NERO

NUUK ECOLOGICAL RESEARCH OPERATIONS

6th Annual Report 2012

Aarhus University
DCE – Danish Centre for Environment and Energy

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AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

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Nuuk Ecological Research Operations (NERO) is together with Zackenberg Ecological Research Operations (ZERO) operated as a centre without walls with a number of Danish and Greenlandic institutions involved. The two programmes are gathered under the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in NERO:
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 Environmental Protection Agency
The Government of Greenland
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The participating institutions

Contents

Summary for policies makers

Lillian Magelund Jensen

The 2012 field season in the Kobbefjord area started 11 January and continued until 8 November. During this period 47 scientists and logisticians spent 381 and 30 'man-days' in the study area, respectively. The total number of 'bed-nights' at the research station was 142.

Greenland Institute of Natural Resources (GINR) received its new research ship in April 2012. The official naming of R/V 'Sanna' took place 14 April at Skonnertkajen in Nuuk.

The ship will be used primarily for the GINR´s monitoring programmes of the life stock of fish and shellfish in Greenlandic waters and for a broad spectrum of scientific research in the marine environment. The ship will also be a part of research and monitoring activities in connection with exploration for oil and gas and for mining activities close to the coast. The ship costs approximately 50 million DKK and is equipped for many different tasks within fishery, environmental and marine research.

In June 2012, GINR received a new boathouse and a new warehouse, which were both donated by Aage V. Jensen Charity Foundation. At the opening of the houses, 20 June, chairman Leif Skov from the Foundation presented a new gift: A donation of 2.25 million DKK for a new research vessel.

Nuuk Ecological Research Operation is involved in several larger international research projects. Greenland Ecosystem Monitoring (GEM) is involved in the EU projects 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT) and 'Svalbard Integrated Arctic Earth Observing System' (SIOS). In 2012, four projects received support for 137 bed nights from INTERACT Transnational Access. Researchers from the GEM programme are also involved in/associated with the Arctic Research Centre at Aarhus University and Arctic Science Partnership.

Results from the Nuuk Basic monitoring programme are continuously published in scientific papers and popular science articles. Furthermore, data from the Nuuk Basic programme is freely available and was in 2012 used for reporting purposes in a number of international fora and by a number of externally funded research projects.

In 2012, more than eleven scientific papers were publish by the researchers from the Nuuk Basic programme and from externally funded research projects.

Executive summary

Per Hangaard, Birger Ulf Hansen, Peter Aastrup, Thomas Juul-Pedersen and Lillian Magelund Jensen

Introduction

The year 2012 was the sixth year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was the fourth 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, two automatic hydrometric stations and three diver stations. The two climate stations are placed next to each other to ensure data continuity. Sixteen climate parameters (including two derived parameters) are monitored and data are stored in the database.

The mean annual air temperature in 2012 was 0.5 °C, which is just a little higher (0.3 °C) than the average for previous years. The temperatures in 2012 are generally comparable to previous years except for the mean air temperature of July, which was the highest mean temperature (12.1 °C) measured since the programme started. The frost-free period was also comparable to previous years.

All radiation data and data from the hydrological stations will be reported in the 2013 Annual Report.

GeoBasis

Data collected by the Danish Meteorological Institute shows that the 2012 annual mean air temperature in Nuuk reached 0.1 °C, which is 1.5 °C warmer than average. All months except March were warmer than average. Two months were especially warm – June with an average monthly temperature of 8.1 °C , which is 1.2 °C warmer than the previous warmest June (1888) and July with 10.4 °C which is 0.9 °C warmer than the previous warmest July (2008). The ice cover of the lakes in the Kobbefjord drainage basin started generally earlier in the winter 2011/2012 than in previous winters. The break-up of the ice-cover on the lakes was approximately five days later than average. When comparing the snow cover survey 2012 with the snow cover surveys in the three previous years, the maximum snow depth of 102 cm makes the winter 2011/2012 the second most snowrich winter since continuous measurements of snow depth started only exceeded by the winter 2010/2011. The average density for the sites was 348 kg m^{-3}, which is similar to the two previous winters.

At the micrometeorological stations in Kobbefjord, temperatures during spring and autumn were close to average, while June and July with respectively 9.2 and 11.7 °C showed the highest summer temperatures ever measured. In the first two months of 2012, the mean air temperature was in the average range, while March with –11.1 °C was a cold month compared to previous years.

The minimum river water temperature from ultimo May to mid-June was 2.1 °C, which was 1.5 °C higher than previous years. The water temperature peaked with a maximum temperature of 16.6 °C ultimo July, which was 3.3 °C higher and two weeks earlier than in 2011. pH shows the normal trend from 6.6 in the beginning of the field season to 7.1 in late October 2012.

In early June, when measurements started, CH_4 fluxes averaged 3 mg CH_4 m^{-2} h^{-1}. As the season progressed, emissions increased steadily and reached a peak in mid-July, amounting to approximately 7.5 mg CH_4 m^{-2} h^{-1}. Together with the result from 2009, this is the highest peak level on record so far. In 2010 and 2011, fluxes rarely reached above 4 mg CH_4 m^{-2} h^{-1}. The inter-annual variation at the site is thus large. The variation between years is likely related to variations in timing of snowmelt, meteorological conditions, and net primary production in the fen. After the CH_4 emission peak in mid-July, CH_4 fluxes decreased steadily and reached low levels around 1 mg CH_4 m^{-2} h^{-1} in October. Overall, the observed temporal CH_4 flux pattern of the Kobbefjord fen displays low shoulder season emissions with a dome-shaped peak during the growing season.

Eddy covariance measurements of the CO_2 and H_2O exchange in the fen were initiated 6 June and lasted until 31 October 2012. Highest daily spring emission (0.59 g C m^{-2} d^{-1}) was measured 14 June. As the vegetation developed, photosynthetic uptake of CO_2 started and 16 June, the fen ecosystem switched from being a net source to a net sink of atmospheric CO_2 on a daily basis.

The period with net CO_2 uptake in 2012 lasted until 31 August. During this period, the fen accumulated -73.1 g C m^{-2}, which is the highest uptake on record so far. Maximum daily accumulation rate amounted to -2.7 g C m^{-2} (measured 22 July), which also is in the higher end compared to previous years. By 31 August, respiration processes exceeded the fading photosynthesis and the ecosystem returned to be a net source of atmospheric CO_2. Highest daily emission during autumn was measured 19 September (1.5 g C m^{-2} d^{-1}). During the entire measurement period (146 days), the fen constituted a sink for atmospheric CO_2 amounting to -33.4 g C m^2.

In 2011, GeoBasis installed a new energy balance station in cooperation with an INTERACT project. The station was located at a new site over a heath vegetation.

BioBasis

The year 2012 had an intermediate timing of snowmelt.

The reproductive phenology of the evergreen dwarf shrub *Loiseleuria procumbens*, the herb *Silene acaulis*, and the shrub *Salix glauca* was followed. The total flower production in some of the individual plants was very low and this may be a result of the impact from noctuid moth larvae the two previous years. However, *Silene acaulis* had the highest number of flowers ever recorded. The timing of 50 % flowering was similar to previous years.

The flower bud production of *Loiseleuria procumbens* occurred approximately two weeks later than in 2010, which was the earliest year of the five years of recording. A second flower bud production occurred in early October more than 40 days later than in 2010, when two budding events also were observed. The onset of flowering 12 June and senescence 18 June was two weeks later than in 2010. *Silene acaulis* displayed the same pattern as *Loiseleuria procumbens* with respect to the timing of budding, flowering and senescence compared to 2010. *Salix glauca* also had a two weeks delay in flower bud production compared to the earliest year 2010.

No noctuid moth larvae, *Eurois occulta*, were found during the season.

The vegetation greenness in three of the four *Empetrum nigrum* plots was the highest ever recorded during most of the growing season. The increasing greening during the growing season is more or less pronounced in all years but this year more than other years. The plants seem to have recovered completely from the 'brown' conditions last year. The highest NDVI values of *Eriophorum angustifolium* were recorded in the middle of the growing season and in three of the four plots, they exceed the values of previous years. In three of the four plots of *Loiseleuria procumbens*, the NDVI-values were within the range of previous years. The three *Salix glauca* plots were almost on the average of previous years. In 2012, the shape of the NDVI-curve was similar to all previous years except 2011, which was exceptional because of the larval outbreak of the noctuid moth, *Eurois occulta*. *Silene acaulis* had generally the lowest NDVI values of all the species monitored and the values were at the same level as the previous three years.

Generally, the NDVI values were significantly higher than previous years and they stayed at a high level throughout the growing season.

The species composition and vegetation structure of the plant communities dominating the landscape at Kobbefjord was investigated by detailed vegetation analyses in the following major vegetation types: 1) dwarf shrub heath, 2) *Deschampsia flexuosa-Juncus trifidus* plant community, 3) fen, 4) copse, and 5) snow patch.

All plots generally functioned as sinks for atmospheric CO_2 at the time of the measurement (midday). In May, net ecosystem exchange (NEE) was generally close to zero. As in previous years, NEE was more negative in the control plots compared to the plots with temperature increase and the shading plots. Highest rates of gross primary production (GPP) were generally observed in control plots, while especially shaded plots had lower GPP rates compared with other treatments.

The ambient UV-B radiation on fluorescence parameters was monitored on *Vaccinium uliginosum* and *Betula nana*. The total performance index (PI_{total}) is an indicator of the viability of a sample. PI_{total} were sensitive to UV-B exclusion in both *Vaccinium* and *Betula*. The average PI_{total} was improved by around 11% in *Vaccinium* and around 24% in *Betula.*

Pitfall traps were established from 25 May through 5 June and they all worked continuously until 2 October when the liquid began to freeze.

Both Lapland and snow bunting arrived very early in the spring, most of them before the first census of the year. The timing of the migration out of the area was a little later than during most previous years, but the number of birds in the area was similar to most previous years.

The high temperatures in 2012 are reflected in the temperature profiles from Badesø and Qassi-sø as illustrated by a strong temperature increase in the upper 10 metres water layer in June and July in Qassi-sø, which has not been observed in previous years.

Chlorophyll *a* levels were similar in the two lakes, which mean that the generally lower Secchi depth in Qassi-sø than in Badesø was created by a glacial run-off, causing higher input of silt to Qassi-sø.

In general, there is no consistent pattern of which lake have the highest total zooplankton biomass. Zooplankton use phytoplankton as a food source and a higher phyto-/zooplankton ratio in Badesø than in Qassi-sø is probably an effect of/related to the fish predation on zooplankton in Badesø.

The phytoplankton in Badesø and Qassi-sø was dominated by flagellated mixotrophic species, mainly chrysophytes, dinoflagellates, and cryptophytes. This dominance was more pronounced in Badesø than in Qassi-sø during the entire phytoplankton succession period. A most remarkable difference in phytoplankton between the years is the occurrence of cyanobacteria *Oscillatoria* and *Anabaena* in Badesø in 2011 and 2012. Cyanobacteria are usually associated with highly eutrophic waters.

MarineBasis

Sea ice was limited to the innermost part and smaller fjord branches of Godthåbsfjord, as it has been seen in previous years. Sea ice partly melted locally but was also exported from the fjord in seasonal bursts. Glacial ice also added to the seasonal melt water and seaward export of ice. Unfortunately, data from the Baffin Bay is missing from 2012, due to technical problems with the satellite collecting the AMSR satellite images.

Hydrographical measurements of salinity, temperature, fluorescence and light along a length and cross section of the fjord was conducted in May. These transects depicted a relatively weak stratified water column within and outside the fjord, while the outer sill region (i.e. fjord entrance) showed largely homogenous vertical conditions due to tidal mixing. The central parts of the fjord along with Fyllas Banke showed high phytoplankton biomass in the surface mixed layer, as reported in previous years. Moreover, the cross section showed that a stronger seaward export occurred along the north-western coastline of the fjord (Akia), mainly due to the Coriolis Effect. Monthly hydrographical measurements at the Main Station at the outer sill region, furthermore, showed that the relatively weak stratification observed in spring was strengthened during summer. Increased terrestrial run-off and melt water, along with atmospheric heat exchange and solar heating, reinforced the stratification to withstand tidal forces at the outer sill region, as it has been described in previous years.

Highest primary production was recorded in April/May, while a slightly less intense bloom was observed during the more stable summer months. The transition between spring and summer production (i.e. late May/June) showed high phaeopigments concentrations and low production, which suggests post-bloom conditions.

Nutrient concentrations in the upper water column also showed a seasonal decrease during the productive months, as observed in previous years. The monthly monitoring also showed the reoccurring early seasonal inflow of deep warm salty coastal water during March (no data exists from February).

The phytoplankton community at the Main Station showed an increasing contribution of *Phaeocystis* sp. from April to June, culminating in an almost single species community in June. During the rest of the year, diatoms dominated the phytoplankton community, as it has been recorded in previous years.

The zooplankton abundance was similarly to previous years dominated by Cirripedia larvae in spring, while copepod nauplii, copepods, and rotifers dominated in summer. The species composition of copepods also resembled previous years dominated by *Microsetella norvegica*, although the overall copepod abundance was lower than in previous years.

The time-series of fish larvae showed a general seasonal succession from sand eel *Ammodytes* sp. and Arctic shanny larvae *Stichaeus punctatus* dominating in spring to capelin *Mallotus villosus* dominating in summer/autumn. Abundance of fish larvae show inter-annual variability, but 2012 showed the highest numbers of fish larvae recorded since 2006 particularly for sand eel and capelin. The annual sampling along a length section showed the highest fish larvae numbers towards the fjord entrance, as it has been observed in most other years. Crab and shrimp larvae showed a similar seasonal succession as observed in most previous years with *Pandalus* spp. dominating in May and the two crab species *Chionoecetes opilio* and *Hyas* spp. dominating in June. Ctenophora, jellyfish and *Sagitta* spp. dominated the larger zooplankton during the less productive months of the year, i.e. outside April-June. The annual spatial study showed similar to previous years that *Hyas* spp., *Pandalus* spp. and *C. opilio* was present at most stations, although depicting variable abundances between stations and years.

Vertical sinking flux from the euphotic zone is the key source of organic material to the benthic communities. Seasonal peaks in phytoplankton production and biomass during spring and summer were also reflected in increased sinking fluxes. The material sinking towards the benthos during the productive seasons is generally of good food quality for benthic organisms (i.e. fresh algal material). Benthic activity driven by this sinking organic material uses oxygen, thus inducing an oxygen uptake from the water column into the sediment. The extent of the oxic zone and the seasonal dissolved oxygen update was

Morning clouds in Kobbefjord, July 2012. Photo: Katrine Raundrup.

similar to the range of values previously recorded. Previous monitoring of benthic fauna and flora has established a solid baseline for future comparisons. Therefore, monitoring of benthic fauna and flora was focused on the intertidal species, which is expected to response strongly to regional temperature changes. Key features affecting the intertidal area include exposure to sea ice and waves. Monitoring plots for knotted wrack *Ascophyllum nodosum* and blue mussel *Mytilus edulis* was established; initial measurements conducted and measured blue mussels placed in cages for monitoring.

Two major seabird colonies near Nuuk are monitored by the MarineBasis programme, but additional colonies are also included. The Qeqertannguit bird colony holds the largest diversity of breeding seabirds in the Nuuk area. The bird colony is influenced by legal egg harvesting. For the first time no kittiwakes were observed near the island during the two samplings in 2012 and the number of breeding Iceland gulls were also less than previous years. Another seabird colony (Nunngarussuit) in the Nuuk area showed the lowest numbers of the two species of guillemots recorded since 2006. Monitoring of other colonies indicate that kittiwakes from the Qeqertannguit colony may have moved to other colonies in the area. The total number of kittiwakes was in the lower range of previous estimates for the area.

A photo-identification programme is used to estimate the number of humpback whales *Megaptera novaeangliae* present in and returning to the Godthåbsfjord system. During this year, 85 ID-pictures were collected from dedicated surveys and contributions from the Nuuk community. From these pictures, 27 different whales were identified in the area during the year.

Research projects

In 2012; eight different research projects were carried out, five of them 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

Lillian Magelund Jensen and Morten Rasch

The year 2012 was the sixth year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was the fourth year with complete annual time series for all sub-programmes.

The 2012 field season in the Kobbefjord area started 11 January and continued until 8 November. During this period 47 scientists and logisticians spent 381 and 30 'man-days' in the study area, respectively.

1.1 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, Aarhus University and University of Copenhagen. Aage V. Jensen Charity Foundation has generously provided most of the necessary research infrastructure, including boats, research house, and office and accommodation facilities at Greenland Institute of Natural Resources.

1.2 Greenland Institute of Natural Resources

Greenland Institute of Natural Resources (GINR) received its new research ship in April 2012. The official naming of R/V Sanna took place 14 April at Skonnertkajen in Nuuk.

The ship will be used primarily for the GINR´s monitoring programmes of the life stock of fish and shellfish in Greenlandic waters and for a broad spectrum of scientific research in the marine environment. The ship will also be part of research and monitoring activities in connection with exploration for oil and gas and for mining activities close to the coast. The ship costed approximately 50 million DKK and is equipped for many different tasks within fishery, environmental and marine research.

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1.3 International cooperation

Nuuk Ecological Research Operation is involved in several larger international research projects.

Greenland Ecosystem Monitoring (GEM) is involved in the EU projects 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT) and 'Svalbard Integrated Arctic Earth Observing System' (SIOS). In 2012, four projects received support for 137 'bed nights' from INTERACT Transnational Access.

In 2012, Aarhus University established an Arctic Research Centre (ARC). The centre is run as an inter-disciplinary centre across the main academic areas, Science and Technology, and Health. The Centre is a partner in the Arctic Science Partnership (ASP) and will have strong collaborative ties with the Greenland Institute of Natural Resources in Nuuk and the University of Manitoba, Canada.

1.4 Further information

Further information about the Nuuk Ecological Research Operations (NERO) programme is collected in previous annual reports, which can be found on the NERO website www.nuuk-basic.dk. 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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Greenland Institute of Natural Resources' new boat house and warehouse donated by Aage V. Jensen Charity Foundation. Photo: Klaus Nygaard.

2 Nuuk Basic

ClimateBasis programme

Mark Andrew Pernosky, Per Hangaard, Louise Holm Christensen, Kisser Thorsøe and Maria Knudsen

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 (including two derived parameters) are monitored and data are stored in a database.

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

2.1 Meteorological data

In 2012, the climate stations in Kobbefjord were visited four times by Asiaq technicians and six times by other Asiaq personnel. The maintenance of the stations included reference tests of important parameters, and replacement of sensors that needed to be changed. A full description of the climate stations are given in Jensen and Rasch 2008.

Meteorological data 2012

This annual report describes the fifth full year of data for all climate parameters and refers to data collected in the period from 1 January to 31 December 2012. Figure 2.2 gives an overview of selected meteorological parameters in 2012.

The annual mean of recorded temperatures in 2012 was 0.5 °C (table 2.1). A very cold two-week period occurred from 28 February to 11 March with an average air temperature of –19.7 °C, which made March the coldest month of 2012 with an

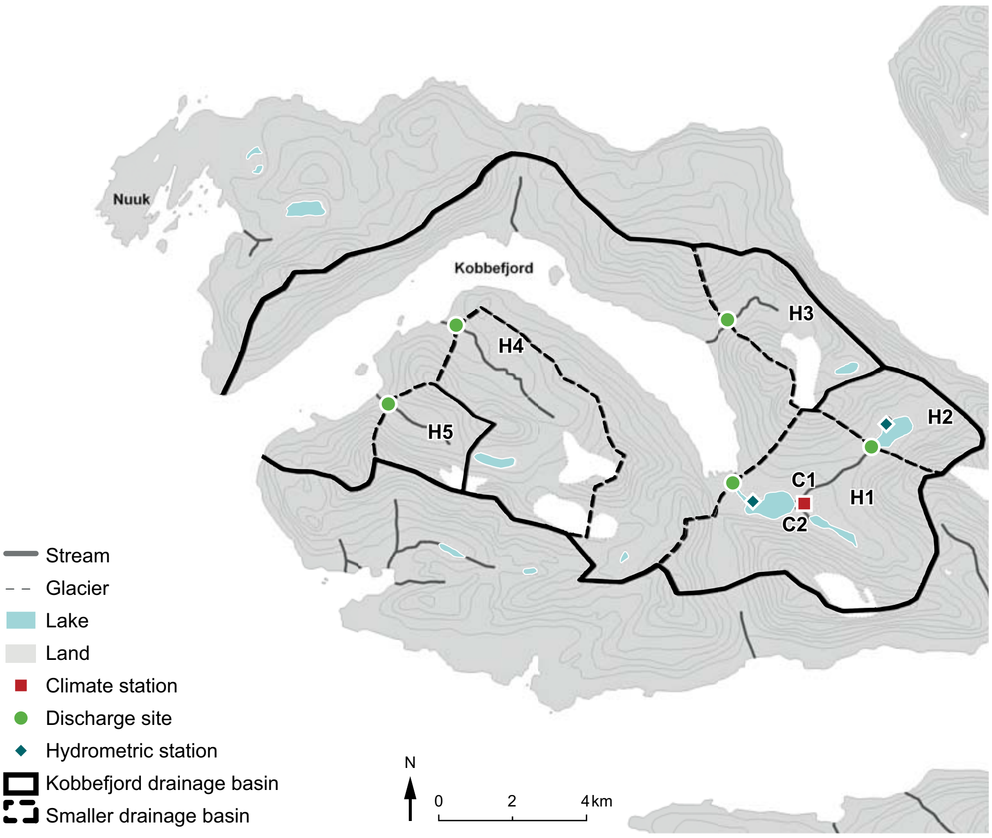

Figure 2.1 Location of the climate (C1, C2), hydrometric (H1, H2) and diver stations (H3, H4, H5) in Kobbefjord together with the drainage basins of Kobbefjord and the drainage basin for the hydrometric stations and the diver stations.

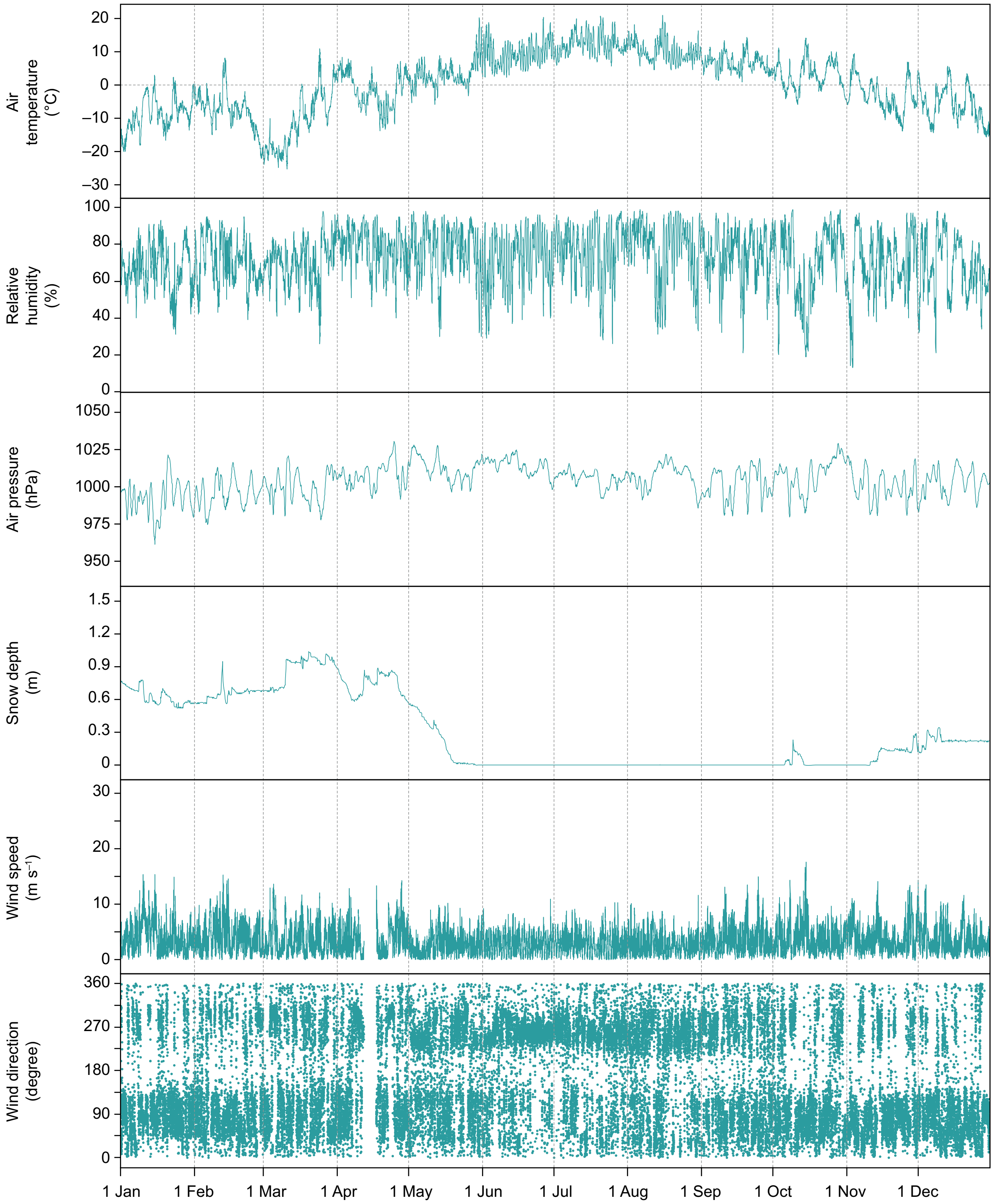

Figure 2.2 Variation of selected climate parameters in 2012. From above: Air temperature, relative humidity, air pressure, snow depth, and wind speed and wind direction. Wind speed and direction are measured 10 m above terrain; the remaining parameters are measured 2 m above terrain.

average air temperature of -11.0 °C (table 2.1) and a minimum temperature as low as –26.1 °C. The warmest month was July with temperatures averaging 12.1 °C (table 2.1), which is the highest mean temperature ever measured by the programme.

The general weather pattern from January to March 2012 was characterized by long periods with easterly winds and temperatures ranging from –25 °C to 11 °C. On 1 January the snow cover at the climate stations in Kobbefjord was 78 cm and it stayed quite stable with a cover around 70 cm until 10 March when it reached 97 cm. Maximum snow depth of 1.04 m was measured 20 March. During the two last days of March and the first week of April the average daily air temperature was above 0 °C and the snow began to melt and pack. Coldness and snow then returned

Table 2.1 Monthly mean values of selected climate parameters from January to December 2012.

Month-year	Rel. hum. (%)	Snow depth (m)	Air temp. (°C)	Air pressure (hPa)	Precip. (mm)	Wind (m s^{-1})	Wind dir. (most frequent)
Jan 12	67	0.63	–8.7	993	–	4.1	E
Feb 12	71	0.64	–7.7	996	–	4.2	E
Mar 12	71	0.88	–11.0	1000	–	3.6	NE
Apr 12	79	0.74	–1.7	1008	129.4	3.5	–
May 12	77	0.22	3.2	1012	71.9	2.6	WSW
Jun 12	71	0.0	9.4	1014	7.0	2.9	WSW
Jul 12	77	0.0	12.1	1006	146.8	2.9	W
Aug 12	78	0.0	10.0	1007	100.0	2.8	WSW
Sep 12	74	0.0	6.6	1002	236.7	3.6	ENE
Oct 12	70	0.0	3.0	1008	173.4	3.6	ENE
Nov 12	69	0.09	–3.0	1001	98.8	3.9	E
Dec 12	67	0.22	–6.1	1003	32.6	3.4	E
2012	73	–	0.5	1004	–	3.4	–

Months with data coverage of less than 80% have been omitted

and the snow cover stayed stable around 80 cm with a maximum of 89 cm from 12 to 26 April. Melt of the snowpack began slowly from 26 April. In addition, the dominant wind direction began to shift to a westerly wind throughout April. In May, the average air temperature was 3.2 °C and there was 72 mm of precipitation. Between 1 and 20 May, the snowpack decreased steadily at an average rate of 1 to 4 cm per day. The last snow disappeared 29 May. The last day with a mean air temperature below the freezing point was recorded 12 May.

During the entire summer the dominant wind direction continued to be a westerly wind. Air temperatures throughout the summer were high, the average air temperature for June and July were 9.4 and 12.1 °C, respectively, which is the highest June and July temperature since the measurements began in Kobbefjord in 2007 (table 2.2). June was very dry with only 7 mm of precipitation. Precipitation in July and August were a little higher than the normal for Nuuk (Cappelen et al. 2001).

Between September and October the dominant wind direction shifted back to an easterly direction. During September and October, several low pressure systems passed resulting in strong winds of up to 17.6 m s^{-1} and maximum wind speeds of up to 30.7 m s^{-1}. The low pressure systems also led to heavy rain events with a total of 236.7 mm precipitation in September and 173.4 mm in October.

The first day with a mean daily temperature below 0 °C occurred 5 October. All snow had melted 14 October.

In November and December the dominant wind direction was still in easterly direction. The average air temperature

Table 2.2 Comparison of monthly mean air temperatures 2007 to 2012.

	Air temperature (°C)					
Month	2007	2008	2009	2010	2011	2012
January	–	–12.0	–5.4	–3.8	–5.4	–8.7
February	–	–13.3	–6.1	–1.6	–8.7	–7.7
March	–	–8.3	–11.7	–4.5	–9.2	–11.0
April	–	–0.9	–3.2	–0.1	–9.5	–1.7
May	0.6	3.9	0.3	7.1	0.3	3.2
June	5.3	7.9	6.4	8.8	6.2	9.4
July	10.8	10.9	10.6	10.7	10.0	12.1
August	10.6	8.7	9.3	11.7	8.7	10.0
September	4.0	4.4	3.8	7.8	3.9	6.6
October	–0.5	0.0	–0.6	2.9	–2.4	3.0
November	–3.5	–1.7	–7.9	1.2	–6.2	–3.0
December	–8.7	–7.8	–2.8	0.5	–7.5	–6.1
Year	–	–0.7	–0.6	3.4	–1.6	0.5

went below 0 °C, and from 10 November, the precipitation came as snow. December was very dry with only 32.6 mm precipitation and a maximum snow cover of 34 cm occurred 9 December. Wind and air temperatures above 0 °C decreased the snow cover to 22 cm 10 December.

All radiation data from 2012 will be reported in the 2013 Annual Report.

2.2 River water discharge

Data from the hydrological stations for the hydrological year 2011/2012 will be reported in the 2013 Annual Report.

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 2012 operated by the Department of Geosciences and Natural Resource Management, University of Copenhagen in collaboration with the Department of Bioscience, Aarhus University. In 2012, GeoBasis was funded by Danish Ministry for Climate, Energy and Building 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 May to the end of October with some year-round measurements from automated stations.

The 2012 season is the fifth full season for the GeoBasis programme. In 2007, the field programme was initiated during a three-week intensive field campaign in August when most of the equipment was installed, although some installations had to be postponed until 2008. Methods and sampling procedures are described in details 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.

In 2011, GeoBasis installed two new energy balance stations (figure 3.1) in co-operation with an INTERACT project. One station is located at a new site over heath vegetation (figure 3.2). The station has sensors measuring air temperature, relative humidity, air pressure, snow depth, summer precipitation, soil temperature (–70 cm, –50 cm, –20 cm, –10 cm and –2 cm), snow temperature (5 cm, 10 cm, 20 cm, 40 cm and 80 cm). In addition, it also measures NDVI, short and long wave radiation (incoming and outgoing), soil moisture (0-5 cm, 25 cm and 50 cm) and soil heat flux (4 cm). A sonic anemometer also measures wind speed and wind direction at high frequency (10 Hz). Soil moisture sensors were also installed at the heath site at 10 cm and 50 cm depths. The remote placing on the heath site and the use of fuel cells have caused numerous breaks in the time-series although the station was visited frequently even outside the normal field season. In 2013, a more stable power supply will be installed.

Figure 3.1 Two new energy balance stations were installed during 2011. One at a new heath site (upper) and one at the fen site (lower).

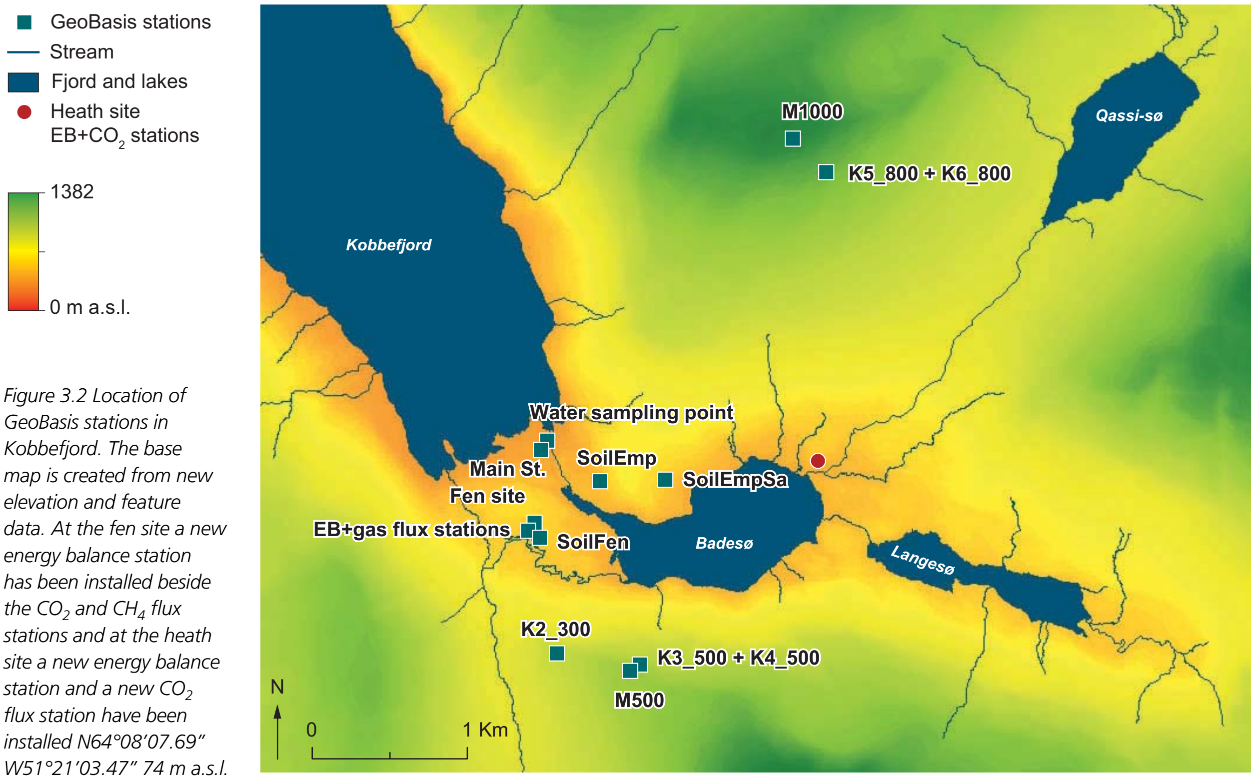
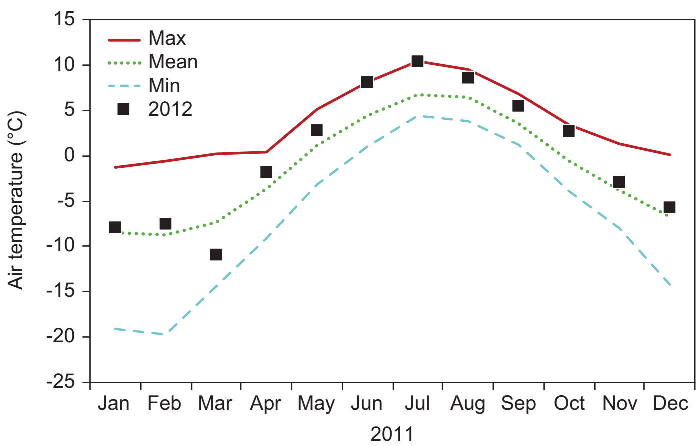


Figure 3.2 Location of GeoBasis stations in Kobbefjord. The base map is created from new elevation and feature data. At the fen site a new energy balance station has been installed beside the CO_2 and CH_4 flux stations and at the heath site a new energy balance station and a new CO_2 flux station have been installed N64°08'07.69" W51°21'03.47" 74 m a.s.l.

A similar energy balance station (figure 3.1) was installed at the fen site, which measures air pressure, snow depth, summer precipitation, soil temperature (–70 cm, –50 cm, –20 cm, –10 cm and –2 cm), snow temperature (5 cm, 10 cm, 20 cm, 40 cm and 80 cm). In addition, it also measures NDVI, short and long wave radiation (incoming and outgoing), soil moisture (0-5 cm), and water table depth.

Data collected by the Danish Meteorological Institute showed that in 2012 the mean annual air temperature in Nuuk reached 0.1 °C, which is 1.5 °C warmer than normal (Cappelen 2013). All months except March were warmer than normal (figure 3.3). Two months were especially warm, June with an average monthly temperature of 8.1 °C, which is 1.2 °C warmer than the previous warmest June (1888) and July with 10.4 °C which is 0.9 °C warmer than the previous warmest July (2008).

Figure 3.3 The monthly minimum, mean and maximum air temperature for the period 1866-2012 measured at Nuuk (lines solid and dashed) and monthly mean air temperature for 2012 (points) (Cappelen, 2013).



3.1 Snow and ice

Snow cover extent

The first four 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 (Tamstorf et al. 2007). In September 2009, two snow-monitoring cameras K5 and K6 were installed. Both cameras were installed at position N64º9'06.25" W51º20'46.47" at 770 m a.s.l. (figure 3.2). K5 is facing to the south monitoring the central parts of the drainage basin with Badesø and Langsø, while K6 monitors Qassi-sø in the northern valley of the drainage basin (figure 3.4). In 2011, a new camera was reinstalled at K1_300 (N64º7'26" W51º22'55") overlooking the fen area. This automatic camera takes photos three times daily March through November, and once daily during the winter months.

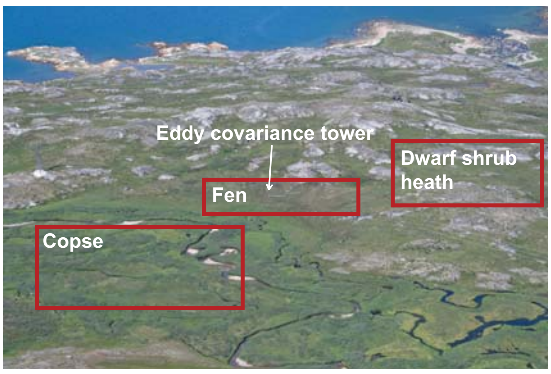
One of the main advantages of camera-based snow monitoring is that it is relatively insensitive to cloud cover (in contrast

Figure 3.4 Camera K5_800 (to the right) and K6 (to the left). (N64o7'26" W51°22'55"). The background is showing the field of view for camera K6, which monitor Qassi-sø and the glacier on the eastern side of the lake.

to satellite-based techniques). Only low clouds and foggy conditions can make the image data unsuitable for mapping purposes. A new updated and more user friendly algorithm for snow cover monitoring has been developed in MatLab, so it is now possible, for each melting season to construct snow cover depletion curves for user specified regions of interest (ROI) on the basis of image data obtained at daily frequency. In previous years, depletion curves for the three regions of interest seen from K2_300 have been shown (Hansen et al. 2012), but due to technical problems, it will not be possible to show any depletions curves from these ROI.

Instead, two new ROI are shown in figure 3.5. They cover the vegetation types, copse (Arctic willow with a maximum height of 1 metre) and fen. Fen is very similar to the footprint for the CO_2-station in the fen. Both ROI are covered by K1_300 and K3_500, so a future monitoring of the two ROIs should be more stable. Figure 3.5 show that 50 % of the snow cover was melted at both sites on DOY 122 in 2010, on DOY 161 in 2011 and on DOY 137 for copse and on DOY 149 for fen in 2012. In both 2010 and 2011, the melting season lasted 12 and nine days, respectively, for both ROI, while in 2012 the melting season in the copse area started already on DOY 126, and the start of the snow melting in the fen area was delayed nine days. The melting season (snow cover fraction < 10 %) ended for both copse and fen sites on DOY 153.

Figure 3.5 Snow cover depletion for two regions of interest copse and fen at 50 m a.s.l. have been analysed using a new snow cover algorithm. The regions are specified on the image to the left, and the depletion curves for each region during the period 2010-2012 are shown in the diagram to the right. DOY = day of year.



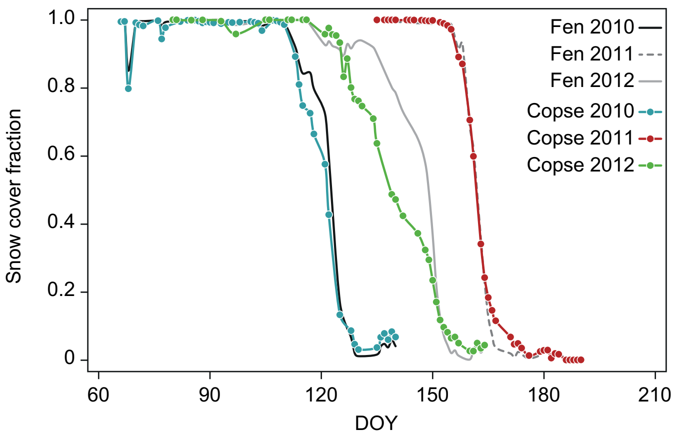


Table 3.1 Comparison of snow depth/densities (in brackets) at GeoBasis sites A-C 2009-2012. No snow pit was dug at SoilEmpSa in 2010.

Snow Survey Dates	Soil Fen (A) Average depth (m) Density (kg m^{-3})	Soil Emp Salix (B) Average depth (m) Density (kg m^{-3})	Soil Emp (C) Average depth (m) Density (kg m^{-3})
April 15-16, 2009	0.91 (237)	0.90 (275)	1.02 (329)
April 15-16, 2010	0.20 (339)	0.19 (n.a.)	0.17 (366)
April 7-9, 2011	0.87 (364)	0.92 (297)	0.91 (383)
April 17-18, 2012	0.96 (373)	0.74 (353)	0.92 (320)

Snow cover

To support the studies under the Nuuk Basic monitoring programme, a snow cover survey using ground-penetrating radar (GPR) and manual stake measurements was carried out in the main parts of Kobbefjord drainage basin 28-30 March and 17-18 April 2012. A comparison of average snow depth for the three GeoBasis sites can be seen in table 3.1. Three of the four years 2009, 2011 and 2012 had snow depths above 70 cm, but with average densities of respectively 280, 348 and 349 kg m^{-3} the average snow water equivalents varies between 264, 313 and 304 mm for 2009, 2011 and 2012.

Even though the snow survey is carried out at nearly the same time every year, snow depth has large variations from year to year, and the maximum snow cover date is strongly variable from year to year, see figure 3.6. The winter 2011/2012 started primo October, and until 1 December the average snow depth was around 10 cm. During December the snow depth steadily increased to 80 cm. Minor snowmelt events during January 2012 causes a decrease in snow depth to 55 cm. In February, minor snowfalls event caused a 10-12 cm increase in snow depth and a major snowfall in the beginning of March caused a further increase in snow depth reaching the winter's maximum of 102 cm. The mild weather in the end of March and in the beginning of April brought the snow depth down to 60 cm followed by a 20 cm of snowfall in mid-April before the final snowmelt season started ultimo April. The maximum snow depth of 102 cm makes the winter 2011/2012 the second most snowrich winter since continuous measurements of snow depth started in 2008, only exceeded by an additional 35 cm during the winter 2010/2011.

Table 3.2 describes snow depths and densities at the three GeoBasis soil microclimate stations SoilFen, SoilEmpSa and SoilEmp using ground penetrating radar (GPR) and manual stake measurements (figure 3.7). The snow survey strategy used in Kobbefjord is outlined in the 3rd Annual Report (Jensen and Rasch 2010). In order to document the properties of the snowpack, snow pits were dug at SoilFen in point A1, at SoilEmpSa in point B1 and at SoilEmp in point C1 (figure 3.7). The examination of the snowpack included temperature profiling, density measurements and texture description.

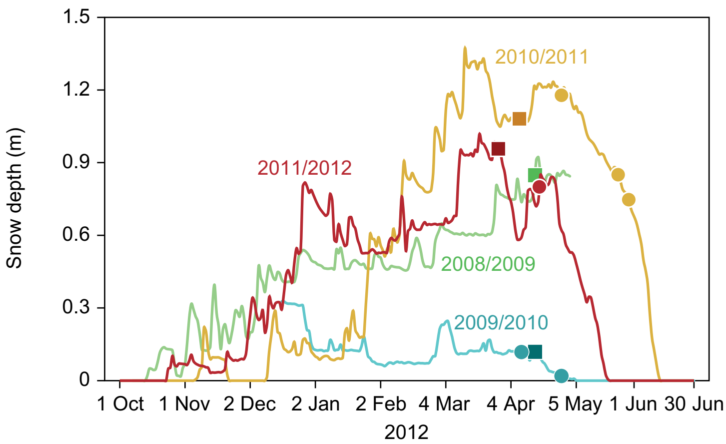
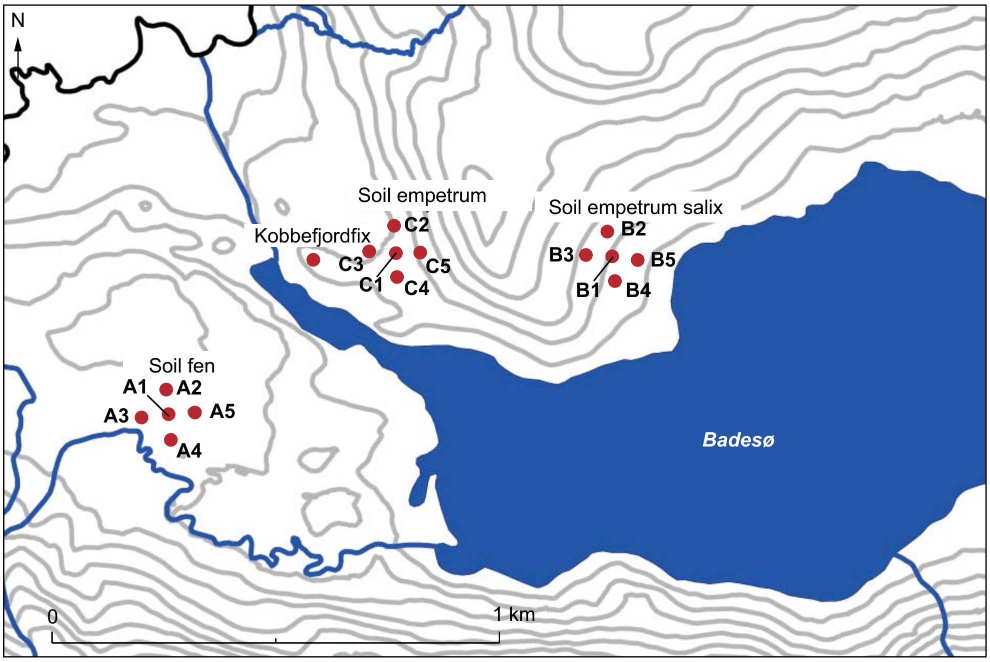


Figure 3.6 Snow depth measured at the ClimateBasis station and placement of snow surveys, 2009-2012. Squares represent the main survey for the year and the bullets represent additional snow surveys.

Table 3.2 Snow pit depth, average density, snow depth, standard deviation of the snow depth, average snow temperature and average water equivalent at the three soil stations (SoilFen, SoilEmp and SoilEmpSa) measured 17-18 April 2012.

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)
SoilFen (A1)	90	373	64-96-152	11	–3.1	380
SoilEmpSa (B1)	82	353	22-74-143	22	–0.1	289
SoilEmp (C1)	85	320	62-92-137	18	–1.0	272



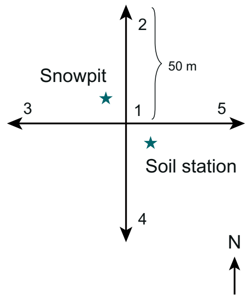


Figure 3.7 Map showing the three snow survey sites. The figure on the right outlines the strategy at each site.

Table 3.2 summarizes the snow depth, density and temperature results from the three stations. The texture of the snow profile at all three sites is characterized as homogenous coarse grained snow, with densities between 320-373 kg m^{-3}. Although the variation in densities are smaller than previous years (Hansen et al. 2011), the huge variation in snow depths of respectively 88, 121 and 75 cm causes huge variations in snow water equivalents ranging from a minimum of 78 mm at SoilEmpSa to a maximum of 567 mm at SoilFen.

Ice cover

The ice cover of the lakes in the Kobbefjord drainage basin was generally formed early in the winter 2011/2012 compared to previous winters (table 3.3). The break-up of the ice cover on the lakes was approximately five days later than average for previous years. Ice cover in Kobbefjord developed 16 November, which is the earliest registration during the five years of monitoring in Kobbefjord. The fjord was ice-free 21 May, which is five days earlier than the average for previous years. In 2011, the ice cover was formed only two days earlier on Qassi-sø (250 m a.s.l.) than on Badesø (30 m a.s.l.) while it the three previous years has been formed 2-3 weeks earlier. As usual, the ice cover on Qassi-sø broke up ten days later than the ice cover on Badesø. The difference in the period of ice cover is due to the difference in elevation of the two lakes.

Micrometeorology

Table 3.4 reports the monthly mean air temperature, relative humidity, surface

Table 3.3. Visually estimated dates for perennial formation (50 %) of ice cover and date for break-up of ice cover on selected lakes within the Kobbefjord drainage basin and on Kobbefjord from 2007 to 2012. Dates are reported for perennial formation of ice cover in the fall and for the break-up of ice cover in the spring. Badesø is the main lake in the area, Langsø is the long lake in the valley behind and to the east of Badesø and Qassi-sø is the lake at 250 m. a.s.l. in the northern valley of the drainage basin. No data indicates failure on the camera system and a '' indicates that it was not possible to estimate an exact date due to low cloud cover in the area.*

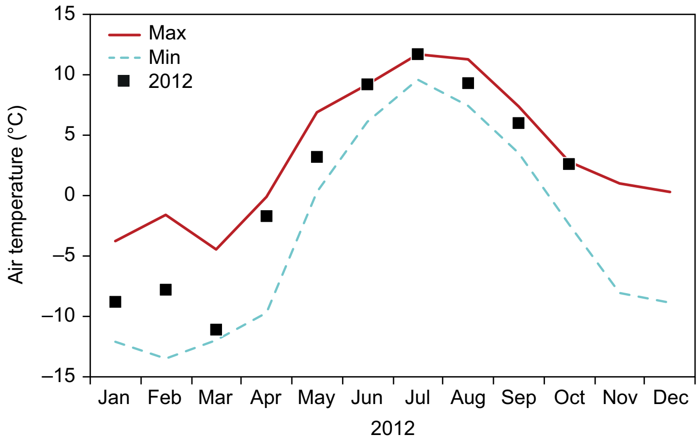
Year	Badesø		Langsø		Qassi-sø		Kobbefjord	
	Break-up	Formation	Break-up	Formation	Break-up	Formation	Break-up	Formation
2007		23 Oct		22 Oct	22 Oct	22 Oct		27 Dec-12 Feb*
2008	2 Jun	5 Nov	13 May	5 Nov	9 Jun	4 Nov		
2009	13 Jun	1 Nov	11 Jun	no data	22 Jun	10 Oct	4 Jun	12 Feb
2010	14 May	22 Nov	no data	no data	24 May	6-11 Nov	2 Jun	23 Nov
2011	18 Jun	22 Oct	no data	no data	28 Jun	20 Oct	23 May	16 Nov
2012	9 Jun		no data		19 Jun		21 May	

temperature and soil temperature measured at SoilFen 2007-2012. In 2012, the temperatures in spring and autumn were close to average, while June and July, with respectively 9.2 and 11.7 °C, were the highest summer temperatures measured during the period 2007-2012. In the first two months of 2012, the mean air temperature was in the average range, while March with –11.1 °C was a cold month compared to earlier measurements at the site. Figure 3.8 shows a comparison between the monthly mean air temperatures in 2012 and the maximum and the minimum monthly mean air temperatures from SoilFen in 2007-2012. These measurements are in line with the air temperatures measured in Nuuk located 30 km away (figure 3.1).

For the GeoBasis monitoring period 2007–2012, the minimum monthly mean air temperature was –13.5 °C measured at SoilFen in February 2008, and the maximum monthly mean air temperature was 11.7 °C measured in July 2012.

The micrometeorological stations M500 and M1000, measure air temperature, relative humidity, surface temperature and short-wave irradiance see tables 3.5 and 3.6. M500 is placed approximately 500 m a.s.l. south of Badesø and M1000 is placed approximately 1000 m a.s.l. north of Badesø. The high monthly mean air temperatures in respectively June and July 2012 are also seen in the data from M500 and M1000. In 2008-2011, the mean air temperature in June at the M500 station was between 3.4 °C and 5.9 °C, in 2012 it was 8.7 °C. In July the monthly mean air temperature in 2008-2011 varies between 7.6 °C and 8.9 °C, in 2012 it was 10.4 °C. The humidity measured at the M500 station in 2012 generated new maximum records in February (81.7 %), April (90.0 %) and May (82.5 %) and a new minimum record for June (68.2 %). The monthly mean incoming shortwave irradiance in general was lower than average.

Figure 3.8 Monthly mean air temperatures in 2012 (black squares), maximum (red line) and minimum (blue line) monthly mean air temperatures from 2007-2012. Measured at the SoilFen station 2.5 metres above ground.



3.2 Soil

Physical soil properties

Selected parameters from the soil stations SoilFen, SoilEmp and SoilEmpSa are presented in tables 3.4, 3.7 and 3.8. The difference in soil properties between the three locations, which were detected in previous years are also seen in the data collected in 2012. Those being higher winter soil temperatures at SoilFen than at SoilEmp and SoilEmpSa, as the snow depth at SoilFen is significantly higher. During summer, the soil temperatures at SoilFen is also 2-3 °C higher, as the site is more protected from cold winds from Kobbefjord and from Badesø. The temperature in 30 cm depth is at SoilFen less affected by fluctuations in surface temperature than at SoilEmp and SoilEmpSa where the soil is well-drained. 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 for the field season was 12 % at SoilEmp and 36 % at SoilEmpSa. At all three soil stations, the soil was approximately 5 °C warmer in June 2012 compared to 2011 due to a three weeks longer winter season in 2011/2012.

Throughout the season, soil water was collected from two depths at three characteristic soil profiles representing the dominating plant communities in the drainage basin. During the period 18 June – 1 October 2012, forty soil water samples were collected from the soil water stations at SoilEmp (10 and 30 cm), SoilFen (10 and 80 cm) and SoilHeath (10 and 50 cm).

At the research house in Kobbefjord, measurements of pH, temperature and conductivity were carried out on the samples. In August 2011, laboratory equipment was installed in the research house, which enabled analyses of soil water alkalinity. After the field season, the soil water samples have been analysed for all major anions and cations as well as for dissolved organic carbon content.

Table 3.4 Air temperature, relative humidity, and surface temperature and soil temperature at six depths (–1 cm, –5 cm, –10 cm, –30 cm, –50 cm and –75 cm) from the SoilFen station in the fen area from August 2007 to December 2012.

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. –5 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	3.9	4.3	5.3	5.9	5.8
October	–0.5	64.6	–4.8	–0.6	–0.1	0.2	1.1	2.3	2.8
November	–3.5	74.2	–7.1	–0.3	–0.2	–0.2	0.4	1.2	1.7
December	–8.9	71.8	–13.1	–0.2	–0.2	–0.2	3.0	0.9	1.3
2008									
January	–12.1	73.2	–16.0	–0.3	–0.2	–0.1	0.3	0.8	1.2
February	–13.5	73.1	–15.7	–0.3	–0.2	–0.1	0.2	0.7	1.0
March	–8.8	75.0	–11.5	–0.3	–0.2	–0.1	0.2	0.7	1.0
April	–	–	–	–	–	–	–	–	–
May	–	–	–	–	–	–	–	–	–
June	–	–	–	–	–	–	–	–	–
July	–	–	–	–	–	–	–	–	–
August	7.4	76.6	7.6	9.3	9.3	9.2	8.6	8.4	7.6
September	4.1	77.8	3.9	4.7	4.9	5.2	5.9	6.0	6.0
October	–0.1	69.3	–2.4	0.1	0.4	0.9	2.6	2.9	3.5
November	–1.9	79.8	–4.4	–0.1	–0.1	0.2	1.3	1.6	2.1
December	–8.1	71.8	–11.9	–0.2	–0.1	0.1	1.0	1.2	1.6
2009									
January	–5.5	67.6	–10.1	–0.2	–0.1	0.1	0.9	1.1	1.4
February	–6.2	69.3	–10.7	–0.3	–0.2	0.0	0.7	0.9	1.2
March	–12.0	73.7	–16.8	–0.5	–0.4	–0.1	0.6	0.7	1.1
April	–3.4	78.8	–6.7	–0.2	–0.2	–0.1	0.5	0.7	1.0
May	0.3	71.7	–3.3	0.0	0.0	0.0	0.5	0.7	1.0
June	6.3	76.6	7.2	7.0	5.7	4.7	2.6	2.3	2.0
July	10.2	72.1	13.1	14.3	13.7	12.7	8.7	7.8	6.3
August	8.7	77.2	10.1	10.8	10.8	10.6	9.1	8.6	7.7
September	3.5	73.9	2.9	3.9	4.3	4.7	5.8	5.9	5.9
October	–0.7	69.2	–3.2	–0.2	0.1	0.5	2.2	2.5	3.1
November	–8.1	74.2	–13.6	–0.3	–0.2	0.0	1.1	1.4	1.9
December	–2.9	61.0	–8.7	–0.6	–0.4	–0.2	0.8	1.0	1.5
2010									
January	–3.8	71.1	–7.0	–1.9	–1.6	–1.0	0.5	0.7	1.1
February	–1.6	67.7	–5.4	–3.2	–2.8	–2.3	0.1	0.3	0.8
March	–4.5	69.8	–7.9	–2.2	–2.1	–1.8	–0.2	0.1	0.5
April	–0.1	74.1	–3.0	–0.5	–0.5	–0.5	–0.1	0.1	0.4
May	6.9	68.8	6.9	6.2	4.3	2.3	0.0	0.1	0.4
June	8.6	73.6	10.7	10.9	9.6	7.8	1.0	0.8	0.7
July	10.2	78.2	12.6	13.8	13.0	12.1	7.9	6.9	5.5
August	11.3	79.8	11.7	12.6	12.4	11.9	9.7	9.0	7.9
September	7.4	73.4	6.5	7.3	7.6	7.7	7.7	7.6	7.2
October	2.8	71.1	0.7	1.5	1.9	2.4	3.9	4.2	4.6
November	1.0	69.7	–2.4	–0.4	–0.2	0.1	1.6	2.0	2.5
December	0.3	75.5	–2.5	–0.1	–0.1	0.0	1.0	1.3	1.8
2011									
January	–5.6	70.6	–8.7	–0.7	–0.5	–0.2	0.7	1.0	1.4
February	–9.1	73.2	–12.0	–0.4	–0.4	–0.2	0.5	0.7	1.1
March	–9.5	73.6	–11.6	–0.2	–0.2	–0.2	0.5	0.7	1.0
April	–9.7	69.5	–12.6	0.0	0.0	0.0	0.5	0.7	1.0
May	0.5	71.5	–1.2	0.0	0.0	0.1	0.5	0.7	1.0
June	6.1	77.0	5.4	4.8	3.5	2.5	1.2	1.1	1.2
July	9.6	78.5	11.2	12.4	11.8	11.0	7.4	6.6	5.3
August	8.2	81.3	9.4	11.0	10.8	10.5	8.6	8.1	7.1
September	3.5	77.8	3.2	4.1	4.5	4.8	5.9	6.0	5.9
October	–2.4	70.5	–4.3	0.0	0.3	0.7	2.3	2.6	3.1
November	–6.2	65.8	–8.7	–2.3	–1.8	–1.1	0.8	1.1	1.7
December	–7.6	74.3	–9.5	–0.7	–0.7	–0.5	0.2	0.5	1.0

continues

2012									*Table 3.4 continued*
January	−8.8	70.6	−11.2	−0.7	−0.7	−0.6	0.1	0.37	0.8
February	−7.8	74.0	−9.8	−0.4	−0.4	−0.4	0.1	0.3	0.7
March	−11.1	73.2	−12.2	−1.2	−1.1	−0.9	0.0	0.23	0.6
April	−1.7	81.0	−2.7	−0.1	−0.1	−0.1	0.1	0.26	0.6
May	3.2	78.8	2.7	1.0	0.3	0.0	0.2	0.31	0.6
June	9.2	74.4	11.2	11.3	9.3	6.6	1.3	1.08	1.0
July	11.7	78.7	13.2	14.7	14.1	13.0	8.6	7.52	5.9
August	9.3	80.2	9.8	11.4	11.3	11.0	9.3	8.73	7.7
September	6.0	76.3	5.7	6.2	6.4	6.6	6.8	6.75	6.5
October	2.6	72.4	1.6	1.6	1.8	2.2	3.4	3.69	4.1
November									
December									

3.3 River water

In 2012, twenty-four water samples were collected from ultimo May to ultimo October, the field season being one month shorter than previous years due to a very late snow/ice melt. *In situ* measurements of river water temperature, conductivity and pH were conducted along with the water sampling. The measured values are presented in figure 3.9. The minimum river water temperature from ultimo May to mid-June was 2.1 °C, which was 1.5 °C higher than previous years. The water temperature peaked with a maximum temperature of 16.6 °C ultimo July, which was 3.3 °C higher and two weeks earlier than 2011. Due to malfunction of the conductivity sensor, the normal decrease in conductivity within the snow-melting period from 30-35 µSc m-1 to a level of 18 ± 1.5 µSc m^{-1} was never registered. From the beginning of July and through the rest of the field season, the conductivity showed no significant trend, which is normal for the period. pH showed a normal trend from 6.6 in the beginning of the field season to 7.1 in late October 2012.

3.4 Vegetation

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

Satellite imagery

Unlike previous years (2008-2010), it has not been possible to acquire QuickBird or WorldView image data, due to cloudy conditions in the requested period. Instead, an Aster L1A product was acquired from LP DAAC, USGS. The scene was geo-referenced and converted to radiance in ENVI 5. The most cloud free conditions were met 25 July 2012 (figure 3.10) close to the optimum of the growing season. Radiance was converted to top of atmosphere reflectance, using constants from Thome et al. 2001. Band 2 and 3 N were atmospherically corrected with the dark object subtraction (regions of interest over the deep fjords constituted the dark areas). The Normalized Difference Vegetation Index (NDVI) was then computed from the corrected bands.

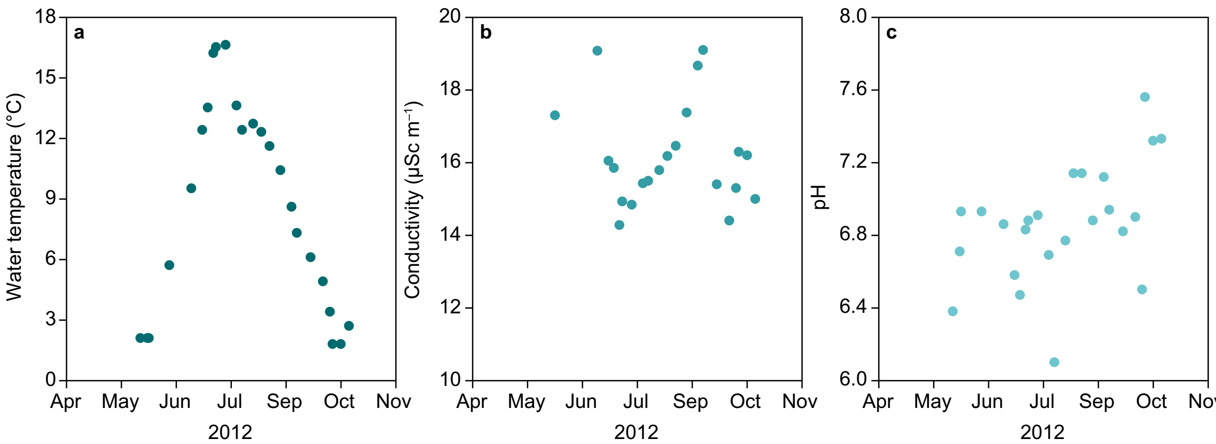


Figure 3.9 a) water temperatures, b) conductivity and c) pH measured in 2012 in the river Kobbefjord at the water sampling point near the research house.

Table 3.5 Air temperature, relative humidity, surface temperature and shortwave irradiance measured at the M500 station from January 2008 to August 2012. (Data from September to December are not retrieved yet).

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	–14.34	78.53	–16.31	6.70
February	–15.64	78.15	–17.34	30.28
March	–10.70	83.47	–12.31	77.22
April	–2.40	67.19	–4.62	172.49
May	2.44	73.17	3.54	237.04
June	5.91	72.09	8.66	295.06
July	8.89	64.30	10.45	253.74
August	5.43	80.09	6.27	157.70
September	0.11	90.02	–0.69	73.98
October	–3.25	77.63	–6.24	38.20
November	–5.04	91.45	–6.24	8.50
December	–10.79	82.16	–12.95	3.29
2009				
January	–7.69	72.02	–11.45	6.86
February	–8.08	69.73	–11.75	30.07
March	–13.06	76.48	–16.06	95.08
April	–5.25	83.88	–7.61	166.91
May	–2.50	79.86	–3.13	254.19
June	3.44	83.19	5.47	220.80
July	8.79	67.76	11.01	287.73
August	7.06	74.19	7.72	188.49
September	–0.19	84.43	–1.17	82.83
October	–3.57	74.90	–6.36	44.59
November	–9.17	75.15	–12.23	11.84
December	–3.76	57.51	–9.27	3.30
2010				
January	–5.49	73.79	–9.08	5.86
February	–2.69	65.42	–7.45	29.62
March	–6.65	73.09	–9.59	80.40
April	–2.86	79.90	–5.44	170.40
May	4.58	71.34	3.84	205.63
June	5.66	79.88	7.86	211.44
July	8.54	76.33	11.17	217.83
August	9.01	81.29	8.83	132.62
September	5.00	73.51	2.99	89.10
October	0.50	73.06	–2.83	35.80
November	–1.30	73.07	–4.57	8.80
December	–1.70	78.72	–4.33	2.30
2011				
January	–7.60	73.77	–10.95	6.80
February	–11.50	78.06	–13.92	27.80
March	–11.70	80.69	–13.86	76.80
April	–12.60	82.25	–14.46	187.50
May	–3.00	81.03	–3.51	239.20
June	4.60	77.89	7.24	238.70
July	7.60	79.20	8.62	165.80
August	6.80	77.00	7.25	149.80
September	0.70	80.16	–0.79	77.90
October	–4.80	73.09	–8.21	43.40
November	–8.80	70.69	–12.69	11.80
December	–10.80	84.10	–12.28	2.40
2012				
January	–11.30	74.76	–13.66	6.50
February	–10.20	81.71	–12.29	29.00
March	–13.10	78.33	–14.86	72.80
April	–4.00	90.02	–5.10	134.60
May	1.20	82.52	0.19	192.30
June	8.70	68.17	11.13	265.90
July	10.40	74.86	12.18	194.60
August	7.50	79.54	7.42	131.60
September				
October				
November				
December				

Table 3.6 Air temperature, relative humidity, surface temperature and shortwave irradiance measured at the M1000 station from August 2008 to January 2012. (Data from February-December except August are not yet retrieved).

Month-year	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface irradiance temp. 0 m (°C)	Shortwave irradiance 2.5 m (W m^{-2})
2008				
August	–	38.17	14.56	0.00
September	–3.10	92.35	–3.07	84.90
October	–7.00	80.77	–8.03	46.30
November	–	–	–	–
December	–	–	–	–
2009				
January	–	–	–	–
February	–	–	–	–
March	–	–	–	–
April	–	–	–	–
May	–	–	–	–
June	–	–	–	–
July	–	–	–	–
August	–	–	–	–
September	–	–	–	–
October	–6.20	90.08	–6.81	25.50
November	–10.40	67.44	–13.18	15.80
December	–5.20	55.37	–10.16	4.50
2010				
January	–6.90	71.15	–9.84	7.10
February	–4.30	62.87	–8.26	32.80
March	–8.70	73.10	–10.01	88.40
April	–7.00	90.86	–7.92	135.50
May	–	–	–	–
June	3.20	94.75	9.27	173.10
July	7.10	75.65	11.83	230.30
August	7.30	82.82	8.67	138.00
September	2.80	75.21	2.79	103.80
October	–1.80	75.23	–3.48	45.20
November	–3.80	79.26	–5.46	9.00
December	–3.60	81.54	–5.44	2.20
2011				
January	–9.70	72.71	–11.47	8.20
February	–13.70	76.27	–14.33	29.60
March	–14.20	83.92	–13.60	80.30
April	–15.00	77.93	–14.69	191.90
May	–5.20	79.95	–3.16	245.90
June	3.80	73.31	7.60	256.90
July	5.60	81.87	7.81	177.30
August	5.20	76.31	6.73	157.10
September	–1.60	81.02	–2.36	97.90
October	–6.80	71.40	–8.71	50.10
November	–11.20	72.58	–13.4	15.8
December	–14.00	91.32	–13.38	2.2
2012				
January	–13.50	74.12	–14.49	6.8
February	–	–	–	–
March	–	–	–	–
April	–	–	–	–
May	–	–	–	–
June	–	–	–	–
July	–	–	–	–
August	–	–	–	–
September	–	–	–	–
October	–	–	–	–
November	–	–	–	–
December	–	–	–	–
August	7.50	79.54	7.42	131.60
September				
October				
November				
December				

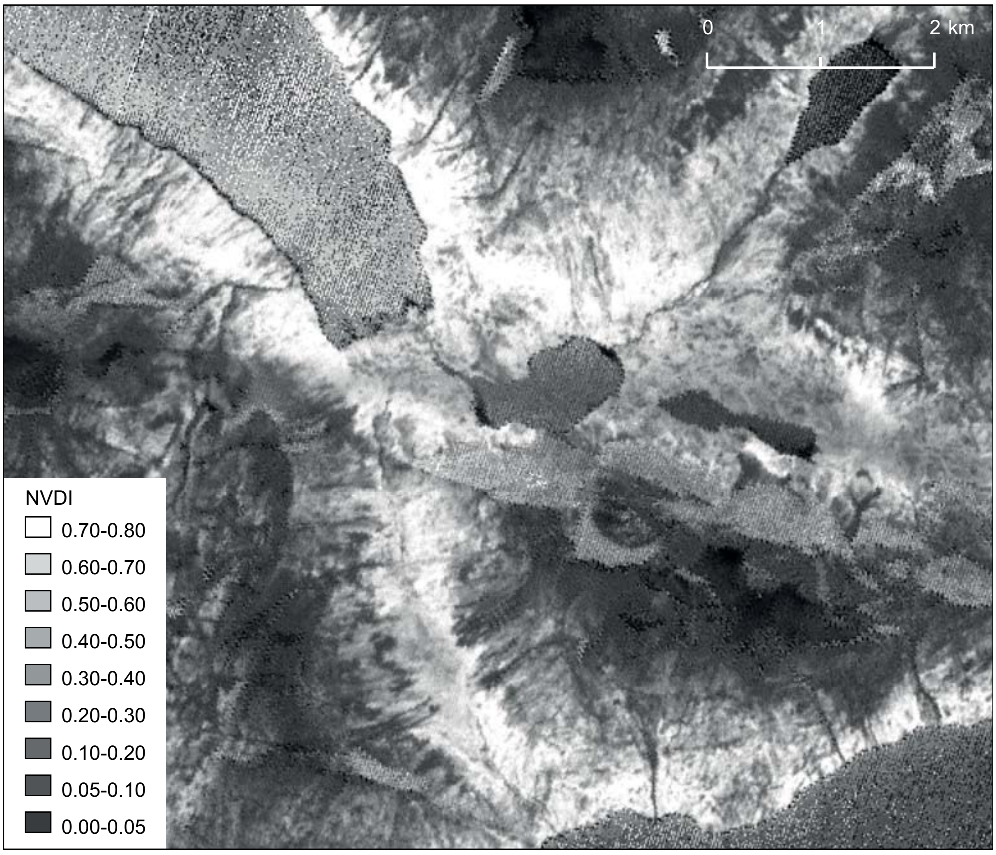


Figure 3.10 Normalised Difference Vegetation Index (NDVI) based on ASTER L1A data from 25 July 2012. Data are dark subtracted as atmospheric correction and lack the topographic correction.

As part of an INTERACT project, a new climate station was installed during the 2011 field season at the heath site north of Badesø. Hence, a new region has been added to the satellite-based NDVI measurements, as seen on figure 3.11. The fell field had significant lower NDVI-values around 0.13±0.04, while copse had significant higher values around 0.60±0.03 in all five years. The four other vegetation types had NDVI-values from around 0.36±0.05 to 0.40±0.05. Most of the vegetation types seem to have recovered after the outbreaks of *Eurois occulta* larvae in the 2011 growing season.

Digital camera imagery

Phenology studies of Arctic ecosystems are still dependent on spatial scale and quality (e.g. percent cloud cover) of the image data. Furthermore, the sparse vegetation and heterogeneous surface can be difficult to trace with coarse spatial resolution NDVI. Greatly improved spatial and temporal scale can be achieved by monitoring the ecosystems with automated digital cameras. Image data can thus be acquired under cloudy conditions, which is advantageous in Arctic ecosystems with short intense growing seasons

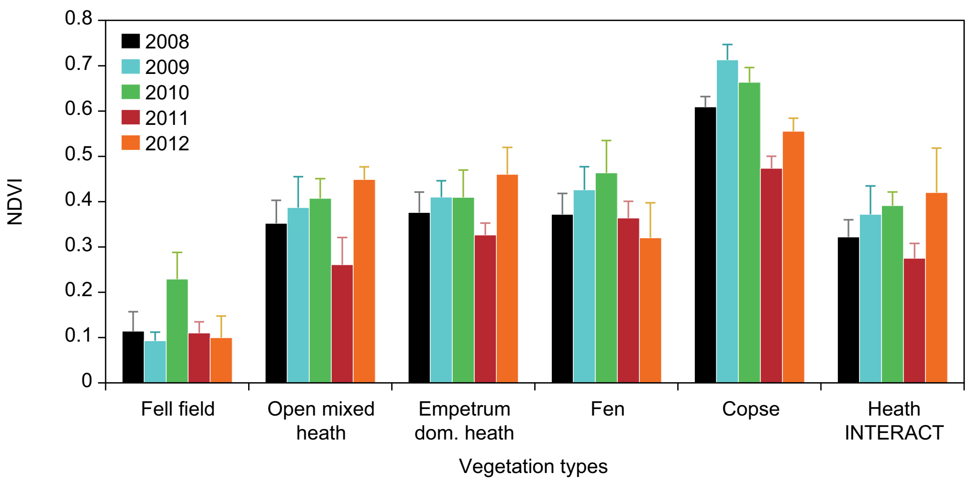


Figure 3.11 NDVI from 17 July 2008 and 2009, 10 July 2010, 14/30 July 2011 and 25 July 2012 for the six different vegetation types. Notice that changes between greenness are due not only to phenology differences between years but also seasonal phenology as the images are acquired approximately two weeks around the maximum greenness dates.

Table 3.7 Soil temperature and soil moisture at four depths measured at SoilEmp from January 2009 to October 2012. Data from November and December are not retrieved yet.

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	–0.85	–0.67	–0.53	–0.11	2.25	12.02	3.90	3.06
February	–1.26	–1.12	–1.01	–0.52	0.84	8.60	1.83	2.28
March	–2.48	–2.33	–2.21	–1.66	0.57	7.23	1.48	1.42
April	–1.44	–1.39	–1.34	–1.14	0.63	7.68	1.46	1.39
May	0.02	0.02	0.02	0.02	13.51	20.83	14.86	13.74
June	7.44	7.03	6.71	5.60	32.06	45.22	39.68	41.08
July	12.41	11.80	11.46	10.36	9.20	34.80	13.96	12.49
August	10.31	10.09	9.97	9.53	2.56	16.85	3.58	3.24
September	4.00	4.40	4.59	5.03	5.64	26.33	6.43	5.15
October	–0.50	–0.29	–0.13	0.39	11.66	25.03	16.64	15.05
November	–1.47	–1.25	–1.11	–0.38	2.03	12.72	3.49	3.50
December	–1.91	–1.81	–1.73	–1.17	0.90	10.11	1.78	2.11
2010								
January	–5.25	–5.07	–4.93	–3.95	0.59	7.96	1.53	1.78
February	–5.29	–5.11	–4.98	–4.10	0.58	7.72	1.47	1.65
March	–4.49	–4.42	–4.36	–3.89	0.56	7.64	1.44	1.60
April	–0.61	–0.75	–0.77	–0.81	6.32	16.20	10.13	8.29
May	6.39	5.57	5.11	3.82	19.47	42.02	33.61	31.23
June	10.11	9.37	8.96	7.71	5.42	35.05	7.63	4.98
July	12.41	11.80	11.45	10.42	4.13	27.84	5.22	4.09
August	11.55	11.33	11.18	10.61	10.61	36.63	15.45	15.23
September	7.01	7.29	7.41	7.62	9.22	38.03	14.07	11.24
October	1.62	2.13	2.38	3.03	6.60	36.39	6.58	4.68
November	–0.68	–0.52	–0.36	0.17	4.61	16.21	6.71	4.85
December	–0.19	–0.15	–0.08	0.17	13.64	35.64	25.71	24.50
2011								
January	–1.73	–1.45	–1.16	–0.41	3.15	13.56	5.23	4.36
February	–1.25	–1.13	–1.00	–0.59	2.40	9.94	3.56	3.51
March	–1.30	–1.22	–1.12	–0.81	2.41	9.74	3.45	3.37
April	–0.73	–0.64	–0.53	–0.32	2.48	10.00	3.45	3.45
May	0.03	0.04	0.05	0.07	11.12	17.85	14.07	15.49
June	5.33	4.72	4.33	3.20	27.06	38.63	26.02	31.82
July	10.92	10.46	10.17	9.13	7.90	37.48	8.91	6.21
August	10.09	9.95	9.83	9.30	7.27	36.25	8.33	6.66
September	3.83	4.22	4.40	4.85	12.58	39.76	22.76	19.98
October	–0.66	–0.32	–0.05	0.67	6.41	25.25	7.74	5.96
November	–4.68	–4.36	–3.97	–2.54	2.80	8.42	3.63	4.86
December	–2.59	–2.52	–2.43	–2.10	2.87	8.53	3.55	4.12
2012								
January	–2.50	–2.42	–2.32	–2.00	2.92	8.74	3.56	4.11
February	–1.66	–1.64	–1.61	–1.54	3.17	10.26	3.67	4.17
March	–3.76	–3.65	–3.51	–3.05	2.82	8.47	3.42	3.98
April	–0.14	–0.18	–0.22	–0.34	3.64	12.93	3.83	4.25
May	1.03	0.88	0.69	0.21	19.49	27.90	18.96	17.54
June	11.32	10.51	9.95	8.21	17.30	40.06	25.73	22.87
July	13.30	12.78	12.44	11.34	7.68	32.52	16.35	12.97
August	10.55	10.40	10.29	9.88	16.33	39.61	23.63	20.28
September	5.92	6.11	6.21	6.43	25.38	41.67	25.64	23.52
October	1.96	2.12	2.25	2.61	31.72	46.10	35.57	32.89
November								
December								

Table 3.8 Soil temperature and soil moisture at four depths measured at SoilEmpSa from January 2009 to October 2012. Data from November and December are not retrieved yet.

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	2.7	3.7	3.1	4.0	58.1	36.0	44.2	43.0
November	–0.2	0.6	0.2	0.9	57.0	36.3	44.2	40.7
December	0.4	0.7	0.6	0.7	60.2	54.4	46.3	46.6
2011								
January	–1.1	–0.2	–0.5	0.0	32.7	25.9	44.5	43.3
February	–0.6	–0.3	–0.5	–0.2	23.5	14.8	41.8	37.0
March	–0.6	–0.4	–0.5	–0.3	23.6	14.5	25.0	33.5
April	–0.7	–0.5	–0.6	–0.4	23.8	14.4	19.3	31.5
May	0.1	0.1	0.1	0.2	30.5	21.5	20.0	32.7
June	3.9	3.2	3.4	3.0	53.4	47.0	35.9	45.1
July	10.3	9.0	9.2	8.9	60.0	51.9	47.4	49.9
August	10.2	9.3	9.6	9.1	58.0	39.9	45.0	44.2
September	4.7	5.1	5.0	5.2	60.1	53.3	46.9	49.4
October	0.2	1.0	0.6	1.3	52.0	40.2	45.2	45.5
November	–1.9	–0.8	–1.4	–0.3	21.9	15.1	40.5	39.4
December	–0.9	–0.7	–0.8	–0.5	21.3	13.5	15.7	35.1
2012								
January	–0.9	–0.7	–0.9	–0.5	21.3	13.4	15.6	32.2
February	–0.6	–0.5	–0.6	–0.4	23.1	14.0	15.8	22.2
March	–1.6	–1.3	–1.5	–1.0	20.0	12.5	14.5	17.0
April	0.0	0.0	0.0	0.0	27.2	14.9	16.2	17.3
May	0.6	0.2	0.3	0.1	45.1	26.4	18.0	18.8
June	8.6	6.3	7.1	5.7	58.8	45.5	44.4	37.6
July	11.9	10.6	11.2	10.2	57.6	42.3	44.9	42.7
August	10.2	9.7	9.8	9.6	59.5	49.7	46.1	47.7
September	6.6	6.8	6.7	6.9	58.9	48.5	45.6	45.7
October	2.8	3.1	3.0	3.1	60.4	56.7	46.8	50.0
November								
December								

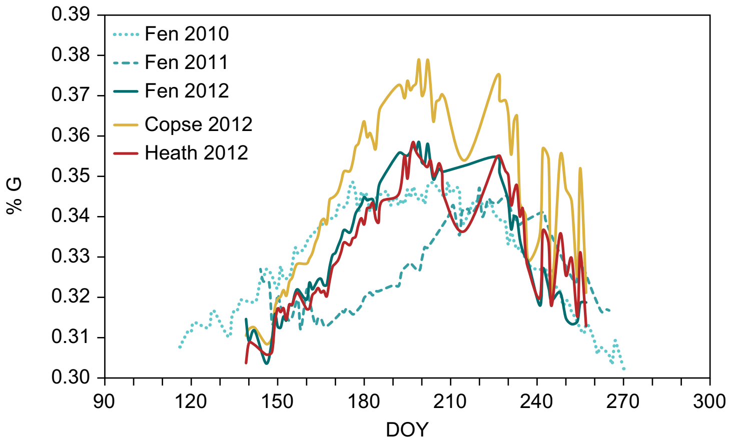


Figure 3.12 Greenness index for the three ecosystems copse, fen and heath at 50 m a.s.l. has been analysed using a new greenness index, %G. The regions are specified in figure 3.5 left, and the fen area is very similar to the footprint for the CO_2-station in the fen. The %G for all three ecosystems in 2012 and for fen in the period 2010-2012 is shown in the figure. DOY = day of year.

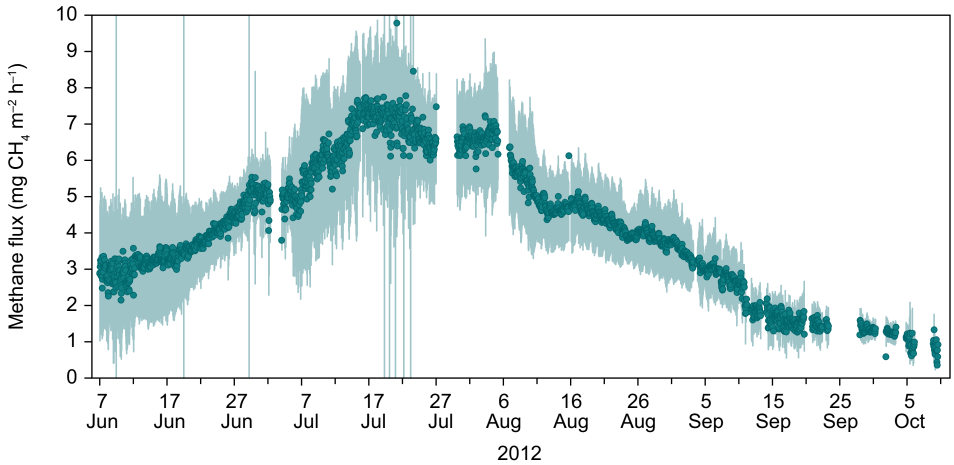
where a high frequency of data is important. Major challenges when using digital cameras is to compensate for changes in incoming radiation, as well as having the limitation of low spectral resolution. Even so, indices based on visual bands available from unmodified digital cameras have been found to correlate with NDVI over numerous types of ecosystems (Richardson et al. 2007). However, of the few existing studies, none investigates the performance in Arctic environments with high variability in species composition. The use of conventional RGB cameras as a tool to monitor landscape wide phenology has gained a lot of attention over the last few years. Mostly a measure of canopy greenness for a region of interest (ROI) is used to produce annual time-series, reflecting canopy phenology. The use of RGB cameras prevent the use of established vegetation indices such as NDVI or Ratio Vegetation Index (RVI). However, since photosynthesis by vegetation is related to chlorophyll content and biomass in various vegetation types, we hypothesize that indices based on the excess of the green channel can describe seasonal growth patterns in vegetation. Earlier studies based on repeated digital camera images have suggested various indices to detect temporal changes in vegetation. Common to them are combinations of the RGB-bands available in ordinary digital cameras, e.g. Richardson et al. 2007 and Migliavacca et al. 2011 have evaluated a greenness index, calculated as percent greenness, $\%G = DN(G)/(DN(R)+DN(G)+DN(B))$, where DN is the digital value in each of the RGB channels. Figure 3.12 shows the significant lower %G-values in 2011 due to the outbreaks of *Eurois occulta* larvae, but the figure also shows that the fen area as most of the other ecosystems seems to have recovered from the outbreak in 2012. Figure 3.12 also shows that copse has a fast and earlier greenness compared to fen and heath, but all three ecosystems reached the maximum within the same week in ultimo July.

3.5 Carbon gas fluxes

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

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

Figure 3.13 Methane (CH_4) emissions from the fen during 2012.



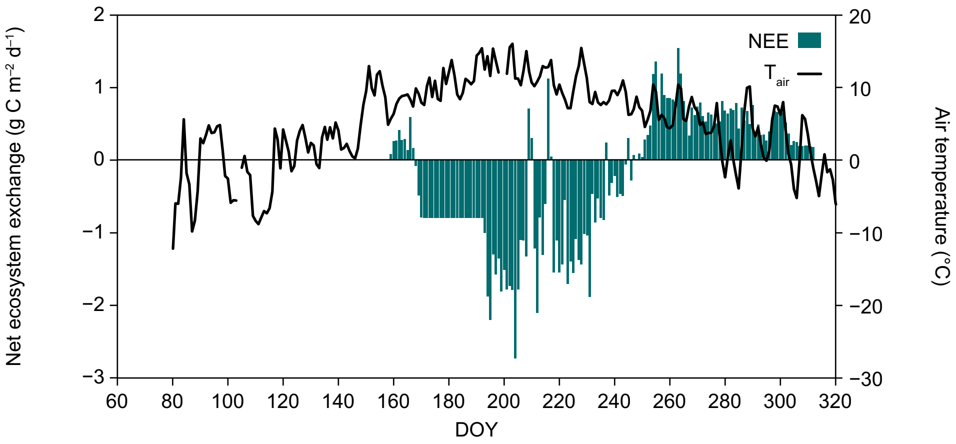


Figure 3.14 Diurnal net ecosystem exchange (NEE) and air temperature (T_{air}) measured in the fen in 2012. There was a long gap between 18 June (DOY 170) and 11 July (DOY 193) caused by instrumental failure, this period has been gap-filled using linear interpolation.

Automatic chamber measurements

An automatic chamber system consisting of six flux chambers for monitoring the exchange of CH_4 and CO_2 was installed in the fen in August 2007 (Tamstorf et al. 2008). In 2012, measurements started 7 June and lasted until 10 October, with only few interruptions in the data record (figure 3.13). During this period, approximately 17 % of the data was lost due to maintenance, calibration and preventive system closedowns (i.e. due to high winds that may break the auto-chamber lids).

The spatial and temporal variation in CH_4 emissions are primarily related to temperature, water table depth and net primary production. The fen in the Kobbefjord area 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 early June, when measurements started, CH_4 fluxes averaged 3 mg CH_4 m^{-2} h^{-1}. As the season progressed, emissions increased steadily and reached a peak in mid-July of approximately 7.5 mg CH_4 m^{-2} h^{-1}. Together with 2009, this is the highest peak level on record so far. In 2010 and 2011, fluxes rarely reached above 4 mg CH_4 m^{-2} h^{-1}. The inter-annual variation at the site is thus large. The variation between years is likely related to variations in timing of snowmelt, meteorological conditions, and net primary production in the fen.

After the CH_4 emission peak in mid-July, CH_4 fluxes decreased steadily and reached low levels around 1 mg CH_4 m^{-2} h^{-1} in October. Overall, the observed temporal CH_4 flux pattern of the Kobbefjord fen displays low shoulder season emissions with a dome-shaped peak during the growing season.

Eddy covariance measurements

In order to describe the inter-annual variation of the seasonal CO_2 balance, the land-atmosphere CO_2, H_2O and energy 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 analyser (Tamstorf et al. 2009). Raw data from the eddy covariance system was calculated using the software package EdiRe (Robert Clement, University of Edinburgh). For more details on the flux calculation procedures see Hansen et al. 2010.

Table 3.9 Summary of the eddy covariance measurement periods and CO_2 exchanges at the fen site. Please note that the measurement period varies from year to year.

Year	2008	2009	2010	2011	2012
Measurements start	05 Jun	15 May	4 May	15 May	06 Jun
Measurements end	29 Oct	31 Oct	9 Oct	14 Oct	31 Oct
Start of net uptake period	–	01 Jul	29 May	28 July	16 Jun
End of net uptake period	16 Aug	27 Aug	18 Aug	7 Sep	31 Aug
NEE for measuring period (g C m^{-2})	–45.5	–14.0	–20.9	42.6	–33.4
NEE for net uptake period (g C m^{-2})	–	–42.5	–65.4	–14.3	–73.1
Max. daily accumulation (g C m^{-2} d^{-1})	–2.27	–1.48	–3.14	–1.58	–2.73

The temporal variation in mean daily net ecosystem exchange of CO_2 (NEE) and air temperature during 2012 for the fen site is shown in figure 3.14, and various variables are summarized in table 3.9. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants, plant respiration and microbial decomposition. The CO_2 exchange is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), along with amount of biomass and soil moisture content. 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 6 June and lasted until 31 October (table 3.9). During this period, 28 % of data were lost due to malfunction, maintenance and calibration; mainly due to a long gap between 18 June and 11 July caused by instrumental failure. The eddy mast (2.2 m above ground) was fixed to the ground and when measurements started, the fen was snow free. Highest daily spring emission (0.59 g C m^{-2} d^{-1}) was measured 14 June. As the vegetation developed, photosynthetic uptake of CO_2 started, and 16 June the fen ecosystem switched from being a net source to a net sink of atmospheric CO_2 on a daily basis.

The period with net CO_2 uptake in 2012 lasted until 31 August. During this period, the fen accumulated –73.1 g C m^{-2}, which is the highest uptake on record so far. Maximum daily accumulation rate amounted to –2.7 g C m^{-2} (measured 22 July), which is also in the higher end of the range based on previous years' measurements. By 31 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 relatively high, allowing decomposition processes to continue at a decent rate. Highest daily emission during autumn was measured 19 September (1.5 g C m^{-2} d^{-1}). During the entire measuring period of 146 days, the fen constituted a sink for atmospheric CO_2, amounting to –33.4 g C m^2.

4 Nuuk Basic

The BioBasis programme

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This chapter presents the results of the sixth year of the BioBasis monitoring programme at Nuuk. The chapter gives an overview of the activities and presents examples of the results. The programme aims at providing long-term data series on biotic variables from the Kobbefjord area, approximately 20 km southeast of Nuuk. 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 (now Department of Bioscience), 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.

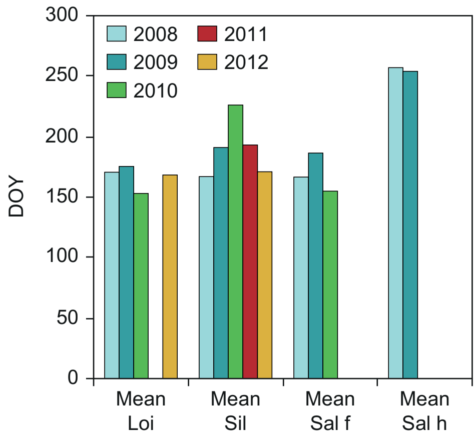


*Figure 4.1 Mean value for days of year (DOY) of 50% flowers/catkins for each of the species (*Loiseleuria procumbens *(Loi),* Salix glauca *(Sal f), and* Silene acaulis *(Sil)) in the plant reproductive phenology plots for 2008-2012. Also included are the senescent catkins (Sal h) of* Salix glauca*. Erratum: Please notice that the similar figures in previous Annual Reports are incorrect.*

4.1 Vegetation

Reproductive phenology

The reproductive phenology of three vascular plant species: The evergreen dwarf shrub *Loiseleuria procumbens*, the herb *Silene acaulis*, and the shrub *Salix glauca* have been studied since 2008. For each species, four phenology plots cover an ecological amplitude with respect to snow cover, soil moisture, and altitude. In 2012, the recording of phenology started 15 May (DOY 136) and ended 18 October (DOY 292). Examples of the results from 2008-2012 are shown and commented in the following text. The total flower production in some of the plants was very low this year, and this may be a result of the impact of noctuid moth larvae *Eurois occulta* in the previous two years. In *Salix glauca*, we only recorded two female flowers (catkins) in 2012; for *Loiseleuria procumbens* the number of flowers was low too, while *Silene acaulis* had the highest number of flowers ever recorded. The timing of 50% flowering was similar to previous years (figure 4.1).

The flower bud production of *Loiseleuria procumbens* occurred ten days later (29 May, DOY 150) compared to 2010 (19 May, DOY 139), which was the earliest year of previous recordings (figure 4.2a). We saw a second flower bud production, but this year it was more than 40 days later (2 October, DOY 276) than in 2010, where two budding events also were observed. The onset of flowering 12 June (DOY 164, figure 4.2b), and senescence 18 June (DOY 170, figure 4.2c), was more than two weeks later compared to 2010 (25 May, DOY 145 and 1 June, DOY 152, respectively). The first recording of budding in the plots was 15 May (DOY 136), and the first flower was seen approximately 5 June (DOY 157).

Silene acaulis displayed the same pattern as *Loiseleuria procumbens* with respect

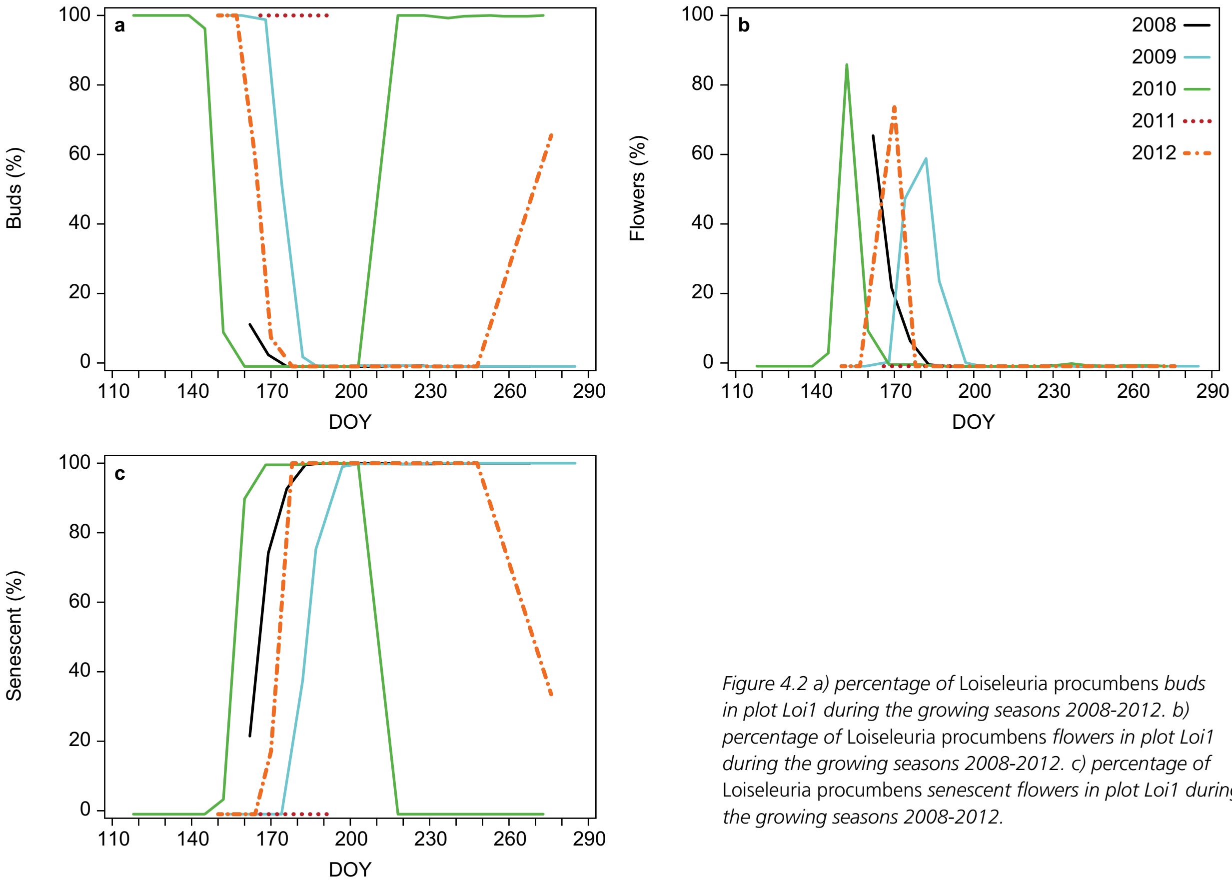


Figure 4.2 a) percentage of Loiseleuria procumbens *buds in plot Loi1 during the growing seasons 2008-2012. b) percentage of* Loiseleuria procumbens *flowers in plot Loi1 during the growing seasons 2008-2012. c) percentage of* Loiseleuria procumbens *senescent flowers in plot Loi1 during the growing seasons 2008-2012.*

to the timing of budding, flowering and senescence compared to 2010. The first buds were seen 5 June (DOY 157), and the first flowers were recorded 12 June (DOY 164). The flowering peaked two weeks later (18 June, DOY 170) than in 2010 (2 June, DOY 153), and at the same time as in 2008, which otherwise was the earliest year of flower peaking (figure 4.3a-c).

Salix glauca also had a two weeks delay in flower bud production (18 June, DOY 170) compared to the earliest year 2010 (2 June, DOY 153). The two flowers recorded in the plots did not produce fertile seeds.

Summing up reproductive plant phenology

The year 2012 had an intermediate timing of snowmelt. A preliminary review of data related to flowering indicates that 2012 was characterized by:

- Two budding events in *Loiseleuria procumbens*
- Hardly any flower buds or flowers produced and thus low seed production in *Salix glauca* and *Loiseleuria procumbens*
- Budding was delayed approximately two weeks compared to the earliest budding in 2010
- No noctuid moth larvae, *Eurois occulta*, were found during the season, but the growth of leaves on e.g. *Salix glauca* and *Vaccinium uliginosum* may have reflected the heavy impact of noctuid moths during the previous two years.

Vegetation greening, NDVI

The seasonal greening of the vegetation was monitored in plots with 1) *Empetrum nigrum* and *Eriophorum angustifolium*, 2) the plant phenology plots, and 3) along the NERO line (Bay et al. 2008). 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 *Empetrum nigrum*-plots, *Eriophorum angustifolium*-plots and the plant phenology plots, and monthly along the NERO line.

NDVI in the *Empetrum nigrum*-, *Eriophorum angustifolium*-plots and plant phenology plots

Empetrum nigrum attained the highest NDVI values of all the species (figure 4.4a). Even though the season started with the lowest values recorded, the NDVI values in three

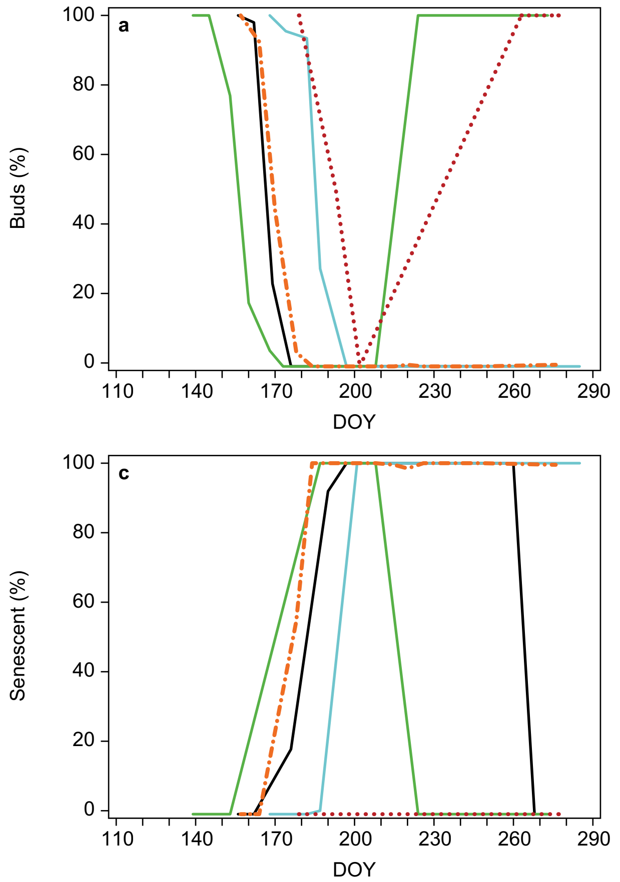


Figure 4.3 a) percentage of Silene acaulis *buds in plot Sil3 during the growing seasons of 2008-2012. b) percentage of* Silene acaulis *flowers in plot Sil3 during the growing seasons 2008-2012. c) percentage of* Silene acaulis *senescent flowers in plot Sil3 during the growing seasons 2008-2012.*

of the four *Empetrum nigrum* plots were the highest ever recorded after 3 June (DOY 185). *Empetrum nigrum* peaked between 15 August and 4 October (DOY 228 to 278). The increasing greening during the growing season is more or less pronounced in all years

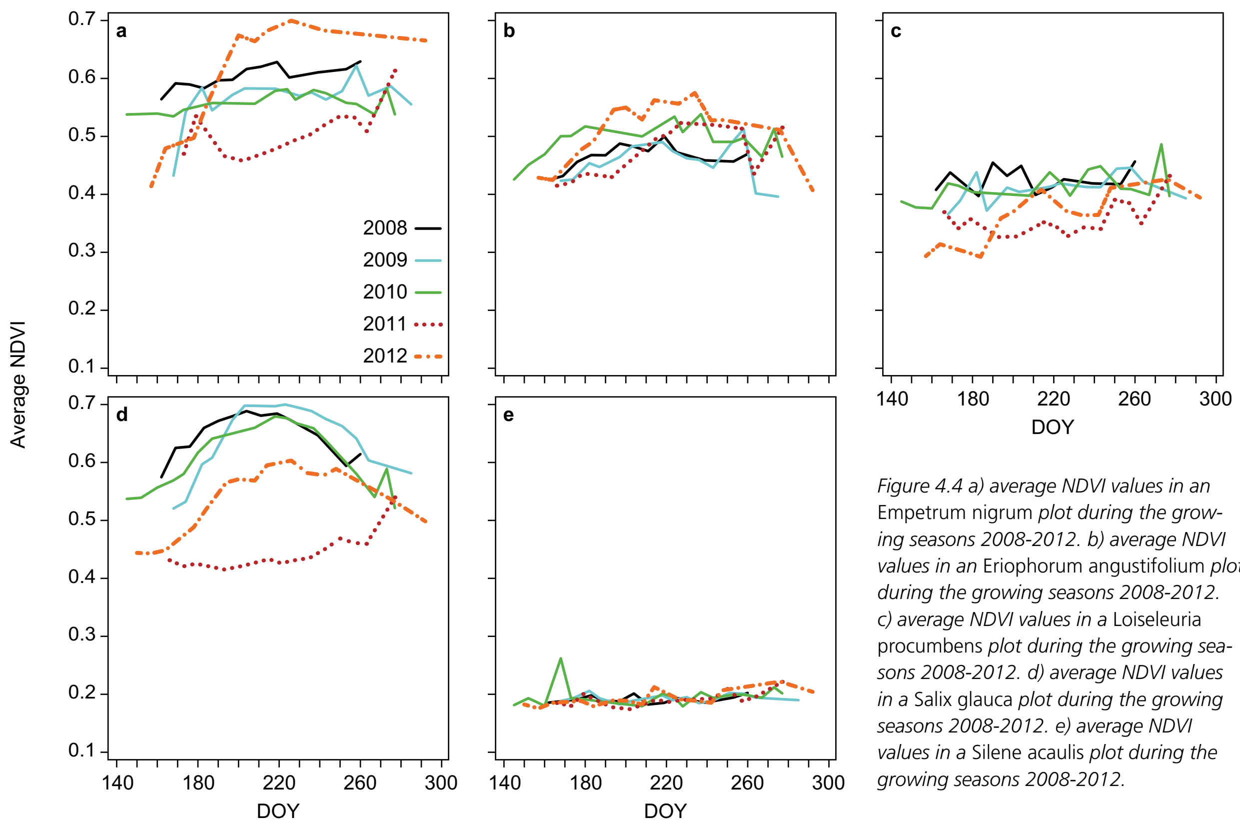


Figure 4.4 a) average NDVI values in an Empetrum nigrum *plot during the growing seasons 2008-2012. b) average NDVI values in an* Eriophorum angustifolium *plot during the growing seasons 2008-2012. c) average NDVI values in a* Loiseleuria procumbens *plot during the growing seasons 2008-2012. d) average NDVI values in a* Salix glauca *plot during the growing seasons 2008-2012. e) average NDVI values in a* Silene acaulis *plot during the growing seasons 2008-2012.*

but this year more than the other years. The plants seem to have recovered completely from the 'brown' conditions last year.

Eriophorum angustifolium reached the highest NDVI values in the middle of the growing season (23 July to 22 August, DOY 205 to 235) and in three of the four plots NDVI exceed the values of the previous years (figure 4.4b). However, plot 1 had average values throughout the season compared to previous years and peaked much earlier (26 July, DOY 208 vs. 7 August, DOY 220 to 17 August, DOY 230).

In the first part of the growing season in the *Loiseleuria procumbens* plots, the NDVI values were generally lower than previous years (figure 4.4c). Later in the season, *Loiseleuria procumbens*' NDVI values in three of the four plots were similar to previous years. In one plot, however, the values exceeded all previous years from the end of July (approximately 26 July, DOY 208) until the end of the growing season.

In 2012, the shapes of the NDVI curves in *Salix glauca* plots were similar to previous years except for 2011, which was exceptional because of the outbreak of the noctuid moth larvae, *Eurois occulta*. Three *Salix glauca* plots had NDVI values comparable to average of previous years (figure 4.4d). In plot 3 NDVI exceeded the previous years from the end of July.

Silene acaulis had generally the lowest NDVI values of all the species monitored, and the values are at the same level as the previous three years (figure 4.4e).

NDVI along the NERO line

The NDVI values throughout the growing season were the highest ever recorded in the heath and the copse (figure 4.5a-b). The fen showed the same pattern except for low values in the beginning of the season until approximately 28 June (DOY 180) (figure 4.5c). Snow patches started to green later than previous years, and NDVI values exceeded previous years from approximately 2 August (DOY 215) (figure 4.5d). All vegetation types reached the NDVI maximum values of the growing season at around 26 July (DOY 210). This is comparable to previous years except 2011.

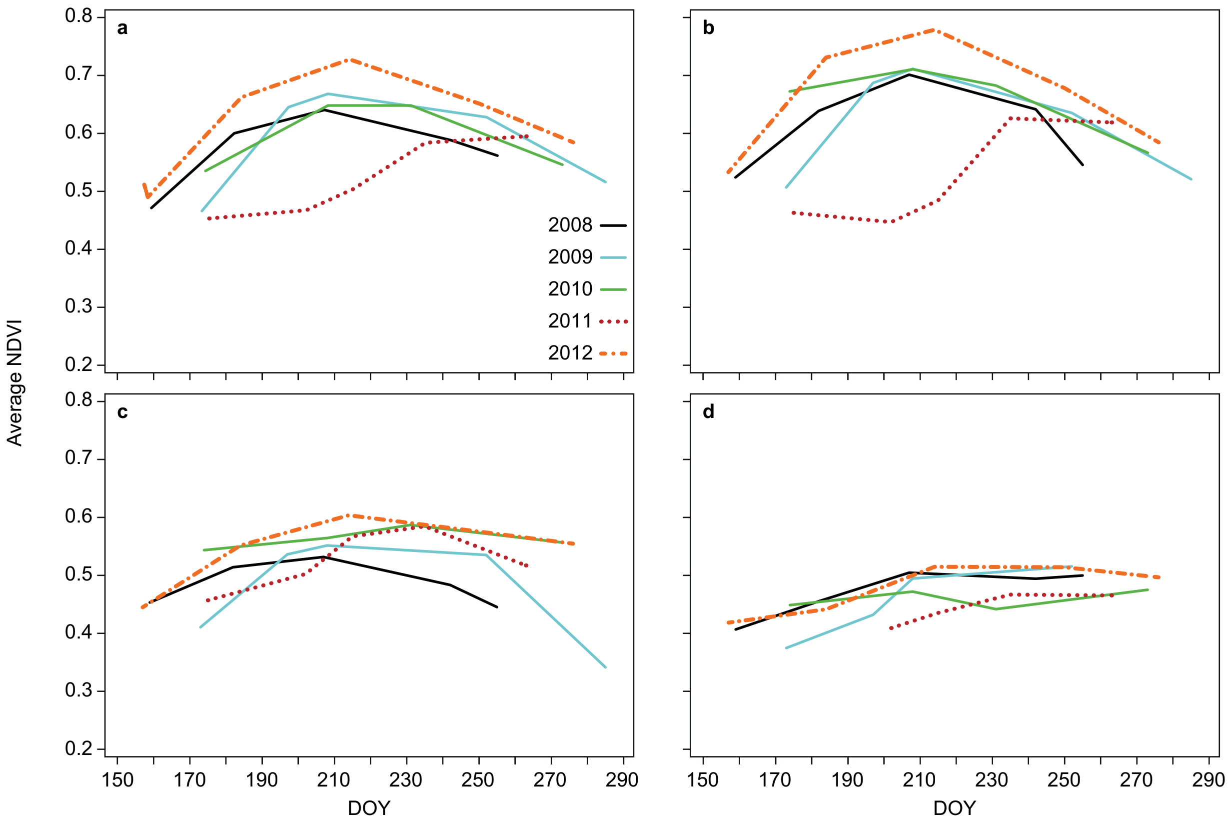
Summing up the vegetation greening

Generally, the NDVI values were significantly higher than previous years and they stayed at a high level throughout the growing season.

Monitoring the NERO line

The NERO line was established in July 2007 to investigate the long-term changes of the species composition of vascular plants, vegetation structure and the distribution of

Figure 4.5 a) average NDVI values along the NERO line from the vegetation types a) dwarf shrub heath, b) copse, c) fen and d) snow patch.



the plant communities along a landscape gradient. The plan is to re-analyse the line every fifth year in order to detect changes in the flora and vegetation structure. The vegetation analyses were carried out in July at the peak of the growing season using the modified Raunkiær method (Bay et al. 2008). The frequency of each vascular plant species is recorded by the given score. Fortunately, only few of the permanent marking sticks were missing and these plots were abandoned. A thorough statistical analysis will follow after next monitoring of the NERO line, thus in 2017.

Vegetation analyses in the Kobbefjord area 2012

The species composition and vegetation structure of the plant communities dominating the landscape in the Kobbefjord area were investigated by detailed vegetation analyses in the following major vegetation types: 1) dwarf shrub heath, 2) *Deschampsia flexuosa-Juncus trifidus* plant community, 3) fen, 4) copse, 5) salt marsh and 6) snow patch. In addition, herb slopes, which only cover minor areas, are included in the investigations. In the coming year, the data will be analysed and changes in the vegetation will be investigated.

The point quadrate concept of vegetation analysis was used to record the vascular plant species, mosses and lichens at 100 points within a frame of 70 cm × 70 cm and five plots were established in each of the vegetation types. They are permanently marked for re-analyses in the near future.

A comparable investigation has been carried out at Zackenberg, Northeast Greenland, in a high Arctic environment. The results from the investigation of the changes in the species composition have been published (Schmidt et al. 2012).

The species composition of vascular plants in the five vegetation types and the herb slope is given in table 4.1.

Carbon dioxide exchange

In 2008, a manipulation experiment was initiated with five treatments, each with six replicates. The experiment is located in a mesic dwarf shrub heath dominated by *Empetrum nigrum* with *Salix glauca* as a subdominant species. Treatments include control (C), shortened growing season (SG: addition of snow in spring), prolonged growing season (LG: removal of snow in spring), shading (S: hessian tents) and increased temperature (T: ITEX plexiglas hexagons). We conducted measurements of land-atmosphere exchange of CO_2, using the closed chamber technique; soil temperature, soil moisture and phenology of *Salix glauca* were measured approximately weekly during June-September each year. The net ecosystem exchange (NEE) was measured with transparent chambers, while the ecosystem respiration (R_{eco}) was measured with darkened chambers. Gross primary production (GPP) was calculated as the difference between NEE and R_{eco}. The SG and LG treatments have not been applied in 2008-2012, therefore results from these plots can be considered as controls.

Seventeen CO_2 flux measurement were carried out between 25 May (DOY 146) and 28 September (DOY 272) (figure 4.6). Generally, all plots functioned as sinks for atmospheric CO_2 at the time of the measurement (midday). In May, NEE was generally close to zero. Similar to earlier years, NEE was more negative (i.e. higher CO_2

Figure 4.6 Monthly means of a) net ecosystem exchange (NEE), b) ecosystem respiration (R_{eco}) and c) gross primary production (GPP) in 2012 in the manipulation experiment. Error bars refer to standard error in spatial variability (six replicates). For explanation of treatment abbreviations, see text.

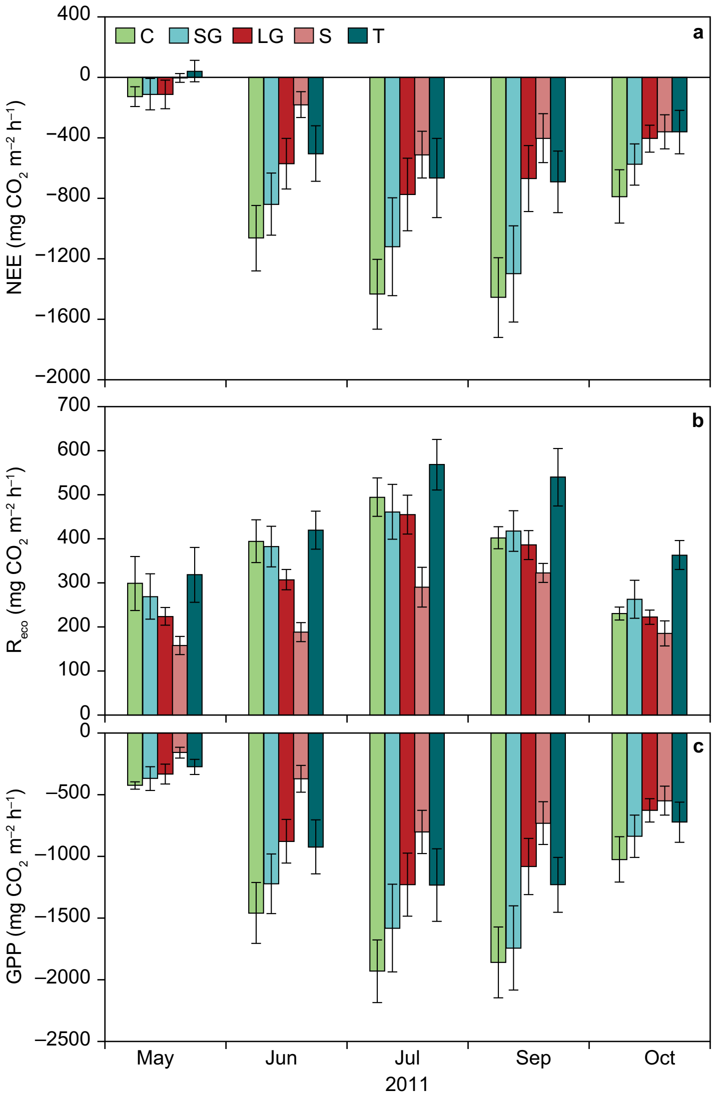


Table 4.1 List of vascular plant species in the different habitat types in the Kobbefjord area.

Vascular species	Dwarf shrub heath	Graminoid community	Fen	Copse	Snow patch	Herb slope
Agrostis mertensii		X				
Alchemilla alpina						X
Alchemilla glomerulans						X
Angelica archangelica				X	X	
Bartsia alpina						X
Betula nana	X		X			
Carex bigelowii	X			X	X	X
Calamagrostis langsdoffii				X	X	
Carex brunescens					X	
Carex canescens			X			
Carex lachenalii					X	X
Carex rariflora			X			
Cerastium cerastoides					X	
Chamaenerion angustifolium						X
Coptis trifolia				X		X
Cornus suesica	X					X
Deschampsia flexuosa	X	X		X	X	
Empetrum nigrum	X	X		X		
Juncus trifidus	X	X				
Epilobium anagallidifolium						X
Equsetum silvaticum				X		
Eriophorum angustifolium			X			
Gnaphalium norvegicum						X
Gnaphalium supinum						X
Gymnocarpium dryopteris						X
Huperzia selago					X	
Juniperus communis		X				
Ledum groenlandicum				X		
Loiseleuria procumbens	X					
Listera cordata						X
Luzula parviflora				X	X	X
Oxycoccus palustris			X			
Oxyria digyna					X	X
Phleum commutatum				X		X
Polygonum viviparum	X			X	X	X
Poa pratensis				X	X	X
Potentilla tridentata		X				
Pyrola minor			X		X	
Rhodiola rosea						X
Rhododendron lapponicum				X		
Salix arctophila			X			X
Salix glauca	X			X		
Salix herbacea					X	X
Saxifraga stellaris					X	X
Scirpus caespitosus			X			
Sibbaldia procumbens						X
Silene acaulis		X				
Taraxacum sp.				X		X
Vaccinium uliginosum	X					
Vahlodea atropurpurea					X	
Veronica alpina					X	X
Veronica wormskjoldii				X		X

uptake) in C plots compared with T and S plots. The ecosystem respiration showed a pattern of higher emissions in T plots compared with other treatments, especially during July through September, which can be explained by warmer and drier conditions resulting in increased respiration rates. Highest rates of GPP were generally observed in C plots, while especially S plots had lower GPP rates compared with other treatments. As photosynthesis is driven by solar radiation, shading decreases GPP and build-up of the biomass.

The differences between treatments during 2012 were in general similar to previous years. However, both net CO_2 uptake (NEE) and GPP were higher compared with previous years, which is in agreement with GeoBasis' eddy covariance measurements in the fen (see section 3.4).

UV-B exclusion plots

Measurements of chlorophyll fluorescence as a measure of plant stress were carried out in the Kobbefjord area in 2012. 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 exclusion plots were set up between 22 and 28 June (DOY 174 and 180, respectively). New frames were used and showed to resist the strong winds much better than the frames used in previous years. The frames were maintained until 14 September (DOY 258).

The ambient UV-B radiation on fluorescence parameters was monitored on *Vaccinium uliginosum* and *Betula nana*. The total performance index (PI_{total} - integrating responses of antenna, reaction centre, electron transport and end acceptor dependent parameters) is an indicator of the viability of a sample. PI_{total} were sensitive to UV-B exclusion in both *Vaccinium uliginosum* and *Betula nana*. The average PI_{total} was improved by around 11 % in *Vaccinium uliginosum* and around 24 % in *Betula nana* when reduced UV-B was compared to near ambient UV-B. The PI_{total} was around four in *Betula nana* and eight in *Vaccinium uliginosum*; the influence of treatment varied with date (figure 4.7).

4.2 Arthropods

In the Kobbefjord area, all four pitfall trap stations established in 2007 and the two window trap stations (each with two traps) established in 2010 were open during the 2012 season. Parts of the samples are being sorted by Department of Bioscience, Aarhus University, Denmark. The material samp-led during the 2012 season is being stored in 70 % ethanol at Greenland Institute of Natural Resources. Pitfall traps were established from 25 May (DOY 146) through 5 June (DOY 157) and they all worked continuously until 2 October (DOY 276), when the liquid began to freeze.

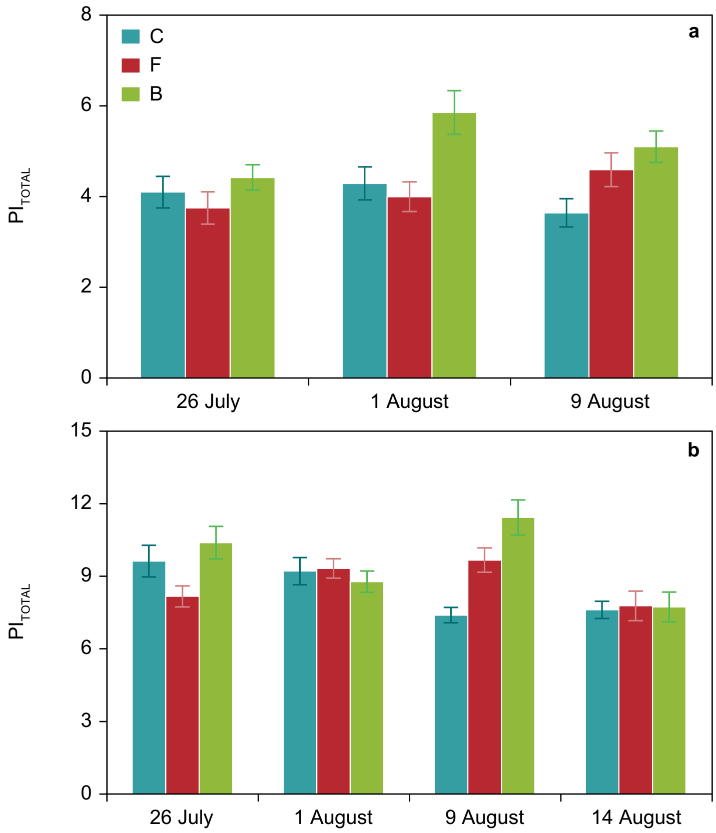


Figure 4.7 The total performance index (PI_{total}) is an indicator of the viability of a sample. PI_{total} is shown by date and treatment. Treatments are: C – Open control (no filter), F – Filter control (transparent filter, Teflon) and B – UV-B-reduction (UV-B absorbing filter, Mylar). a) is Betula nana *and b) is* Vaccinium uliginosum.

Microarthropods

The 2012 season was used for a research project. See project description and results in section 6.4.

4.3 Birds

Passerine birds were counted at 13 census points within the 32 km² Kobbefjord catchment area. Thirteen censuses were carried out from 30 May (DOY 151) to 2 October (DOY 276). When arriving at a census point five minutes were used as a 'settling period', and a following five minutes period was

Table 4.2 Total number of passerines counted and the number of censuses per year. For explanation of the bird abbrevations, see text.

Total no of birds	LB	SB	NW	RP	No of census's
2008	57	61	44	7	9
2009	39	40	33	37	5
2010	182	152	110	49	17
2011	166	131	146	7	14
2012	102	69	109	37	13

Table 4.3 Meteorological data from the official DMI station in Nuuk. A precipitation day is defined as a day with >1 mm precipitation.

	Climate data from Nuuk				
	2008	**2009**	**2010**	**2011**	**2012**
Annual precipitation (mm)	1041	537	733	748	1201
Precipitation May-Aug (mm)	214	122	400	220	411
Annual precipitation days	134	82	102	123	129
Average temp May-Aug	6.5	4.9	7.3	5.2	7.5
Average temp May-Jun	4.7	2.3	5.9	2.8	5.5

used for counting birds. If none was seen during the 'counting period', the observations from the 'settling period' are used.

The total number of Lapland buntings (LB), snow buntings (SB), northern wheatears (NW), and redpolls (RP) varies between the years (table 4.2). Figure 4.8 shows the number of passerines counted per census from 2008 to 2012.

Both Lapland and snow bunting arrive very early in the spring, most of them before the first census. The Lapland bunting is the most abundant passerine bird in the area; in 2012, it arrived in Kobbefjord before we started the census (figure 4.9). The timing of the migration out of the area was a little later than in most previous years, but the number of birds in the area was similar to most previous years.

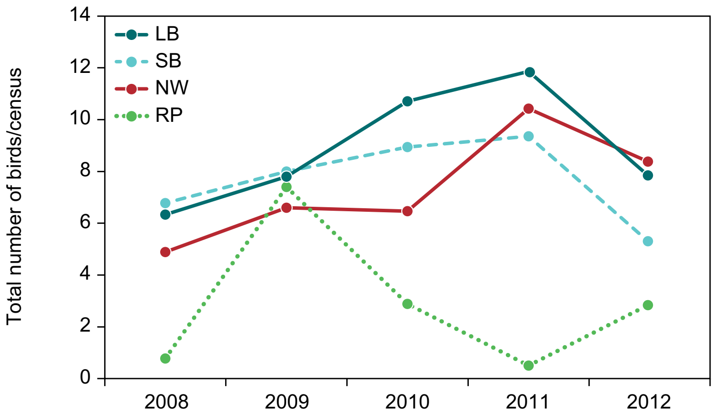


Figure 4.8 Total number of birds counted per census in 2008-2012. For explanation of the bird abbreviations, see text. The lines connecting the dots are only used for illustrative purposes.

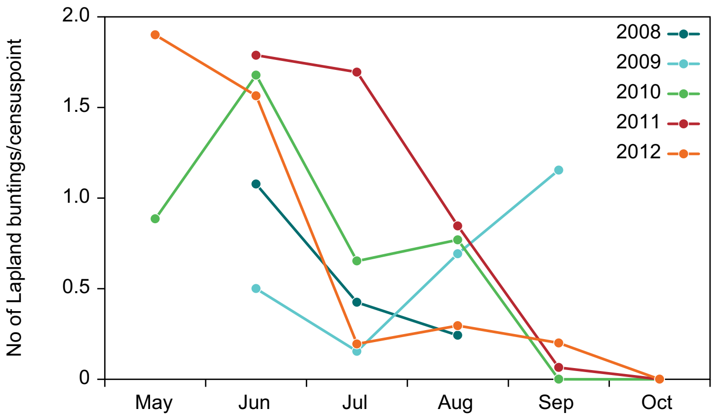


Figure 4.9 Number of Lapland buntings per census during the season in 2008-2012. The lines connecting the dots are only used for illustrative purposes.

4.4 Mammals

The Kobbefjord catchment area is only sparsely populated with mammals. Arctic hare, Arctic fox and caribou have been sighted in previous years but in 2012, only tracks of Arctic fox were seen.

4.5 Lakes

In the Kobbefjord catchment area, two of three lakes have been monitored since 2008. Badesø (80 ha) and Qassi-sø (52 ha) are both deep with maximum depths of 35 and 27 m, respectively, and mean depths of 9.2 m and 7.8 m, respectively. The deepest, west-east oriented lake, Badesø, is located downstream, approximately 50 m a.s.l., while the other lake, Qassi-sø, is located upstream, approximately 250 m a.s.l. Qassi-sø is the most wind exposed of the two lakes, and a small glacier drains into the lake implying a relatively large input of silt. Due to the higher altitude of Qassi-sø, the duration of ice cover is generally longer than in Badesø.

In this year's report, more emphasis has been put on phytoplankton than in previous reports, and the section on macrophytes has been omitted.

Climate

The year 2012 has so far been the wettest year during the monitoring period, precipitation being >150 mm higher than the second wettest year, 2008, and with more than twice the precipitation of the driest year, 2009 (table 4.3). However, the number of precipitation days remained in the same range as previous years (table 4.3). The year 2012 was a warm year and showed a pattern comparable to 2010, during both the pre-summer period (May-June) and the entire summer/growing season (May-August, table 4.3).

The high temperatures in 2012 are also reflected in the temperature profiles from Badesø and Qassi-sø (figure 4.10). The profile is particularly evident for Qassi-sø, il-

Table 4.4 Morphometric data, time weighted mean values of water chemistry (min-max values) and physical data measured in Badesø and Qassi-sø during the ice-free periods from 2008-2012.

	Badesø					Qassi-sø				
	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012
Total phosphorus (mg l^{-1})	0.005 (0.001-0.012)	0.004 (0.003-0.005)	0.004 (0.003-0.004)	0.004 (0.003-0.005)	0.006 (0.002-0.008)	0.015 (0.005-0.029)	0.002 (0.001-0.005)	0.005 (0.003-0.009)	0.005 (0.003-0.006)	0.006 (0.004-0.008)
Total nitrogen (mg l^{-1})	0.084 (0.040-0.140)	0.027 (0.020-0.033)	0.080 (0.04-0.11)	0.17 (0.14-0.23)	0.06 (0.03-0.15)	0.090 (0.30-0.150)	0.022 (0.019-0.029)	0.084 (0.050-0.14)	0.138 (0.09-0.23)	0.03 (0.02-0.06)
pH	6.92 (6.59-7.13)	6.85 (6.46-7.14)	6.62 (6.09-7.3)	7.1 (6.51-7.85)		6.72 (6.44-6.96)	6.87 (6.79-6.93)	6.84 (6.37-7.31)	7.59 (6.79-7.97)	
Conductivity (µS cm^{-1})	20 (19-22)	22 (21-23)	21 (18-26)	21 (15-27)	18 (14-19)	20 (15-24)	16 (16-17)	17 (15-18)	18 (15-20)	15 (10-20)
Ice-free, date	3 Jun	15 Jun	20 May	23 Jun	9 Jun	12 Jun	28 Jun	31 May	1 Jul	18 Jun
Ice-covered, date	24 Oct	30 Oct	13 Dec	25 Oct	14 Nov	18 Oct	17 Oct	10 Nov	20 Oct	1 Nov
Ice-free period, days	143	137	207	124	158	128	111	163	112	136

lustrated by a strong temperature increase in the upper 10 metres in June and July, which has not been observed before.

Water chemistry and ice cover

Like most Arctic lakes Badesø and Qassi-sø are nutrient poor and the nutrient levels in 2012 did not differ significantly from previous years. Total nitrogen levels decreased, however, to levels (0.06 and 0.03 mg TN l^{-1}, in Badesø and Qassi-sø, respectively) similar to those of 2008-2010 after somewhat higher concentrations in 2011 (0.17 and 0.138 mg TN l^{-1}, respectively, table 4.4). Total phosphorus levels were similar to or slightly higher (0.006 mg l^{-1} in both lakes) than in previous years. The ice-out date was 9 June (DOY 161) in Badesø and nine days later, 18 June (DOY 170) in Qassi-sø. The lakes were ice covered again 14 November (DOY 319) and 1 November (DOY 306), respectively, resulting in an ice-free period of 158 and 136 days, respectively (table 4.4).

Chlorophyll and Secchi depth

Chlorophyll *a* (Chl *a*) is correlated to nutrient levels and the Chl *a* levels of the two lakes are consequently low (figure 4.11a). Chl *a* has varied notably between years, but compared to more nutrient rich lakes, the variation remains within a very narrow range due to the low nutrient levels. Over the five-year period Chl *a* exhibited an increasing trend in both Badesø and Qassi-sø; however, average concentrations in 2012 were still low: 0.78 and 0.65 µg Chl *a* l^{-1}, respectively (figure 4.11a), with slightly higher Chl *a* levels in Badesø. In correspondence with this, a dramatic decreasing trend in Secchi depth occurred. Thus, in Badesø, the Secchi depth decreased from 8.2 m to 4.6 m in 2012 (figure 4.11b). In Qassi-sø, Secchi depth decreased from 3.7 m to 2.8 m in 2012 (figure 4.11b). In 2012, Chl *a* levels were similar in the two lakes (figure 4.11a), which means that the generally lower Secchi depth in Qassi-sø than in Badesø is created by a glacial run-off, causing higher input of silt to Qassi-sø.

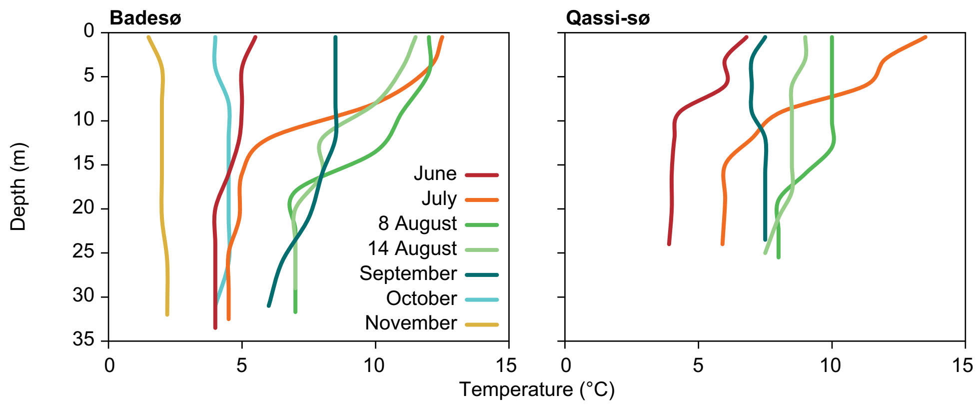


Figure 4.10 Temperature profiles on sampling dates from Badesø and Qassi-sø 2012.

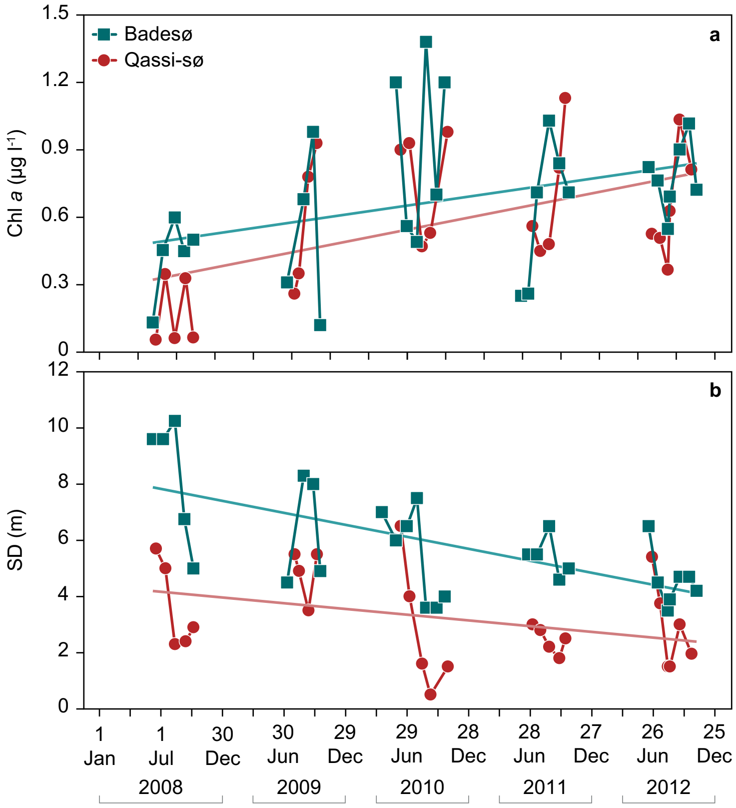


Figure 4.11 a) chlorophyll a levels and b) secchi depth in Badesø and Qassi-sø 2008-2012.

One may ask, why does Secchi depth decline, when nutrient levels remain unchanged during the monitoring period? An explanation may be the more frequently occurring warm periods. In periods with warm surface water and a stronger stratification in Badesø or a beginning stratification in Qassi-sø (figure 4.10), phytoplankton will concentrate in the photic zone, where primary production will increase due to higher temperatures creating a decrease in Secchi depth. This phenomenon can also explain the increasing Chl *a* concentration, substantiating the fact that at certain nutrient levels and temperatures, shallow lakes will have higher chlorophyll levels compared to deeper lakes.

Zoo plankton

In general, there is no consistent pattern of which lake having the highest total zooplankton biomass. Some years the highest biomass is observed in Badesø and other years, for instance 2008 and 2010, in Qassi-sø (figure 4.12). In the entire monitoring period, the zooplankton communities in both Badesø and Qassi-sø were generally dominated by calanoid copepods (only *Leptodiaptomus minutus* was found). Occasionally, rotifers played an important role in the zooplankton biomass in Badesø, mainly due to high occurrences of the large *Asplanchna* sp., but also smaller rotifers (like *Keratella* spp. and *Polyarthra* spp.) were found in large numbers. In Qassi-sø, biomass of cyclopoid copepods were high, especially in 2008 and 2010, and to a lesser extent in 2012. Cladoceran abundances were smaller in both lakes (figure 4.12). The composition of the different groups in Badesø (fewer cyclopoid

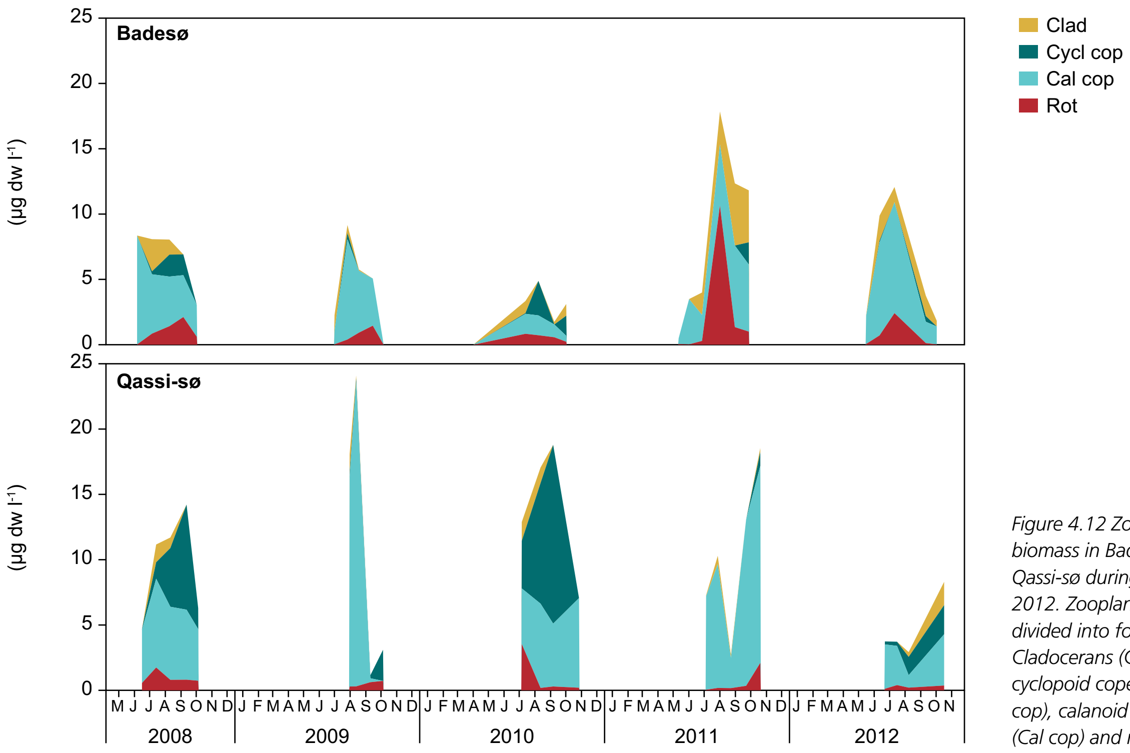


Figure 4.12 Zooplankton biomass in Badesø and Qassi-sø during 2008-2012. Zooplanktons are divided into four groups: Cladocerans (Clad), cyclopoid copepods (Cycl cop), calanoid copepods (Cal cop) and rotifers (Rot).

copepods, smaller cladocerans and more rotifers) reflects the fact that Badesø contrary to the fishless Qassi-sø, holds zooplankton-eating fish. Another indicator of the lack of fish in Qassi-sø is the occurrence of the large cladoceran *Daphnia pulex*, which is very susceptible to fish predation.

Zooplankton use phytoplankton as a food source, and a higher phyto-/zooplankton ratio in Badesø than in Qassi-sø (figure 4.13) is probably an effect of/related to the fish predation on zooplankton in Badesø. Another characteristic feature of the phyto/zooplankton ratio is that the ratio is higher early than later in the season, which can be explained by a high primary production prior to and immediately following the ice melt. This is followed by an increasing zooplankton biomass, causing a reduction in the phytoplankton biomass.

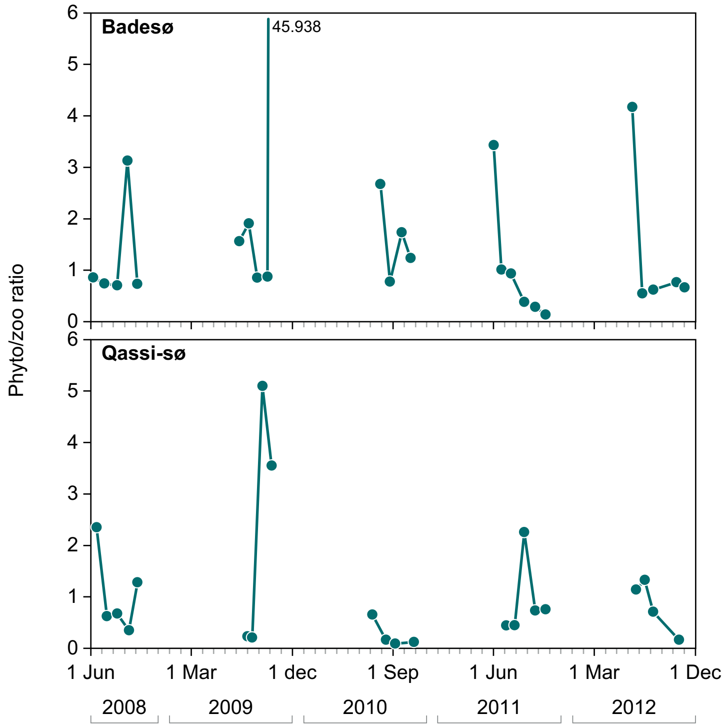


Figure 4.13 Biomass based phytoplankton/zooplankton ratio in Badesø and Qassi-sø during 2008-2012.

Phytoplankton

The phytoplankton in Badesø and Qassi-sø was dominated by flagellated mixotrophic[1] species, mainly chrysophytes, dinoflagellates, and cryptophytes (figure 4.14 and 4.15). This dominance was more pronounced in Badesø than in Qassi-sø during the entire phytoplankton succession period.

In 2008-2012, chrysophytes (*Dinobryon* and *Ochromonas*), and smaller dinoflagellates started the succession during the ice-free period. In mid-summer, they were accompanied by larger dinoflagellates (*Gymnodinium* and *Peridinium*), and in late summer, diatoms (*Cyclotella*, *Tabellaria* and *Rhizosolenia*) became important. In 2011-2012, the succession was completed by chlorophytes, accompanied by cyanobacteria. The dominance of diatoms and chlorophytes in the later stages of the succession was more pronounced in Qassi-sø than in Badesø.

The sampling season changes from year to year according to duration of the ice-cover, but this supposedly has no effect on mean phytoplankton biomass values (tables 4.5 and 4.6). Growth under ice of mixotrophic flagellates, which prefer calm water, most certainly occurs and is the reason behind the large population of mixotrophic flagellates immediately after the ice-breakup.

[1] Mixotrophic organisms: Organisms partly photosynthetic, partly particle eaters on smaller flagellates, diatoms, bacteria, and the cryptophytes, dissolved organic matter.

A most remarkable difference in phytoplankton between the years is the occurrence of cyanobacteria (*Oscillatoria* and *Anabaena*) in Badesø 2011–2012. Cyanobacteria are usually associated with highly eutrophic waters, and Badesø has an extremely low TP-concentration, 0.005 µg l^{-1}, which normally does not support growth of cyanobacteria. Despite this, cyanobac-

Table 4.5 Badesø. Phytoplankton biomass, (mg wet weight (ww))/litre (l) = mm^3 l^{-1} (mean from sampling season 2008-2012).

Group/Year	2008-2009	2010	2011	2012
Cyanobacteria	–	–	0.0001	0.0004
Cryptophyta	0.001	0.002	0.005	0.002
Dinoflagellata	0.003	0.014	0.005	0.014
Chrysophyta (naked)	0.067	0.056	0.024	0.028
Diatomophyceae	0.004	0.002	0.002	0.007
Prymnesiophyceae	–	0.001	–	–
Prasinophyceae	0.001	–	–	–
Chlorophyta	0.006	0.001	0.004	0.005
SUM	0.082	0.077	0.040	0.056

Table 4.6 Qassi-sø. Phytoplankton biomass, (mg wet weight (ww))/litre (l) = mm^3 l^{-1} (mean from sampling season 2008-2012).

Group/Year	2008-2009	2010	2011	2012
Cryptophyta	–	0.0001	0.0001	0.0002
Dinoflagellata	0.002	0.005	0.021	0.007
Chrysophyta (naked)	0.049	0.027	0.006	0.013
Diatomophyceae	0.014	0.003	0.052	0.008
Prasinophyceae	–	–	–	–
Chlorophyta	0.009	0.005	0.001	0.001
SUM	0.073	0.040	0.080	0.029

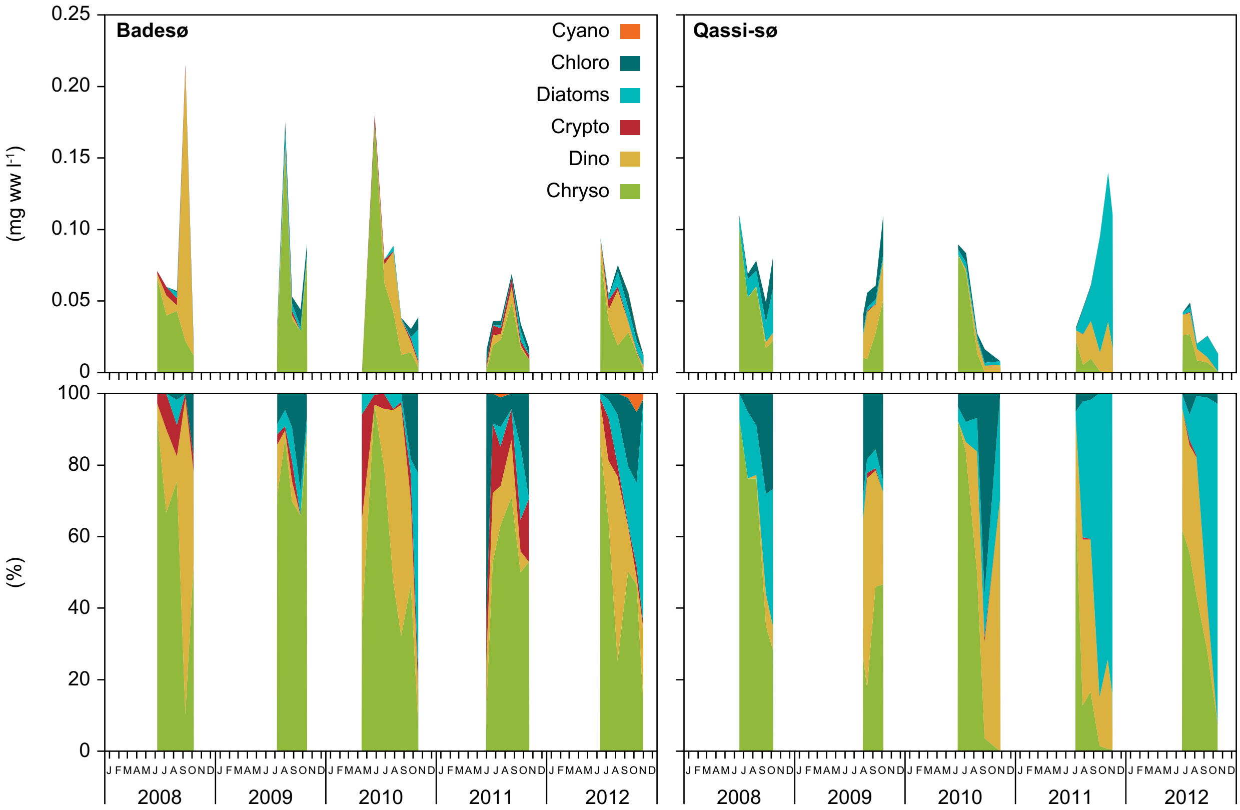


Figure 4.14 Badesø and Qassi-sø. Phytoplankton seasonal variation during 2008-2012 (mg wet weight (ww))/litre (l) = mm³ litre⁻¹ and %. Autotrophic groups: Cyano = Cyanobacteria; Chloro = Chlorophyta; Diatoms = Diatomophyceae. Mixo- and osmo-heterotrotrophic groups: Crypto = Cryptophyta; Chryso = Naked Chrysophyceae; Dino = Dinoflagellata.

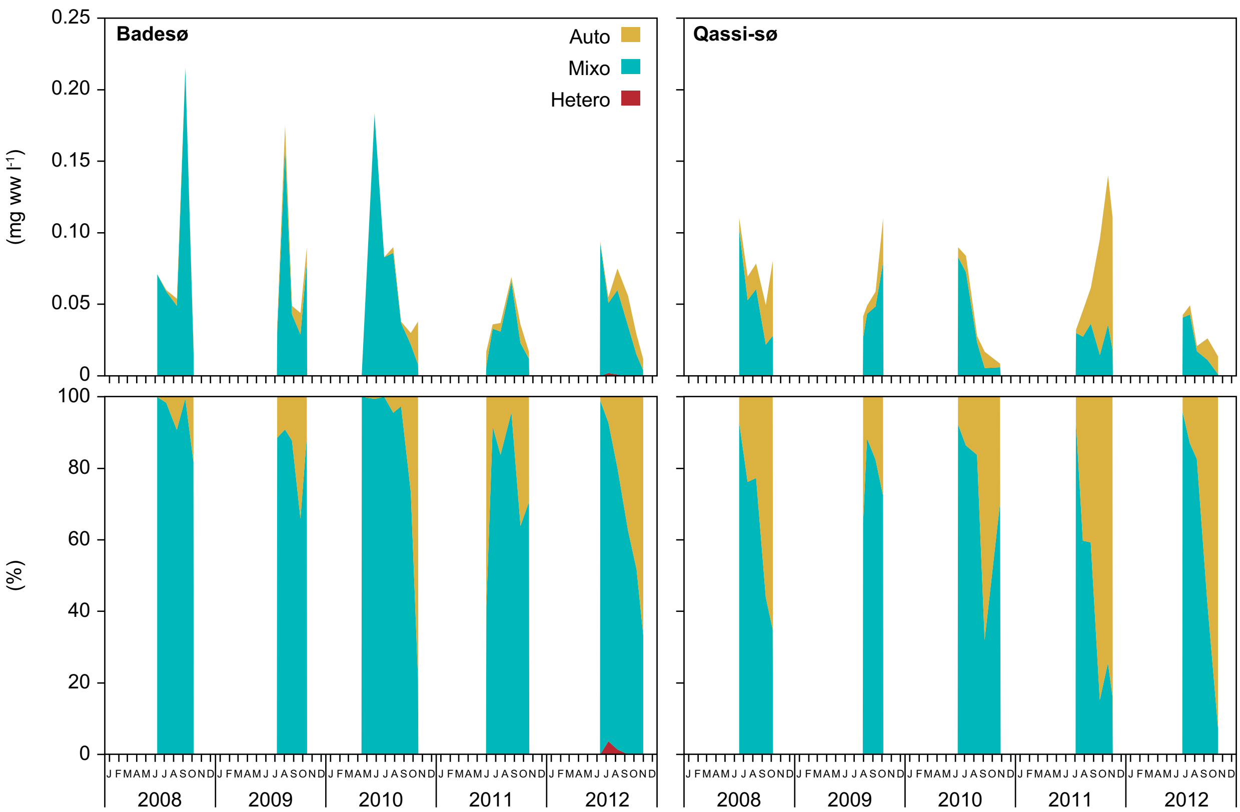


Figure 4.15 Badesø and Qassi-sø. Seasonal variation of phytoplankton trophical groupings during 2008-2012, $mm^3\ l^{-1}$ = $mg\ l^{-1}$ and %. Auto = Autotrophic species; Mixo = Mixotrophic species; Hetero = Heterotrophic species.

Table 4.7 Badesø 2008-2012. Chrysophyte and desmid species.

Year	2008-2009	2010	2011	2012
CHRYSOPHYCEAE				
Chrysophyceae spp. (cyste)	x		x	x
Bicosoeca planctonica				x
Bitrichia chodatii	x		x	x
Bitrichia longispina	x			
Chrysolykos planctonicus		x		
Chrysolykos skujai	x	x	x	x
Dinobryon asmundiae			x	
Dinobryon attenuatum	x			
Dinobryon bavaricum	x	x	x	x
Dinobryon bavaricum v. vanhöffenii	x			x
Dinobryon crenulatum	x	x	x	x
Dinobryon cylindricum	x	x	x	x
Dinobryon cylindricum v. Palustre	x		x	x
Dinobryon hilliardii	x	x	x	x
Dinobryon mucronatum	x	x	x	x
Dinobryon pediforme				x
Dinobryon sertularia	x	x	x	x
Dinobryon tubaeforme			x	
Mallomonas spp.	x	x	x	x
Mallomonas akrokomos		x		x
Ochromonas spp. (5-10 µm)	x	x	x	x
Ochromonas spp. (10-15 µm)	x	x	x	x
Uroglena spp. (5-10 µm)	x		x	x
Chromulina spp. (2-5 µm)	x	x	x	x
Chromulina spp. (5-10 µm)	x	x	x	x
DIATOMOPHYCEAE				
Rhizosolenia eriensis	x	x	x	X
Rhizosolenia longiseta	x	x	x	X
Fragilaria arcus				X
Tabellaria binalis			x	X
DESMIDIACEAE				
Actinotaenium cucurbita			x	
Closterium abrubtum			x	
Cosmarium abbreviatum			x	
Cosmarium contractum		x		
Cosmarium fastidiosum				X
Cosmarium depressum	x			X
Cylindrocystis brebissonii				X
Desmidium swartzii				X
Euastrum elegans	x			
Gonatozygon brebissonii			x	X
Staurastrum avicula				X
Staurodesmus extensus	x			X
Staurodesmus extensus v. joshuae	x	x	x	
Staurodesmus extensus v. malaccensis				
Staurodesmus indentatus	x			
Staurastrum polymorphum	x			X
Staurodesmus sellatus	x			
Staurodesmus subulatus			x	
Staurodesmus triangularis	x	x	x	X
Staurastrum kouwetsii		x		
Teilingia granulata	x			
Xanthidium bifidum	x	x		X
Xanthidium variabile	x			

teria have spread in oligotrophic lakes in recent years, most likely because of global warming and its influence on the nitrogen circle, changing the growth conditions in oligotrophic lakes from early P-deficiency to early inorganic N-deficiency (Goldman et al. 2013). Cyanobacteria adapt better to this situation than 'true' autotrophic species of diatoms and chlorophytes that need dissolved inorganic nutrients.

Another feature of the phytoplankton, particularly evident for Badesø, is the long list/high number of chrysophytes and desmid species (table 4.7).

The phytoplankton in Qassi-sø was less species rich than in Badesø. The quantitative dominance of 'true' autotrophic diatom and chlorophyte species in late stages of the succession is most likely due to more stagnant water in Badesø than in Qassi-sø, which has shorter retention time than Badesø.

5 Nuuk Basic

The MarineBasic programme 2010

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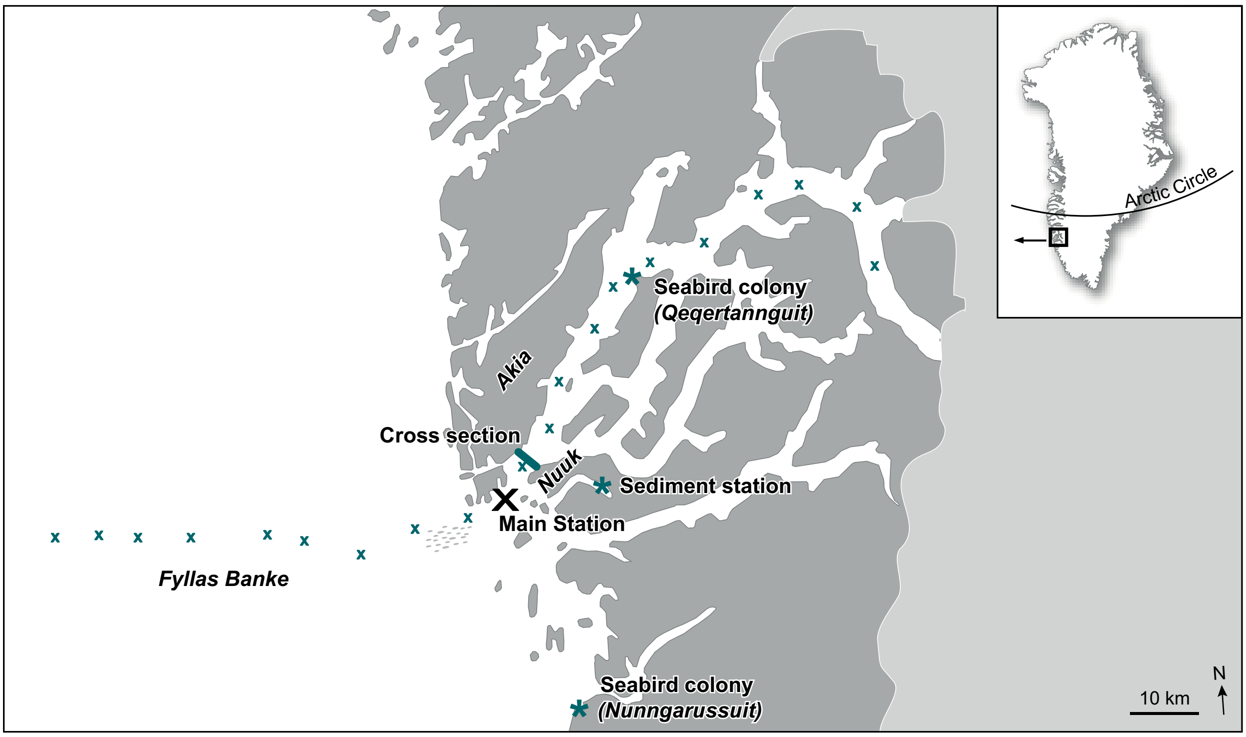
This chapter presents data from the seventh year of marine monitoring in Godthåbsfjord. The programme collects long-time series of key parameters of physical, chemical and biological oceanography relevant for identifying and describing effects of climatic change on the low Arctic marine ecosystem in Godthåbsfjord (Kobbefjord). The monitoring is comprised of collecting daily satellite information on sea ice conditions and monthly pelagic sampling, combined with seasonal sampling of sediment-water exchange, studies of macroalgae and macrobenthos, counting of seabirds at selected colonies and photo identification of marine mammals. This comprehensive dataset describe seasonal, annual and inter-annual variation and patterns of the marine ecosystem. These time series also provide a foundation for identifying and quantifying effects of climatic forcing. Pelagic sampling is conducted at a permanent sampling station ('Main Station' (GF3); 64°07'N, 51°53'W) located at the fjord entrance, while the other parameters are sampled in and around the Godthåbsfjord system (figure 5.1). Methods are briefly described throughout the report, for more details please consult the MarineBasis-Nuuk manual (www.nuuk-basic.dk).

5.1 Sea ice

Sea ice condition within Godthåbsfjord was monitored using daily satellite images (MODIS, 250 m resolution; figure 5.2), along with several images per day from a camera system covering a cross section of the fjord near Nuuk. These images show that similar to previous years the Godthåbsfjord system only experiences sea ice cover in smaller fjord branches and in the innermost part of the fjord near the glaciers. They also show that sea ice is exported out of the fjord in bursts at different times of the year; while only little or no ice

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



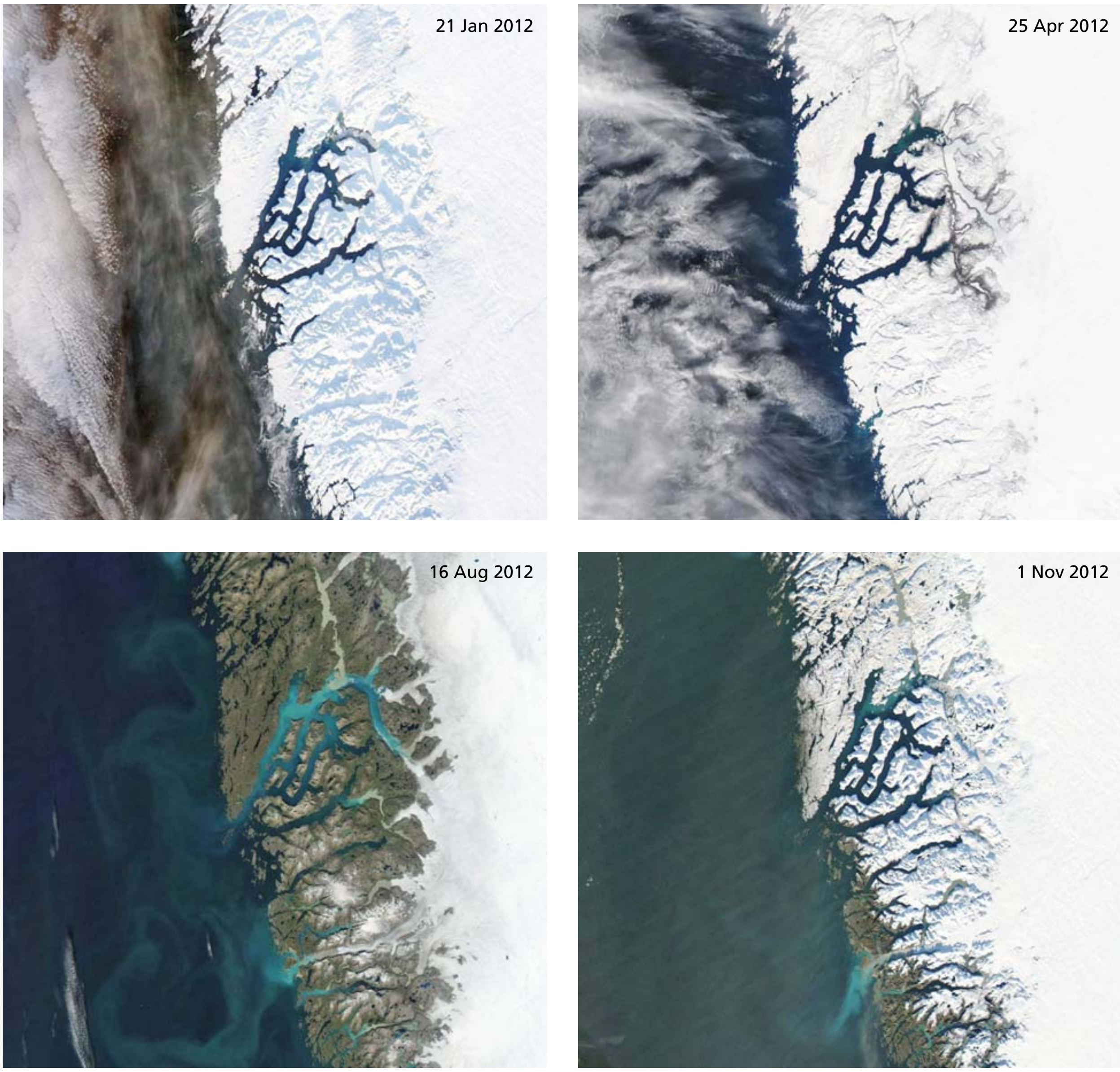


Figure 5.2 Satellite images (AQUA-MODIS) showing sea ice conditions in Godt-håbsfjord during January, April, August and November 2012.

is transported past the outer region near Nuuk during much of the year (figure 5.3). No record of the sea ice conditions in Baffin Bay exists for 2012, due to technical problems with the satellite collecting ASMR-E images (3-6 km resolution).

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

5.2 Length and cross-sections

The monitoring programme also comprises annual sampling along a length and a cross section of Godthåbsfjord (figure 5.1). Sampling along these sections includes hydrographical parameters using a SBE19+ CTD profiler measuring salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence. In May, the cross section showed a rather uniform stratification of the water column across the fjord, as depicted in the salinity and temperature profiles (figure 5.4). In previous years, a stronger stratification was recorded towards the Akia side. Still higher phytoplankton biomass, as illustrated by fluorescence, towards the Akia side depicted a seaward surface export of biomass already in May.

Figure 5.3 Digital images from Godthåbsfjord showing a burst of glacial ice in January and open water in August 2012.

A length section from outside Fyllas Banke to the innermost part of the fjord (approximately 200 km; figure 5.1), was sampled onboard the R/V 'Sanna' in May. The length section demonstrated a near surface stratification of the water column within the fjord (figure 5.5). This stratification was, however, not strong enough to withstand tidal mixing near the fjord entrance, thus rather homogenous conditions throughout the water column were observed in this region in May, as in previous years. Hence, biomass is vertically mixed in the water column and partly subducted below the surface layer into the fjord at the outer sill region. High biomass was also recorded on top of Fyllas Banke, as in previous years.

5.3 Pelagic sampling

Monthly sampling at the fjord entrance (approximately 360 m; figure 5.1) includes abiotic and biotic parameters. Vertical profiles of salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence is measured using a SBE19+ CTD profiler, along with water samples collected for pigments (chlorophyll *a* and phaeopigments), nutrients (NO_x, PO_4^{3-}, SiO_4 and NH_4^+) at the stand-

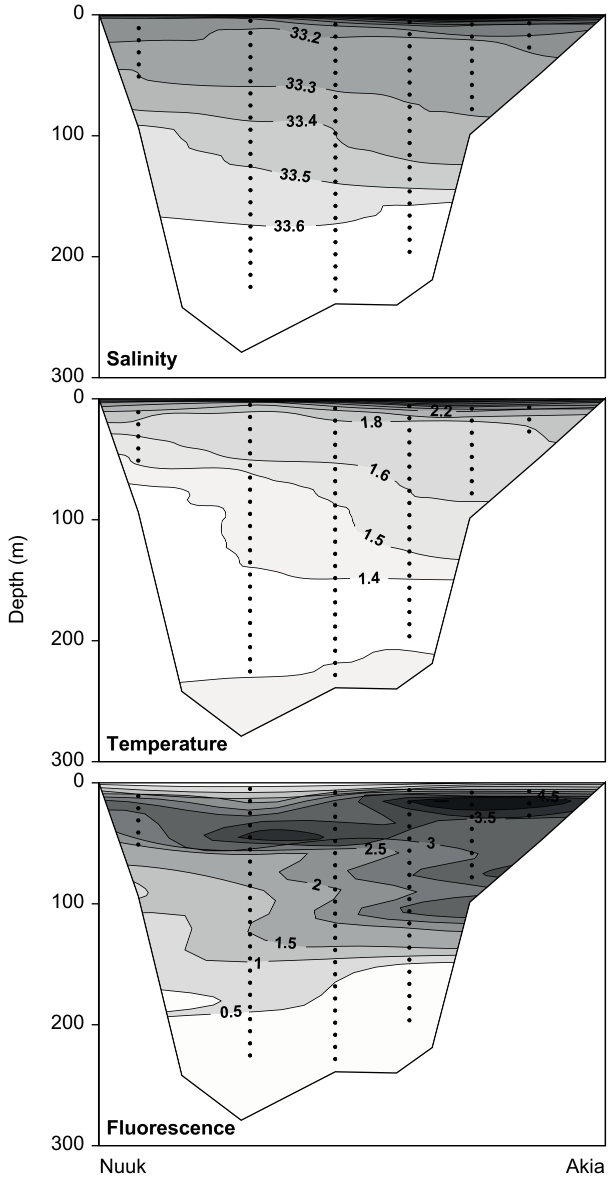


Figure 5.4 Salinity, temperature (°C) and fluorescence along the cross section from Nuuk to Akia in May 2012. Vertical dotted lines represent sampling stations and depths in increments.

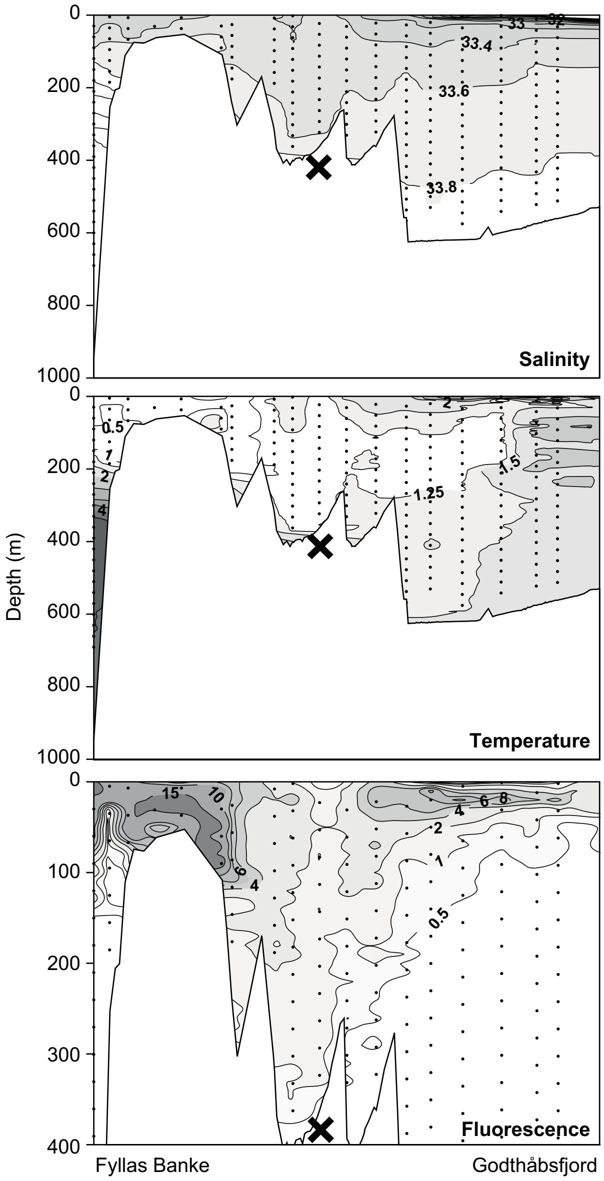


Figure 5.5 Salinity, temperature (°C) and fluorescence along the length section from Fyllas Banke to the inner part of Godthåbsfjord in May 2012. Vertical dotted lines represent sampling stations and depths in increments. X marks the location of the 'Main Station'.

ard depths 1, 5, 10, 15, 20, 30, 40, 50, 100, 150, 250 and 300 m. Technical problems have delayed analyses of NO_x and NH_4^+ and they are omitted from the present report. In addition, samples for dissolved inorganic carbon (DIC) and total alkalinity (TA) were collected from 1, 5, 10, 20, 30 and 40 m, representing the euphotic zone. Due to technical problems, there is a delay in analysing TA and DIC samples; hence, we are at present unable to include pCO$_2$ values from the monthly sampling programme, which is derived from DIC and TA data. Particulate primary production was measured using the *in situ* C^{14} incubation method corrected for *in situ* light conditions, thus incubation bottles were deployed at 5, 10, 20, 30 and 40 m on a free-drifting mooring array for approximately two hours. Vertical sinking flux was measured using four particle interceptor traps also deployed on a free-drifting mooring array at 60 and 65 m (considered the same depth) for approximately two hours. The collected material was analysed for pigments (chlorophyll *a* and phaeopigments), total particulate carbon and nitrogen, and a sample was saved for identification. Triplicate plankton net tows were also taken for zooplankton (45 µm WP2 net from 0-100 m) and phytoplankton (20 µm net from 0-60 m). Larger planktonic organisms, such as fish, shrimp and crab larvae as well as jellyfish, were sampled using single oblique hauls (0-100 m) with a 335 µm Bongo net during 2008 (except June), 2009 (except October) and from 2010–2012 (except for February in 2012). Double Bongo net hauls (335 and 500 µm) were also conducted at selected stations along the annual length section in May (typical stations FB3.5, FB2.5, GF3, GF7, GF7 and GF10).

Abiotic parameters

Hydrographical profiles collected monthly at the 'Main Station' showed homogenous conditions, i.e. salinity and temperature, in January (figure 5.6). A deep coastal inflow in March was depicted in high salinity and temperatures below 200 m. Fresher surface waters formed a weak stratification in April (i.e. halocline). The surface layer showed the highest phytoplankton biomass. Increasing freshwater input from ice melt and/or terrestrial discharge, combined with atmospheric heat exchange and solar heating, strengthen the stratification during summer. The stratification weakened again in autumn as the freshwater input and heating decreased. Light conditions, i.e. irradiance, varied during the year in accordance with seasonally incoming solar radiation, but are also influenced by absorption of suspended material in the water column. Particularly phytoplankton affects the light penetration, as illustrated by the reduced irradiance levels in April and May when the biomass is high and terrestrial freshwater possibly containing silt is low.

Nutrient levels were measured at the selected depths during the monthly sampling programme (figure 5.7). High nutrient levels, i.e. phosphate and silicate, were observed during winter. Low production and tidal mixing resulted in homogenous nutrient profiles during this period. In April, a narrow surface stratum of low nutrient concentrations signifies early primary production. Similar low concentrations are observed during summer, i.e. June and September. Reduced production in autumn, combined with a weaker stratification, replenishes nutrient levels in the upper part of the water column.

Biotic parameters

Autumn and winter depicted very low phytoplankton biomass (< 0.4 µg l^{-1}; figure 5.8), mainly due to the seasonally low solar radiation at this high latitude. The improved light conditions and weak stratification in spring, therefore, triggered a spring phytoplankton bloom, which peaked in April and early-May (max. chlorophyll *a* of 7.9 µg l^{-1}). The bloom was subsequently followed by a post-bloom scenario with lower chlorophyll *a* concentrations and high phaeopigments values. Low pigment values are generally observed in June indicating a transition between higher production in spring and summer, as described in previous years. Increasing freshwater input combined with atmospheric heat exchange and solar heating strengthened the stratification of the water column, thus withstanding the tidal mixing at the 'Main Station' during June. A summer bloom followed in July elevating pigment concentrations in surface waters (up to 1.9 and 1.2 µg l^{-1} for chlorophyll *a* and phaeopigments, respectively). The short summer bloom was followed by progressively decreasing phytoplankton biomass during late summer and autumn.

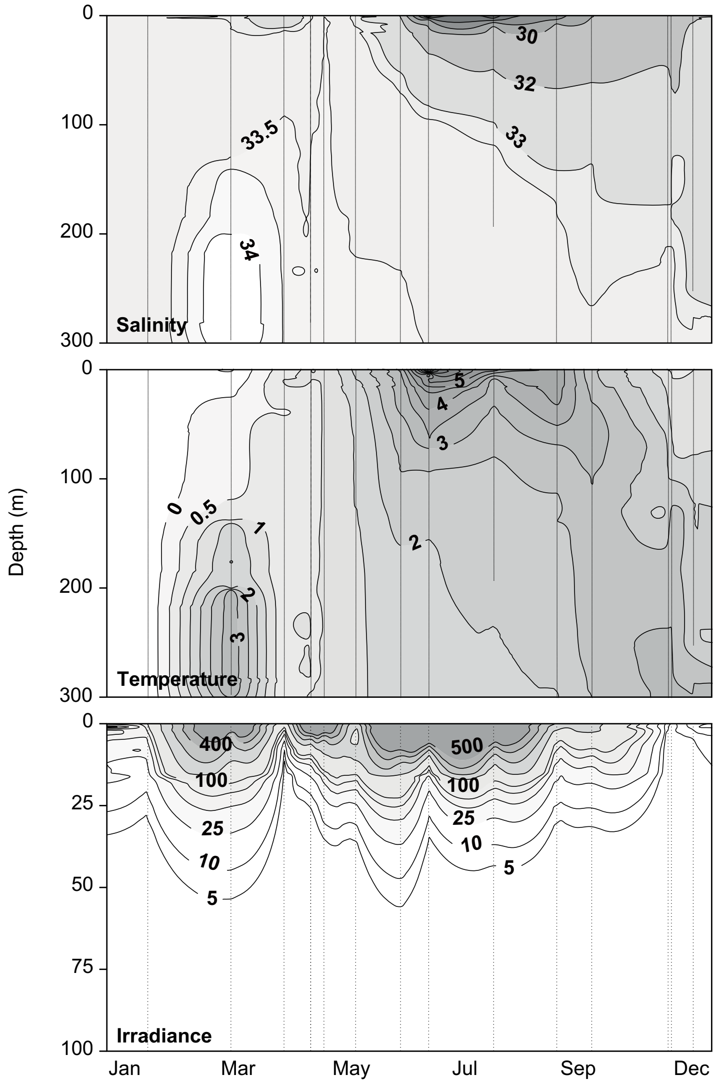


Figure 5.6 Annual variation in salinity, temperature (°C) and irradiance (PAR) at the 'Main Station' in 2012. Vertical dotted lines represent sampling days and depths in increments.

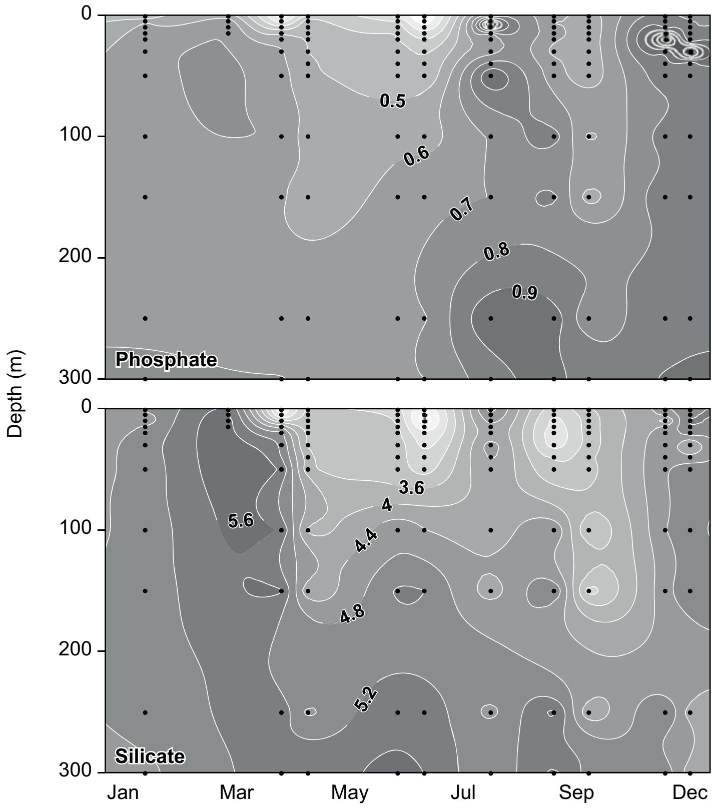


Figure 5.7 Annual variation in nitrate and nitrite (µM), phosphate (µM) and silicate (µM) concentrations at the 'Main Station' in 2012. Vertical dotted lines represent sampling days and depths.

Seasonal primary production measurements followed the same trend as seen for the phytoplankton biomass (maximum of 953.8 mg C m^{-2} d^{-1} in May; figure 5.8). Values are missing in February and March due to sampling problems and in October due to loss of our mooring that was trapped in sea ice and exported seawards. The estimated integrated annual primary production (108.2 g C m^{-2} y^{-1}) was the second highest value recorded (84.6-139.1 g C m^{-2} y^{-1} from 2006 to 2012; data not shown).

The plankton community

The phytoplankton species composition was sampled using vertical net (20 µm) hauls from 0-60 m at the 'Main Station' near the fjord entrance. Diatoms were the dominant phytoplankton group throughout the year, except in May and June, as described in previous years (figure 5.9). This general dominance of diatoms is characteristic of Arctic marine ecosystems. *Phaeocystis* sp. (Haptophyceae) showed an increasing relative contribution to the phytoplankton community from April to June (up to 98.4 %). Moreover, this species is characteristic of the spring bloom at this location, although they did not appear in 2009 when a prolonged coastal inflow induced a species shift. Still, the diatom dominance returned within a couple of weeks and no *Phaeocystis* sp. cells were present in the system outside April to June. Diatoms and dinoflagellates were the only significant groups present from July to October, while silicoflagellates and other species also contributed during January-March and December. Integrated over the year *Phaeocystis* sp. contributed almost half of the phytoplankton counts, while different diatom species comprised the other half (table 5.1). Integrated annually, *Thalassiosira* spp., *Skeletonema* spp. and *Chaetoceros* spp. were the dominant diatom species, as it has been described in previous years.

Vertical zooplankton net hauls (45 µm WP2 net) were conducted from 0-100 m. Abundances of both copepods and nauplii were low during the mid-summer months of 2012. *Calanus* spp. nauplii dominated in June whereas *Microsetella norvegica* nauplii dominated in July, both appeared in lower abundances than in previous years (figure 5.10). The copepod community was dominated by *Microsetella norvegica*, *Oncaea* and Oithona spp. during the spring. The rise in copepod abundance appeared relatively late and was due to an increase in *Calanus* spp. abundances in June. Here *Calanus* spp. comprises 39 % of the total copepod community composition (figure 5.10). The copepod abundance peaked in July although abundances were significantly lower than in previous years. Species composition was comparable to previous years with dominance of *Microsetella norvegica* (68 % of total copepod abundance).

Abundances of other zooplankton groups increased in April (figure 5.10). Here a considerably part was due to Cirripedia nauplii, which are comparable to previous years. During June, Bivalvia larvae peaked. The peak in total abundance of non-copepod

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 2012.

2012	
Phaeocystis sp.	46.9
Thalassiosira spp.	61.5
Skeletonema spp.	74.0
Chaetoceros spp.	85.7
Pseudonitzschia spp.	88.6
Fragilariopsis spp.	91.5
Nitzschia spp.	93.5
Bacterosira bathyomphala	95.1
Thalassionema nitzschioides	96.2
Centric not det.	97.0

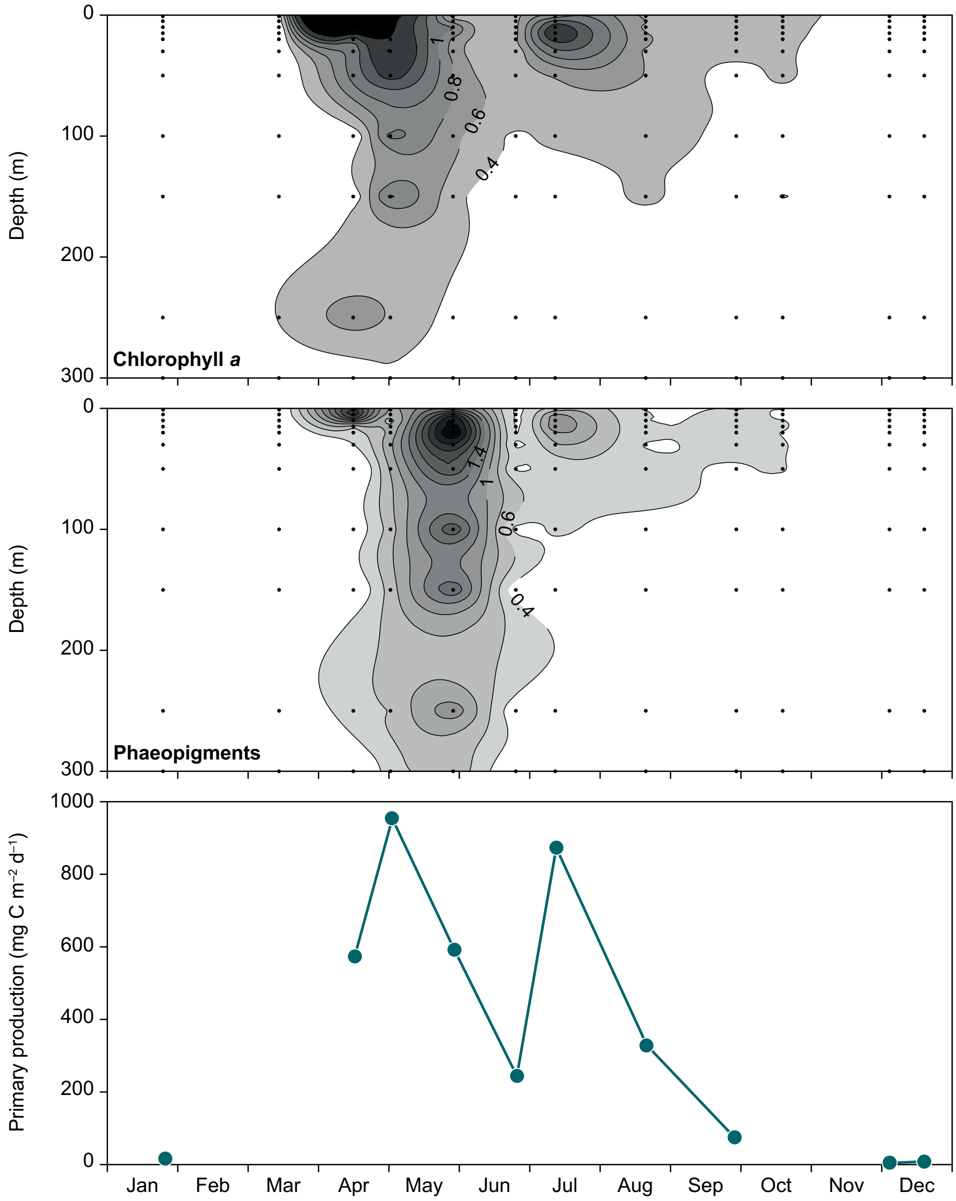


Figure 5.8 Annual variation in chlorophyll a *concentration (µg l^{-1}), phaeopigments concentration (µg l^{-1}) and primary production (mg C m^{-2} d^{-1}) at the 'Main Station' in 2012. Vertical dotted lines on chlorophyll* a *and phaeopigments plots represent sampling days and depths*

zooplankton that occurred in July was due to high abundances of rotifers.

Unfortunately, the zooplankton sampling was omitted in March 2012, whereas the samples from the autumn period September – December has not been worked up in time for this report. Since the beginning of sampling of larger planktonic organisms at the 'Main Station' (GF3) in 2008, the abundance of fish larvae has varied over the years with a temporal shift in species composition during summer (figure 5.11). In general, sand eel *Ammodytes* sp. and Arctic shanny *Stichaeus punctatus* larvae dominated the abundance in spring followed by capelin *Mallotus villosus* dominating the abundance in summer/autumn. The abundance of sand eel larvae was very high in spring 2006 and 2007 with concentrations as high as 25 individual's pr 100 m^{-3}. In the period 2009-2011, the abundance of sand eel larvae was very low, but in 2012, the abundance in the samples was

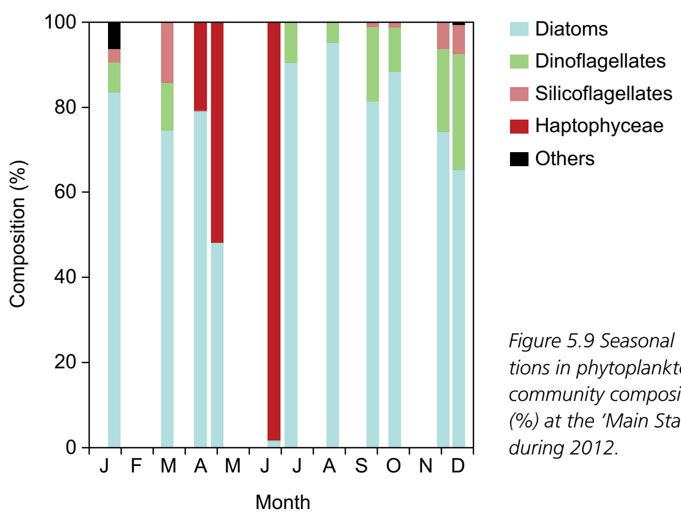


Figure 5.9 Seasonal variations in phytoplankton community composition (%) at the 'Main Station' during 2012.

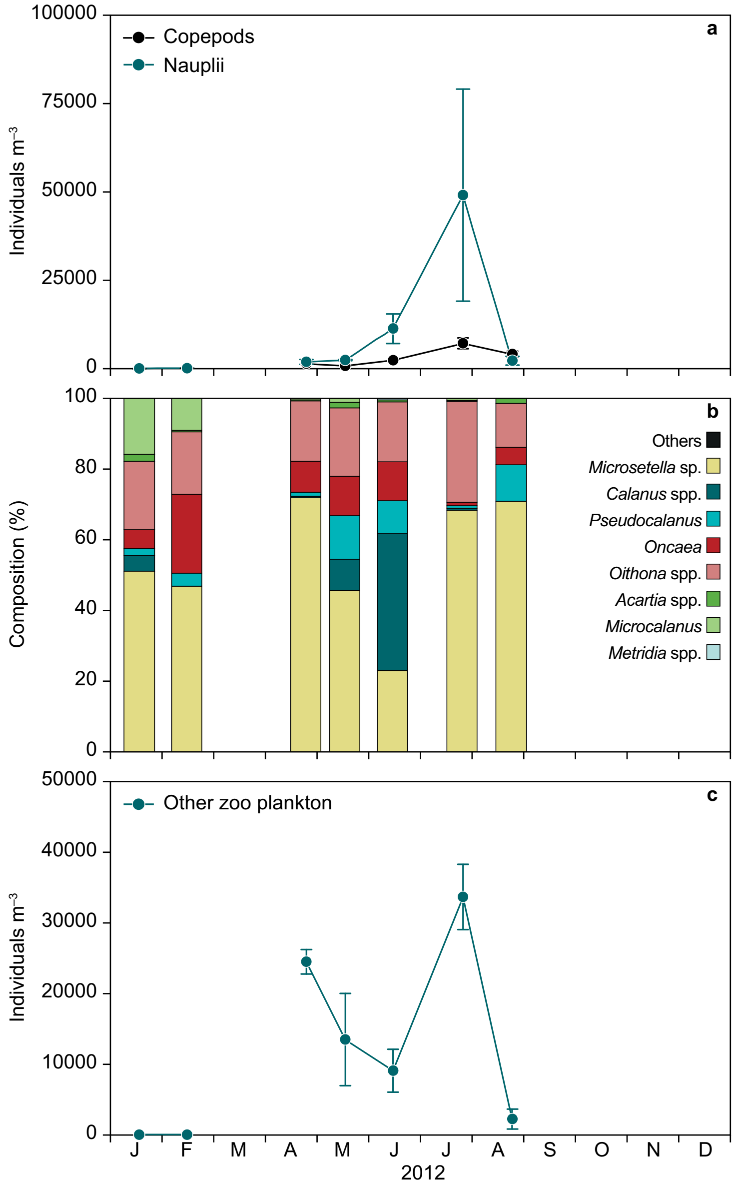


Figure 5.10 Annual variations in abundance (individuals m-3) of a) copepod nauplii and copepods (i.e. copepodites and adult stages), b) copepod community composition (%) and c) abundance of other zooplankton groups (individuals" m-3) at the 'Main Station' in 2012. Error bars represent standard deviation.

almost as high as in 2008. The abundance of Arctic shanny also increased in the samples in 2012 to the same level as in 2008. Capelin larvae also increased in abundance in 2012 with the highest abundance seen throughout the time series in July 2012. Overall, 2010 was a year with very low abundance of fish larvae in all months, and 2012 was a year with the highest abundance of fish larvae in the time series caused mainly by an increase in sand eel and capelin larvae.

In 2012 the highest concentration of fish larvae was found in July (figure 5.12a), where capelin larvae accounted for 99 % of the total abundance (figure 5.12b). Sand eel were caught from January to July and again in December, and capelin was caught from July to October. Only capelin was caught in August and September. Most species were caught in May.

In May 2012, the length section in the fjord show a similar pattern in fish larvae abundance and species composition as in the years 2008, 2009 and 2010 with the highest abundances found closer to the inlet of the fjord at the 'Main Station'. In 2006, 2007 and 2011 abundance was highest on Fyllas Banke due to high abundances of capelin especially in 2006 and 2007 (112 and 35 individuals pr 100 m^{-3} in 2006 and 2007, respectively, at station FB2.5). Only one station was however sampled in 2012 on Fyllas Banke (FB2.5 on the top of the bank). Here sand eel larvae accounted for 79 % of the total abundance, followed by redfish *Sebastes* sp. 9 %, goiterblack smelt *Bathylagus euryops* 7 % and Greenlandic halibut *Reinhardtius hippoglossoides* 4 % larvae (figure 5.13).

Species composition varied on the length section with fewer species in the samples from Fyllas Banke and from deeper inside the fjord (figure 5.13b). Arctic shanny and Atlantic cod larvae were only found in the fjord, but on all stations (GF3-GF10), whereas redfish and Greenlandic halibut were only found on the bank. Fish larvae species composition seems to vary between years with most species found in 2011 and 2012 (table 5.2).

The shellfish larvae community at the 'Main Station' (GF3) showed the characteristic pattern with peak abundance of *Pandalus* spp. in May, and in June for the two crab species *Chionoecetes opilio* and *Hyas* spp. Only 2010 differed from this general observation, where peak abundance was one month earlier (May) for both *C. opilio* and *Hyas* spp., while for *Pandalus* spp. was postponed to June. Density of *Pandalus* sp. decreased significantly from 2010 to 2011, but was comparable with the 2009 level. In May 2012, number of individuals per m^3 of *Pandalus* spp. increased with approximately 82 % compared to the 2011 level, but was only 48 % of the highest observed density from 2010. Density of *C. opilio* was estimated to a record high level for the time series in 2012 and was significantly higher than observations from previous years. The continued increasing trend from 0.05 individuals m^{-3} in 2008 to 0.46 individuals m^{-3} in 2011 of *Hyas* spp. was followed by a 35 % drop from 2011 to 2012 (figure 5.14). Larvae stage zoae I of *C. opilio* and *Hyas* spp. dominated samples in April to June whereas larvae stage zoae II were more prevalent in July. Low concentra-

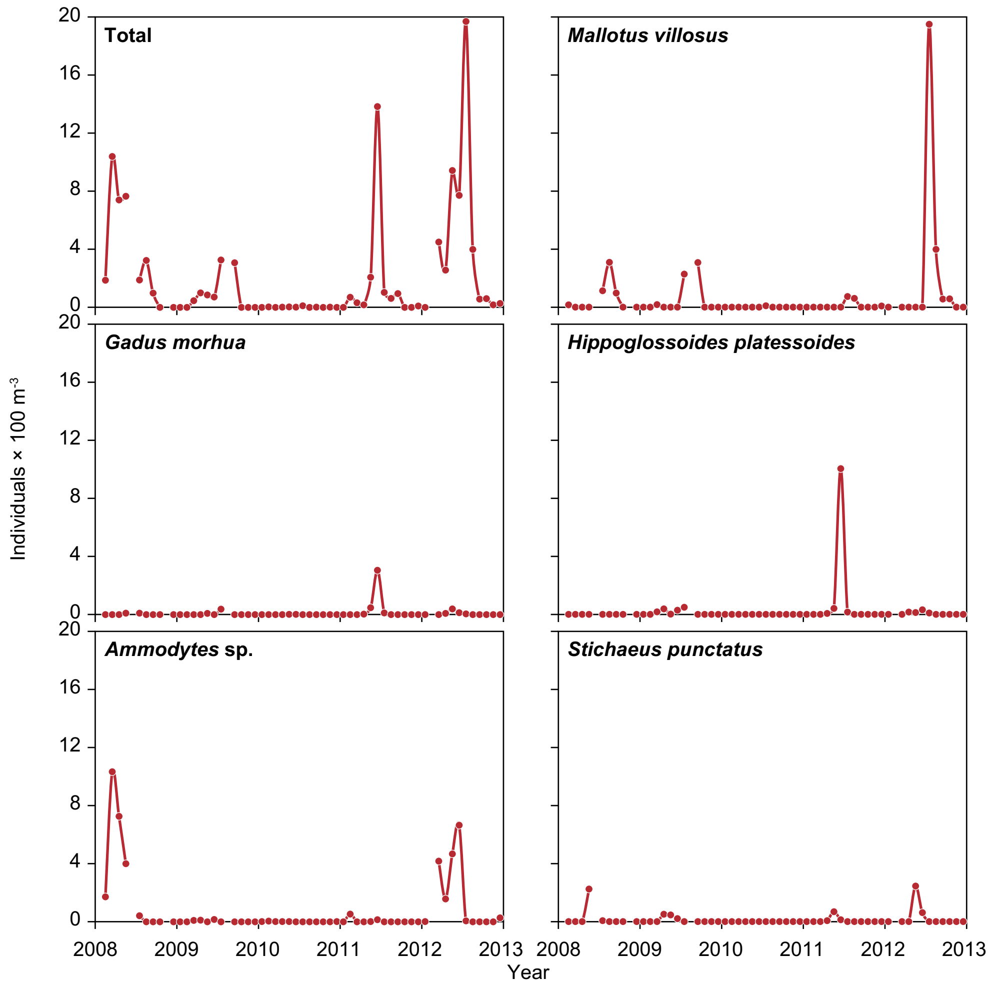
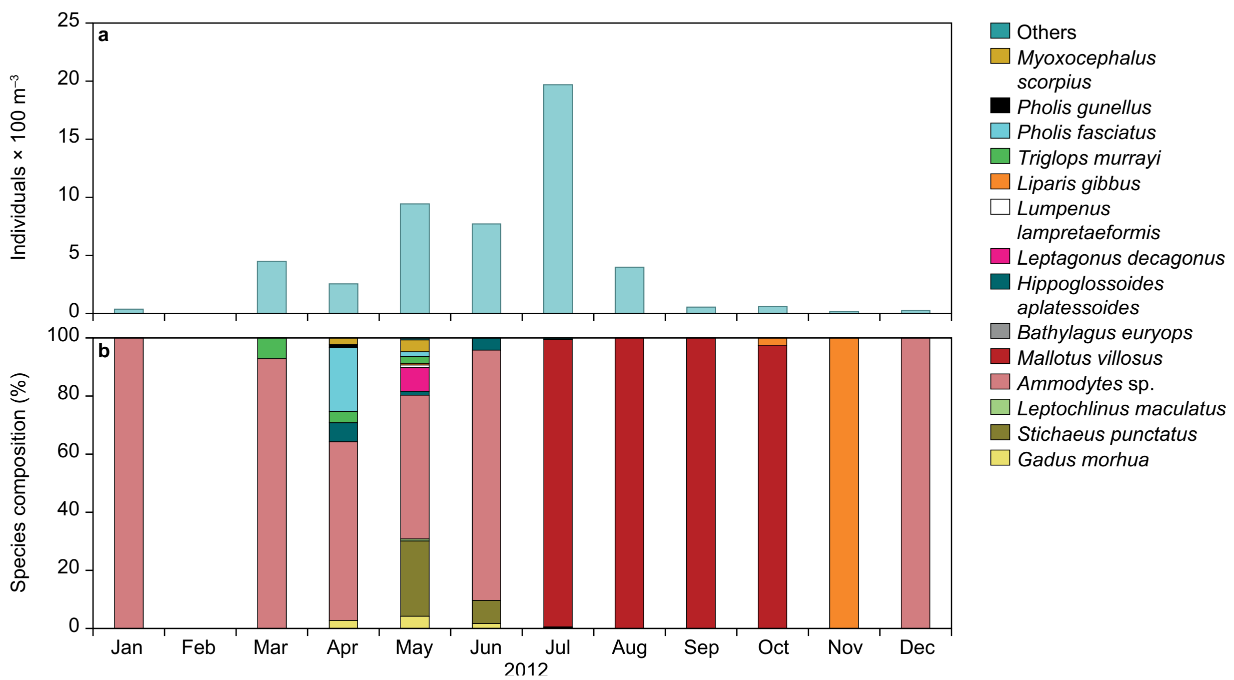


Figure 5.11 Annual variation in abundance of fish larvae in total, capelin Mallotus villosus, *Atlantic cod* Gadus morhua, *American plaice* Hippoglossoides platessoides, *sand eel* Ammodytes *sp. and Arctic shanny* Stichaeus punctatus *from 2008 to 2012 at the 'Main Station' (GF3). Samples were collected each month except January, June and November 2008, August 2009 and February 2012.*

tions of megalope stage of *C. opilio* and *Hyas* spp. were observed in October. Abundance of *C. opilio* has been low compared to *Hyas* spp. and *Pandalus* spp. throughout the years of sampling.

At the 'Main Station' (GF3) Ctenophora, jellyfish and *Sagitta* spp. dominated the community in all months of sampling, except in the period from April to June were *Pandalus* spp. and *Hyas* spp.

Figure 5.12 Annual variation in a) abundance (individuals per 100 m³) and b) community composition (%) of fish larvae at the 'Main Station' (GF3) in 2012.



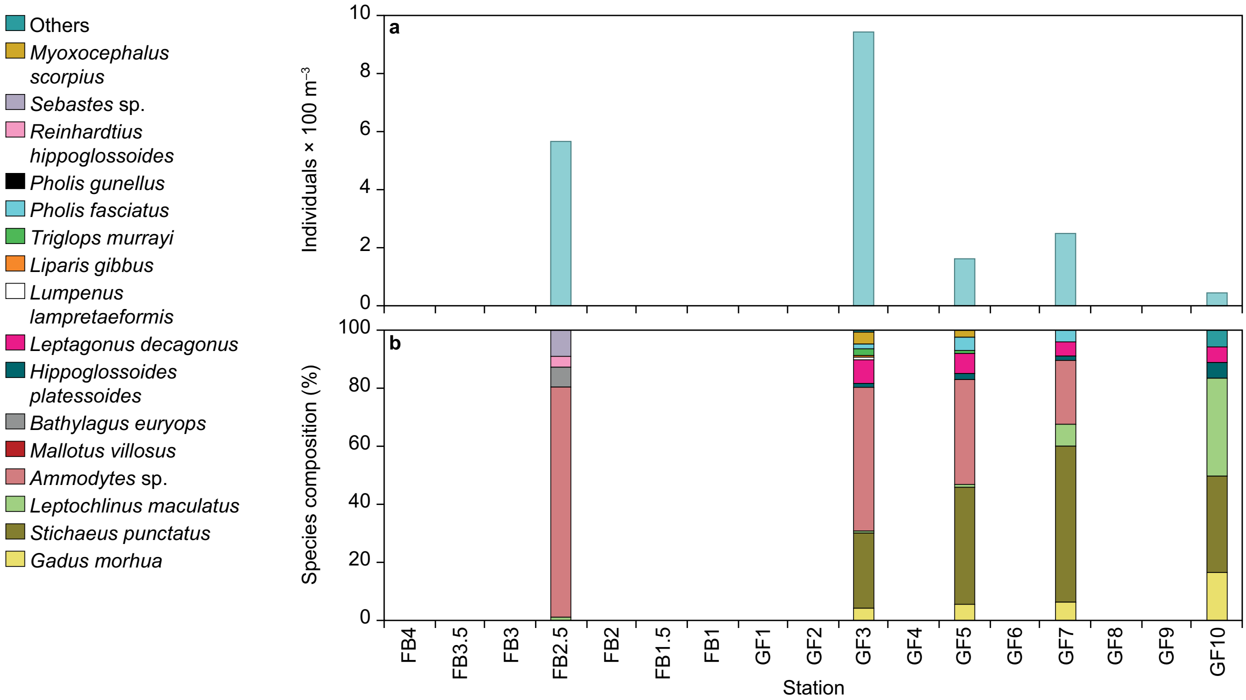


Figure 5.13 Variation in a) abundance (individuals per 100 m³) and b) community composition (%) of fish larvae on the length section in May 2012.

became more abundant. As a contrast, *Sagitta* spp. became the most dominating species in July (2012), one month earlier than observed in previous years (figure 5.15). However, unlike in 2011, *Sagitta* spp. was less abundant in November and in December 2012. However, *Sagitta* spp. has been recorded in considerably high number and peaked at four individual's m^{-3} in August 2012 (figure 5.14). Other consistently abundant species has been Ctenophoras (39 to 55 % from January to March and 62 % in July 2010 and 2011), but a significantly decrease of Ctenophores were observed in 2012, while other jellyfish became more abundant compared to previous years (figure 5.14).

Table 5.2 Species list of fish larvae 2006-2012.

Species list	2006	2007	2008	2009	2010	2011	2012
Gadus morhua	X	X	X	X	X	X	X
Stichaeus punctatus	X	X	X	X	X	X	X
Leptochlinus maculatus	X	X	X	X	X	X	X
Ammodytes sp.	X	X	X	X	X	X	X
Mallotus villosus		X	X	X	X	X	X
Aspidophoroides monopterygius	X	X	X			X	
Bathylagus euryops		X	X	X	X	X	X
Cyclothone sp.		X					
Liparis sp.		X				X	
Liparis gibbus					X		X
Pholis sp.	X	X	X				
Pholis fasciatus					X	X	X
Pholis gunellus							X
Reinhardtius hippoglossoides	X		X			X	X
Myoxocephalus scorpius			X		X		X
Hippoglossoides platessoides			X	X	X	X	X
Sebastes sp.			X			X	X
Gadus ogac			X	X	X		
Leptagonus decagonus				X	X	X	X
Agonidae				X			
Lumpenus lampretaeformis				X	X		X
Triglops murrayi						X	X
Cottidae						X	
Anarchias sp.						X	
Total	**7**	**10**	**13**	**11**	**13**	**16**	**16**

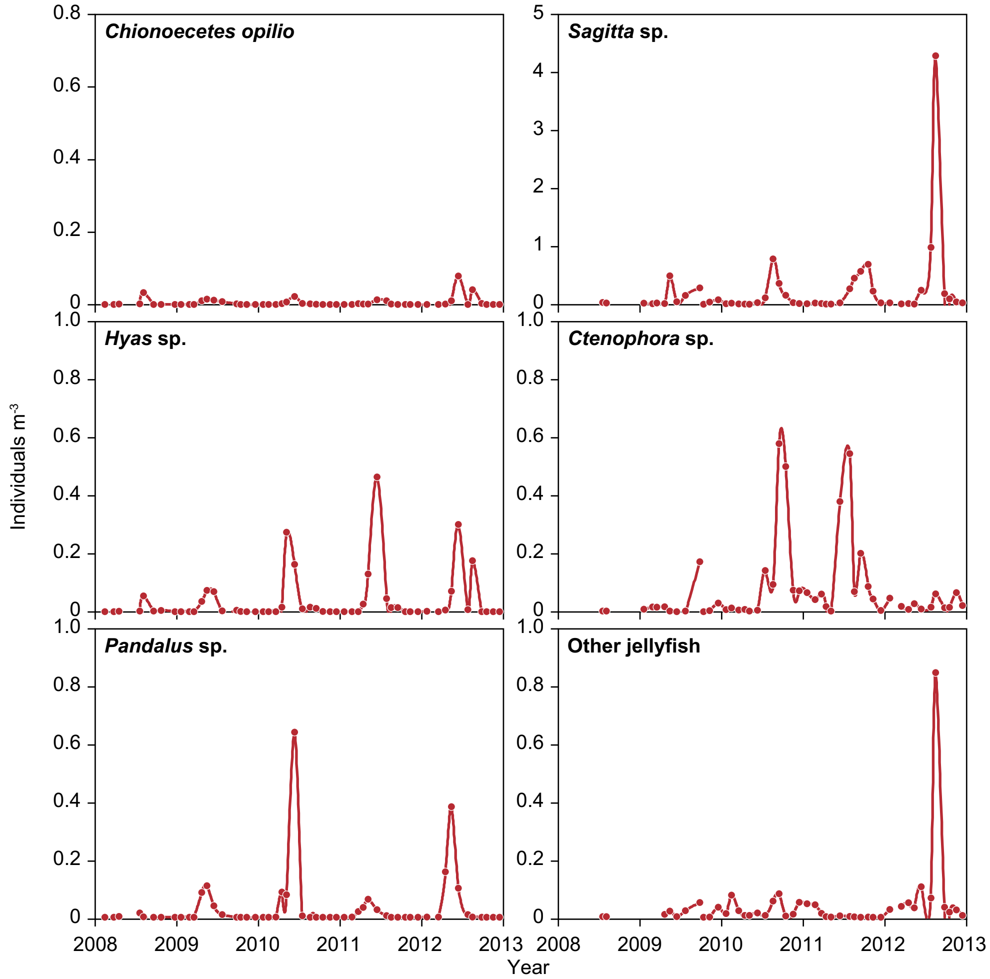


Figure 5.14 Annual variation in abundance (individuals m^{-3}) of Chionoecetes opilio, Hyas *sp.,* Pandalus *sp.* Sagitta *sp.,* Ctenophora *and other jellyfish at the 'Main Station' (GF3) from 2008 to 2012. Samples were collected each month except November 2008 and August 2009.*

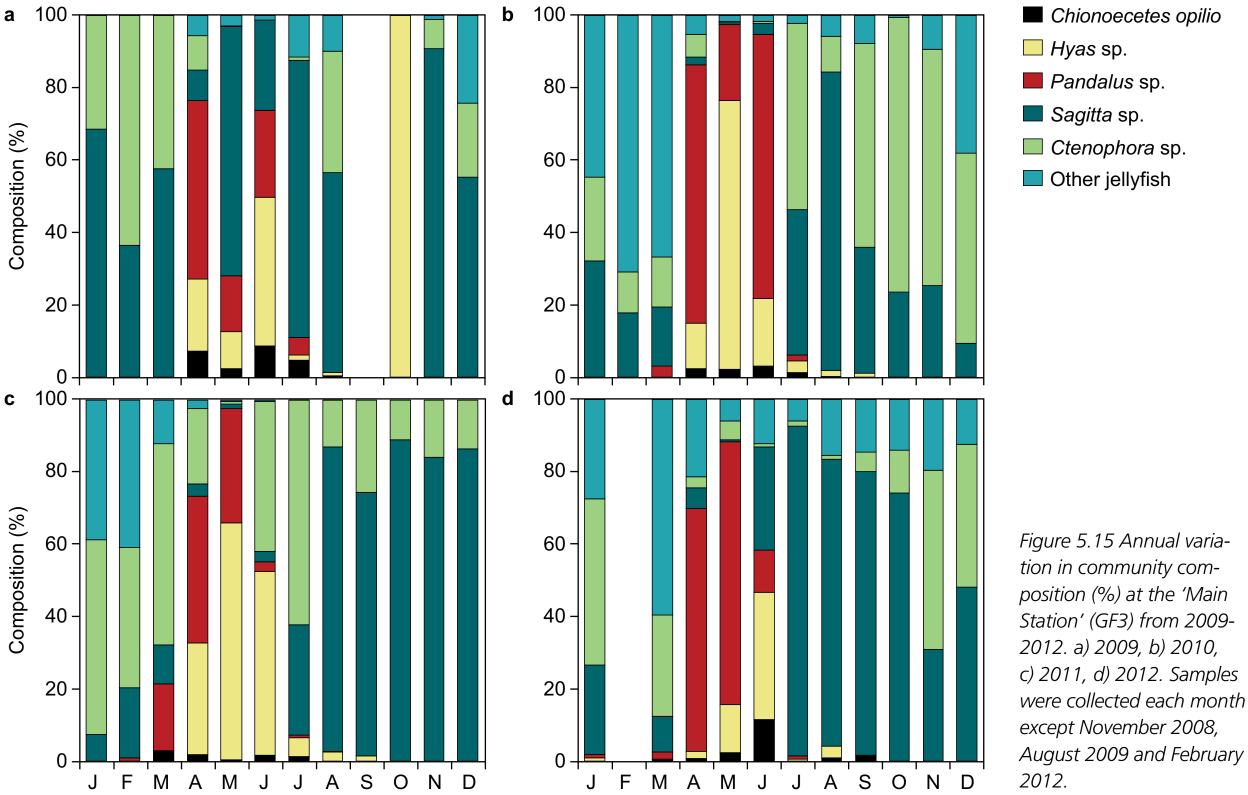
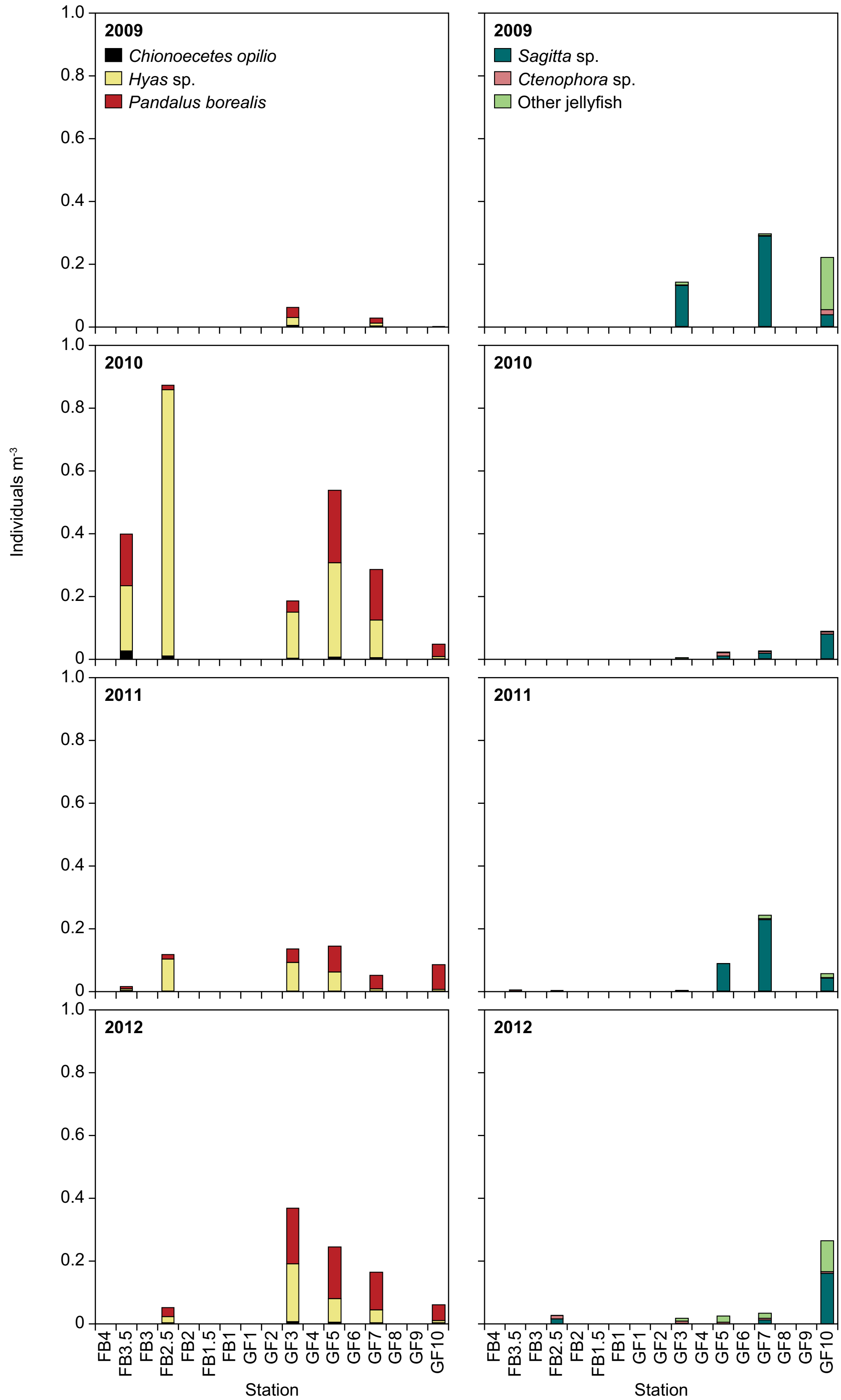


Figure 5.15 Annual variation in community composition (%) at the 'Main Station' (GF3) from 2009-2012. a) 2009, b) 2010, c) 2011, d) 2012. Samples were collected each month except November 2008, August 2009 and February 2012.

Figure 5.16 Annual variation in abundance (individuals m^{-3}*) of* Chionoecetes opilio, Hyas *sp.,* Pandalus borealis. Sagitta *sp.,* Ctenophora *and other jellyfish along the length section from Fyllas Banke (offshore) to the inner part of Godthåbsfjord conducted in May 2009 to 2012. In 2009, no sampling was carried out at Fyllas Banke.*



Along the length transect from Fyllas Banke (offshore) to the inner part of the fjord (GF10) concentration of crab larvae *Hyas* spp. and *C. opilio* were low compared to 2010 (figure 5.16). Both *Hyas* spp. and *Pandalus* spp. are to be found at almost all stations along the fjord transect, with variations in density among species and between stations. The community composition differed not only between stations but also between years (figure 5.17). In 2010 and 2011, larvae of *C. opilio* were far more abundant at all stations, except at GF10, compared to 2009 and 2012. In contrast to

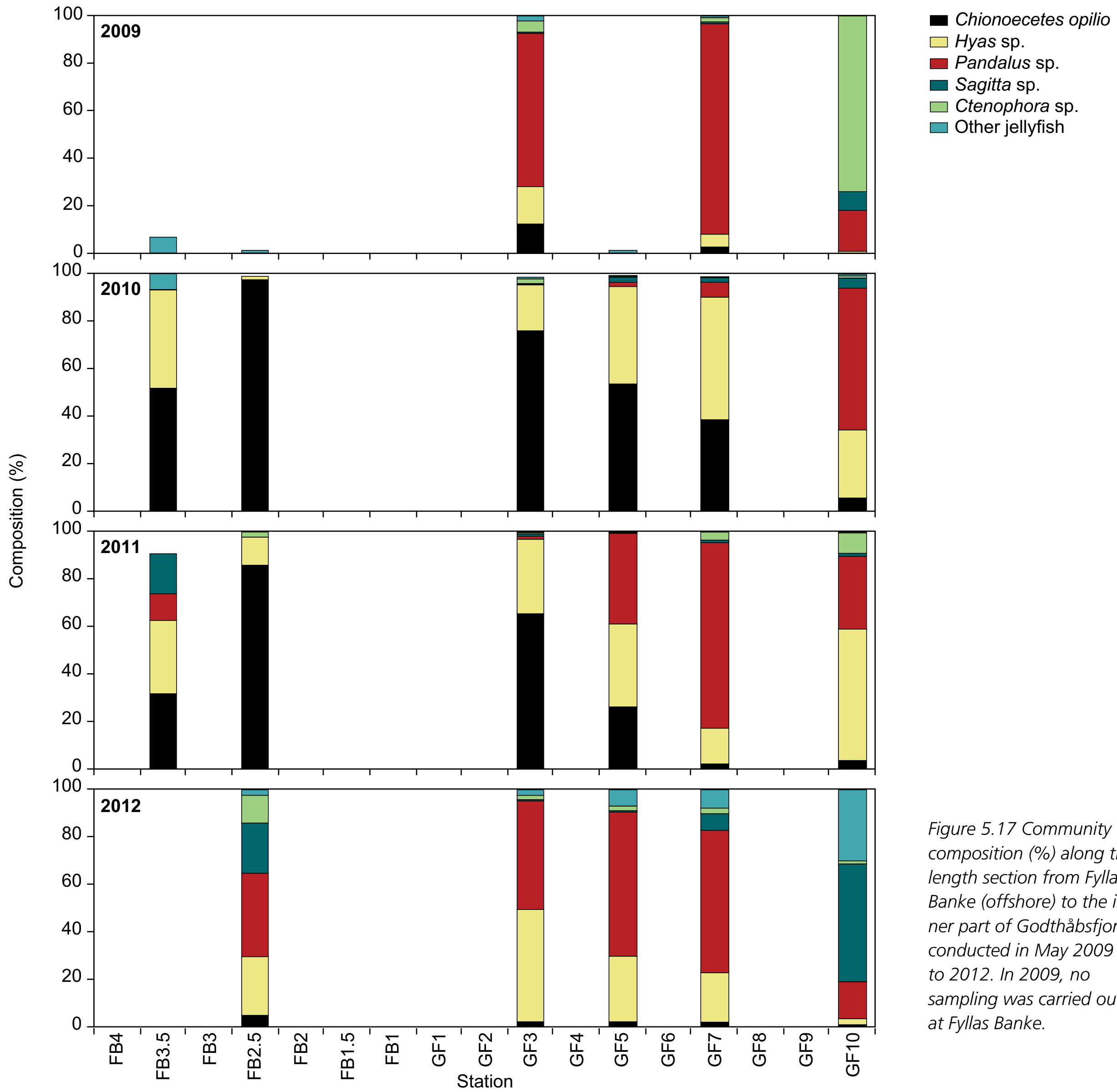


Figure 5.17 Community composition (%) along the length section from Fyllas Banke (offshore) to the inner part of Godthåbsfjord conducted in May 2009 to 2012. In 2009, no sampling was carried out at Fyllas Banke.

previous year *C. opilio* and *Hyas* spp. was dominating the community at the inner station GF10, whereas *Sagitta* spp. and jellyfish were far more abundant in 2012.

Vertical sinking flux

The vertical export from the euphotic zone is the primary sources of organic material to the benthos. During the monthly sampling programme free-drifting sediment traps are deployed for approximately two hours below the euphotic zone (at 60 and 65 m, but considered the same depth). The collected particulate material is analyzed for chlorophyll *a*, total particulate carbon (TPC), C:N ratio and isotopic composition. Winter conditions with low primary production and phytoplankton biomasses also showed low sinking fluxes of TPC and chlorophyll *a* (figure 5.18). During spring production in April and early May, sinking fluxes increased abruptly to 1306.0 and 15.9 mg m^{-2} d^{-1} for TPC and chlorophyll *a*, respectively, while subsequent post-bloom conditions in late May resulted in a similar decrease. A peak in the summer production also induced increased sinking fluxes. The C:N ratio remained close to the Redfield Ratio (6.6) during the productive season, indicating a high content of fresh algal material in the sinking material, which is also supported by higher $\delta^{13}C$ values. The annually integrated TPC sinking flux (272.0 g C m^{-2} y^{-1}) was in the lower end of the range of values previously estimated from 2006-11 (from 253.9 to 431.5g C m^{-2} y^{-1}).

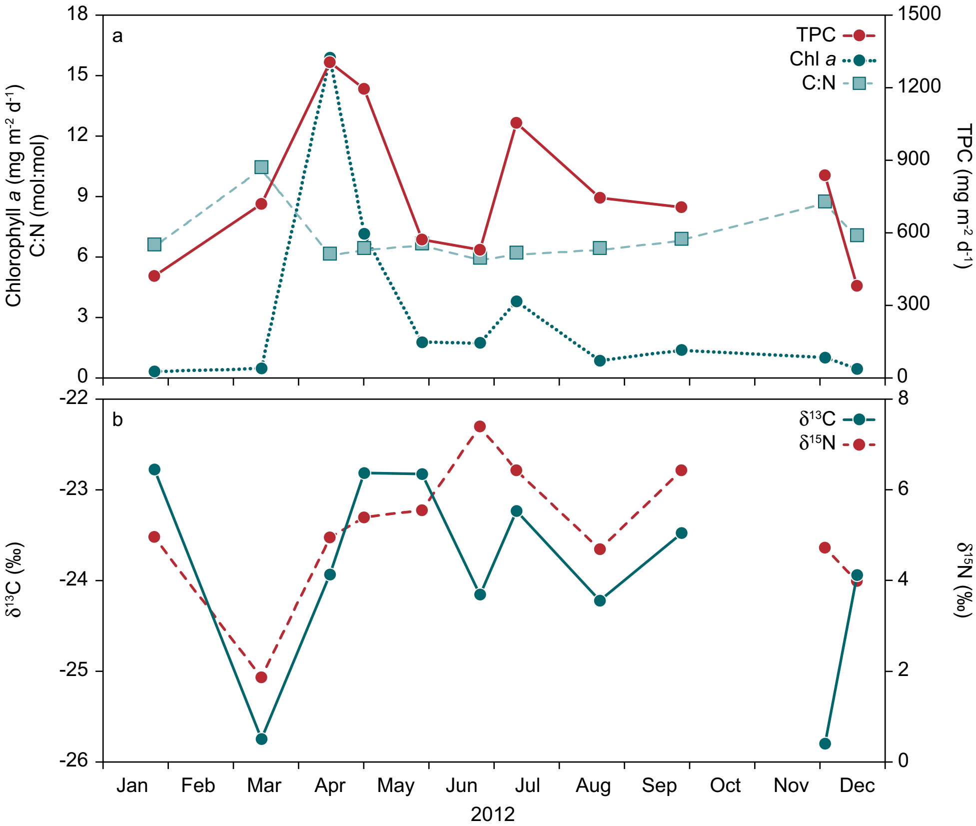


Figure 5.18 Annual variation in vertical sinking flux of a) total particulate carbon (mg m^{-2} d^{-1}), chlorophyll a (mg m^{-2} d^{-1}) and the carbon to nitrogen ratio (mol:mol) b), $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) of the sinking particulate material collected at the 'Main Station' in 2012.

5.4 Sediments

The benthic communities are mainly fuelled by organic material sinking from the euphotic zone. Organic material is either mineralized by benthic heterotrophic organisms or buried in the sediment. In the oxic upper part of the sediment, oxygen is the key electron acceptor, while in the anoxic sediment below sulphate remains the primary acceptor. Oxygen is therefore used either directly or indirectly in the mineralization of organic material, and the oxygen flux into the sediment is therefore used as a measure of the remineralisation rate.

Seasonal monitoring include sampling and laboratory experiments on sediment cores collected at a permanent sediment sampling station in Kobbefjord ('Sediment station', depth approximately 120 m; figure 5.1). Microprofiling is used for measuring the diffusive oxygen uptake (DOU) into the sediments. The oxygen profiles showed that the oxic zone ranged between 0.8 and

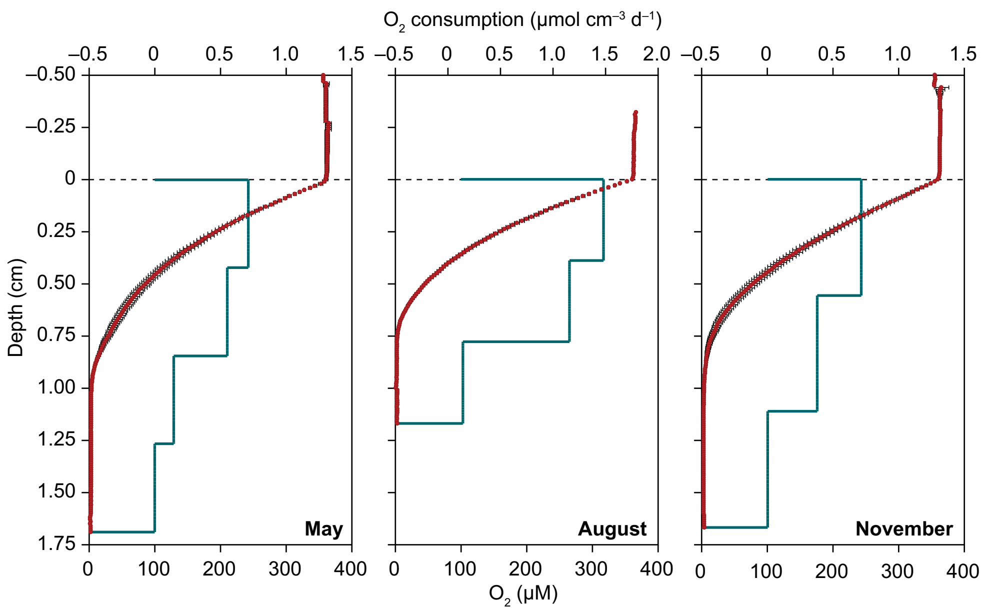


Figure 5.19 Vertical concentration profiles of oxygen (closed dots) and modelled consumption rates (solid line) from microelectrode profiles with sediment depth for each of the three sampling periods. Error bars represent standard error of the mean.

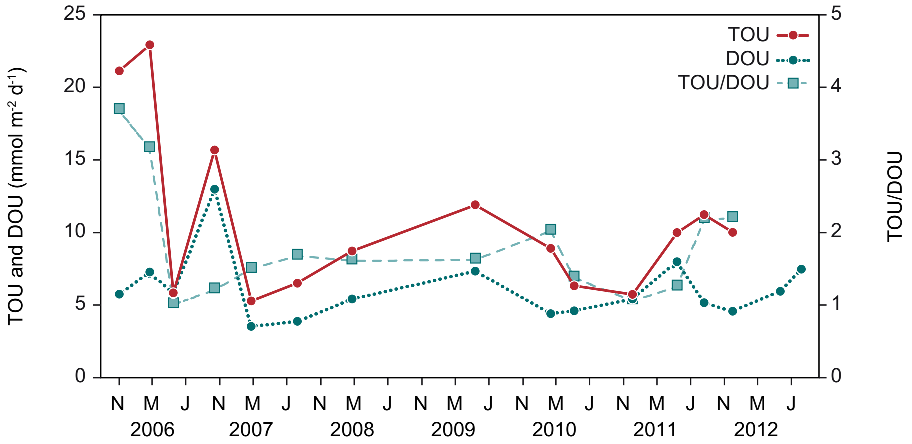


Figure 5.20 Variation in total oxygen uptake (TOU) and diffusive oxygen uptake (DOU) (mmol m^{-2} d^{-1}) and in the TOU/DOU ratio from 2005-12.

1.2 cm and that DOU ranged between 6.0 and 7.5 mmol m^{-2} d^{-1} during the three seasonal samplings (figure 5.19 and 5.20, respectively).These results correspond with measurement recorded during previous years (figure 5.20).

5.5 Benthic fauna and flora

The monitoring of kelp and fauna conducted from 2007 to 2011 has been replaced by a reduced programme in the intertidal zone centred on population dynamics of the key species, knotted wrack *Ascophyllum nodosum* and blue mussel *Mytilus edulis* in relation to temperature, ice cover/light availability and tidal level. The rationale for this change is that sufficient data on the parameters monitored in 2007-2011 are available to provide solid baseline information from which future changes can be detected. Also, knotted wrack and blue mussel are key species of the intertidal community and likely to respond positively to increases in water temperature in the waters around Nuuk as they are both north-temperate species with temperature optima (between 15 °C and 20 °C for *A. nodosum*, Fortes and Lüning 1980) considerably higher than those at Nuuk during summer (10 °C, Krause-Jensen et al. 2012). Therefore, they are expected to be sensitive indicators for ecological effects of Arctic warming. The fact that growth rates of these species can be easily recorded on the morphology and that they are easily accessed in the tidal zone make them further advantageous for monitoring.

The coastal waters around Nuuk have a tidal range of 3-5 m, and the tidal zone thus represents a broad belt along the coasts (figure 5.21). The composition of the tidal community varies markedly with exposure to ice and waves, with *Ascophyllum* being a dominant habitat former of protected inner fjords such as the monitoring site in inner Kobbefjord.

We conducted the monitoring in late August/early September 2012 in the mid-intertidal zone as well as in the upper (MWL + 0.5 m) and lower intertidal (MWL -0.5 m) and established permanent plots to be followed over the coming years.

Figure 5.21 a) sampling in the tidal zone in inner Kobbefjord, where knotted wrack Ascophyllum nodosum *dominates the algal community, bladder wrack* Fucus vesiculosus *and* Fucus evanescence *are also abundant. Photo: Peter Bondo Christensen. b) tips of* A. nodosum *with knots/bladders. Photo: Núria Marbà. c) blue mussel. Photo: Peter Bondo Christensen.*

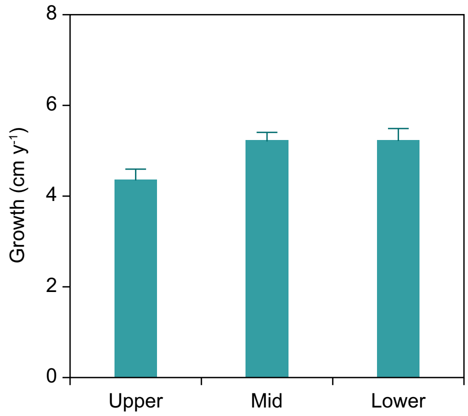


Figure 5.22 Growth of Ascophyllum *tips in the upper, mid and lower tidal zone. Data represent the length from the base of the youngest bladder to the base of the second youngest bladder. Error bars represent standard error of 43-65 measurements on a total of 20 tips in each tidal zone.*

Population dynamics of *Ascophyllum*

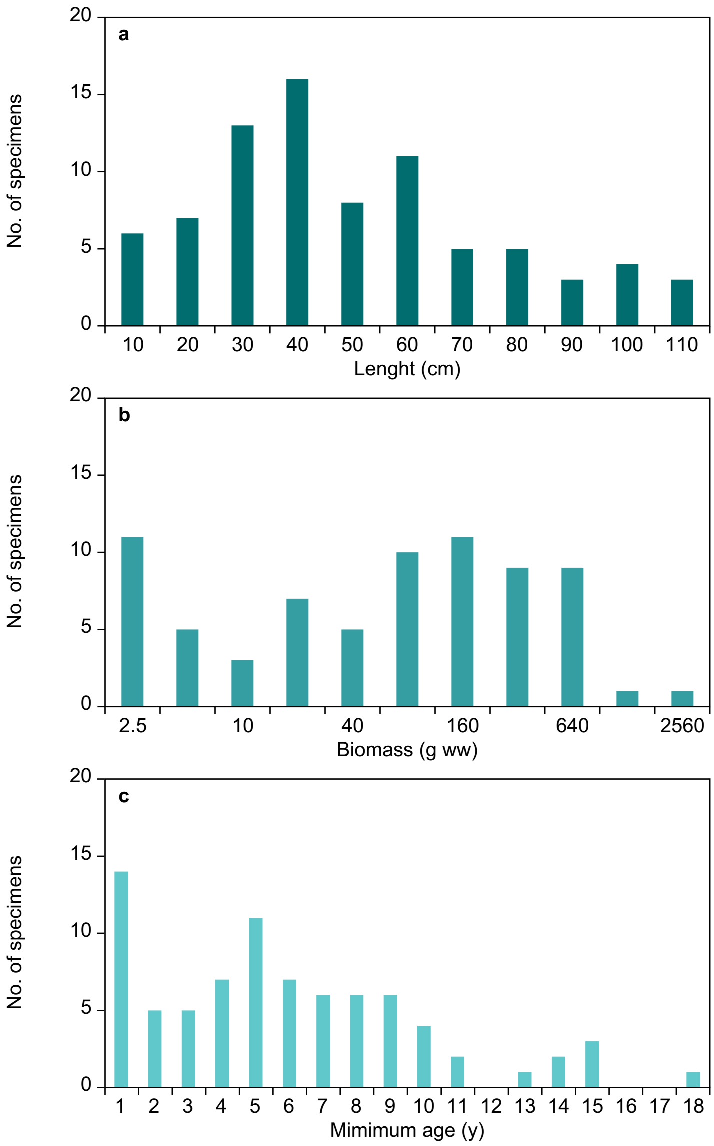
Knotted wrack grows from the tip and forms a bladder/knot every year allowing an assessment of annual growth, as the annual elongation rate, just by measuring the distance between consecutive bladders. Actively growing tips were sampled randomly in the population outside the permanent sampling plots in each of the tidal zones (upper, mid, lower). Tip growth ranged from 4.3 cm y^{-1} in the upper tidal zone to 5.2 cm y^{-1} in the mid and lower tidal zone (figure 5.22).

We also quantified population structure of the knotted wrack non-destructively in 10 permanent plots (0.25 m × 0.25 m) in the mid-tidal zone. Each individual represents one to several 'shoots' arising from a common basal disk. We counted all the individuals exceeding a minimum length of approximately 5 cm, measured their length and minimum age (=number of bladders) of the longest shoot. We also measured the circumference at the base of these individuals and estimated individual biomass (B) based on information on circumference (C) and length (L) ($B=0.1057*LC^2$, Merzouk et al. unpublished).

The population had a density of 128±12 individuals m^{-2} and an estimated biomass of 19.0±2.8 kg ww m^{-2} thus providing a very dense habitat completely covering the rocky shore. The longest individual was 110 cm long, but most had a length of 30-60 cm (figure 5.23). The oldest individual was at least 18 years, but the majority of them were young with just 0-1 bladders, and quite a large number of individuals were around five years old. The largest individual had a biomass of 2560 g ww, but most had a biomass of less than 2.5 g fw or a few hundred g ww (figure 5.23).

We further tagged and numbered each individual in the permanent plots with a cable tie in order to be able to follow growth, mortality and recruitment of new individuals over the coming years and relate these to variations in water temperature and ice cover/scouring.

Figure 5.23 Population structure of knotted wrack Ascophyllum nododum *in 10 permanent plots located in the mid-tidal zone in inner Kobbefjord. a) length distribution, b) age distribution and c) biomass distribution of individuals are shown.*



Population dynamics of *Mytilus edulis*

Mussels (25-35 mm) collected in the intertidal zone in Kobbefjord were marked with number tags, measured to nearest 0.5 mm and placed in each of five cages in the upper intertidal (MWL+0.5 m), mid-intertidal (MWL) and lower intertidal (MWL-0.5 m) in order to follow their growth and mortality (figure 5.24). Fifteen individuals were placed in each cage (15 cages total), resulting in 225 mussels for the annual experiment. In each cage were also placed a temperature logger (Hobo Pendant) logging temperature at 15 minutes intervals. A CTD mooring (SBE 37) was deployed just below minimum water level at the fjord mouth near the monitoring station in order to follow changes in salinity, tempe-

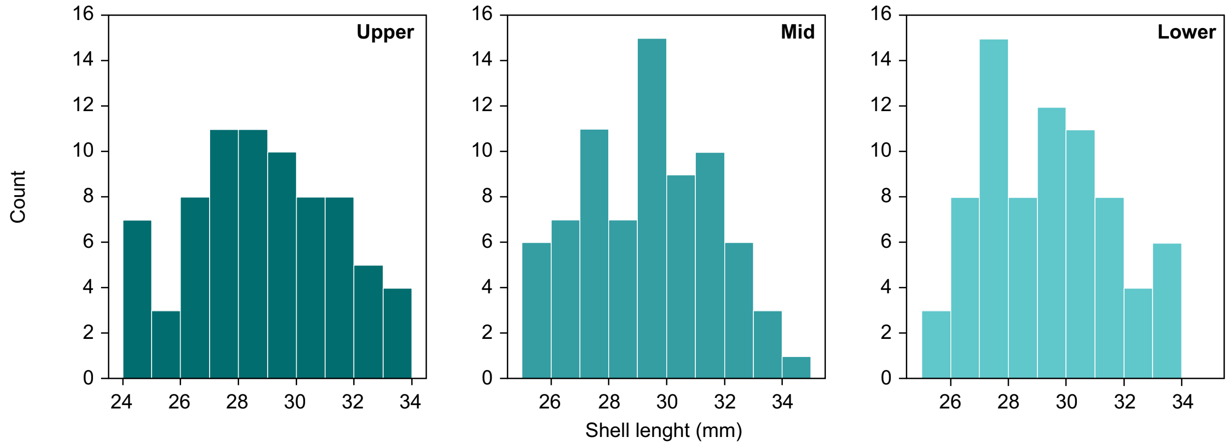


Figure 5.24 Size distribution of mussels Mytilus edulis *placed in cages for quantification of annual shell growth and mortality at three intertidal levels.*

rature and tidal level throughout the year. Thus, the length of the period exposed to air can be calculated for the cages at each tidal level.

The experiment was started 28 August 2012 and run for one year. The mussels will then be collected, and the mortality, and shell growth rate of surviving specimens are recorded and data from the temperature loggers collected.

5.6 Seabirds

Two key seabird colonies near Nuuk are included in the MarineBasis programme. Additional seabird colonies in the Nuuk area have also been visited since 2007. Amongst them, the blacklegged kittiwake *Rissa tridactyla* colonies of 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 Department of Bioscience, Aarhus University (http://dce.au.dk/old/danmarksmiljoeundersoegelser/en/arctic/oil/seabird_colonies/).

Qeqertannguit (colony code: 64035)

Qeqertannguit in the inner part of Godthåbsfjord (figure 5.1) is a low-lying island and holds the largest diversity of breeding seabirds in the Nuuk District. Especially surface feeders such as gulls (Laridae), kittiwake and Arctic tern *Sterna paradisaea* are well represented at the site (table 5.3). This year the island was surveyed 8 June. 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 northwest facing side (Iceland gull) were counted from the sea using a boat as platform. Counts of the remainder of the island were conducted by foot using direct counts of Apparently Occupied Nests (AON) or territorial behaviour as a criterion of breeding pairs.

Table 5.3 Breeding seabirds pairs (P), individuals (I) or Apparently Occupied Nests (AON)) at Qeqertannguit since 2006.

Year	2006		2007		2008		2009		2010		2011		2012	
Species	No.	Unit	No.	Unit	No.	Unit	No.	Unit	No.	Unit	No.	Unit	No.	Unit
Black-legged kittiwake	45	AON	45	AON	20	AON	55	AON	42	AON	80	AON	0	AON
Iceland gull SE side	118	AON	82	AON	33	AON	40	AON	31	AON	31	AON	11	AON
Iceland gull NV side	-	AON	**	AON	12	AON	19	AON	13	AON	20	AON	9	AON
Great black-backed gull	46	P	38	P	44	P	24	P	40	P	17	P	16	P
Lesser black-backed gull	10	P	11	P	25	I	21	I	27	I	18	I	1	I
Glaucous gull	10	P	14	P	13	P	5	P	4	P	2	P	6	P
Herring gull	-	P	1	I	2	P	1	P	0	P	0	P	1	P
Arctic tern	150-220	I	150	I	0	I	150	I	54	I	50	I	50-100	I
Arctic skua	2	P	2	P	2	P	2	P	2	P	0	P	2	P
Black guillemot	615	I	562	I	689	I	637	I	790	I	1047	I	708	I
Red-throated diver (*Gavia stellata*)	1	P	1***	I	1	P	1	P	0	P	0	P	0	P
Red-breasted merganser (*Mergus serrator*)	*		4	P	3	P	0	P	1	P	0	P	0	P

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

Other birds observed (not considered breeding or not systematically censured) included two great cormorants *Phalacrocorax carbo* flying from the island when we arrived by boat. A male mallard duck *Anas platyrhynchos* and two ravens *Corvus corax* were observed during the walk. About 50-100 Arctic terns were observed at the south end of the island 8 June, but no nests were found. About the same number of birds was observed at the colony from the boat 20 June and they seemed to be more established. On 6 August, a couple of youngs of the year were observed sitting on an iceberg near the island.

For the first time, no kittiwakes were observed breeding or even present near the island 8 June 2012 or later during the season. In 2011, the highest number since before 2006 was observed (80 pairs). The number of breeding Iceland gulls was also less than usual though with a relatively high number of individual (58 SE side, 18 NW side) present (table 5.3). They most probably initiated nesting after 8 June. About 48 chicks of Iceland gull at the SE colony were observed 8 August.

Qeqertannguit is influenced by legal egg harvesting (great black-backed gull *L. marinus* and glaucous gull *L. hyperboreus* prior to 31 May). Illegal egg harvesting (illegal species, e.g. Iceland gull, lesser black-backed gull *L. fuscus*, herring gull *L. argentatus*) and egg harvesting after 31 May) 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 the Nuuk District. The colony includes both Brünnich's guillemot *Uria lomvia* and common guillemot *U. aalge*. These alcids are deep divers preying on fish and large zooplankton. Photo counts of birds present on the cliff were conducted from the sea (boat) 3 July (table 5.4). The number of guillemots on the water was estimated to 200-400 individuals (difficult to count due to the swell). The number of guillemots (both species) on the cliff was the lowest since 2006.

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 where the proportion of common guillemot could be expected to increase in a warmer climate (table 5.4). Unfortunately, it was not possible to make a proper classification of the two species due to limited photo equipment. An objective of minimum 400 mm is recommended. Otherwise, the conditions were good with quiet weather and a high cloud cover.

Other seabird observations south of Nuuk

Simiutat consist of three smaller islands. The following was observed:

Simiutat (63011) 3 July: 11 puffins *Fratercula arctica*, nine black guillemots *Cepphus grylle*, five pairs of great black-backed gulls, one male and four female common eiders *Somateria mollissima*.

Simiutat (63012) 3 July: 47 puffins, 110 razorbills Alca torda, three black guillemots, two pairs of glaucous gull, four pairs of great black-backed gull, one herring gull, 12 male and 18 female common eider, three resting great cormorants (one adult and two juveniles), two Arctic skuas *Stercorarius parasiticus* (light morph) on the water and about 40 resting gulls with

Table 5.4 Counts of breeding seabird at Nunngarussuit since 2006. Counts in Pairs are marked (P), and the remaining counts are of Individuals.

Year	2006	2007	2008	2009	2010	2011	2012
Species	No.	No.	No.	No.	No.	No.	No.
Guillemot unspecified	694	–			–	514	375
Brünnich's guillemot	–	705	388	475	–	–	–
Common guillemot	–	87	36	47	–	–	–
Guillemots on the water	2–300	450	450	–	–	500	2–400
Glaucous gull	20	14	14	12	–	11	4 (P)
Great black-backed gull	5	5	2	5	–	4	2 (P)
Northern fulmar	23	13	17	11	–	21	10 (P)

a mix of juveniles and adults (six to eight glaucous gulls and the rest great black-backed gull).

Between 63012 and 63013, 3 July: 12 puffins and five razorbills on the water.

Simiutat (63013) 3 July: Five puffins, 24 razorbills, 14 black guillemots, 10-12 pairs of glaucous gull, four pairs of great black-backed gull, one herring gull, nine male and 11 female common eider, 21 resting great cormorants (including two juveniles), 17 resting Canada geese *Branta canadensis*, three pairs of ravens and two pairs of northern fulmar *Fulmarus glacialis*.

'The puffin island' at Ravneøerne (63020) 3 July: 135 puffins, 15 razorbills, 37 black guillemots and one pair of great black-backed gull were observed at the island. One to two pairs of great black-backed gull were observed on the neighbour island to the south.

Qarajat qeqertaat (63019) 10 July: This site consists of two islands with breeding common eiders:

West Island: 28 nests of common eider (four empty nests and four nests with clear signs of predation) with an average of 2.85 eggs per nest. Otherwise 182 black guillemot, 12-14 lesser black-backed gull, four great black-backed gull, two herring gull, six to eight glaucous gull, four snow bunting, one purple sandpiper and two female king eiders were observed. Two nests (one and three eggs respectively) of gull were found (possibly lesser black-backed) besides two nestlings on the water.

East Island: 17 nests of common eider (two empty and two with nestlings) with an average of 3.1 eggs/chicks per nest. A group of 13 chicks were observed on the water together with four female eiders. Additionally 115 eiders (45 females and 70 males) were resting on the water. Otherwise 207 black guillemots, 35-40 great black-backed gulls (primarily juveniles flying above the island), 60 mixed glaucous and Iceland gulls (mostly Iceland gull and juveniles) resting on skerries at the west end of the island, eight great black-backed gulls (most not breeding), eight snow buntings and two pairs of purple sandpiper were observed on the east island.

Other kittiwake colonies in Godthåbsfjord (see the Seabird database for details):

The number of kittiwakes and Iceland gull at the five kittiwake colonies in Godthåbsfjord, are listed in table 5.5, including counts since 2006.

The total number of breeding kittiwakes of all five colonies since 2007 has shown a somewhat different pattern than the Qeqertannguit numbers alone. Generally, the numbers seem to vary between the colonies - the colony with the largest number of kittiwakes has alternated between Kangiusaq and Innajuattoq, and in 2012, it appeared as all the birds from Qeqertannguit had moved to Innaarsunnguaq. This highlights the importance of counting all the colonies. The total num-

Table 5.5 Counts of breeding kittiwakes and Iceland gulls at the five kittiwake colonies of Godthåbsfjord. Counts in Individuals are marked (I), and the remaining counts are of Apparently Occupied Nests. These numbers have been corrected since the 2011 Annual Report.

Year	2006	2007	2008	2009	2010	2011	2012
Kittiwake							
Innaarsunnguaq (64015)	240 (I)	62	33	12	16	27	115
Kangiusaq (64018)	-	217	450	284	370	509	463
Alleruusat (64022)	-	276	369	164	260	168*	152
Innajuattoq (64019)	-	302	309	458	375	399*	250
Qeqertannguit (64035)	45	45	20	55	42	80	0
Sum	**-**	**902**	**1181**	**973**	**1063**	**1183**	**980**
Iceland gull							
Innaarsunnguaq (64015)	1580 (I)	-	961(I)	435	477	518	452
Kangiusaq (64018)	-	300	494(I)	261	277	262	242
Alleruusat (64022)	-	45	140	80	100	118*	111
Innajuattoq (64019)	-	342	1497(I)	1553(I)	335/1535(I)	1538*	1015
Qeqertannguit (64035)	118	82	45	59	44	51	20
Sum	**-**	**-**	**-**	**-**	**1233**	**2487**	**1840**

ber of kittiwakes in 2012 was in the lower range and similar to the 2007 and 2009 numbers. The numbers from 2011 has been adjusted down since the last report, after a new photo count of Innajuattoq. The 2011 total is still the highest but similar to the 2008 total (table 5.5).

The numbers of Iceland gulls since 2007 are more difficult to compare, since they have been counted by different methods (different units (I/AON)/direct or photo counts) between years. In 2011, the number of breeders of this species was also re-counted at Innajuattoq but still showed a notably higher number than previous years. Some of the Iceland gulls at this colony occupy areas high above sea level where nests can be difficult to see from the boat, and former numbers might have been underestimated. In 2011, a complete photo survey of this colony was carried out for the first time. However, the number of breeders in 2011 was almost as high as the former numbers of individuals, and it is expected that the increase in the number of breeders is real. The 2012 count is also high though not as high as in 2011.

Remaining species in the kittiwake colonies observed in 2012 were:

- Innaarsunnguaq (64015) 25 May: 45 razorbills and 150 black guillemots
- Alleruusat (64022) 25 May: Eight nests of great cormorants (32 individuals observed in total)
- Innajuattoq (64019) 14 June: 43 black guillemots and 13 nests of great cormorant nests

5.7 Marine Mammals

West Greenland is a summer feeding ground for an estimated 3200 humpback whales, *Megaptera novaeangliae* (Heide-Jørgensen et al. 2012). Most of them stay on the offshore banks, but some visit the fjords and bays to feed on zooplankton and capelin *Mallotus villosus* (Heide-Jørgensen and Laidre 2007). Some of these whales have a high degree of site fidelity to Godthåbsfjord and return year after year to feed, but also new individuals visit the fjord annually (Boye et al. 2010). In the MarineBasis monitoring programme we use photo-identification to estimate the number of humpback whales feeding in Godthåbsfjord each summer and the turnover of whales during a season to understand how much these top-predators eat and thus affect the Godthåbsfjord ecosystem.

Photo-identification is a technique used to identify individual animals from photographs showing natural markings such as scars, nicks and coloration patterns (Katona et al. 1979). The technique can, in combination with mark-recapture analysis be used for estimating abundance of marine mammals in specific areas. Photo-identification is also used to investigate residence time (i.e. how long the animals stay in a given area) and site fidelity (i.e. individuals returning to an area in different years) (e.g. Bejder and Dawson 2001). In humpback whales, the ventral side of the fluke is used for identification as the tail contains individual colour patterns,

Table 5.6 Humpback whale site fidelity to Godthåbsfjord in 2007-2012. Percentage of whales (within 2007-2012), identified in a given year and re-identified the following year in brackets.

Year	No. of photos	ID	N	No. of whales seen in each subsequent year				
				2008	2009	2010	2011	2012
2007	49	20	20	8 (40)	6 (40)	7 (27)	5 (24)	5 (19)
2008	143	20	12		6 (40)	10 (39)	7 (33)	9 (33)
2009	38	15	8			7 (27)	6 (29)	8 (30)
2010	68	26	13*				9 (43)	9 (33)
2011	130	21	10*					10 (37)
2012	85	27	13*					
Total	513	126	76					

*Contains individuals photographed in the fjord prior to 2007
ID number of whales identified the given year
N the number of new individuals the given year

which in a way is comparable to human fingerprints. Photo-identification pictures were taken with a 350 EOS Canon camera with a 300 mm Canon lens. In addition to dedicated surveys, guides on the local whale tourist boats and the public kindly contributed with identification-photos. Surveys were carried out twice a week depending on weather from May to September 2012 from small research boats.

A total of 85 ID pictures were collected in Godthåbsfjord in 2012 from which 27 different whales were identified. Of the identified whales, 52 % had been identified previously (2007-2011) in the fjord and 37 % of the whales identified in 2012 had also been identified in 2011. During the period 2007-2012, 513 identification pictures have been collected and within these, a total of 76 individual whales have been identified in Godthåbsfjord (table 5.6).The re-identification rate for subsequent years varies between 19-43 %.

The results confirm that individual whales have a high degree of site fidelity for Godthåbsfjord. The individuals with the highest degree of site fidelity are also the individuals staying within the fjord for the longest period during the feeding period (figure 5.25).

For example, individuals that returned to Godthåbsfjord six years in a row were on average encountered eight times per year. In contrast, individuals that were observed in the fjord one year were only encountered on average twice during that year. In Godthåbsfjord, between 15 and 27 individuals have been encountered each year.

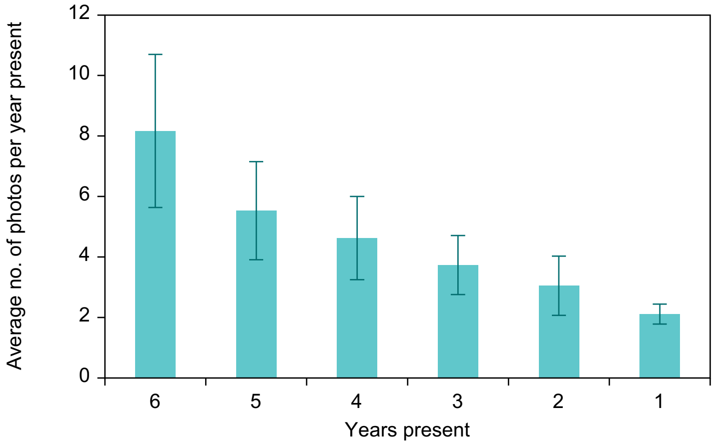


Figure 5.25 The average times individual humpback whales are identified relative to the number of years the individual has been identified in Godthåbsfjord.

6 Research projects

6.1 Comparative studies of land-atmosphere energy exchange in a low Arctic tundra ecosystem

Christian Stiegler, Anders Lindroth, Magnus Lund and Mikkel P. Tamstorf

The energy balance of Arctic terrestrial ecosystems is of crucial importance for understanding future climate change in high northern latitudes. Despite a growing interest in Arctic measurements, observations of local-scale climate characteristics are still scarce. Therefore, we conducted comparative measurements of energy balance components during a two-week summer period in the Kobbefjord area.

By using a mobile eddy covariance and energy balance tower, we measured radiation components (net radiation, long- and short-wave radiation), ground heat fluxes, turbulent fluxes as well as air temperature. In addition, we collected data on soil moisture and soil temperature at various depths. With our measurements, we covered characteristic types of vegetation in the valley: meadows with sedge vegetation (A), bare soils with scattered cushion plants (B) and shrub vegetation up to 100 cm in height (C). Figure 6.1 shows the mobile energy balance tower at location A. Energy balance components were collected for at least 24 hours at each of the mentioned sites. Nevertheless, rough weather conditions with heavy rainfall and strong winds limited the amount of collected data at location B.

Figure 6.2 illustrates the first results of our measurements at location A. The six-day measurement period is characterized by high values of net radiation (Rn) and sensible heat fluxes (H) during the first four days. Rn and H are significantly reduced in the remaining measurement period whereas ground heat fluxes (G) remain constant during the entire period. Mean wind speeds, soil temperature and air temperature follow a clear daily cycle.

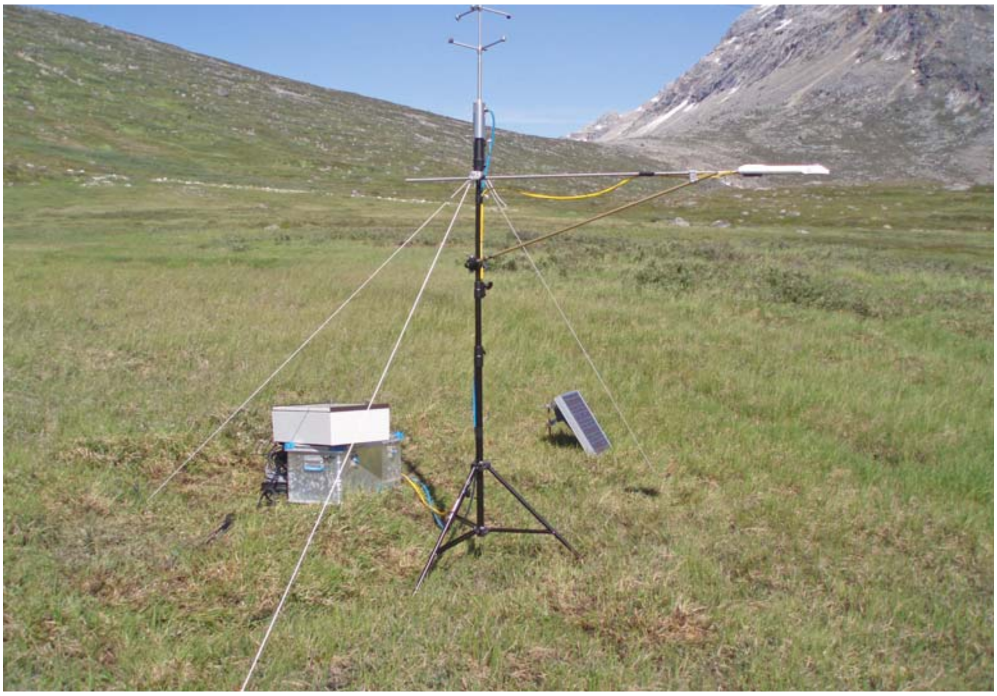


Figure 6.1 Mobile energy balance tower in operation on a mainly sedge-covered meadow. Photo: Christian Stiegler.

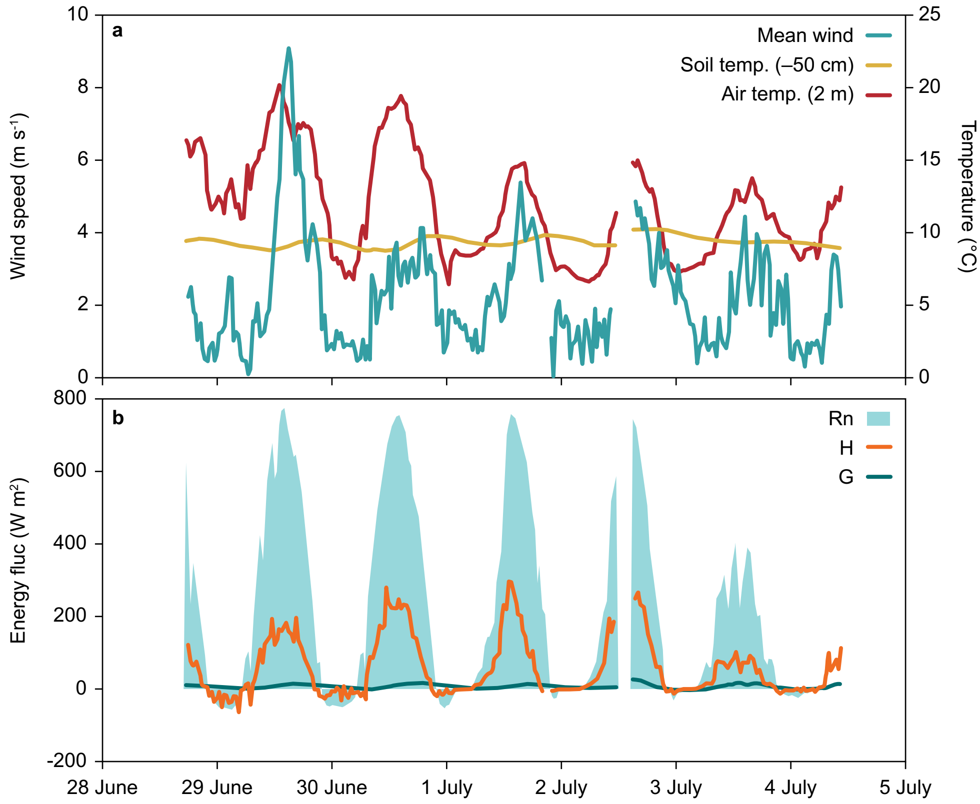


Figure 6.2 a) mean horizontal wind speed, soil temperature, air temperature, b) net radiation (Rn), sensible heat flux (H) and ground heat flux (G) at a mainly sedge-covered meadow (see figure 6.1). Due to changes in the setup, data was not collected for four hours 2 July 2012.

Table 6.1 summarizes the average values of the collected parameters at each location. Rn at location B is strongly reduced due to cloud cover during measurements. Ground heat fluxes at the same location reflect the strong cooling of the bare soil during night. Values of albedo show no significant difference between the various locations. Soil moisture content is strongly reduced at location B due to sandy soils and lack of vegetation.

Besides our short-term mobile measurements, additional data collection of energy balance components is conducted by two permanent eddy covariance towers. As a future step, we will try to combine our measurements with the permanent installations to investigate the surface-atmosphere energy exchange in the area.

*Table 6.1 Average values of measured parameters at location A, B and C. *) Data only available from 4 July 16:30 to 5 July 10:00.*

	Location A	Location B	Location C
Parameter	**28 June-4 July 2012**	**4-6 July 2012**	**6-9 July 2012**
Rn (W m^{-2})	222.0	39.6	117.8
H (W m^{-2})	57.4	-3.4 (*)	7.2
G (W m^{-2})	7.1	-6.4	11.1
Wind speed (m s^{-1})	2.3	2.4 (*)	1.6
Albedo	0.14	0.10	0.11
Air temp. (°C)	11.8	11.3	13.3
Ground surface temp. (°C)	12.9	11.4	11.8
Soil temp. (-2 Cm, °c)	11.4	12.9	10.2
Soil temp. (-20 Cm, °c)	8.2	12.9	6.6
Soil temp. (-50 Cm, °c)	9.5	13.4	9.5
Soil moisture (-5 cm, %)		8.1	71.4
Soil moisture (-25 cm, %)		2.1	66.6
Soil moisture (-50 cm, %)		1.0	66.5

6.2 Functional distribution of *Carex bigelowii* in sub-arctic regions

Chris Andrews, Claire McDonald and Jan Dick

The genus *Carex* is one of the most species-rich in the sedge family. It is an important genus in Arctic and sub-arctic environments often being the dominant vegetation. Although several studies have considered the influence of climate change or nutrient dynamics of specific species of *Carex*, to date an assessment of the functional distribution of *Carex* species within and between sites has not been attempted.

The aim of this study is to record specific physical traits of *Carex bigelowii* collected from a variety of habitats and landscapes at sites in Kobbefjord (Greenland), Litla-Skard (Iceland) and Cairngorms (Scotland; to be completed 2013); and using the traits collected to determine the response of *Carex bigelowii* to environmental conditions.

To achieve this aim we set out to:

- Examine and report on the physical traits of *Carex bigelowii*, in relation to each specimen's immediate habitat, landscape and geographic location.
- Classify habitat preferences based on functional traits.
- Determine the spatial distribution of *Carex bigelowii* in varying environmental conditions.

At each site we set out transects along an altitudinal gradient, to include a variety of altitudes, slopes and aspects. Plots consisted of a 2 m × 2 m plot subdivided into twenty-five 40 cm × 40 cm subplots. In each subplot, all *Carex* species were identified, whilst all *Carex bigelowii* ramets were mapped to provide spatial information on density and proximity of visible plants. Five complete plants were extracted from each plot with the underground stolons added to the spatial map. Soil bulk density and samples were collected at the plot level where possible. The full list of determinants collected in the field or laboratory can be seen in table 6.2.

Initially ordination analysis (Principal component analysis (PCA)) was used to explore the variation in trait data of *C. bigelowii* across the study sites to determine if traits of *C. bigelowii* varied either within or between plots and between study sites. All plant traits listed in table 6.2, except those marked with an asterisk, were included in the analysis. The environmental variables collected at the plot level were also used to explore the variation across the study sites.

The PCA results (figure 6.3) indicate that there is variation in trait data collected for *C. bigelowii*, not only between countries, but also for plants situated at the same site. The first two axes of figure 6.3b use trait data (leaf thickness, width, length and weight) which were found to be positively correlated with each other, and explains 52.6% of the variation in the data. The distinction between plants in Greenland and Iceland is also shown. Figure 6.3a shows the geophysical and environmental effects on plant traits. The first two axes use a subset of the environmental variables, and explain 66.8% of the variation in the data. The PCA analysis also highlights that there are plots in both countries, which have similar altitudes and slopes.

Leaf traits including length, width and thickness were used as response variables in linear mixed effect models to quantify the difference in the trait across the environmental variables. However, no significant relationships were found to exist between the leaf traits and the environmental variables, although significant differences between Iceland and Greenland for all

Table 6.2 Full list of determinants for which data was collected categorized by scale and type. Determinants marked with an asterisk (*) are still to be processed.

Level	Category	Determinant
Plot determinants	Environmental	Grid Ref Slope Aspect Altitude
	Soil	Soil water content (g g^{-1}) Soil bulk density (g cm^{-3}) Volumetric water content (g cm^{-3}) Soil porosity (%) Soil water filled pore space (%) Soil nutrients*
	Biological	Sward height (cm)
Plant traits measured		Stolon length between ramets (cm) Stolon width (cm) Leaf width (mm) Leaf length (mm) Leaf thickness (mm) Specific leaf area* Wet leaf weight (g) Dry leaf weight (g) Stomatal density* Number of newly emerging tillers Number of ramets in flower Releasing height (cm) Ramet spread/diameter (cm) Density of ramets (per m^2) Number of ramets dead or alive

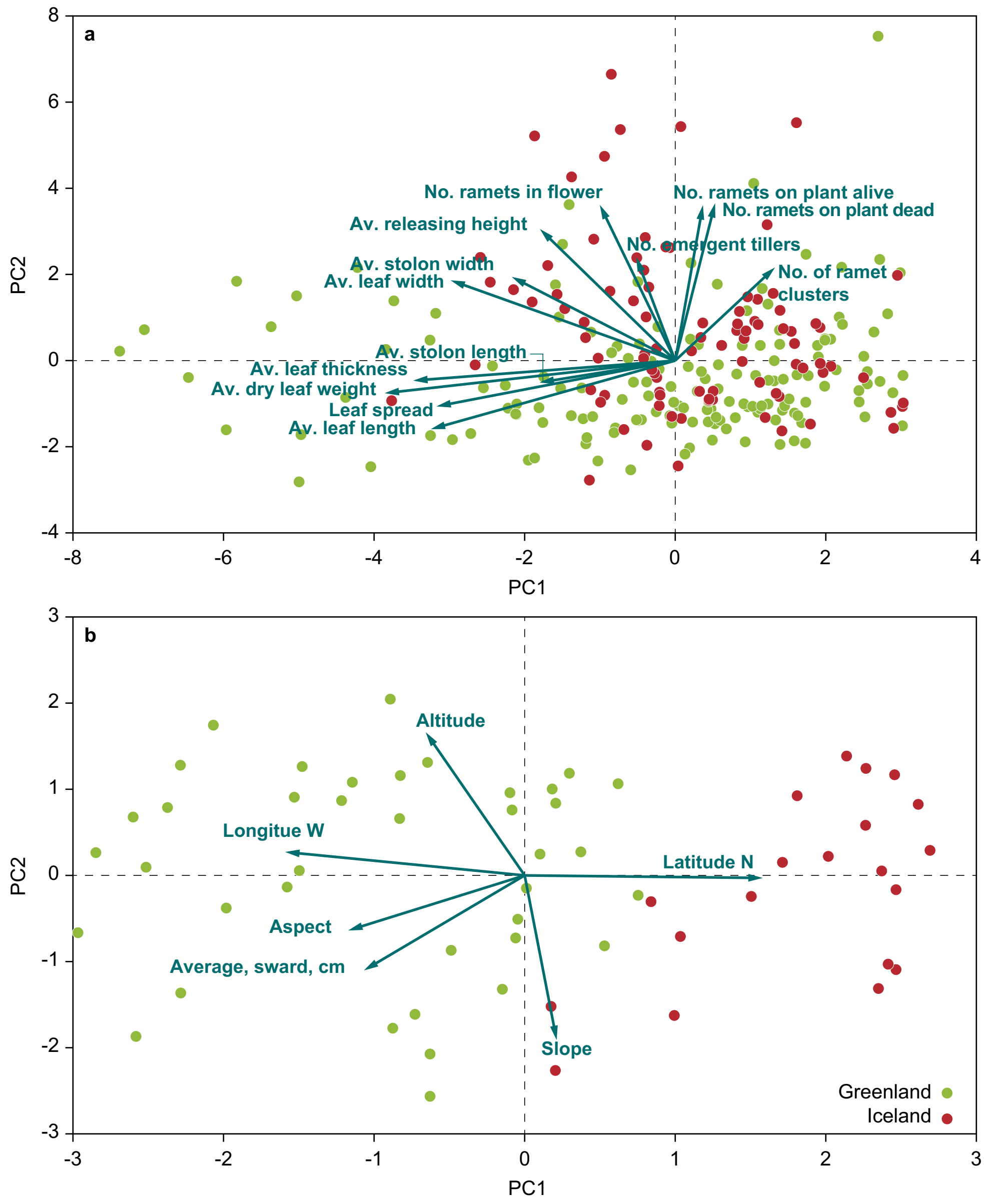


Figure 6.3 PCA ordination of leaf traits and environmental determinants. a) First axis (PC1) represents the negative correlation between the latitude and longitude of the plots whilst the second axis (PC2) represents the negative correlation between slope and altitude. b) The first axis uses leaf traits (thickness, width, length and weight). General ramet traits such as ramet number and the number of ramets dead or alive are represented by axes PC2.

leaf traits were found. *C. bigelowii* leaves in Greenland were longer and thicker than leaves from plants in Iceland, but *C. bigelowii* in Iceland had significantly wider leaves than in Greenland (figure 6.4).

The difference in leaf traits for *C. bigelowii* across sites suggests there could be potential differences in the environments the plants inhabit. The differences in traits due to soil properties is still to be fully ex-

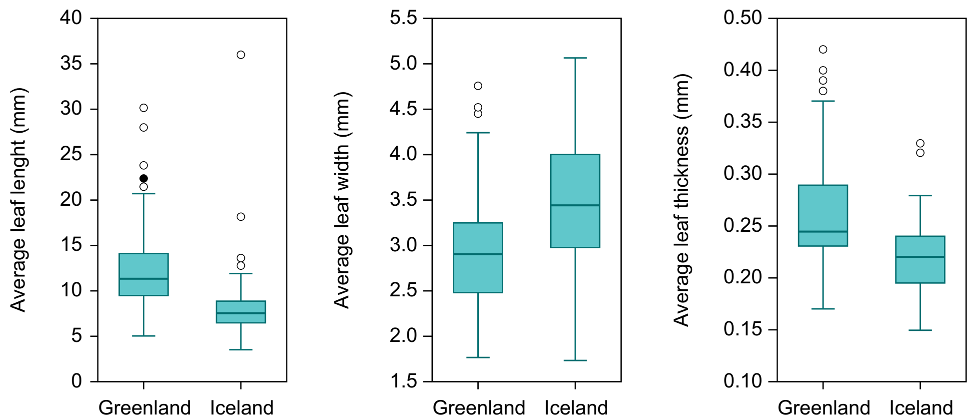


Figure 6.4 Differences in average leaf length, width and thickness of Carex bigelowii between Greenland and Iceland. The dark green line represents the median value for the site and the circles represent average leaf lengths at the plot level.

Figure 6.5 Preparation of the shrub samples subsequent to the harvest, and according to the serial sectioning technique at the research house in Kobbefjord. Photo: Allan Buras.

amined although initial analyses found no significant differences for any of the leaf traits across the soil variables, and that soil variables do not differ between sites, plots or transects.

This project is still in the analysis phase, and we still have several further determinants to be analysed, including environmental factors such as soil nutrients and local climatic data (temperature, wind speed, snow days, frost-free days, growth degree-days etc.) as well as several important traits including specific leaf area and stomatal counts.

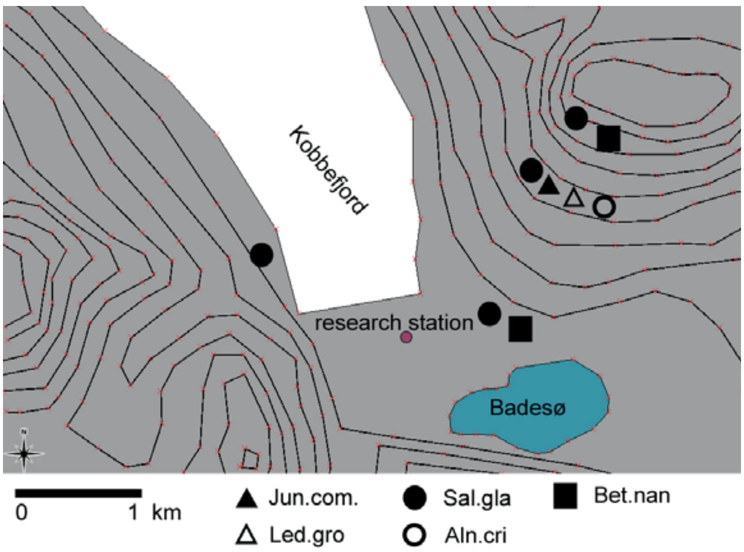


Figure 6.6 Schematic map of the study site indicating the location of the sampled shrubs. Jun.com = Juniperus communis *ssp.* alpina, *Led.gro =* Ledum groenlandica, *Sal.gla =* Salix glauca, *Aln.cri =* Alnus crispa, *Bet.nan =* Betula nana. *The contour lines indicate 50 m elevational differences.*

6.3 Dendroecological investigations on shrubs in Kobbefjord

Allan Buras, Martin Wilmking and Mateusz Zimowski

Funded by the INTERACT Transnational Access programme and collaborating with Greenland Institute of Natural Resources (GINR), dendroecologically investigations of several dwarf-shrub species in Kobbefjord were carried out in August 2012. Altogether, the respectively largest stems from 120 living shrubs were sampled, including the species from *Alnus crispa* (20 specimen), *Betula nana* ssp. *tundrarum* (20 specimen), *Juniperus communis* ssp. *alpina* (19 specimen), *Ledum groenlandica* (10 specimen) and *Salix glauca* (51 specimen). Subsequent to the harvest, the sampled stems were prepared according to the serial sectioning technique. That is, stem discs for the dendrochronological analysis were taken at every 10 cm of the stem elongation (figure 6.5). To represent the supposed altitudinal climatic gradient, the individuals belonging to *Betula nana* and *Salix glauca* were sampled on three (20-50 m a.s.l., 200-250 m a.s.l., and 350-400 m a.s.l.) and two (20-50 m a.s.l. and 350-400 m a.s.l.) different elevational levels, respectively. While most of the shrubs were sampled on a southwest-facing slope, twenty specimen of *Salix glauca* were sampled on a northeast-facing slope to represent ecological features related to the locally most unfavourable slope exposition (figure 6.6). Several samples on the south-facing slope were taken close to the NERO line, possibly allowing for synergies among the long-term monitoring programme and our analyses.

Preliminary results: First analyses indicate that the growth of *Juniperus communis* ssp. *alpina* in Kobbefjord is positively correlated with summer temperatures and negatively correlated with summer precipitation (climate data from the Nuuk climate station; figure 6.7). However, the individual signal varied largely among individuals, most likely due to micro-topographic variations of soil properties. Yet, we have only analysed one specimen of *Betula nana* spp. *tundrarum* as these show very narrow rings (the smallest measured ring was only 20 µm wide!) therefore the measuring procedure is very time consuming. However, for *Juniper* the first

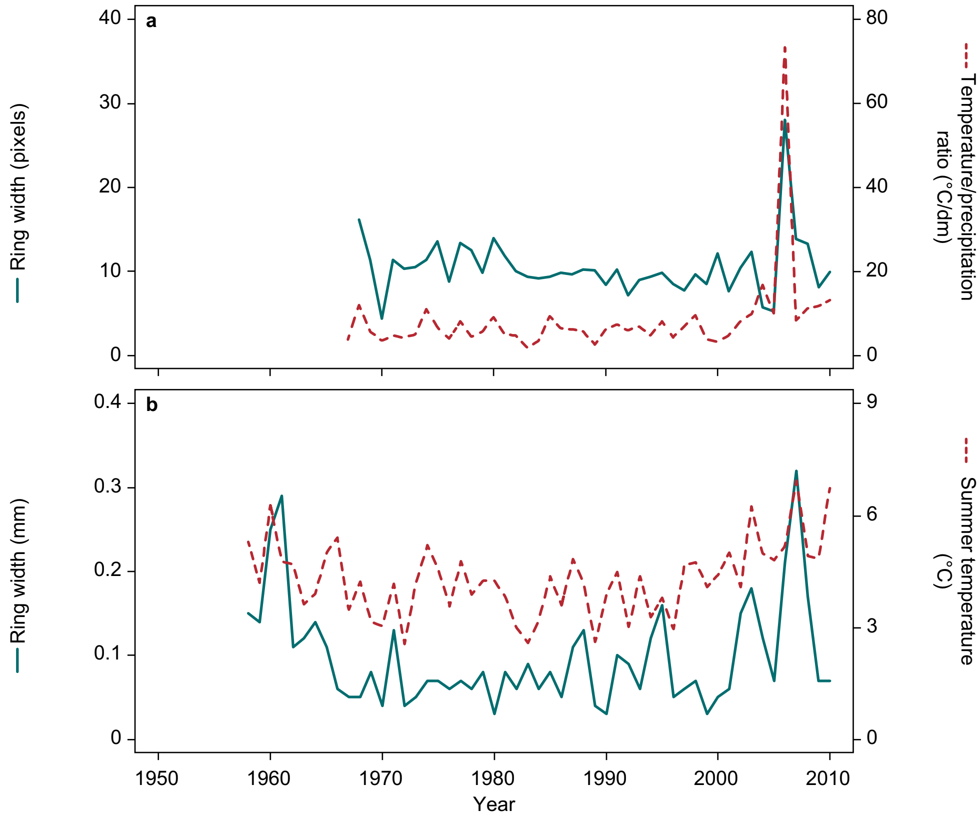


Figure 6.7 a) Average residual chronology of three Juniper *shrubs (blue line) and summer temperature/precipitation ratio (red line) are positively correlated (r = 0.75, p < 0.001) and react rather synchronously (glk =0.68). The temperature/precipitation ratio was calculated to include the diverse effects of temperature and precipitation on the growth of* Juniperus communis *ssp.* alpina. *b) Raw ring width measurements of one* Betula nana *ssp. tundrarum specimen (blue line) and summer temperature (red line) are positively correlated (r = 0.51, p < 0.001) and react rather synchronously (glk = 0.72).*

results are promising, showing a positive correlation with summer temperatures but a lower impact of summer precipitation (figure 6.7).

Outlook and perspectives: Further statistical analyses aiming at the identification of shrub growth drivers will also take into account the length of the growing season, as well as late frost events. By this, we hope to be able to reduce the error noise of possible climate reconstructions. We are happy, that Mateusz Zimowski – a new PhD candidate in our DendroGreif laboratory – since January 2013 actively contributes to the dendroecological analyses. Therefore, we are confident to have measured a large proportion of the sampled stem discs by the end of 2013. By including these measurements in our chronologies, we hope to be able to reconstruct past climate conditions (temperature and precipitation) within the Kobbefjord area. Many of the already investigated shrubs (so far 10 specimens) were older than 70 years (and few even older than 100 years) by the time of the harvest. Thus, if successfully disentangling the precipitation and temperature signals within the shrubs, the achieved climate reconstructions could extent the recently available instrumental records (dating back until 1958). Furthermore, we plan to measure densities and element concentrations of some of the shrub samples with an XRF-multiscanner (ITRAX), possibly achieving additional and/or more precise proxies for environmental parameters. Finally, a combined analysis of the different shrub species partly distributed over an altitudinal gradient may allow us to understand the different ecological needs of these species and thus for describing the dynamics of shrub expansion in the Kobbefjord area along an altitudinal gradient.

6.4 Barcoding of soil microarthropods in Kobbefjord

Paul Henning Krogh, Helena Wirta, Tomas Roslin, Peter Gjelstrup, Zdenek Gavor, Elin Jørgensen, Niels Martin Schmidt, Henning Petersen, Katrine Raundrup, Josephine Nymand and Peter Aastrup

Since it was proposed to identity species by small sequences of DNA with e.g. less than 1000 bp (base pairs) popularized by the term barcode, monitoring of biodiversity has included barcoding (Hebert et al. 2003, Hogg and Hebert 2004 and Rougerie et al. 2009). It is now a rapidly increasing

Table 6.3 The range of habitats in the Kobbefjord area that were sampled for barcoding of soil collembolans and mites, i.e. microarthropods.

Habitat name	Collection date August 2012	Ref.	Habitat description	Lat, Long, m a.s.l.
Empetrum	14	MArt2	The vegetation is dominated by *Empetrum nigrum*. The soil appears dry and some parts also covered by lichens.	64.13071456, -51.38899547, 44
Salix	14	MArt3	The vegetation is dominated by *Salix glauca* thicket with some *Betula nana* and *Empetrum nigrum*. The area is flat.	64.13157974, -51.37105895, 27
Silene	14	MArt5	South facing slope dominated by *Silene acaulis*. MArt5 and MArt7 are dry habitats with similar soil type (Raundrup et al. 2010)	64.13665549, -51.3710882, 73
Loiseleuria	14	MArt7	A south facing slope dominated by Loiseleuria *procumbens* with some *Empetrum nigrum* and lichens.	64.1325984, -51.37386672, 35
Snow patch	14		Smaller protected spots in the area. Snow cover duration is considerably longer than usual. Vegetation dominated by *Salix herbacea*. The site is on an east facing slope.	64.13321145, -51.38460553, 42
Herb slopes	22	UTLI	Vegetation dominated by *Vaccinium uliginosum*, *Polygonum viviparum*, *Luzula multiflora*, *Hieracium* sp., *Coptis Trifolium*, *Agrostis hyperborea*, *Carex* cf. *praeticula* and moss.	64.13956108, -51.36518676, 117
Fen	14		A marsh vegetation dominated by *Carex rariflora, Scirpus caespitosus* and *Eriophorum angustifolium* in the wettest areas and *Vaccinium uliginosum* on mossy tussocks.	64.13049596, -51.38805561, 41
Copse	22		Heavy scrub (willow) on south-facing slope. Vegetation dominated by *Salix glauca, Vaccinium uliginosum, Ledum groenlandicum, Lycopodium annotinum*.	64.14054469, -51.37211113, 22

collectively endeavour supported by the infrastructure of the iBOL project (the International Barcode of Life project). The other important ecosystem descriptor, the ecosystem functioning, while not readily obvious from taxonomic information, can be derived from a recently established collembolan trait database, where each collembolan species is characterized by its morphological and ecological traits. Hence, for the collembolans found in the Kobbefjord area and at Zackenberg we have defined the basic collembolan morphological and ecological traits now ready to be analysed against local environmental variables according to the RLQ concept (Kleyer et al. 2012). RLQ is a joint data matrix holding environmental information, R, a trait matrix, Q, and a population abundance matrix, L, subject to a multivariate analysis.

By supporting the iBOL project, the Nuuk BioBasis monitoring programme has now initiated the study of the population genetic level of biodiversity and links to the Zackenberg BioBasis monitoring programme by enabling a comparison of the same microarthropod species from these two distant Greenland locations. The barcoding project is carried out in collaboration with the Spatial Foodweb Ecology Group, University of Helsinki within the programme 'DNA Barcode Library for (Northeast) Greenland' (Wirta et al. 2013). Forthcoming analyses of the mitochondrial cytochrome c oxidase I, i.e. CO I, barcode DNA sequences would include comparison of the Greenland species with existing CO I in the Barcode of Life Database (BOLD). To enable efficient future monitoring of the soil microarthropod diversity in the Kobbefjord area we have initiated this barcoding campaign for soil microarthropods living in the most common obvious eight habitat types within the area (table 6.3). The four habitats already used for soil microarthropod monitoring, MArt 2, 3, 5 and 7, and four additional habitats have been included.

From the two locations, the Kobbefjord area and Zackenberg, collembolans and mites have been sampled and prepared for barcoding at CCDB (Canadian Centre for DNA Barcoding). Cryptic diversity is expected to be revealed for species from Greenland as has been demonstrated for some common collembolans (Porco et al. 2012a). For oribatids, the CO I barcode consisting of 658 bp's seems sufficient to establish species identities (Young et al. 2012), while often rRNA sequences are employed for genetic diversity of individual species population (Porco et al. 2012b, Schneider et al. 2011). Thus, the 'barcoding gap' holds promise for oribatid mites, but it is certainly expected that we will employ new sequencing methodology when determining soil biodiversity in the near future (Taylor and Harris 2012).

Figure 6.8 Eurois occulta *feeding on* Betula nana *foliage, Kangerlussuaq, Greenland. Photo: Gergely Várkonyi.*

Species found in the Kobbefjord area with parthenogenetic strains (Chernova et al. 2010) such as *Neanura muscorum*, *Isotomiella minor*, *Parisotoma notabilis* and *Oligaphorura groenlandica*, may display a higher population genetic diversity, as they could consist of more than one lineages or at least more than one clone per species. This remains to be proven after the on-going analysis of barcodes have been made available.

Our own list of collembolan species from Greenland now counts 46 species about half the number of species reported in 2008 by Arne Fjellberg (Fjellberg, in press). Presently ten species have been sent for barcoding at CCDB and roughly, thirty species of mites are expected to be barcoded from the Kobbefjord area including the oribatids reported in Bay et al. 2012.

The barcodes of the collembolans *Folsomia quadrioculata* and *Oligaphorura groenlandica* in the Kobbefjord area will be compared with the same species found in Zackenberg.

6.5 Climate, phenology and invertebrate population ecology in Greenland

Michael Avery, Tomas Roslin, Tapani Hopkins, Riikka Kaartinen and Gergely Várkonyi

While Arctic plant and vertebrate species have been a focus of recent research on population and community responses to warming (Walker et. al. 2006, Post and Forchhammer 2008 and Post and Pedersen 2008), considerably less attention has been paid to the role and importance of invertebrates in far northern ecosystems. A collaborative INTERACT Transnational Access funded project involving Penn State University (USA), the University of Helsinki, and the Finnish Environment Institute aims to understand the dynamics of Arctic invertebrate communities and their influence on broader ecological processes. In the Nuuk region, this research focuses on the ecologically influential noctuid moth species *Eurois occulta* (figure 6.8) and the species with which it trophically interacts. *Eurois occulta* undergoes rapid and regional population explosions in Greenland (Wolff 1964, Fox et. al. 1987, Post and Pedersen 2008 and Avery unpublished). In boom years, its larvae defoliate the landscape, altering the trophic structure of the ecosystem by transforming plant biomass into animal biomass available for exploitation by other species.

In a highly seasonal Arctic environment with a compressed period of productivity, the timing, duration, and intensity of species interactions are major determinants of the population dynamics of interacting species, with periods of high resource requirement in consumer species adapted to coincide with periods of high resource availability or quality in the species it exploits (Durante et. al. 2007 and Post and Forchhammer 2008). A major step forward for climate change eco-

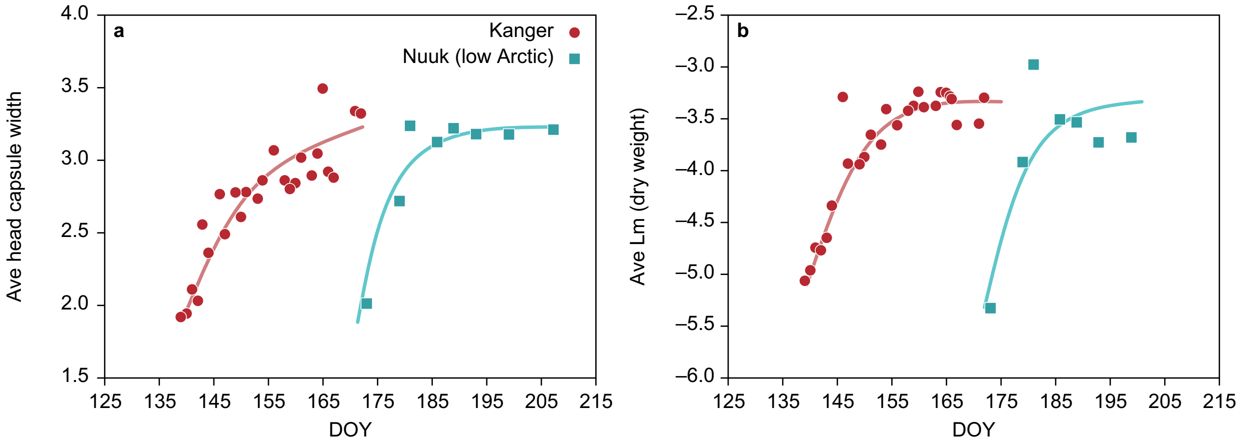


Figure 6.9 Differences in emergence (first appearance) and maturation (slope) phenology for Eurois occulta *between the Kangerlussuaq and Nuuk sites. a) shows growth in head capsule width, and b) mass accumulation over the larval active period.*

logy has been the recognition of the critical influence of indirect climate effects, wherein climatic factors directly and differentially affect the phenology – the timing of cyclic biological events such as germination, migration and breeding – of species that interact with one another.

In Nuuk, as well as at a second site to the north in Kangerlussuaq, emergence and maturation phenologies are being developed for *Eurois occulta* and trophically linked species, such as the forage plants *Salix glauca* and *Betula nana* (dwarf willow and birch, respectively). This entails, predominantly, re-sampling of the invertebrate collection of the BioBasis programme from the Kobbefjord field site to identify, count, and measure moth larvae in order to model emergence time, maturation rate, and density across the Kangerlussuaq and Nuuk regions as a function of various climate predictors to determine the effects of projected warming on the frequency and severity of future outbreak events.

Preliminary data shows dramatic shifts in both the emergence time and rate of growth for *Eurois occulta* larvae between the drier, colder, Kangerlussuaq region, and the wetter, warmer Kobbefjord site, suggesting snow cover may play an important role in onset of grazing, while cooler average temperatures may extend the pre-pupal stage (figure 6.9). Current analyses incorporate local density of larvae and phenologies for forage plant species.

Figure 6.10 Growth registration of Callithriche hamulata *in Badesø. Photo: Joanna Birch Olsen.*

6.6 The influence of climate change on the growth of submerged macrophytes in low Arctic lakes

Tina Mønster and Joanna Birch Olsen

A short ice-free period, low water temperatures, a short growing season and a low input of nutrients characterize Arctic lakes. Due to these harsh conditions, few species of vascular macrophytes are able to live in Arctic lakes, and therefore studies have most often focused on mosses, instead of vascular submerged macrophytes. With the increasing climate changes, we expect a longer ice-free period, due to earlier ice melt and later freeze-in of the lakes, higher water temperatures, as well as a higher nutrient load.

Fieldwork experiments were carried out in the two lakes (Badesø and Quassisø) included in the Nuuk BioBasis programme from June to September 2012. The first investigating whether the growth of the vascular freshwater macrophyte *Callithriche hamulata* was nutrient limited or not, the second investigating the growth of *C. hamulata* in different depths during the ice-free period.

With combined fieldwork in Greenland and laboratory work in Denmark we were able to show that growth of *C. hamulata* is nutrient limited, and that the short growing season and low water temperatures most likely limit the production and depth distribution. At lower latitudes, the transparency and light often controls the depth distribution. We were able to show that the investigated freshwater macrophytes show great potential for acclimation to higher temperatures, and that their optima for growth lie above ambient temperatures in low Arctic lakes.

With a longer ice-free period and higher water temperatures, the growing season will increase for the freshwater macrophyte *C. hamulata*, which could result in increasing depth distribution and increasing amount of biomass of the submerged freshwater macrophyte in the lakes. Due to the important structural role, submerged freshwater macrophytes have in lakes, this will have an effect on overall ecosystem and structure of the low Arctic lakes.

6.7 Winter mooring

Kunuk Lennert, John Mortensen, Ivali Lennert, Søren Rysgaard and Martin Truffer

The purpose of the project is to investigate the effect of the earth's rotation on winter circulation of fresh water in Kangersuneq, the inner fjord branch of Nuup Kangerlua. To solve this problem, two current meters will be deployed to a cross-section, centrally located in Kangersuneq and supplemented with hydrographic measurements. All work will be conducted from the fjord ice (figure 6.12). This is a contribution to a major survey of the Greenland Ice Sheet mass loss, which has recently been observed to spread along Greenland's northwest coast.

Figure 6.11 Nutrient enrichment experiment. Photo: Tina Mønster.

The deployments of both moorings and recovery were successful, and the additional hydrographic measurements were also successful during deployment. But, no additional measurements were carried out during recovery due to the fast melting of the fjord ice and potential danger of going through the ice. Data from the wanted period was obtained and is now being analyzed.

6.8 Role of bacteria in pelagic carbon turnover in low Arctic Godthåbsfjord, Greenland

Isak Rasmussen, Martin E. Blicher, Thomas Juul-Pedersen, Mikael K. Sejr and Mathias Middelboe

The aim of the study was to determine the bacterial carbon turnover in the low Arctic Godthåbsfjord. The study took place during May 2012 in the experimental framework of the annual May cruise, a part of Nuuk MarineBasis programme (figure 6.13).

The study was conducted along a transect running from the inner part of the fjord near the Ice Cap and to Fyllas Banke, 30 km offshore. The transect included eight sampling stations with four to seven depths either for filtrated or *in situ* samples. At the time of the experiment it was expected that the primary production was at its highest,

Figure 6.12 Moorings deployed under the sea ice. Photo: Greenland Climate Research Centre.

and it was therefore expected that the bacterial respiration and production should reflect differences in temperature along the transect. The study was conducted by ^{3}H-Thymidine measurements of bacterial production, 24-hour measurements of bacterial respiration, bacterial carbon demand and bacterial growth efficiency. As part of the monitoring programme, primary production was measured and these results were used in the examination to determine the role of primary production in the bacterial carbon turnover. Dissolved organic carbon (DOC) is the main labile source of energy for heterotrophic bacteria microorganisms in the water column, and the processes are thrived by abiotic factors such as temperature and the availability of inorganic nutrients. The bacterial consumption of DOC is one of the largest factors in the global carbon cycle and a main source of removal of carbon from the oceans, and this process is thought to change in the future due to the rising temperatures. This experiment and future similar experiments are important in the process of understanding the global carbon cycle, and the ability of the oceans to take up excess amounts of carbon due to the rising emissions from human activity.

Figure 6.13 Experimental setup in the cold room. Photo: Greenland Climate Research Centre.

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 in the bottom of the fjord – no landing.
- Visits by boats in the bottom of the fjord – the persons take a short walk inland and returns within a few hours or less.
- Visits by boats in the head of the fjord – the persons go on land and spend the night in a tent close to the coast.
- Hiking through the area – there is a hiking route from Nuuk to the inland passing through the area.
- Visits by snowmobile – during winter people visit the area from Nuuk.
- The electrical power transmission line between Nuuk and the hydropower plant in Buksefjord runs through the area.
- 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 or following the transmission line at low altitude.

In 2012, there were only few interactions between visitors in the study area and the different setups and the research house.

Foxes have moved and taken pit-fall traps and laid droppings in the pit-fall traps.

There was a single incident where three persons unexpected needed access to the cabin in order to stay over. A window was broken.

The monitoring programme itself has brought disturbance to the area i.e. transportation between Nuuk and the bottom of the fjord, housing of personnel, walking between study plots and around study plots. Especially the permanent plots in *Empetrum* heath and the fens have signs of wear.

Transportation between Nuuk and the study site in the Kobbefjord area has been conducted on an irregular basis, but during most of the season, there were transport two or three times a week (Tuesdays and Thursdays in one week and Mondays, Wednesdays, and Fridays in the next week). During most of the season, the cabin was used temporarily by two to four persons. On few occasions more than 10 people stayed overnight for one to two nights. At those occasions, people were also sleeping in tents close to the cabin.

Walking around the study plots has had a wearing effect on the vegetation and it should be considered to mark permanent trails between the research house 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 2012, Greenland Institute of Natural Resources (GINR) took care of the logistics related to Nuuk Basic in the Kobbefjord area.

The 2012 field season in the Kobbefjord area started 11 January and continued until 8 November. During this period 47 scientists and logisticians spent 381 and 30 'man-days' in the study area, respectively.

The winter 2011/2012 was relatively mild with ice one mile out from the bottom of Kobbefjord. It was possible to sail to the bottom of Kobbefjord from 1 May to 8 November.

GINR carried out transportation of staff, technicians, scientists and guests from Nuuk to the Kobbefjord area with the boats 'Aage V. Jensen II Nuuk' and 'Erisaalik'. The total number of sailing days to the Kobbefjord area used by logisticians, BioBasis, GeoBasis and ClimateBasis was 77 in 2012. MarineBasis used 26 sailing days to go to the study areas in Kobbefjord and Godthåbsfjord.

In 2012, scientists spent 142 'bed nights' in the research house in Kobbefjord. In Nuuk, the Nuuk Basic scientists were accommodated in the annex of GINR, with 331 'bed nights'.

Water for drinking and other purposes were taken from the nearby river.

Electrical power was provided by two portable gasoline generators (2 and 4 kW) and a 5 kW diesel generator. A new gasoline generator was bought in 2012.

Communication to/from Nuuk was made by Irridium satellite telephones, while local communication within the study area was by portable VHF-radios. Two new portable VHF-radios were bought in 2012.

Fuel consumption for the generators was 150 litres of diesel and 800 litres of gasoline. Fuel consumption for the oven in the research house was 40 litres diesel.

Freshwater consumption was 4000 litres.

A drainpipe for grey household water was connected from early June to late September.

All garbage (approximately 300 kg) was removed by ship to Nuuk during the season.

28 March 2012, a Bell 212 helicopter from Air Greenland made one flight with a group of Geo- and ClimateBasis scientists from Nuuk to the Kobbefjord area. The scientists carried out snow monitoring in the area using a snowmobile. The snowmobile with a cargo sledge transported a small boat to the lake K2. 1 April 2012, the same helicopter picked up the scientists and flew them to Nuuk.

17 April 2012, a Bell 212 helicopter from Air Greenland made one flight with two Geo- and ClimateBasis scientists from Nuuk to the Kobbefjord area. 18 April 2012, the same helicopter picked up the scientists and flew them to Nuuk.

18 May 2012, three persons in need of shelter broke a window to get into the research house. They paid for all expenses.

1 July 2012, there was a burglary in the research house. Two windows were broken and a rifle, a flare gun and a multi-tool box were stolen.

The study area in Kobbefjord was during 2012 visited by several honourable guests:

31 May 2012: Jens Hesselbjerg Christensen, Scientific Head, Danish Meteorological Institute and Martin Stendel, Senior Scientist, Danish Meteorological Institute.

18 June 2012: Leif Skov, Chair of Aage V. Jensen Charity Foundation, Vagn Forring, board member of Aage V. Jensen Charity Foundation, Klaus Nygård, Director of GINR, Søren Rysgaard, Professor, Arctic Research Centre, Aarhus University and GINR.

26 June 2012: Ulrik Bang, photographer, Najaraq Klemensen, journalist, Tor Svanes, author, Ross Virginia, Professor, Darthmouth University, USA and 6 Ph.D. students from the Integrative Graduate Education and Research Traineeship (IGERT) programme.
15 August 2012: Martin Lidegaard, Danish Minister for Climate, Energy and Buildings, Jens B. Frederiksen, Vice Chair of the Government of Greenland and ten civil servants.
4 September 2012: Poul-Erik Philbert, editor of 'Polarfronten', Uffe Wilken, editor of the journal 'Grønland' and journalist at 'Polarfronten'.
7 September 2012: Fourteen officials from the Greenlandic Ministry of Domestic Affairs, Nature and Environment, Greenland.
24 October 2012: Nine members from the Kommissionen for Videnskabelige Undersøgelser i Grønland (KVUG).

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11 Publications

Scientific papers

Arendt, K.E., Juul-Pedersen, T., Mortensen, J., Blicher, M.E. and Rysgaard, S. 2012. A five years study of seasonal patterns in mesozooplankton community structure in a sub-arctic fjord reveals dominance of *Microsetella norvegica* (Crustacea, Copepoda). Journal of Plankton Research 0(0):1-16. Doi:10.1093/plankt/fbs087.

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Appendix

Julian days

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