonad index. The condition index is calculated by relating the total soft tissue biomass to the shell mass and the gonad index is the gonad mass related to the shell mass. For both indices it is assumed that favourable conditions will affect total soft tissue weight or gonad weight positively leading to higher-than-average indices. Thus, the index is assumed to reflect inter-annual changes in energetic status whereas long-term changes in e.g. deposition of shell material related to acidification will have minimal influence on the inter-annual variation in indices.

For the gonad index (figure 5.22), the two species do not show a similar pattern from 2007-2010. The scallops show the highest index in 2007 and 2010, whereas the sea urchins have the highest index in 2007 and 2009. Since the specimens for the analysis is collected at the same locality they can be assumed to experience similar temperature regimes. Scallops spawn in July and gonads build up gradually through the spring and summer, whereas sea urchins may spawn in mid-summer. When collected in May, the gonads of the two species are thus at different stages, the sea urchins are almost mature, whereas the scallops are still at an early stage. One potential consequence of this is that the gonad indices of the two species may integrate the energetic status over different time intervals. Moreover, the importance of reproductive tissue as an energy storage organ may differ between the two species

The condition index also shows considerable variation between years for both species. For the sea urchins the index value was highest in 2007 with a lower level found in 2008-2010. For the scallops, 2007 and 2008 displayed low index values, whereas 2009 and 2010 was higher. As for the gonad index, the two species does not seem to follow the same inter-annual pattern. A range of factors could be involved. Benthic fauna are generally thought to be food limited, and since the two species rely on different food sources, it is not surprising to see difference in their inter-annual variation. Scallops are filter feeders and thus rely on suspended particles, whereas sea urchins are omnivores that can utilize several different food sources including macro algae and detritus.

With four years of data we have seen significant inter-annual differences in the condition and gonad index of two dominant benthic species in Kobbefjord. Food availability and temperature are expected to be important factors influencing both indices, but it is apparent that there is considerable variation between species and indices in the inter-annual pattern. Different ecology of the two species combined with different reproduction timing can explain some of the differences.

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



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 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 e.g. also the case in the subarctic Kobbefjord 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 coastal areas (Mann 1973, Rysgaard and Glud 2007, Juul-Pedersen et al. 2009). The genus

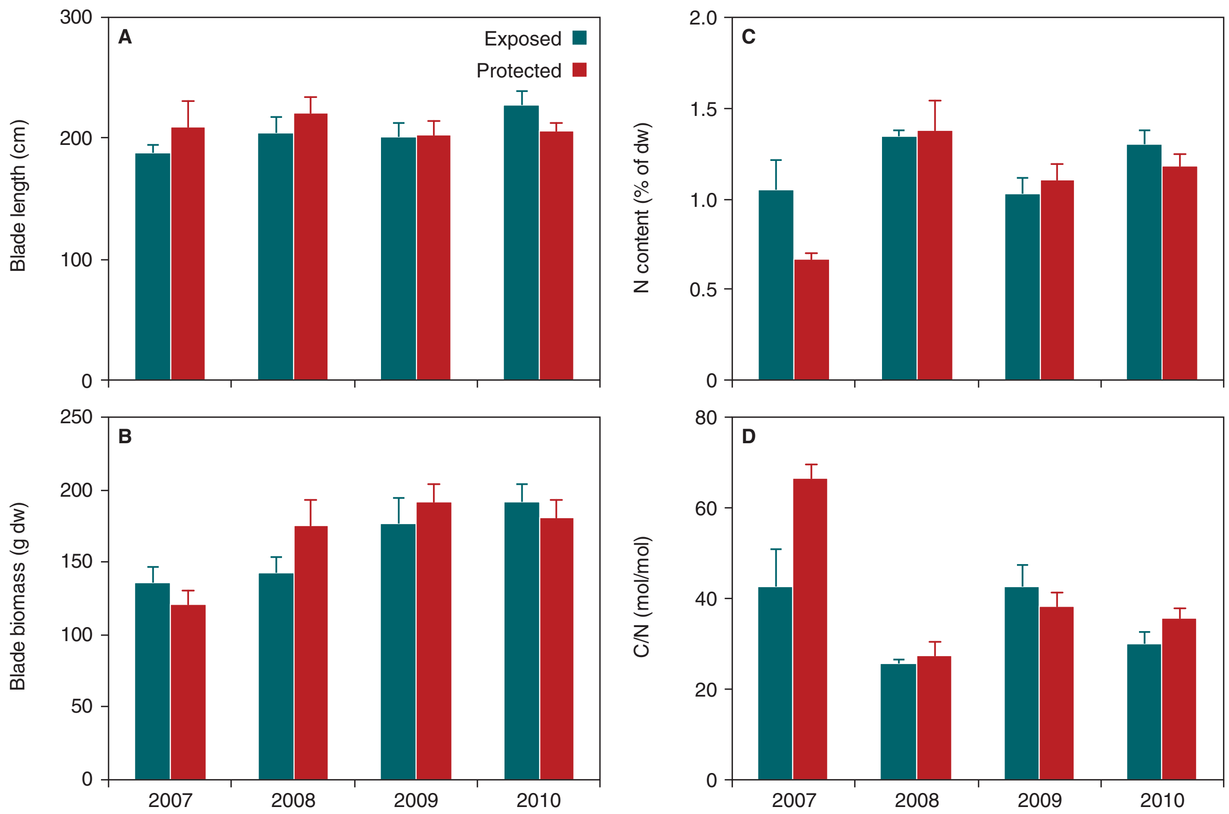
Laminaria and related species produce an annual blade, the size of which reflects growth conditions of the preceding year with respect to e.g. light availability and thus sea ice cover. The size of the annual blade is therefore selected as a monitoring variable. In higher latitudes the annual growth of sugar tangle, *Saccharina latissima*, can be estimated based on a single sampling in late summer, since the new blade is separated by clear constrictions from the old blade, which may remain for 1-2 years (Lund 1951, Dunton 1985, Borum et al. 2002). At lower latitudes like in Nuuk the blades are turned over at faster rates, however, and the tip may be worn off before the annual growth is completed. *Laminaria longicruris* shares many morphological characteristics with *S. latissima*, and also produces a new blade each year, but does not seem to form as clear constrictions between years as do *S. latissima*.

In Kobbefjord, *L. longicruris* is a dominant kelp, while *S. latissima* has not been recorded. The programme therefore uses the size of the annual blade of *L. longicruris* as a monitoring variable. Because of fast growth rates and wearing off at the tips, the new blades are typically long but lack their extremity by the end of summer, and blade size therefore reflects a minimum estimate of annual growth (Juul-Pedersen et al. 2009).

L. longicruris was collected by diver at 5-6 m depth in the outer, southern part of Kobbefjord on 17 August 2010. A total of 18 mature specimens having blades longer than 1.5 m was collected at a protected site where sea ice is expected to form in winter (64°08.408’N; 51°35.158’W) and 17 specimens were collected at an exposed site with less sea ice (64°07.782’N; 51°37.113’W). As *Laminaria* was grazed down by sea urchin at the usual exposed sampling site, we sampled a few hundred meters closer to the mouth of the fjord compared to 2007-2009. At the original sampling site, remains of some stems and blades were still being grazed and thereby evidenced the cause of the loss of the population.

The size of the blades did not show any consistent difference between the protected and the exposed site over the monitoring period 2007-2010 (figure 5.23; left panel), even though the sites likely experienced differences in sea ice cover. Apparently, Kobbefjord was moderately covered by sea ice during the winter 2007/2008, markedly covered in the winter 2008/2009 (3-4.5 months in 2007/2008 and 5.5 months in 2008/2009, Hansen et al. 2010) but only slightly covered during the winter 2009/2010 (satellite images indicate that the fjord was free of ice all winter: http://ocean.dmi.dk/arctic/nuuk.php). In particular, during 2009, algae at

Figure 5.23 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 in September 2007 and August 2008-2010.*



the protected site were likely to have experienced a longer ice covered period and thus to have received less incoming light than those at the protected site, but there was no difference in growth rate between the two sites. 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).

The average length of the blades was relatively similar between years as well, varying from a minimum of 188 cm at the exposed site in 2007 to a maximum of 227 cm at the same site in 2010 (figure 5.23; left panel). The biomass of the blades varied more between years, showing a minimum of 120 g dw at the protected site in 2007 and a maximum of 192 g dw at the exposed site in 2010. The generally low values recorded in 2007 could be related to the later sampling that year (September) than the following years (August), resulting in a larger risk of blade erosion by autumn storms.

Nitrogen and carbon content also did not show any consistent differences between the two sites. In most years, N-le-vels and C/N-levels at the two sites were relatively similar, only 2007 showed a marked difference with an extremely low N-content and an extremely high C/N-ratio at the protected site. Overall N-levels varied with a factor of about 2 from a minimum of 0.67% at the protected site in 2007 to a maximum of 1.38% at the same site in 2008 (figure 5.23; right panel). The C/N levels ranged from a minimum of 26 at the exposed site in 2008 to a maximum of 67 at the protected site in 2007 (figure 5.23; right panel).

*Kittiwake (*Rissa tridactyla*).*
Photo: Carsten Egevang.

The nitrogen content reflects the balance between demand and supply. In winter, when the supply of inorganic nutrients is relatively high and the demand low, nitrogen reserves build up, and are drained during the following summer when the demand is high and the supply 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 in late summer, as carbohydrates have been built up by photosynthesis over 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 2008-2010. The differences in levels of nitrogen content and C/N ratio between August samplings of 2008-2010 must reflect additional year-to-year variation in supply and demand of N and carbon storage (figure 5.23; right panel).

With four years of data, the last three representing August, we see that the blades of the kelp vary around a mean length of about 2.1 m, a biomass of about 176 g dw, a nitrogen content of about 1.2% dw and a C/N ratio of about 33 at the two sites (mean of the last three years of data). As the blades apparently do not reflect the expected differences in sea ice cover between sites nor between years, quite large variations in growth conditions are likely needed to identify a significant change in blade size of *Laminaria longicruris*.

5.6 Seabirds

Two major seabird colonies near Nuuk are included in the MarineBasis programme. Additional seabird colonies in the Nuuk area have been visited since 2007. Among them, the kittiwake (*Rissa tridactyla*) colonies of the Godthåbsfjord (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 (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 that holds the largest diversity of

Table 5.4 Breeding seabirds (pairs (P), individuals (I) or Apparently Occupied Nests (AON)) at Qeqertannguit since 2006.

Year	2010		2009		2008		2007		2006	
Species	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**
Black-legged kittiwake (*Rissa tridactyla*)	42	AON	55	AON	20	AON	45	AON	45	AON
Iceland gull SE side (*Larus glaucoides*)	31	AON	40	AON	33	AON	82	AON	118	AON
Iceland gull NV side	13	AON	19	AON	12	AON		AON*	–	AON
Great black-backed gull (*L. marinus*)	40	P	24	P	44	P	38	P	46	P
Lesser black-backed gull (*L. fuscus*)	27	I	21	I	25	I	11	P	10	P
Glaucous gull (*L. hyperboreus*)	4	P	5	P	13	P	14	P	10	P
Herring gull (*L. argentatus*)	0	P	1	P	2	P	1	I	–	P
Arctic tern (*Sterna paradisaea*)	54	I	150	I	0	I	150	I	150-220	I
Arctic skua (*Stercorarius parasiticus*)	2	P	2	P	2	P	2	P	2	P
Black guillemot (*Cepphus grylle*)	790	I	637	I	689	I	562	I	615	I
Red-throated diver (*Gavia stellata*)	0	P	1	P	1	P	1	I **	1	P
Red-breasted merganser (*Mergus serrator*)	1	P	0	P	3	P	4	P	observed	

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

breeding seabirds in the Nuuk District. Especially surface feeders such as gulls (*Laridae*) and arctic tern (*Sterna paradisaea*) are well represented at the site (table 5.4). Counts of the entire island were conducted 3 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 side, using a boat as platform while all other counts were conducted on land.

Other birds observed 3 June (not considered breeding or not systematically censured) included one long-tailed duck (*Clangula hyemalis*), several snow buntings (*Plectrophenax nivialis*) and one Red-breasted merganser (*Mergus serrator*). Black-headed gull (*Chroicocephalus ridibundus*) was observed on the island 17 May.

The arctic tern colony appeared not to have active breeders 3 June, when 54 birds were observed. On 17 May, about 80 individuals was observed. The colony was not revisited later in the season to see if they actually bred this year.

The number of breeding kittiwakes and Iceland gulls were about average of the numbers since 2006, fewer than in 2010, but more than in 2008. Breeding of arctic terns have not been confirmed in recent years. The number of great black-backed gull (*Larus marinus*) was similar to numbers before 2009. Numbers of the other bird species are similar to former counts (table 5.4).

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 and illegal species (e.g. Iceland gull, lesser 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* 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. Unfortunately, the weather prevented an attempt to count the colony 5 July at the usual time visiting the colony (table 5.5). A visit to the colony 17 June gave a count of 300 Brünnich's guillemot, 25 common guillemots and three hybrids. However, the colony was too disturbed to consider the numbers representative.

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 is usually carried out. This is interesting in the context of climate change in which the proportion of common guillemot could be expected to increase in a warmer climate (table 5.5).

Table 5.5 Counts of breeding seabird (individuals = I) at Nunngarussuit since 2006.

Year	2010	2009	2008	2007	2006	Unit
Species	**No.**	**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

Other seabird observations near Nunngarussuit

- Simiutat (63013) 5 July: Unfortunately, the weather was very foggy during an attempt to reach the colony.
- Qarajat qeqertaat (63019) 5 July – the site consists of two islands:
- West Island: Common eider: 47 nests found (six empty showing signs of predation), average of 2.9 eggs in the remaining. One nest with young. Numbers of apparently breeding individuals were 19 great black-backed gulls, 10 lesser black-backed gulls, two glaucous gulls, four herring gulls (one nest with one egg, probably two nesting pairs), three arctic skuas (light morph) and 229 black guillemots. No breeding arctic terns.
- East Island: Eleven nests of common eiders found (two empty, none with chicks, average of 3.8 eggs in nests with eggs), two purple sandpiper adults, 145 black guillemots, three arctic skuas (one light two dark morphs), 30 great black-backed gulls, two lesser black-backed gulls, two glaucous gulls, and snow bunting feeding young.

Twenty common eiders were counted on the water around both islands. No breeding arctic terns were seen on any of the islands. There were no signs of foxes or ground predation.

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

The number of kittiwakes and Iceland gulls at the four remaining kittiwake colonies in the Godthåbsfjord, are listed in table 5.6 including counts since 2006.

The total number of kittiwakes of the four colonies has a somewhat different pattern than the Qeqertannguit numbers alone (highest and lowest number in 2008 and 2007 respectively). This indicates some movement of birds between the colonies and the necessity to survey all the colonies of the fjord system to monitor the local population trends. The numbers of Iceland gulls have been monitored regularly in four colonies since 2008 and more consistent counts of this species at these four colonies will turn out valuable although there are a few more minor colonies of Iceland gull in Godthåbsfjord.

Remaining species in the four colonies observed in 2010 were:

- Innaarsunnguaq (64015): 34 razorbills and 100 black guillemots 27 April 36 razorbills (six on cliff and 30 on the water) and several black guillemots 4 June.
- Kangiusaq (64018): 32 black guillemots 4 June.
- Alleruusat (64022): 10 great cormorants observed but not breeding 27 April.
- Innajuattoq (64019): 112 black guillemots, 29 (eight nests) of great cormorants and three red breasted merganser 4 June.

5.7 Marine mammals

West Greenland is a summer feeding ground for an estimated 3000 humpback whales, *Megaptera novaeangliae* (Heide-Jørgensen et al. 2008). Most of them stay on the off-shore banks, but some visit the fjords and bays to feed on zooplankton and capelin, *Mallotus villosus* (Heide-Jørgensen and Laidre, 2007). In the 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. Furthermore we investigate

Table 5.6 Counts of breeding kittiwakes (Kit) and Iceland gulls (Ice) at the remaining four kittiwake colonies of the Godthåbsfjord fjord system.

Year	**2010**		**2009**		**2008**		**2007**		**2006**	
Colony / Species	**Kit**	**Ice**	**Kit**	**Ice**	**Kit**	**Ice**	**Kit**	**Ice**	**Kit**	**Ice**
Innaarsunnguaq (64015)	16	477	12	435	33	961(I)	62	–	240 (I)	1580 (I)
Kangiusaq (64018)	370	277	284	261	450	494(I)	217	300	–	–
Alleruusat (64022)	260	100	164	80	369	140	276	45	–	–
Innajuattoq (64019)	375	335/1535(I)	458	1553(I)	309	1497(I)	302	342	–	–
Total	**1021**		**918**		**1161**		**857**		**0**	

residence time and the degree of site fidelity in humpback whales (i.e. individuals returning to the same area in different years) to better understand the behavioural ecology of the whales present in the fjord.

Photo-identification is a technique used to identify individual animals from photographs showing natural markings such as scars, nicks and coloration patterns. In humpback whales, the ventral side of the fluke can be used for identification (Katona et al. 1979) as the tail contains individual colour patterns, which are different in a way comparable to human fingerprints (figure 5.24). Here, photo-identification pictures are used to estimate the minimum number of individual humpback whales entering the Godthåbsfjord each summer. In addition, photo-identification pictures are used to determine residence time and the degree of site fidelity by comparing ID photos from consecutive years in Godthåbsfjord (Boye et al. 2010). Photo-identification can, in combination with

Figure 5.24 Photo identification pictures of two different humpback whales (WG_0021 and WG_0038) in Godthåbsfjord in 2010 from the Greenland Institute of Natural Resources archive.

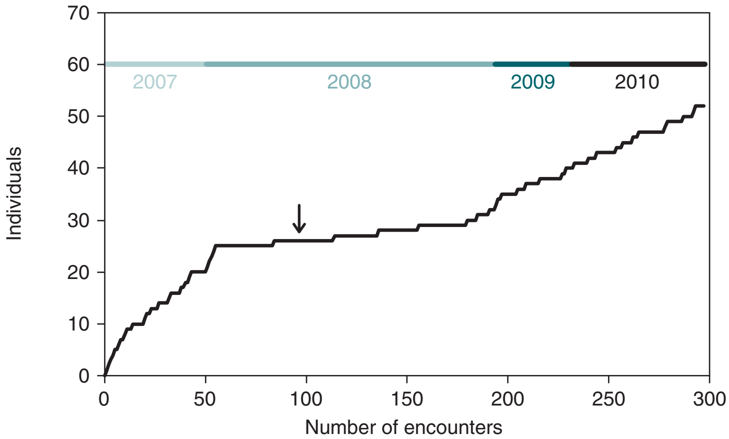


Figure 5.25 A discovery curve of humpback whales in Godthåbsfjord. The plateaus of the curve (exemplified by arrow) illustrate encounters with previously identified individuals.

mark-recapture analysis, be used for estimating abundance of animals in a specific area. However, as the humpback whales in Godthåbsfjord are part of an open population covering the Greenlandic West coast, mark recapture methods cannot be applied when estimating abundance of humpback whales in Godthåbsfjord.

Photo-identification of humpback whales in Godthåbsfjord has been carried out in the period 2007-2010 using a 350 EOS Canon camera with a 300 mm lens. During the four-year period a total of 297 ID photos have been collected in cooperation with whale watching tour operators in Nuuk and local whale watching boats. From the 297 ID photos, 52 different individuals have been identified in Godthåbsfjord from 2007-2010, of which 12 new individuals were identified in 2010. Two of these had actually been identified in 2004 and 2006, previous to the start-up of this project in 2007 and others were calves accompanied by either new or known grown-up individuals. New individuals are identified in the fjord system each year. Hence, the 'population' of humpback whales in Godthåbsfjord is an open population in which animals move in and out of the fjord during the season. This is also obvious from the discovery curve in which new animals keep being added to the 'population' of photographed individuals (figure 5.25).

Despite the open population of humpback whales in Godthåbsfjord, the four years of photo-identification data show a strong degree of site fidelity for several of the individuals visiting Godthåbsfjord (table 5.7). Of the 20 whales identified in 2007, seven (35 %) were present in 2010. Of the 20 whales identified in 2008, 10 (50 %) returned in 2010 and of the 15 whales identified in 2009, seven (46.6 %) were re-identified in 2010. This gives a re-sight rate between 35-50 % regardless of the open fjord system and the possibility to migrate in and out freely. For the entire four year period the re-sight rate is however smaller. Of the 40 different individuals identified from 2007-2009, a total of 13 (33 %) were re-identified in 2010. The identification data so far shows that while the majority of the individuals are only spotted in one year during the four year period, more than a quarter of the individuals are re-sighted in at least two different years within the four year period. Furthermore, the individuals that show site fidelity towards Godthåbsfjord also constitute the majority of sightings within a year. Hence, individuals with greater site fidelity have a longer residence time within Godthåbsfjord than new individuals.

There appear to be a limited number of whales within Godthåbsfjord during the entire feeding season. From 2007-2010 the number of identified whales within the fjord has not exceeded 25 individuals per year. The lowest number of whales identified was in 2009, where only 15 whales were identified. However, the effort in 2009 was low. In all years, it is likely that individuals may have been missed. Therefore, the estimate of 15-25 individuals per year is most likely an underestimate of the actual number of whales visiting the fjord.

Table 5.7 Re-sight rate of humpback whales in Godthåbsfjord during the period 2007-2010.

				No. of whales seen in each subsequent year		
Year first seen	**No. ID photos**	**ID**	**New ID**	**2008**	**2009**	**2010**
2007	49	20	20	8 (40.0)	6 (30.0)	7 (35.0)
2008	134	20	12		6 (30.0)	10 (50.0)
2009	38	15	8		–	7 (46.6)
2010	67	25	12*			–
Total	297	80	52			

ID = no. of individuals identified from the ID photos, New ID = no. of new individuals the given year
*Two individuals have been sighted in Godthåbsfjord in 2004 and 2006. Numbers in brackets are percentages

6 NUUK BASIC

Research projects

6.1 Heat sources for glacial melt in a sub-arctic fjord (Godthåbsfjord) in contact with the Greenland Ice Sheet

John Mortensen, Kunuk Lennert, Jørgen Bendtsen and Søren Rysgaard

Recent warming of Subpolar Mode Water off Greenland has been suggested to accelerate the mass loss from tidal outlet glaciers of the Greenland Ice Sheet. We present a comprehensive analysis of water masses, dynamics, and inter-annual hydrographic variability in Godthåbsfjord, a sill fjord in contact with tidal outlet glaciers on the west coast of Greenland. Through seasonal observations we recognize an intermediate baroclinic circulation mode driven by tidal currents and an associated important local heat source for the fjord. During summer this results in significant warming and freshening of the intermediate layer of the main fjord, and the increase in heat content is equivalent to melting of 2.1 km^3 of glacial ice. This is comparable to 8 km^3 glacial ice discharge estimated from the Kangiata Nunâta Sermia calving front per year. During winter the external heat source in the West Greenland Current enters the fjord as intermittent inflows of either cold (<2 °C) or warm (>2 °C) dense water in pulses of one to three months duration. Four distinct circulation modes are observed in the fjord, of which all can contribute to glacial ice melt. An important aspect of the ice distribution in the fjord is that only a minor fraction is exported out of the fjord (Mortensen et al. 2011).

Godthåbsfjord. Photo: Peter Bondo Christensen.

6.2 Dana cruise in Godthåbsfjord

Karen Riisgaard

On 6 June 2010 the Danish research vessel 'Dana' left the harbour of Nuuk, West Greenland, to carry out an extensive field investigation on the complex interaction between climate changes and the marine food web. Twenty-two international scientists participated in the three-week long cruise from Fyllas Banke outside Nuuk to the inner part of Godthåbsfjord. The overall aim for the cruise was to investigate the impact of changing climate on ocean circulations and biological processes in a subarctic marine ecosystem. As the research vessel moved into the fjord, it followed a climate gradient from high saline warm Atlantic water outside the fjord to cold water influenced by glacial melt water runoff in the innermost parts of the fjord.

The hydrography was mapped along the transect and field samples were collected at each station. Special emphasis was put on factors controlling vertical carbon fluxes and the biology of selected pelagic organisms including fish larvae, krill, copepods, jelly fish, microzooplankton and bacteria (figure 6.1).

Figure 6.1 Sampling zooplankton onboard R/V Dana. Photo: Thomas Juul-Pedersen.

The cruise successfully collected more data than expected due to calm weather. The data collected on the cruise will be used to develop models of the circulation in the fjord and allow scientists to forecast how the system will respond to climate change.

More information about the cruise, BOFYGO (Biological Oceanography at Fyllas Banke and in Godthåbsfjord), can be found at www.aqua.dtu.dk.

6.3 The Atlantic cod (*Gadus morhua*) in Greenlandic waters: Past and future during climate change

Einar E. Nielsen, Peter Grønkjær, Mary S. Wisz, Kaj Sünksen, Rasmus Hedeholm and Nina O. Therkildsen

The marine resources in Greenland have great commercial and cultural importance for the Greenland society. The climatic changes in Greenland are expected to have a crucial effect on the future distribution and productivity of various fish populations. One species expected to increase its Greenlandic distribution and productivity in a warmer climate is the Atlantic cod. Using a combination of genetic, biological and chemical analyses, this project attempts to understand and predict the population dynamics of Atlantic cod in Greenland waters.

Historically, the distribution and size of the Atlantic cod population has been highly variable. However, knowledge of the processes governing this variability has been scarce. Firstly, fundamental knowledge on the number of genetically and ecologically isolated populations that exist is needed together with investigations of whether or not these populations have separate dynamics. To address hypotheses regarding population structure, spawning cod have been sampled from both in- and offshore locations on Greenland's east and west coast (figure 6.2). This provides a genetic baseline allowing for identification of the population origin of a given individual cod. Using the Greenlandic collection of cod otoliths collected over the past century and new techniques to extract DNA from them, the population structure at various time during the past century can be compared to the contemporary baseline.

Another important factor in determining cod productivity is feeding potential. Since preferred cod prey is known to shift distribution and productivity partly in response to climatic changes, cod productivity will expectedly also change. However, historical information on prey distribution is sporadic and information on actual cod prey choice is virtually absent. Using a novel technique to extract protein from the historical otoliths, the feeding of cod and possible changes are described using stable isotope analyses. This will document not only the trophic level of feeding but also any shift between pelagic and benthic feeding. In support of this, an extensive study on the isotopic signature of the food web along the Greenland coast has been carried out in 2010.

These data on population structure and feeding, along with knowledge on current cod distribution, current climate and future climate scenarios, will be combined and used in landscape genetics. This modelling approach will integrate the knowledge obtained about the system and the Atlantic cod's response to changes. This will in turn allow for predictions on future cod populations changes in Greenland, forming the quantitative background for initiating objective precautions to ensure sustainable management of the Atlantic cod in Greenland.

6.4 Developing guidelines for sustainable whale watching with special focus on humpback whales

Tenna Boye, Malene Simon and Fernando Ugarte

Whale watching is an increasing industry worldwide and in Greenland. Unregulated whale watching in Godthåbsfjord can have a short-term negative effect on humpback whale behaviour in terms of increased speed, fewer surfacing and abbreviated dives (Boye et al. 2010). Potential consequences of these quantified behavioural changes include reduced foraging and increased energy consumption. It is not known to what extent these short term effects can accumulate to long-term effects on various fitness parameters such as skipped breeding, lower fecundity and reduced calf survival. As humpback whales are often approached closely by both commercial and private whale watching boats in Godthåbsfjord, the aim of the study was to test a set of whale watching guidelines to help whale watching become more sustainable.

From May to September 2010, the behaviour of humpback whales and whale watching boats in Godthåbsfjord were recorded. Observations were then divided

Figure 6.2 Collecting cod specimens for sampling. Photo: Rasmus Hedeholm.

into the three categories, according to the presence and behaviour of whale watching boats: *undisturbed* (i.e. no boats), *boats following guidelines* and *intensive whale watching*. The blow rates of humpback whales along with surfacing/dive ratio for each category were calculated (figure 6.3).

Previous observations of blow rates and dive patterns collected in 2006-2008 were included in the data analyses to increase the number of observations as humpback whales proved hard to find during 2010.

Our results indicate that whales under the influence of intense whale watching tended to have a higher blow rate and a reduced number of surfacing before each dive as compared to undisturbed whales and whales under the influence of whale watching boats following guidelines.

Although data was not sufficient to make conclusive statements on the guidelines tested, the results did signify a positive outcome on whale behaviour around whale watching boats following guidelines, and based on the preliminary results we recommend the following set of guidelines:

- Slow down to 'no wake' when within 500 m of the whale
- Do not approach the whale directly from behind or in front
- Do not actively move closer to the whale than 50 m

6.5 Climate effects on land-based ecosystems and their natural resources in Greenland

Mads C. Forchhammer and Erik Jeppesen

This project collects existing and new data on land-based ecosystems in Greenland with the objective of investigating how the expected changes in climate will affect terrestrial and limnic ecosystems and their natural resources. Combined with data from detailed studies in West and East Greenland, respectively, we apply up-to-date analytical techniques to quantify the spatio-temporal relationships between previous changes in natural resources, their environment and climate. These data will form the basis for implementing predictive models to be used under different climate scenarios. Hence, our project will provide an assessment of future performance of land-based natural resources in a warming Arctic.

The terrestrial component

In the projects first year, 2010, efforts were primarily focused on establishment of terrestrial and limnic plots along the environmental gradient of Nuup Kangerlua. A total of 12 terrestrial sites were visited during June 2010, where the landscape structure and distribution of vegetation types were generally identified and described.

Figure 6.3 Counting the blows of a humpback whale. Photo: Maria Iversen.

Furthermore, a number of samples from *Salix glauca* and *Betula nana* were collected for dendrological analysis. Based on the overall evaluation of the 12 sites, three sites were selected for long-term monitoring of vegetation and herbivores. Several of the dwarf shrubs sampled were over 50 years old and one even 94 years old (figure 6.4), providing a unique opportunity to describe and contrast decadal and inter-annual variations in the vegetation along Nuup Kangerlua.

Preliminary results indicate that there is a clear gradient from the estuary of the fjord to the Greenland Ice sheet, where the innermost sites exhibit relatively highest annual growth. Furthermore, in years with extreme climatic conditions during winter (expressed in high or low indices of the North Atlantic Oscillation), there is an increased synchronization of vegetation growth along the entire fjord.

The limnic component

In late summer 2010, a survey of 13 lakes was completed by an international team of scientists and students from six countries (Denmark, Spain, Brazil, Turkey, Germany and England). The aim was to provide a first limnological description of the lakes and to identify food chains and biological interactions in lakes, including the use of stable isotopes.

The lakes ranged in size from 0.3 to 380 ha and in depth from 0.6 m to 152 m. Water clarity was moderately high in all lakes and highest in the deep lakes, with a maximum of 11.6 m. Three of the lakes were without fish, one had only trout, while the rest of the lakes contained both char and three-spined stickleback. In lakes with fish, the catches with survey nets were very variable. Total catches in lakes ranged between 1 and 138 fish per net per night and for trout between 1 and 13.

These results and the first visual impression of samples taken suggest a very large effect of fish on the zooplankton and macro-invertebrates, on plants and in the sediment, with secondary effects on phytoplankton (higher biomass of fish) and biofilm on stone in the edge zone of the lakes (much larger biomass here if fish are present). The effects are far greater than we have seen in Northeast Greenland, and attributed to higher nutrient levels determined by a warmer climate, which enables more extensive plant growth in lakes basins and a major weathering.

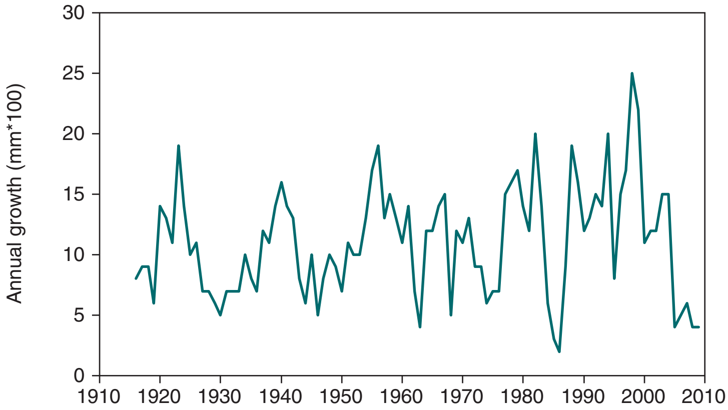


Figure 6.4 Time series of the width of annual growth rings in a Betula nana *sampled at the estuary of Nuup Kangerlua. The individual was 94 years old.*

Finally, sediment cores (30-80 cm of length) were sampled from the deepest of the lakes (figure 6.5) to analyze biological remains in the sediment in order to describe changes in biodiversity and trophic structure and biological interactions in the past centuries. These samples are now being processed.

The ecosystem data generated at the Greenland Ecosystem Monitoring (GEM) sites, Zackenberg and Nuuk, are important components of this project and so far, one PhD has started focussing on the phenology of the terrestrial and limnic habitat systems. As a novel measure of outreach, the project has its own Facebook page, where activities, results and education are announced on a regular basis (http://www.facebook.com/pages/ GCRC-Projekt-6502-Landbaserede-okosystemer-ressourcer-og-klima-i- Gronland/127979750567866).

Figure 6.5 Sediment core taken from the bottom of one of the lakes at station 1. The layered structure of the core is clearly visible. Photo: Erik Jeppesen.

7 Disturbance in the study area

Josephine Nymand

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 boats 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 snowmobile – 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 2010, there were only few interactions between visitors in the study area and the different setups and the research hut. Foxes have been eating wires connecting temperature probes with loggers (TinyTags) in the ITEX-plots; they have physically moved TinyTags, moved pit-fall traps, dug up some 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 i.e. transportation between Nuuk and the head of the fjord, housing of personnel, walking between study plots and around study plots.

Transportation between Nuuk and the study site in Kobbefjord was on an irregular basis, but during most of the season, there was transportation two to three times a week (mainly on Tuesdays and Thursdays). During most of the season, the research hut was used temporarily by two to four persons.

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

In conclusion, it is estimated that monitoring activities only had minor impact on the vegetation and terrain.

8 Logistics

Henrik Philipsen

In 2010, Greenland Institute of Natural Resources took care of the logistics related to Nuuk Basic in Kobbefjord.

The 2010 field season in Kobbefjord was from 7 January to 16 December. During this period, 38 scientists and logisticians spend approximately 360 'man-days' and 75 'man-days' respectively, in the study area.

The winter of 2009/2010 was very mild with almost no ice in Kobbefjord. It was possible to sail to the bottom of Kobbefjord with Greenland Institute of Natural Resources boats 'Erisaalik' and 'Aage V. Jensen II Nuuk' during the entire year.

Greenland Institute of Natural Resources carried out transportation of staff, construction workers, scientists and guests from Nuuk to the study area in Kobbefjord with the boats 'Aage V. Jensen II Nuuk' and 'Erisaalik'. The total number of sailing days to Kobbefjord used by Logistics, BioBasis, GeoBasis and ClimateBasis was 63 in 2010. MarineBasis used 35 sailing days to go to the study areas in Kobbefjord and Godthåbsfjord.

In 2010, scientists spend 99 bed nights in the research hut in Kobbefjord. In Nuuk, the Nuuk Basic scientists were accommodated in the annex of Greenland Institute of Natural Resources, with 263 bed nights.

Water for drinking and other purposes were taken from the nearby river. Electrical power was provided by two portable 2 kW gasoline generators from 2008.

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

Aage W. Jensen's Charity Foundation has financed the two huts in Kobbefjord. The research hut has a ramp for skidoos, a terrace and 11 m² storage room under the living room. The hut is fitted with an entrance, laboratory with hot and cold water, bathroom with closet and shower, living room with kitchen, four berths and an oven. A generator hut houses the generator and is equipped with a ramp and a working bench.

15 April 2010, a Eurocopter AS 350 Ecureil B2 helicopter from Air Greenland made one sling with a skidoo plus one flight with a group of Geo- and Climate-Basis scientists from Nuuk to Kobbefjord. The scientists carried out snow monitoring in the area using the skidoo. 16 April 2010, the same helicopter picked up the scientists and flew them to Nuuk.

17-18 May 2010, minor construction work and furnishing of the two huts was carried out by two carpenters from BJ Enterprise A/S (extension and covering of the 1000 litre water tank) and logisticians from Greenland Institute of Natural Resources to complete the interior of the huts.

27 May 2010, Keld Hornbech Svendsen, Asiaq – Greenland Survey, and the head of a local construction company inspected river banks for future placement of a bridge.

1 June 2010, an Arctic fox was shot and killed after attacking a person just outside the research hut. A subsequent investigation showed that the fox had rabies.

In 2010, one riffle and two flare guns were bought for permanent use as polar bear protection in the Kobbefjord area.

Fuel consumption for the generators was 40 litres of diesel and 864 litre of gasoline. Freshwater consumption was 3200 litres.

A drainpipe for grey household water was connected from 1 June until 25 September.

256 kg non-burnable garbage was removed by ship to Nuuk during the season. Burnable garbage was burned on the site 25 June 2010.

The research area in Kobbefjord was during 2010 visited by several honourable guests:

6 May: Seven members of the Environment Committee from the Government of Greenland.

29 July: One teacher and five students from the Cirius programme, Copenhagen.

10 August: Charlotte Sahl-Madsen, Minister for Science, Technology and Innovation, Denmark; Mimi Karlsen, Minister for Culture, Education, Research and Church Affairs; Morten Meldgaard, Director of Natural History Museum of Denmark and six other attendants.

11 August: Nine teachers and PhD students with the IGERT-programme, Dartmouth, USA.

1 September: Klaus Nygaard, Director of Greenland Institute of Natural Resources and two persons from Aage V. Jensen Charity Foundation.

28-30 September: One teacher and 12 students from GU (High school), Nuuk

3 October: Nine members from the board of Greenland Institute of Natural Resources.

22 October: 20 students from a local school in Nuuk.

Snowmobile and AS 350 helicopter in Kobbefjord, April 2010. Photo: Henrik Philipsen.

9 Acknowledgements

MarineBasis wish to acknowledge the crew onboard the R/V 'Adolf Jensen' for their valuable assistance during the 2010 May Cruise. We also thank Anna Haxen, Lars Heilmann, Flemming Heinrich, Kunuk Lennert, Susanne S. Hvass, Sofie R. Jerimiassen, Sascha Schiøtt, Kaj Sünksen, Lars Witting, Finn Christensen, Andrzej Witkowski, Diana Krawczyk and Marek Zajaczkowski for field and technical assistance. MarineBasis also acknowledges Henrik Philipsen for co-ordinating the logistics of the programme.

Finally, we would like to acknowledge Morten S. Frederiksen, Carsten Egevang, Bo Bergstrøm and Ditte M. Mikkelsen for their contribution to the programme in previous years.

10 Personnel and visitors

Compiled by Lillian Magelund Jensen

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Peter Aastrup, National Environmental Research Institute, Aarhus University, Denmark

Please notice that the list of visitors is not complete as the Greenland Institute of Natural Resources has stopped their registration of visitors.

11 Publications

Scientific papers

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Reports

Andreasen, R.H. 2010: Influences on a low arctic ecosystem from spatiotemporal variations of insolation, soil moisture and temperature. Master thesis at Department of Geography and Geology, University of Copenhagen. 60 pp.

Blicher, M.E. 2010. Structure and dynamics of marine macrozoobenthos in Greenland – and the link to environmental drivers. PhD thesis. Greenland Institute of Natural Resources & Department for Biology, University of Copenhagen. Greenland Institute of Natural Resources, 162 pp.

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Juul-Pedersen, T. Oral presentation/education: Nordisk Klimadag 2010, Nuuk, Greenland, 22 Oktober, 2010.

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Versteegh, E.A.A., Blicher, M.E., Troelstra, S.R. and Dehairs, F. 2010. Oral presentation: Bivalve sclerochemistry as a proxy for past Greenland melt water runoff. 2nd International Sclerochronology Conference, Mainz, Germany, 24-28 July, 2010.

General information

Juul-Pedersen, T. Go North! Internet chat event with schools from around the world. Theme: "World Resources", Topic: "Ecology: Sustainable Development". 23 April, 2010.

Mikkelsen, P.S., Juul-Pedersen, T. and Batty, P. ICC Event – GCRC Stand. 28 June - 2 July, 2010.

Mikkelsen, P.S. and Juul-Pedersen, T. Climate change in Greenland. Taiwan TV. 15 September, 2010.

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13 Appendix

Day-of-year (DOY)

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

Day-of-year (DOY)

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