Nuuk Ecological Research Operations

1st Annual Report, 2007



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0. Executive Summary

Kisser Thorsøe, Mikkel P. Tamstorf, Peter Aastrup, Ditte Marie Mikkelsen and Morten Rasch

0.1 Summary

This is the first Annual Report for Nuuk Ecological Research Operations (NERO), a science based, cross-disciplinary, ecological monitoring and research programme, which observes the effect of climate change and variability on the terrestrial and marine compartments in a low arctic ecosystem in Kobbefjord (64°07' N, 51°21' W) in West Greenland near Nuuk, the Capital of Greenland.

The newer history of Nuuk Basic started in 2005 when the Danish Environmental Protection Agency decided to provide means for establishment and long-term run of a low arctic equivalent to the Zackenberg Basic monitoring programme in Northeast Greenland. Means for establishment and run of a Marine Basic programme were funded already in early 2005. At the same time, the Danish Environmental Protection Agency asked a group of scientists to provide a conceptual framework for a low arctic ecosystem monitoring programme. A number of workshops were held and a report with recommendations was prepared. Funding was achieved in late 2006, and the Nuuk Basic programme was in practice fully established by 1 January 2007.

Nuuk Basic consists of four sub-programmes, involving several research institutions. ClimateBasic, which studies the climate and hydrology in the study area, is operated by Asiaq - Greenland Survey. GeoBasic, which studies the physical landscape processes including a number of feedbacks to climate change in the study area is operated by Department of Arctic Environment, National Environmental Research Institute, University of Aarhus in cooperation with Department of Geography and Geology at University of Copenhagen and Asiaq - Greenland Survey. BioBasic, which studies the biological processes in the study area, is operated by Department of Arctic Environment, National Environmental Research Institute, University of Aarhus in cooperation with Department of Biology,

University of Copenhagen. Finally, MarineBasic, which studies the biotic and abiotic processes in the marine compartment of the study area, is operated by Greenland Institute of Natural Resources. Logistics is maintained by Greenland Institute of Natural Resources.

The run of Nuuk Basic is mainly funded by The Danish National Environmental Protection Agency. Aage V. Jensen Charity Foundation has been very generous to the project by providing means for the necessary infrastructure.

0.2 ClimateBasic

The meteorological monitoring programme in Kobbefjord was set up in May 2007 and consists of two identical meteorological stations. The two stations are placed next to each other. The double station improves the overall quality of data and ensures the continuity of measurements.

Because of problems with the stations no radiation data are available before 22 October and for the other parameters the only months with full data coverage is August and September. The mean air temperature for August and September are 9.8°C and 3.2°C. The relative humidity is generally higher and more stable during August than in the beginning of the fall. In September the dominant wind direction shifts from WSW to NE and periods with strong winds occur more often than in August.

In 2007 hydrological measurements have been carried out in four rivers in Kobbefjord area. Two hydrometric stations and two stations only with measurements of water level have been established.

The hydrometric station, H1, monitoring the main river in Kobbefjord, with a drainage basin of 31 km², has been running from 20 June to 22 October 2006 and from 8 March 2007 and onwards. The total calculated discharge during 20 June to 22 October 2006 was 21 million m³. From 8 March 2007 and until data was collected 26 September 2007, 35 million m³ of water have passed the gauging station.

0.3 GeoBasic

The implementation of the GeoBasic monitoring programme was initiated during a three week intensive field campaign in August 2007. GeoBasic provides long term data of climatic, hydrological and physical landscape variables describing the environment at Kobbefjord close to Nuuk. The GeoBasic programme will include monitoring of the physical variables within: Snow and Ice, Soils, Vegetation and Carbon Flux. The implementation of the GeoBasic programme will continue in 2008 with installation of the remaining systems and the field based monitoring going on from May through September.

Four automatic oblique cameras were installed on the mountain ridges for snow distribution monitoring. A digital terrain model for the orthorectification of the images is under development. As part of the snow monitoring an initial snow survey was carried out during spring 2008 in cooperation with ClimateBasic. This survey will be repeated every year in late winter to approximate the maximum snow cover. A simple automatic weather station for micro-meteorological measurements of air temperature, humidity, incoming shortwave radiation and surface temperature has been installed at 554 meter above sea level (m a.s.l) on Qaqarssuaq in the middle, south part of the drainage basin. A similar station is planned for setup in approximately 1000 m a.s.l. in the northern part of the drainage basin. Data from these stations will mainly be used for monitoring inversion and radiation for use in the snow distribution and melt models.

The soil sub-programme will monitor the annual and seasonal variations in nutrient content as well as the physical characteristics of the soil. The two stations include a fen site and a heath site with mixed heath vegetation. Each station consists of an automatic logger measuring soil moisture and soil temperature at 3-4 depths depending on the thickness of the soil profile. Air temperature and relative humidity at 2 m, soil surface temperature and soil heat flux is also measured by the stations. A third station will be installed during the 2008 season.

The GeoBasic programme monitors the phenology of the vegetation communities using satellite imagery and automatic cameras. The landscape vegetation monitoring is made by two NDVI cameras installed at 297 and 554 m a.s.l. respectively overlooking the main part of the valley floor. Several high resolution satellite images were acquired from previous as well as the initial growing seasons.

The carbon flux sub-programme consist of a plot scale methane (CH₄) and carbon dioxide (CO₂) flux system and a landscape scale carbon dioxide and water vapour (H₂O) flux system monitoring a wetland area in Kobbefjord. The CH₄ plot scale system is based on the chamber technique: a box of known volume isolates a known area of the surface and can be opened or closed. It consists of six automated chambers. The CO₂ landscape scale system is based on an eddy covariance tower. The eddy covariance technique provides the net ecosystem exchange of CO₂ giving information on the total flux, i.e. from both soil and vegetation, to or from the ecosystem. Power to the systems is delivered by large battery systems charged by solar panels in combination with a generator.

0.4 BioBasic

The BioBasic programme was initiated in 2007 by the National Environmental Research Institute, University of Aarhus, in cooperation with the Greenland Institute of Natural Resources.

We established plots for monitoring reproductive phenology for four plants species: *Silene acaulis, Salix glauca, Eriophorum angustifolium,* and *Loiseleuria procumbens.* For each species four phenology observation plots were set up to cover the ecological amplitude of the species with respect to snow cover, soil moisture and altitude.

Weekly monitoring of CO_2 flux between the soil/vegetation cover and the atmosphere was made in a mesic dwarf shrub heath dominated by *Empetrum nigrum* with *Salix glauca* as a sub-dominant species. The monitoring includes experimental plots to study the effects of increased shading from clouds and increased temperature. Monitoring of the effect of UV-B radiation on plants was established by setting up five plots each with three treatments: Control, UV-B filter, and filter control in a mesic dwarf shrub heath dominated by *Empetrum nigrum*.

The permanent vegetation transect, the NERO-line, was established in order to monitor future changes in the location of boundary lines between vegetation zones and in the species composition of the plant communities. The NERO-line consists of three transects (the main transect, a short salt marsh transect, and a very short *Deschampsia-Juncus* transect). The total length of the main vegetation transect is approximately 3 km and it intersects 83 vegetation zones.

Furthermore, ground-truth data for vegetation mapping were sampled. The vegetation is classified into seven types (dwarf shrub heath, snow bed, herb slope, fen, early snow free grassland, lake/pond vegetation, and salt marsh) based on the species composition, physiognomy and species diversity in addition to water contents of the soil, expected snow cover and terrain aspects.

Four pitfall trap stations for arthropods were established in connection to three different plant phenology plots (*Eriophorum, Salix glauca*, and *Silene acaulis*). Further, one plot was established in *Empetrum nigrum* heath. Three microarthropod sampling plots, each with two replicates of three different plant phenology plots (*Silene acaulis, Salix glauca* and *Empetrum nigrum*), were established. Samples indicated that microarthropods are abundant at all three habitats, and 17 different collembolan species were recorded.

Data were collected on the distribution of birds, including some nests. The data will be compiled in a master thesis and published in 2008.

A monitoring programme was established for two lakes, one with arctic char at low altitude ("Badesøen") and one presumably without arctic char at a higher altitude ("K2"). Four taxa of zooplankton larger than 140 µm were observed. Moss vegetation and macrophytes are found in the more shallow parts of "Badesøen", but is very sparse in comparative areas in "K2". In both lakes moss were found in the very near shore areas, and especially in "Badesøen" it was common along the entire lake shore.

0.5 MarineBasic

MarineBasic was initiated in 2005, and thus already comprises data from several years. MarineBasic has monthly pelagic sampling throughout the year, combined with seasonal recordings of sea ice, benthic flux, fauna and flora, marine mammals and sea birds in Godthåbsfjord.

Monitoring of Baffin Bay shows a seasonal cycle of ice cover with a maximum sea ice cover in March/April. The ice cover is influenced by the West Greenland Current, which conveys warm water masses northwards. Minimum sea ice extent is in July/August where no sea ice was observed. Digital photos and satellite images showed that Godthåbsfjord is generally ice-free throughout the year, apart from sea ice formed in some smaller inlets and inner part of the fjord system near the Greenland Ice Sheet. The neighbouring fjord, Kobbefjord, showed large inter-annual variation with a sea ice cover of six months in the winter 2005-2006 and virtually no sea ice in 2006-2007, partly due to repeated storms which exported sea ice to offshore waters.

Hydrographical measurements from Godthåbsfjord revealed large variation in salinity, temperature and algal biomass along a length transect from the inner part of the fjord to Fylla Banke. Some interannual variation were observed between May 2006 and May 2007, but the overall picture each year was similar with a wide salinity range (31-33.8) and warm (1.5-2°C) water in the inner part of the fjord, a section of more isohaline (33.4-33.6) and colder (1-1.5°C) water in the outer fjord and wider salinity range (33.3-35.0) and wide temperature range (0-4°C) water over and around Fylla Banke. The algal biomass was largest in the inner part of the fjord and over Fylla Banke with low levels at the fjord entrance, where tidal mixing is high. Low levels of pCO₂ in the surface layer were observed in the inner part of the fjord (~100 µatm) increasing to a maximum of 240 µatm in the outer fjord. Over Fylla Banke, the pCO₂ decreased below 200 µatm. Hydrographical cross sections across Godthåbsfjord from Nuuk to Akia showed some variation, reflecting the effect of the Coriolis force.

The detailed monitoring of the water column at the fjord entrance revealed a distinct annual pattern in the more than 30 measured biological, chemical and physical parameters. Though differences in annual variation, abundances and concentrations are evident between the vears 2006 and 2007 (see table 4.1), an overall pattern can be described. The surface pCO₂ exhibited maxima in autumn. All measured surface pCO₂ values are below the concentration of the atmosphere, indicating the Godthåbsfjord acts as a sink throughout the year. The upper water column was well mixed during winter, with periodic inflow of warm and saline water below 150 m during the same period. The water column was stratified in autumn with low salinity and high temperature in the upper 100 m. The light attenuation in the water column varied, with maximum attenuation in May and minimum in November; very little irradiance was available for primary production during winter.

Chlorophyll a concentration and primary production were low in winter and began to increase in April. Two blooms in algal biomass were distinguished, one in May and a minor bloom in July. This productivity was reflected in the vertical sinking flux of chlorophyll *a* which peaked in May. Nutrients (silicate, phosphorus and nitrate) concentrations were high in winter, and decreased to a minimum in July. In autumn, nutrient levels increased again, presumably due to remineralisation or inflow of nutrient rich waters. Remineralisation of organic matter in the sediment can be estimated by the oxygen flux, with the lowest rates in winter and highest rates in late summer.

The algal bloom in May consisted mainly of the prymnesiophyte *Phaeocystis* sp. while diatoms dominated the algal community the rest of the year, complimented by silicoflagellates in winter.

The detailed taxonomic analysis of the zooplankton community reflects the life cycle of copepods with maxima of egg abundance in May/June, nauplii abundance in July and copepodite and copepod abundance in August/September. The zooplankton community was diverse. *Calanoid* copepods were present in June, while the genera *Microsetella* was dominant the rest of the year. Ichthyoplankton (fish larvae) was dominated by sand eel (*Ammodytes* sp.) and arctic shanny (*Stichaeus punctatus*), and the

highest abundance was observed in May. The benthic fauna and flora monitoring was initiated in 2007, with analysis of gonad and condition indices for *Chlamys islandica* and *Strongolycentros droebachiensis*. The macroalgae *Laminaria longicruris* is monitored at two sites for annual growth (150-180 cm yr⁻¹) and C:N content.

The number of breeding seabirds at Qeqertannguit was comparable in 2006 and 2007 with dominance of surface feeders such as kittiwake and arctic tern. Nunngarussuit was dominated by guillemot, with an increased abundance from 2006 to 2007. Though a few humpback whales may overwinter in Godthåbsfjord, the majority arrives early May, and stay until September.

O.6 Research

Sixteen different research projects have been carried out in cooperation with Nuuk Ecological Research Operations, all in the marine compartment of the ecosystem. The results of the projects are presented with short abstracts in this report.

0.7 Nuuk Basic concept

The overall purpose of Nuuk Basic is to collect long-term data quantifying seasonal and inter-annual variations and long-term changes in the biological and geophysical properties of the terrestrial, freshwater and marine ecosystem compartments in relation to local, regional and global climate variability and change. The overall aim of Nuuk Basic is to establish a data platform which enables (i) a thorough description and analysis of climatic effects on the structure, function and feedback dynamics of a low arctic ecosystem, (ii) together with its exiting high arctic counterpart, Zackenberg Basic, a more complete spatial coverage of the general climate-ecosystems interactions across the Arctic, and (iii) an understanding of the interactions between human utilization of natural resources and climate effects. The successful implementation and continued operation of Nuuk Basic is secured by the internationally unique operational expertise Denmark/Greenland has gained through ten years operation of Zackenberg Basic. The chapter describes the scientific concept behind Nuuk Basic, and how Nuuk Basic will act as a Danish/Greenlandic contribution to the climate change related research in the arctic, including a follow-up on the recommendations given in the Arctic Climate Impact Assessment (ACIA).

1 Introduction

Morten Rasch

This is the first Annual Report for Nuuk Ecological Research Operations (NERO), a science based, cross-disciplinary, ecological monitoring and research programme, which observes the effect of climate change and variability on the terrestrial and marine compartments in a low arctic ecosystem in Kobbefjord (64°07' N, 51°21' W) in West Greenland near Nuuk, the Capital of Greenland. Nuuk Ecological Research Operations and its monitoring component, Nuuk Basic, are both closely affiliated with their older sister programmes at Zackenberg, i.e. Zackenberg Ecological Research Operations (ZERO) and Zackenberg Basic, which since 1995 has studied the same effects of climate change and variability but in a high arctic setting at Zackenberg (74°28' N, 20°34' W) near Daneborg in Northeast Greenland. The two monitoring programmes study the same parameters, they are operated by the same institutions, and structurally they are organised in the same way.

Already from Day 1, Nuuk Basic was, together with its sister programme at Zackenberg, among the two most extensive ecosystem monitoring programmes in the polar region (The Arctic and Antarctic). The marine part of Nuuk Basic, i.e. MarineBasic, was established in August 2005 and the terrestrial part of Nuuk Basic came along in early 2007. In the 2007 field season, efforts in the terrestrial part of the programme, i.e. ClimateBasic, GeoBasic and BioBasic, have been on establishing the monitoring sites. As consequence this report focuses on the establishment of the three terrestrial programmes (chapters 2-4) together with a reporting of the monitoring and research in the marine compartment of the ecosystem (chapters 5-7).

1.1 History

Nuuk Basic is established, as a consequence of the success of Zackenberg Research Station and its climate change effects monitoring programme, Zackenberg Basic, to extend the monitoring at Zackenberg with a low arctic component in West Greenland and thereby to allow for comparative studies across the climate gradients of the Arctic in Greenland.

As such the history of Nuuk Basic can be dated back to the early reconnaissance expedition to Zackenberg in 1992 under the leadership of Dr. Hans Meltofte, to the first marine investigations in Young Sund outside Zackenberg in 1994 carried out by a young scientist from National Environmental Research Institute, Dr. Søren Rysgaard, to the establishment led by Dr. Henning Thing from Danish Polar Centre of Zackenberg Research Station in 1995-97, and to the official opening of Zackenberg Research Station in August 1997.

However, the newer history of Nuuk Basic started in 2005 when the Danish Environmental Protection Agency decided to provide means for establishment and long-term run of a monitoring programme in the low arctic environment in addition to the equivalent Zackenberg Basic monitoring programme in Northeast Greenland. Means for establishment and run of a Marine Basic programme, led by the same Dr. Søren Rysgaard (now professor at Greenland Institute of Natural Resources), who started the marine investigations in Zackenberg, were funded already in early 2005. At the same time, the Danish Environmental Protection Agency asked a group of scientists, led by Professor Mads C. Forchhammer, at National Environmental Research institute to provide a conceptual framework for a low arctic ecosystem monitoring programme with the purpose of establishing long time series of ecosystem response to climate change and variability in a low arctic setting near Nuuk. A number of workshops were held among the original partners in the Zackenberg Basic monitoring programme during late 2005 and early 2006, and a reconnaissance in Godthåbsfjord was carried out in August 2005. Based on the results from this work, a report with recommendations was prepared, and in September 2006, at a workshop in Roskilde near Copenhagen,

the partners in Nuuk Basic decided on the structure for the programme and how to prioritise and share the different scientific components between the partner institutions. Funding was achieved in late 2006, and the Nuuk Basic programme was in practice established by 1 January 2007, when the marine component of the programme was supplemented with a terrestrial component.

1.2 Scientific framework and organisation

Nuuk Basic is an ecosystem monitoring programme under the framework of Nuuk Ecological Research Operation (NERO) which also encompasses the logistics and the research carried out in cooperation with Nuuk Basic. The Nuuk Basic monitoring programme focuses on providing long time series of data on the dynamics of a low arctic ecosystem. Focus is on climate change effects and feedbacks in both the marine and the terrestrial compartments of the ecosystem.

It is the ambition that Nuuk Basic shall comprise the same components as Zackenberg Basic and as such allow for comparative studies of ecosystem dynamics in relation to climate variability and change in respectively a high arctic and low arctic setting.

The new Nuuk Basic monitoring programme comprises systematic studies of the low arctic climate and ecosystem processes in parallel to the studies at Zackenberg. The inclusion of a low arctic programme makes it possible to study and document climate impacts and their effects in the arctic on a broader basis. The scientific concept of Nuuk Basic is in accordance with the recommendations of AMAP's Climate Change Effects Monitoring Programme and designed as a follow up on the recommendations given in Arctic Climate Impact Assessment (an extensive description of the Nuuk Basic concept is given in Chapter 8).

Nuuk Basic consists of four sub-programmes, involving several research institutions:

ClimateBasic, which studies the climate and hydrology in the study area. The sub-programme is operated by Asiaq – Greenland Survey.

GeoBasic, which studies the physical landscape processes including a number

of feedbacks to climate change in the study area. The sub-programme is operated by Department of Arctic Environment, National Environmental Research Institute, University of Aarhus in cooperation with Department of Geography and Geology at University of Copenhagen and Asiaq – Greenland Survey.

BioBasic, which studies the biological processes in the study area. The sub-programme is operated by Department of Arctic Environment, National Environmental Research Institute, University of Aarhus in cooperation with Department of Biology, University of Copenhagen.

MarineBasic, which studies the biotic and abiotic processes in the marine compartment of the study area. The sub-programme is operated by Greenland Institute of Natural Resources, Nuuk.

Logistics is maintained by Greenland Institute of Natural Resources who arranges accommodation of Nuuk Basic staff and visiting scientists in Nuuk (at Greenland Institute of Natural Resources), arranges transportation between Nuuk and the study area in Kobbefjord and maintains the local logistics in the Kobbefjord study area.

1.3 Funding

The run of Nuuk Basic is mainly funded by The Danish National Environmental Protection Agency with co-financing from the involved institutions, i.e. Greenland Institute of Natural Resources, Asiaq – Greenland Survey, National Environmental Research Institute at University of Aarhus, University of Copenhagen and the Danish Polar Centre.

Aage V. Jensen Charity Foundation has been very generous to the project by providing means for the necessary infrastructure, i.e. boats, field huts etc., and by providing generous funds to Greenland Institute of Natural Resources for, among other things, a professorship in marine ecology and the establishment of a centre for marine ecology and climate effects in Nuuk. Nuuk Basic has to a great extent benefited from this.

Besides this more concrete funding, Nuuk Basic has also benefited from synergy with a number of "externally" funded research projects. Until now this has mainly been the case for the Marine Basic programme, due to its longer history, but as is the case at Zackenberg Ecological Research Operations, it is also the intention that Nuuk Ecological Research Operations shall develop a synergy between research, monitoring and logistics to produce science of excellence.

1.4 Plans for the 2008 field season

In 2008 we will finish the establishment of the different monitoring plots, and we will continue the measurements carried out during 2007. In terms of logistics, it is the plan that a hut with laboratories, storage room and facilities for accommodation shall be erected in the terrestrial study area near the bottom of the fjord, Kobbefjord.

1.5 Further information

Information about Nuuk Basic and the study area in Kobbefjord is available on the Nuuk Basic homepage (www.nuukbasic.dk).

The scientific components of Nuuk Basic are coordinated by a secretariat at Danish Polar Centre, which also coordinates the monitoring and research at Zackenberg Research Station. For further information about Nuuk Basic, please contact:

Morten Rasch Research coordinator, PhD The Nuuk Basic secretariat Danish Polar Centre Ministry of Science, Technology and Innovation Strandgade 102 DK-1401 København K, Denmark Phone: +45 72 48 8110 E-mail: mr@fi.dk

The logistics in the Nuuk area, including access to the field sites in Kobbefjord, is taken care of by the Greenland Institute of Natural Resources. For further information, please contact:

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2 NUUK BASIC

The ClimateBasic programme

Karl Martin Iversen, Søren Højmark Rasmussen, Kisser Thorsøe

The ClimateBasic Monitoring Programme gathers and accumulates data describing the climate and the hydrology in Kobbefjord. The core of the programme is four automatic measuring stations, which ensures continually collection of data. ClimateBasic is operated by Asiaq – Greenland Survey.

2.1 Meteorological data

The meteorological monitoring programme in Kobbefjord is based on data from two identical meteorological stations. The two stations are placed next to each other and were set up in May 2007. The double station ensures the continuity of measurements and improves the overall quality of data in case one sensor falls out.

Each station is build up around a Campbell Scientific CR1000 data logger. A multiplexer of the type Campbell Scientific AM 16/32 is used to extend the number of input channels. The system is powered by two 12 V batteries that are charged by a BP Solar SX 20U solar cell. Two metal lockers containing the data logger and batteries are placed on a 10 meter mast. A wind direction and a wind speed sensor are placed on top of the mast. Two meters above ground a cross beam is mounted carrying the air temperature, relative humidity, snow depth, photosynthetic active radiation (PAR), and ratio vegetation index (RVI) sensors. A precipitation gauge with a wind screen is mounted a couple of meters from each mast. Around 10 meters south of each climate mast an additional two meter mast is located with a cross beam at two meters above ground. On the cross beam the following sensors are installed: a wind speed sensor, a UV-biometer, a net radiometer and a long and short wave net radiometer. A barometer is placed inside the metal locker. Table 2.1 gives an overview of the sensor types and specifications and figure 2.1 shows the location of the two stations.

Air temperature, relative humidity and air pressure are logged every 30 min.

Table 2.1. Sensor specifications according to sensor manufacturers.

Parameter	Sensor type	Sensor placement (metres above terrain)	Measuring range	Sensitivity (resolution)	Accuracy
Air temperature	Vaisala HMP 45D	2 m	-40 – +60 °C	0.1 °C	+/- 0.4 °C
Relative humidity	Vaisala HMP 45D	2 m	0.8-100% RH	0,10%	+/- 3%
Air pressure at station	Campbell Scientific PTB101 E	1.5 m	600-1060 hPa	0.1 hPa	+/- 4 hPa
Wind speed	Met One 034B	10 m	0.4-49 m s ⁻¹	0.1 m s ⁻¹	+/- 0.12 m s-1 (>10.1 m s-1 1.1%)
Wind speed	Theodor Friedrichs & Co. 4034.0000	2 m	0.5-60 m s ⁻¹	0.1 m s ⁻¹	+/- 0.3 m s ⁻¹
Wind direction	Met One 034B	10 m	0-360°	0.5°	+/- 4°
Short wave radiation, incoming and outgoing	CNR1	2 m	0-1000 W m ⁻²	0.6-2.7 W m ⁻²	+/- 10% for daily sums
Long wave radiation, incoming and outgoing	CNR1	2 m	-250-250 W m ⁻²	0.3-1.1 W m ⁻²	+/- 10% for daily sums
UV-B	Solar Light & Co. 501A	2 m	0-583 mW m ⁻²	< 0.583 mW m ⁻²	+/- 5% for daily total
Net radiation	NR Lite	2 m	+/- 2000 W m ⁻²	0.7 W m ⁻²	+/- 10%
PAR	Kipp & Zonen PAR Lite	2 m	0-3700 µmol s ⁻¹ m ⁻²	1.2-1.8 µmol s ⁻¹ m ⁻²	+/- 10%
Relative vegetation index	Skye Instruments SKR110	2 m	<500 µmol m ⁻² s ⁻¹	100 µmol m ⁻² s ⁻¹	+/- 3-5%
Precipitation	Ott Pluvio	-	0-1000 mm	0.05 mm h ⁻¹	
Snow depth	Campbell Scientific SR 50	1.85/2.16 m	0.5-10 m	0.1 mm	+/- 1 cm or 0.4%



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

Table 2.2. Monthly mean values of climate parameters. Time series are not complete for all month. * Metres above ground. Wind speed and wind direction are logged every 10 min. All radiation parameters are logged each 5 min as average values over the period. The precipitation intensity is monitored by saving a record per 1 mm of precipitation and the accumulated precipitation is recorded every 60 min. The snow depth is measured every third hour.

When the stations were set up on 14 May 2007 interfaces connecting the data logger with the radiation parameters had not arrived. These interfaces were set up on 22 October. This means that no radiation parameters have been measured before 22 October. Since the station was set up all other parameters has been recorded 79% of the time; see the data coverage column in table 2.1.

Meteorological data 2007

This section reviews some of the data recorded in the period from 14 May to 22 October 2007. The only months with full data coverage is August and September. The mean air temperatures for August and September are 9.8°C and 3.2°C respectively, table 2.2. The relative humidity is generally higher and more stable during August than in the beginning of the fall.

Month	Air Temperature	Relative Humidity	Air Pressure	Wind Speed, 2 m*	Wind Speed, 7 m*	Wind Direction	Data Complete
	°C	%	hPa	m s⁻¹	m s ⁻¹	Dominant	%
May	-0,2	66	1007	2,5	3,3	WSW	First measurement 14 May
Jun	4,1	75	1012	2,5	3,2	WSW	38
Jul	9,1	69	1004	2,5	3,3	WSW	48
Aug	9,8	78	1005	2,2	3,1	WSW	100
Sep	3,2	68	1002	2,9	4	NE	100
Oct	1,9	58	998	2,7	3,6	NE	Last collected data 22 October

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In September the dominant wind direction shifts from WSW to NE and periods with strong winds occur more often than in August, figure 2.2. These directions are parallel to Qasinnguaq valley and this supports that the local topography is an important factor in the local wind pattern. One snow event was recorded in late May just after the meteorological stations

were established, figure 2.3. Precipitation

Figure 2.3. Variation of selected climate parameters from mid July to late October. From above: Air temperature, relative humidity, air pressure, precipitation, wind speed and wind direction. Wind speed is measured 10 metres above ground while the remaining are measured two metres above ground. All values are instantaneous.



Figure 2.2. Meteorological stations in Kobbefjord. Photo Bent Olsen.



Figure 2.4. Snow events in late May. Graph of snow depth, precipitation and air temperature. started on 18 May as rain but on 19 May the air temperature dropped below zero and snow started to accumulate (the precipitation data presented here are not corrected for the catch efficiency of the precipitation gauge). In the following period the air temperature rose, and this resulted in a thinning of the snow cover. On 25 May three cm snow remained and during the following days all snow melted away. The rest of the summer all precipitation fell as rain.

2.2 River water discharge

Hydrometric Stations

Hydrological measurements are carried out in four rivers in Kobbefjord area. Two hydrometric stations and two diver stations have been established. The drainage basins of the four rivers cover a total of 58 km² corresponding to 50% of the 115 km² catchment area to Kobbefjord.

The hydrometric station, H1, is located at a lake in the bottom of Kobbefjord, and the hydrometric station, H2, is located at Qasinnguag by a lake northeast of the hydrometric station H1; figure 2.1. The drainage basin of H2 is a sub-basin of H1. The drainage basin of H1 covers 31 km² of which the drainage basin of H2 covers 7 km². These stations are mounted with a Campbell Scientific CR1000 data logger, two Drück PTX1730 water level sensors and two Campbell Scientific 107 water temperature sensors. The station H1 is also equipped with one Campbell Scientific 107 air temperature sensor whereas the H2 station is equipped with a Vaisala HMP 45D temperature and humidity probe. Data from the sensors in the water is recorded every 60 minutes, whereas the air temperature and relative humidity is recorded every 30 minutes. The hydrometric stations H1 and H2 were set up in May 2007, but the hydrometric monitoring at H1 started running in June 2006 with



Figure 2.5. Water level – discharge relation curve (Q/h-relation) at the hydrometric station H1. divers and barodivers from Van Essen Instruments.

The diver station, H3, is located in a small rivulet on the northern side of Kobbefjord at Oriartorfik. The drainage basin of H3 is 10 km². The diver station, H4, is located at Teqqinngallip Kuaa on the south side of the fjord; see figure 2.1 for both locations. The drainage basin of H4 covers 17 km². Both H3 and H4 consist of two divers and a barodiver from Van Essen Instruments. The divers are placed in the rivulets in early spring and are collected late fall before the river freezes. The divers at H3 and H4 are logging every 15 minutes.

Q/h-relation

Manual discharge measurements have been carried out at each station. The purpose is to establish a stage-discharge relation (Q/h-relation). It is generally recommended to base a Q/h-relation on a minimum of 12-15 discharge measurements covering the water levels normally observed at the station (ISO 1100-2, 1998).

For H2, H3 and H4 a Q/h-relations has not been established yet. Therefore data from these stations are not presented.

At H1 nine discharge measurements have been carried out. The measurements span over the lower half of the measured water levels corresponding to discharges ranging from 0.07 to $3.15 \text{ m}^3 \text{ s}^{-1}$. The total measured span in the water level during 2006 and 2007 is 0.59 m. A preliminary Q/h-relation valid for ice free conditions has been established based on these measurements. The preliminary Q/h-relation will be refined when additional measurements have been carried out.

Two of the discharge measurements at H1 were carried out on the same day with

two different instruments. As this is not two independent measurements only one of them is used for establishing the Q/h-relation. Two other measurements were carried out when the lake was covered with ice. One of these measurements is not used for the Q/h-relation because it was affected by ice in the outlet and therefore not representative for ice free conditions. The preliminary Q/hrelation for H1 is shown in figure 2.4.

River water discharge at H1

The discharge, Q, at H1 is calculated from the measured water level by use of the Q/h-relation in figure 2.4. In 2006 the water level has been recorded from 20 June to 22 October. The total calculated discharge over this period was 21 million m^3 , figure 2.5.

In 2007 measurements of water level started 8 March and data were collected at 26 September. During this period 35 million m³ of water passed the gauging station, figure 2.6. The peak discharge in 2007 was recorded on 9 June during spring melt. From July and the rest of the measuring period the discharge was characterised by a number of smaller peaks caused by rain events. The accumulated discharge of 35 million m³ corresponds to a runoff of 1141 mm over the entire catchment of H1. 20% of the accumulated discharge is calculated using extrapolation from the Q/h-relation.

Comparison of discharge with precipitation has been made in the period 17 July 2007 to 26 September 2007. The accumulated runoff in this period is estimated to 579 mm. In the same period the meteorological stations C1 and C2 collected 348 mm of precipitation. The difference between the runoff and the precipitation is caused by many uncertainties in the understanding of the hydrology in

Figure 2.6. Discharges at the hydrometric station H1 2006.





Figure 2.7. Discharges at the hydrometric station H1 2007. Kobbefjord. The lacks of discharge measurements at high water levels induces extrapolation uncertainties when using the Q/h-relation at water levels that exceed the discharge measurement interval, the precipitation record is not yet corrected for wind effects and therefore underestimates precipitation and the contribution of melt water from the glacier in the area is not yet investigated. One of the aims of the programme is to understand the hydrological processes in the low arctic area around Kobbefjord and the above mentioned factors will, among others, be investigated in the following years.

3 NUUK BASIC

The GeoBasic programme

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GeoBasic provides long term data of climatic, hydrological and physical landscape variables describing the environment at Kobbefjord close to Nuuk. GeoBasic is operated by the Department for Arctic Environment at National Environmental Research Institute, University of Aarhus in collaboration with Institute of Geography and Geology, University of Copenhagen. GeoBasic was in 2007 funded by the Danish Environmental Protection Agency as part of the environmental support programme Dancea – Danish Cooperation for Environment in the Arctic. A part-time position is placed in Nuuk at Asiaq – Greenland Survey.



Figure 3.1. Location of GeoBasic stations and plots: K1-K5= Cameras for snow distribution monitoring. Triangles indicate direction and width of image (field of view) for each camera. Stars: Automated soil temperature and moisture monitoring. *CO*₂= *Eddy* covariance tower for carbon dioxide flux monitoring. $CH_4=$ Automated chambers for methane flux monitoring. NDVI= Cameras for vegetation indices monitoring. MikMet= Automated micrometeorological stations. Brackets indicate that installations will not be made before the 2008 field season.

StationID	Variable	Methodology	Subprogramme	UTM-X	UTM-Y	Elevation (m a.s.l.)
K1 300	Snow distribution	Camera	Snow and ice	481391	7110902	299
K2 300	Snow distribution	Camera	Snow and ice	481414	7110848	314
K3 500	Snow distribution	Camera	Snow and ice	481884	7110731	554
K4 500	Snow distribution	Camera	Snow and ice	481921	7110740	515
K5 1000	Snow distribution, glacial extent	Camera	Snow and ice	To be installed in 2008		1000 ¹
M 500	Micrometeorology	Automatic weather station	Snow and ice	481885	7110715	554
M 1000	Micrometeorology	Automatic weather station	Snow and ice	To be installed in 2008		1000 ¹
SoilFen	Soil climate	Automatic soil station	Soil	481245	7111632	50
SoilEmpSa	Soil climate	Automatic soil station	Soil	482108	7111956	42
SoilEmp	Soil climate	Automatic soil station	Soil	To be installed in 2008		501
NDVI 300	Vegetation greenness	Camera	Vegetation	481374	7110906	297
NDVI 500	Vegetation greenness	Camera	Vegetation	481883	7110730	554
CO ₂	Carbon dioxide landscape flux	Eddy covariance tower	Carbon flux	To be installed in 2008		50 ¹
CH_4	Methane and carbon dioxid plot flux	Automatic chamber system	Carbon flux	481215	7111689	50

Table 3.1. UTM coordinates for the installed and planned GeoBasic installations. The GeoBasic programme will include monitoring of physical variables within the following four sub-programmes:

- Snow and ice
- Soils
- Vegetation
- Carbon flux

The programme will run each year from 1 May to the end of September with some year round measurements from the automated stations. In 2007, the field programme was initiated during a 3 week intensive field campaign in August where most of the equipment was installed. Therefore, this first annual report will only document the installations that were performed and show examples of the first data. The first full season will be 2008 and data from fall 2007 and 2008 will be reported in the next annual report.

Figure 3.1 shows an overview of the installed and planned equipment within the Kobbefjord drainage basin while the actual positions of the installations are given in Table 3.1.

3.1 Snow and ice

The snow and ice monitoring in the Nuuk Basic programme is carried out in cooperation between the ClimateBasic and the GeoBasic programmes. The main aim of the monitoring is to become able to estimate the snow and ice component in the hydrological budget of the drainage basin and to monitor the timing and influence of snow distribution (including depth, density, timing of melt etc.) on the ecosystem. The monitoring uses several different approaches to fulfil the aim of the sub-programmes:

- Snow distribution and glacial extent monitoring through the use of automated cameras
- Automated snow depth monitoring at the climate station
- End-of-winter snow depth and density transects
- Temperature and radiation measurements at several altitudes

Snow distribution

The camera monitoring uses the same setup as has been used in Zackenberg since 1997 (Meltofte & Rasch, 1998) although with updated cameras. A total of five cameras will be installed for snow and ice monitoring (table 3.1). Figure 3.2 shows an example of the images from 2 September 2007. However, only four cameras were installed in 2007 and hence, the remaining camera will be installed during the 2008 field period.

All cameras are calibrated to make an ortho rectification possible. However, we are currently working on a solution that will enable batch processing of the images to ensure more efficient and better processing. The procedure for ortho rectification that will be used is explained in Hinkler et al. (2002). We expect to be able to report data from the camera images in the next annual report.

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Figure 3.2. Snow and ice monitoring images from 2 September 2007. The position of the cameras is shown in figure 3.1 and table 3.1. The elevation and orientation of each of the cameras is shown in the upper left of the images.

Snow depth and density

Snow depth measurements are obtained continuously from the main climate masts in the central part of the valley. Further, several surveys along transects covering the valley areas and surrounding slopes will be carried out during April to obtain the end-of-winter snow depth. These measurements are carried out in cooperation between the ClimateBasic and the GeoBasic programmes and will use a 500 MHz shielded antenna georadar system from Malå Geoscience. The georadar will be pulled after a snowmobile. Further details will be reported in the next annual report with results from the late winter 2008 campaign.



Figure 3.3. The micrometeorological station on Qaqarssuaq 28 November 2007. Photo Karl Martin Iversen. Finally, snow depth is also measured continuously by ClimateBasic at the climate station using a sonic range sensor.

Micrometeorology

A simple automatic weather stations for micrometeorological measurements of air temperature, humidity, incoming shortwave radiation and surface temperature has been installed at 554 m a.s.l. on Qagarssuag in the middle, south part of the drainage basin (Figure 3.3). A similar station is planned for setup in approximately 1000 m a.s.l. in the northern part of the drainage basin (Figure 3.1). Data from these stations will primarily be used for describing the altitudinal changes (e.g. inversion layers and clouds). Figure 3.4 show data from the M 500 station from the installation in late August and until the end of November 2007. First freeze occurred in the beginning of august followed by a month with varying temperatures above and below freezing. More consistent freeze settled in, in the middle of October, although there was a few occasion with temperatures close to or above 0° C before that. The prolonged periods with 100% relative humidity are due to low cloud cover that frequently occurs at altitudes below 500 m. A comparison with air temperature from the

SoilFen station (Figure 3.2) shows that inversions (rising temperature with altitude) occurred 12% of the time from September to October. The strongest inversion occurred on 9 October with a lapse rate of $+1.84^{\circ}$ C/100 m.

3.2 Soil

The soil sub-programme will monitor the annual and seasonal variations in nutrient content as well as the physical characteristics of the soil. Three installations are planned of which two was partly installed in 2007. The currently installed stations include a fen site and a heath site with mixed heath vegetation. Each station consists of an automatic logger station measuring soil moisture and soil temperature at 3-4 depths depending on the thickness of the soil profile. Air temperature and relative humidity at 2 m above terrain, soil surface temperature and soil heat flux is also included on the stations. Figure 3.5 shows the SoilFen station (logger box will be raised above the surface during the 2008 season to avoid flooding during the melt season) while figure 3.6 shows a photo taken during the installation of the soil sensors at the SoilEmpSa (Empetrum-Salix dominated) site. The soil profile is relatively shallow in







Figure 3.5. Automatic soil station at the SoilFen site. Air temperature and relative humidity is placed 2 m above the ground. The station is powered by the solar panel on the mast. The box includes a Campbell Scientific C1000 logger and battery. Photo Mikkel P. Tamstorf.

Kobbefjord (5-40 cm deep profile) outside the fen areas. On the SoilEmpSa site the ground water was standing only 15 cm below the surface during the august field campaign. A data example from the SoilEmpSa station is shown in figure 3.7. There is a long period in September and October with temperatures close to 0° C followed by a more consistent freeze of the upper soil layers in late October.



Figure 3.6. Each automatic soil station includes soil thermistors (sensors to the left), soil moisture probes (in the middle) and soil heat flux plates (to the right). Above ground the sensor cables are in metal tubes to protect them against foxes. Photo Karl Martin Iversen.



Figure 3.7. Data from the SoilEmpSa station from the installation in late August until the beginning of November 2007. In addition to the automatic soil stations a soil water sampling site will be installed at each soil plot location in 2008. These will include soil water samplers (suction cup lysimeters) from Prenart. The suction sampler to be used in GeoBasic Nuuk is "Prenart Super Quartz" made of porous PTFE (Teflon) and quartz. They can be applied for soil water sampling in all soil types and are most applicable for investigations of soil nutrient status. The samplers will be installed during the 2008 season and used from the beginning of the 2009 field season.

3.3 Vegetation

Vegetation in the Kobbefjord area is monitored both by the BioBasic and the GeoBasic programmes. While BioBasic monitors individual plants and plant phenology using plot scale and transects the GeoBasic programme monitors the phenology of the vegetation communities using satellite imagery and automatic cameras.

Satellite imagery

The entire Kobbefjord drainage basin is covered by satellite images once a year – around 1 August. The type of satellite images used for the coverage varies but is optical data with spectral bands around the red and near infrared wavelengths. Several satellites provide this kind of data at high resolution, e.g. SPOT (15 m pixels), ASTER (15 m pixels), Ikonos (4 m pixels), Quick Bird (4 m pixels), and Formosat (8 m pixels).

All images used will be atmospherically corrected to ensure that values can be compared from year to year. Part of this process includes a correction for topographic effects from the surrounding mountains. However, the digital elevation model that is necessary for the processing is currently under development and results from the satellite images in 2007 will therefore not be reported before 2008. A non-corrected normalised difference vegetation index (NDVI) view of the valley with the Ikonos images from 10 July 2007 is shown in figure 3.8. The NDVI image clearly shows the difference



Figure 3.8. Greyscale NDVI image of the Kobbefjord drainage basin on 10 July 2007. The image is acquired by the Ikonos satellite. Dark shades are areas with no or little vegetation and lighter areas indicate more dense and sumptuous vegetation.

in vegetation abundance within the valleys. The most luxurious (sumptuous) and lush vegetation is found at lower elevations and on the lower slopes of the valley sides. Especially willow copse, consisting mainly of Salix glauca, is found on the lower slopes while the valley floor is covered mostly by dwarf shrub heath types like Empetrum nigrum and Betula nana and wet fens with Carex rariflora and Eriophorum angustifolium. The more dry areas is characterized by vegetation types like steppe and abrasion plateaus are less dominating although present especially on south facing slopes and hill tops.

Camera imagery

One problem for satellite imagery cover of the Nuuk region is the frequent cloud cover. Only few images covering the region under clear sky conditions are available. Therefore, the landscape vegetation monitoring is supplemented by two NDVI cameras installed at 297 and 554 m a.s.l. respectively (Figure 3.1 and 3.9). These cameras will take daily pictures of most of the valley enabling an analysis of the vegetation greenness phenology in the Kobbefjord drainage basin. Currently, a new set of cameras are tested and will be installed permanently during the 2008 season.

3.4 Carbon flux

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

- Automatic chambers for methane (CH₄) and carbon dioxide (CO₂) plot measurements
- Eddy covariance for CO₂/H₂O landscape measurements

Figure 3.9. NDVI camera from TetraCam Inc. placed at 300 m above sea level. This camera monitors the greenness of the drainage basin that is close to the fjord. The wet fen area is seen along the meandering river on the valley floor. Photo Karl Martin Iversen.



Figure 3.10. Photo from the wet fen showing the automated chambers in the front, and in the background the position of the eddy covariance mast (right) and the SoilFen soil station (left). Photo Mikkel Tamstorf.

Carbon flux chamber monitoring

Six automatic chambers for methane plot monitoring were installed in August 2007 (Figure. 3.10). The system use a DLT-100 methane analyzer (LGR) and an EGM-4 carbon dioxide analyzer (PP Systems, UK) controlled by an internal computer running Linux. The flux measurements are based on the chamber technique: a box of known volume isolates a known area of the surface and can be opened or closed (Figure 3.11). When open, the gas mixture inside the box is equal to the atmospheric; when closed the concentrations of some gases can increase due to emission, for others it can decrease due to consumption.





As those processes can occur concurrently, the method is able to register only a net flux.

CO₂ and H₂O eddy covariance monitoring

An eddy covariance tower equipped with a closed path Licor 7000 analyzer for CO_2 and H_2O (LI-COR, Nebraska, USA) and a 3D sonic anemometer, Solent R3-50 (Gill Instruments, Lymington, United Kingdom) placed 2 m above the surface will be installed in the wet fen area close to the automatic chambers in 2008. The eddy covariance technique is one of the commonly used micro-meteorological methods for providing the net ecosystem exchange of CO_2 and hence, yields information on the total flux, i.e. from both soil and vegetation, to or from the ecosystem.

Power to the chamber and eddy systems are delivered by a large battery system charged by solar panels in combination with a generator. The power system was installed in august 2007 and the eddy covariance system will be installed in June 2008 when the snow has melted. No data are therefore reported here. Figure 3.11. Photo showing one of the automatic chambers for the methane plot measurements. The lid is closed and opened by the small engine on each chamber. The fan inside the chamber ensures mixing of the air when the lid is closed while the air for analysis is sucked through the tubes to the analyser. Photo Mikkel P. Tamstorf.

4 NUUK BASIC

The BioBasic Programme

Josephine Nymand, Peter Aastrup, Torben L. Lauridsen, Paul Henning Krogh, Malene H. Petersen, Lotte Illeris and Helge Ro-Poulsen

This is the first report from the BioBasic programme at Nuuk. The programme aims at providing long-term data on biotic variables from the Kobbefjord area (Figure 4.1). The programme was initiated in 2007 by the National Environmental Research Institute, University of Aarhus, in cooperation with the Greenland Institute of Natural Resources. BioBasic is funded by the Danish Energy Agency as part of the environmental support programme DANCEA - Danish Cooperation for Environment in the Arctic. The authors are solely responsible for all results and conclusions presented in this report, which do not necessarily reflect the position of the Danish Energy Agency.

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



Methods and sampling procedures are briefly described in each section. For detailed methodology consult the Nuuk BioBasic Manual (available online, ultimo 2008).

4.1 Vegetation

Reproductive phenology

In Kobbefjord, monitoring plots for three different plant species (*Silene acaulis, Salix glauca* and *Eriophorum angustifolium*) were established 13-20 August 2007. Further, we will establish monitoring plots for *Loiseleuria procumbens* in June 2008. For each species four phenology observation plots

0 0,45 0,9 Kilometers

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0,125 0,25 Kilometers

were set up and these are intended to cover the ecological amplitude of the species with respect to snow cover, soil moisture

and altitude (Figure 4.2). Each plot is marked with iron pegs at each corner. No measurements were made in 2007.



Figure 4.2. Map showing the positions of the reproductive phenology plots that will be monitored in the Kobbefjord area. The species monitored are shown by the abbreviations: Sil – Silene acaulis, Loi –Loiseleuria procumbens, Sal – Salix glauca, Eri – Eriophorum angustifolium.

Figure 4.3. ITEX chamber with a metal frame in the Kobbefjord study area. The metal frame forms the basis for the chamber in which the CO2 concentration is measured. Photo Lotte Illeris.



Figure 4.4. Vegetation plot with shading provided by hessian cover (left) and a plot in which the temperature is increased by using an Itex Plexiglas hexagon (right). Photo Lotte Illeris. Vegetation greening in the study plots will be followed by use of a handheld Crop Circle TM ACS-21 0 Plant Canopy Reflectance Sensor which calculates the greening index (NDVI).

Summertime carbon budget

Monitoring of CO₂ flux between the soil/ vegetation cover and the atmosphere under "natural" and "manipulated" conditions was established 13-22 August



Figure 4.5. UV-B study plots being established on dwarf shrub heath on 22 August 2007. Photo Lotte Illeris.



Figure 4.6. Map of the Kobbefjord study area showing the vegetation transect lines (NERO lines). The main transect appears as two transects on the figure, as it has a gap to the north-east because of steep terrain. The short line near the coast represents the second vegetation transect (salt marsh). The black dot shows the position of a third very short vegetation transect covering a specific vegetation type dominated by Deschampsia flexuosa and Juncus trifidus (see figure 4.7)

by setting up six replicates, each with five different treatments: Control, increased temperature (ITEX Plexiglas hexagons), shading (hessian tents), prolonged growing season (removal of snow in spring) and shortened growing season (addition of snow in spring) in a mesic dwarf shrub heath dominated by Empetrum nigrum with Salix glauca as a sub-dominant species. CO2 flux will be measured weekly together with soil moisture and phenology of Salix glauca during the summer season. Soil temperature is measured continuously in the plots. C0₂ flux measurements will be carried out by the closed chamber technique in which each frame measures 31 cm x 31 cm (Figure 4.3). Figure 4.4 shows a vegetation plot with shading (left) and a plot in which the temperature is increased by use of an ITEX Plexiglas hexagon (right). No measurements were made in 2007.

UV-B exclusion

Monitoring of the effect of decreasing UV-B radiation on plants was established 13-22 August by setting up five replicates each with three different treatments: Control, UV-B filter (Mylar film, with exclusion of UV-B) and filter control (Teflon film, without exclusion of UV-B) in a mesic dwarf shrub heath dominated by Empetrum nigrum and with Betula nana and Vaccinium uliginosum as sub-dominant species. Each treatment plot measures 60 cm x 60 cm; they are marked with white plastic tubes at each corner and covered with a frame with the appropriate filter placed approximately 10 cm above the vegetation. Measurements of chlorophyll fluorescence as a measure of plant stress will be carried out on Betula nana and Vaccinium uliginosum once a week every year from week 29 to 31. No measurements were made in 2007. Figure 4.5 shows the study site.



Figure 4.7. The short vegetation transect covering a vegetation type dominated by Deschampsia flexuosa and Juncus trifidus. Photo Lotte Illeris.

The NERO lines

Three permanent vegetation transects (NERO lines) were established in July 2007 (Figure 4.6). The three lines together represent the vegetation zones from the shore-line to altitudes, where vegetation cover is extremely sparse or non-existent. The concept is the same as used on the ZERO line at Zackenberg in high arctic Northeast Greenland (Fredskild & Mogensen 1996, Bay 2001, 2006). The line consists of three segments: The main Nero line, a short line near the shore and a short line close to the main line representing a vegetation type not found on the main line. The main NERO line is approximately 3 km long, and it crosses 85 vegetation zones from 166 m a.s.l. at a north-east facing slope to 400 m a.s.l. at a south-west facing slope including zones running from sea level and 225 m up a south facing heath. The short line near the shore represents the second vegetation transect (salt marsh). The black dot shows the position of a third very short vegetation transect (Figure 4.7) covering a specific vegetation type dominated by *Deschampsia flexuosa* and *Juncus trifidus*. The borders between major vegetation zones are marked by a total of 94 numbered iron pegs.

The vegetation is classified into 7 types (dwarf shrub heath, snow bed, herb slope, fen, early snow free grassland, lake/pond vegetation and salt marsh) based on the species composition, physiognomy and species diversity in addition to water contents of the soil, expected snow cover and terrain aspects. The width of the zones varies from 2 m to 129 m. Within each zone, 10 Raunkiær circle centres were established with aluminium pegs, and vegetation analyses were carried out at each of them during 1-22 July 2007 according to the Böcher-modified Raunkiær method (Böcher 1935). The Raunkiær circle centres were established as follows: Five pegs were established on the line at the beginning of each zone and another five pegs were established on the line at the end of each zone, with intervals of two meters between them. Species and their frequencies were recorded, and it was also recorded if the species were reproductive (presence of buds, flower or fruits) within ca. 0.1 m² circle around each peg. Photos were taken of all the permanent pegs from the south-western side of the line. Reanalysing of the plots is planned to take place every five years in order to identify possible major vegetation changes.

Of the 138 species of vascular plants found in the Kobbefjord area, 88 species were recorded around the 629 pegs along the NERO lines. The Nuuk area is the best investigated locality in this floristic region of West Greenland, and according to Fredskild (1996), 155 species of vascular plants have been recorded in the area. For detailed information about the NERO lines see https://www.nuuk-basic.dk

The vegetation greenness (NDVI) along the vegetation transect will be followed monthly during the growth season by use of the Crop Circle TM ACS-210 Plant Canopy Reflectance Sensor which is also used in the reproductive phenology plots.

Vegetation mapping

Collection of ground-truth data was initiated in July 2007 in order to interpret satellite images. Fifty-two GPS positions in five different plant communities of fen, grassland, dwarf shrub heath, abrasion

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Figure 4.8. Map showing the positions of arthropod sampling plots.

0 0,125 0,25 Kilometers

plateau and herb slope were sampled. A more thorough ground truthing is scheduled for the field season 2008.

4.2 Arthropods

Four pitfall trap stations (Figure 4.8), each with eight sub-plots (yellow trap cups) were established in connection to three

different plant phenology plots (*Eriophorum, Salix glauca*, and *Silene acaulis*). Further, one plot was established in *Empetrum nigrum* heath. None of the traps were kept open during the season due to late establishment, but in connection with another study, arthropod frequency was studied/monitored once a week in five habitats (hummock mossy dwarf shrub heath, open dwarf shrub heath, mesic



Figure 4.9. Map showing the positions of microarthropod sampling plots.

Table 4.1. Mean abundances X1000 individuals per m² of the mites, at order level, and collembolans, at (preliminary) species level. Significant differences according to Tukey's test between habitats are indicated by different superscript letters: a, b, and c. Figures with the same letter are not significantly different from each other. Microarthropods are the sum of mites and collembolans. S: species richness. H' = Σ pi log₂ pi, where pi is the proportion of species in the sample to total microarthropods. E = H'/log₂ n, where n is number of species (cf. Keylock 2005).

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		Empetrum	Salix	Silene
	Microarthropods	127ª	93.2ª	248 ^b
s	Collembola	31.9ª	30.8ª	109 ^b
ulat ure:	S, species richness	10.0ª	9.9ª	8.0 ^b
fig	H', diversity index	2.07ª	2.30 ^b	1.74 ^c
<u> </u>	E, equitability	0.62ª	0.70 ^b	0.58ª
	Oribatidae	63.8ª	41.0 ^b	73.7ª
	Actinedida	28.3ª	14.8 ^b	61.8 ^c
es	Gamasida	3.2ª	6.2 ^b	0.8 ^c
Mit	Pygmephoridae	0.09 ^a	0.40ª	3.00 ^b
	Acaridida		0.07	
	Tarsonomidae			0.02
	Tetracanthella arctica ¹	3.9ª	0.0 ^b	82.5 ^c
	Mesaphorura tenuisensillata	3.3ª	7.1ª	16.3 ^b
	Isotomiella minor	2.1ª	11.4 ^b	3.0ª
	Folsomia quadrioculata	12.3ª	2.0 ^b	0.0 ^c
	lsotomidae (grey)	3.69ª	6.17ª	0.02 ^b
	Folsomia alpha	4.12ª	1.30 ^b	3.19
	Willemia scandinavica	1.40 ^a	0.47 ^b	2.51ª
ola	Micranurida pygmaea	1.04ª	0.31 ^b	1.11 ^a
dms	Isotoma notabilis	0.00 ^b	1.09 ^a	0.05 ^b
Colle	Oligaphorura ursi	0.02ª	0.71 ^b	0.00ª
0	lsotoma sp. (blue)			0.19
	Sminthurid (blue)		0.12	
	Brachystomelle parvula			0.07
	S. cf. elegans	0.02	0.02	
	Sminthuridae sp.		0.02	
	lsotomidae sp. green		0.02	
	Isotoma violacea ¹	0.024		

¹ T. arctica is well-established as an arctic species and I. violacea (present name Desoria violacea) is considered a high arctic form from Babenko (2000).

mossy dwarf shrub heath, copse and fen) with five sub-plots in each during 5 June-20 July. These samples are not fully sorted yet. The results will be presented online and in the 2nd NERO Annual Report. All collected arthropod samples will be stored at the Greenland Institute of Natural Resources.

Microarthropods

Three microarthropod sampling plots (Figure 4.9), each with two replicates of three different plant phenology plots (*Silene acaulis, Salix glauca* and *Empetrum nigrum*), were established 13-17 August 2007. Each plot measures 4 m x 4 m and each corner is marked with iron pegs. Within each plot eight sub-samples were collected on 16 August 2007.

Microarthropods were extracted from soil cores, 5.8 Ø x 5.5 cm depths, in a high gradient extractor, at the National Environmental Research Institute, Silkeborg, University of Aarhus, for one week or more (Table 4.1). The log(x+1) transformed data were analysed and figure 4.10 shows the PCA plot of the samples. Microarthropods are abundant at all three habitats, and 17 different collembolan species were recorded during the routine enumeration and identification procedure; however, some species need further investigation. In the future, microarthropods will be sampled three times during each season.

The *Silene* habitat held the most abundant microarthropod community with an average of 250,000 individuals per m². It was dominated by orbatid and actinedid mites and the collembolan *T. Tetracanthella arctica*. The euedaphic species *Mesaphorura tenuisensillata* was also found in high numbers not exceeded by any other collembolan species in the three habitats. The uneven population abundance-density structure in the *Silene* habitat resulted in the lowest species diversity and evenness. The lack of dense vegetation cover probably shapes this habitat and stimulates the euedaphic species (*Willemia*, Tullbergiinae and Actinedidae including Pygmephoridae) and species adapted to harsh environments. All habitats seem to lack epigeic species as found in temperate climates.

The three habitats are clearly discriminated by the absence/presence of species: *I. notabilis* absent from *Empetrum*, *T. arctica* absent from *Salix*, and *F. quadrioculata* absent from *Silene*. The *Salix* habitat was the most species rich with the highest diversity, Shannon's H'=2.3, and a total of 13 species.

As visualised by a principal component analysis the three habitats do not seem to be homogenous because the two replicate plots consistently forms non-overlapping clusters (Figure 4.10). A comparison of the two plots within each habitat revealed that at the single population level the plots differed significantly.

4.3 Birds

The first initiative in relation to monitor passerine birds in the Kobbefjord area was a number of field trips early in the season (end of May) when logistic conditions were difficult because of the late snow melt. Data were collected mainly on the distribution of birds, but some nests were also located, to allow for breeding phenology to be followed. The data will be compiled in a master thesis and published in 2008. Final reporting of bird observations will take place when the master thesis is finished, and it will constitute the background for the future bird monitoring programme.

Bird census

The following breeding birds were monitored during 5 June-22 July 2007: Lapland bunting *Calcarius lapponicus*, snow bunting *Plectrophenax nivalis*, common redpoll *Carduelis flammea* and northern wheatear *Oenanthe oenanthe*.

During 25 May-5 June random daytrips were performed and from 6 June to 22 July, the area was surveyed on an almost daily basis when weather and logistics permitted. Data were collected along transects as well as at fixed stations (point sampling). Data were also collected on single trips to neighbouring parts of the valley. For Lapland bunting and snow bunting most birds were observed on 6 July (84 and 29 individuals, respectively). For northern wheatear and common redpoll most birds were observed on 21 July (39 and 100 individuals, respectively); these numbers include yearlings.

In mid to late June thorough survey trips were conducted in the survey area. The area was covered by the observer passing snow free spots at a distance of less than 100 m. The surveys were performed in fine weather (windy days and days with precipitation were avoided as far as possible).

From late June to the end of July surveys were conducted within the areas I-III every third day, with special emphasis/attention on area I. On each survey trip, all bird observations were recorded in a notebook using specific abbreviations for each species and type of behaviour.

Breeding phenology of birds

Breeding performance of the same passerines was monitored between 5 June and 22 July. Nests were spotted by keeping an eye on birds lifting from nests and by investigating sites where birds exhibited intensively alarm calling or distraction display. When a nest was found it was checked for eggs or young ones and marked with a stick few meters from the nest. The nests were revisited every 2-4 days. When eggs were close to hatching, and later when the young ones were close to leaving the nest, the nest was Figure 4.10. PCA plot of the samples represented each by a symbol. Empetrum: ☆★ Salix O O, Silene ★★. Different symbols indicate different plots.



revisited every day when possible. Chicks that were only observed at a distance were 'aged' by comparing them with the state of development of chicks experienced at previous occasions. Newly fledged young ones, still accompanied by an adult, were recorded too.

Bird observations

During the summer period the following bird species were seen: great northern diver Gavia immer, mallard Anas platyrhunchos, common eider Somateria mollissima, harlequin duck Histrionicus histrionicus, longtailed duck Clangula hyemalis, red-breasted merganser Mergus serrator, white-tailed eagle Haliaeetus albicilla, rock ptarmigan Lagopus mutus, purple sandpiper Calidris maritima, red-necked phalarope Phalaropus lobatus, lesser black-backed gull Larus fuscus, Iceland gull Larus glaucoides, glaucous gull Larus hyperboreus, black guillemot Cepphus grylle, northern wheatear, raven Corvus corax, common redpoll, Lapland bunting and snow bunting.

4.4 Mammals

Throughout the season arctic fox *Alopex lagopus* was seen occasionally and most often close to the shore-line. Arctic hare *Lepus arcticus* faeces were registered at several places 350 m a.s.l., but no animals were observed. One group of harp seals (approximately 25 individuals) was observed in the fjord on 2 June 2007.

4.5 Lakes

The BioBasic standard programme includes a monitoring programme for two lakes, one with arctic char (Salvelinus alpinus) at low altitude and one presumably without arctic char at a higher altitude. The two lakes are located in the Kobbefjord catchment area in the bottom of Kobbefjord. "Badesøen" is an approximately 80 ha, 34 m deep lake and "K2" is an approximately 52 ha, 30 m deep lake. They are connected by water running from "K2" to "Badesøen". Several of the different plant communities monitored and illustrated in figure 4.2 are situated in the catchment area of "Badesøen".

Ice cover in the lakes will be monitored continuously with web-cams mounted on the two mountain peaks by GeoBasic (see section 3). Selected physical (ice cover and temperature), chemical (pH, conductivity, total and dissolved nitrogen and total and dissolved phosphorous) and biological parameters, such as phytoplankton and zooplankton, will be measured monthly during the summer from mid May to mid October, or during the ice free period. Macrophyte coverage and species composition will be measured annually in August. The monitoring programme also includes sampling of benthic invertebrates together with an investigation of the fish population and the paleo-ecology every fifth year. In addition, isotope analyses on fish tissue and their food items such as phytoplankton, zooplankton and macroinvertebrates will be conducted every fifth year in order to identify changes in the fresh water food chain.

After establishing the sampling stations and sediment traps in 2007, both lakes were sampled once on 15-17 August in order to test the equipment and to collect initial data. Results on the water chemistry and selected biological parameters are summarised in table 4.2.

In "Badesøen" the transparency is relatively high (5.4 m). In "K2", which has an inflow of silt from a glacier, water transparency is lower, i.e. 3.5 m. The average depth of "Badesøen" is 9.2 m and that of "K2" is 7.8 m. The surface water temperature in "K2" is lowest probably due to the amount of inflow of glacier runoff but also due to the higher altitude. Besides "K2" is highly exposed to the cold northerly winds. The bottom of "K2" is covered with sandy sediments and scattered boulders. The bottom of "Badesøen" is covered with pebbles and sandy sediments. In both lakes, the deepest parts are dominated by clay.

The content of total phosphorus (Table 4.2) and dissolved phosphate is the same in the two lakes, while the ammonium concentration is higher in "K2" than in "Badesøen", 106 and 22 μ g/l, respectively. There was a higher concentration of chlorophyll *a* in "Badesøen" than in "K2", however in both lakes the chlorophyll *a* concentration is very low.

In 2007, the ice did not melt until the end of June and ice started forming again by the mid October.
Zooplankton

Only few species of zooplankton were registered in the lakes. This is characteristic for the Greenland lakes. In total four taxa of zooplankton larger than 140 µm were observed: Two taxa of Cladocera (*Daphnia* and *Holopedium*) and two taxa of Copepoda (*Leptodiaptomus minutus* and *Cyclopoid copepods*). Nine taxa of rotifers were registered (Table 4.2).

The communities differ between the two lakes. In "Badesøen" *Daphnia pulex* is lacking, *Leptodiaptomus minutus* is common and the rotifers are numerous (*Concochilus*, *Keratella* and *Polyarthra*). In contrast *Daphnia pulex* is present in "K2" and *Leptodiaptomus* and rotifers are less numerous.

Fish

Based on experiences from other Greenland lakes, the zooplankton communities indicate presence of fish in "Badesøen" and absence of fish in "K2". A proper fish survey was not performed in 2007, but a single gill net was set overnight in "Badesøen". Arctic char Salvenus alpinus were abundant in the lake with a catch of 35 fish per net (2.2 fish net⁻¹ hr⁻¹) and four three-spined sticklebacks Gasterosteus aculeatus per net. This is preliminary data, but they indicate a high arctic char population compared to other low altitude lakes in this part of western Greenland (Riget et al. 2000). No nets were set in "K2".

Macrophytes

Moss vegetation and macrophytes (*Calli-triche hamulata*) are found in the more shallow parts of "Badesøen" (between approximately 1 and 5 m depths), but is very sparse in comparable parts of "K" (Table 4.2). In both lakes moss were found in the very near shore areas, and especially in "Badesøen" it was common along the entire lake shore.

Lake	"Badesøen"	"К2"
Date	Aug. 16	Aug. 17
Ice cover (%)	0	0
Secchi depth (m)	5.4	3.5
Chlorophyll a (µg l-1)	0.317	0.191
Total nitrogen-N (µg l-1)	117	94
Total phosphorus (µg l-1)	≈ 4	≈ 4
Temperature (°C)	11.5 (0m)	9.5 (0m)
	8 (5m)	9.5 (4m)
	8 (10m)	9 (8m)
	6 (15m)	9 (12m)
	5.5 (20m)	9 (16m)
	5 (25m)	8.9 (20m)
	5 (30m)	8.9 (24m)
Zooplankton	••••••	••••••••••••••••••••••••••••••
	No. liter ¹	No. liter ¹
Leptodiaptomus minutus, male	0.9	0.2
Leptodiaptomus minutus, female	0.4	0.05
Calanoide nauplier	0	0.05
Calanoide copepoditer	1.25	0.35
Daphnia pulex	0	0.1
Holopedium	0.7	0.25
Calanoidea sp. adult	0.2	0
Cycl. copepodit	0	0.9
Cycl. nauplier	0.15	0.1
Asplanchna sp.	0.99	0
Asplanchna priodonta	0	3.1
Conochilus uni/hipp	13.2	0.2
Filinia sp.	1.32	0.05
Kellicottia longispina	0.33	0
Keratella cochlearis	22.77	3.95
Keratella quadrata	1.98	1.3
Lecane sp.	0	0.05
Polyarthra spp.	7.095	2.3
Rotatorie sp.	3.3	0.6
	••••••	••••••
macrophytes	Depth limit metres	Depth limit metres
Callitriche hamulata	5	3.5

2.5

4.6 Other observations

Moss

The BioBasic personnel collected other relevant information on an opportunistic basis, while doing the primary tasks. This kind of information include: ice cover and first free water in ponds and lakes, birds encountered with numbers and sex when possible, and sightings or signs of mammals. Table 4.2. Physicalchemical conditions and selected biological parameters sampled in "Badesøen" and "K2" in August 2007.

1.1

5 NUUK BASIC

The MarineBasic Programme 2005-2006

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The arctic climate is displaying rapid changes. During the last 50 years, air temperature increases of 2-3°C have occurred throughout the Arctic (Chapmann & Walsh 2003). Models predict temperature increases of 6-8°C in Northeast Greenland following the expected retreat and reduction in sea ice cover and temperature increases of up to 2-5°C in West Greenland by the end of the 21st century (Rysgaard et al. 2003, Kattsov et al. 2005). In addition, precipitation in Greenland, particularly winter precipitation, has been predicted to increase 20-30% (minus evaporation) during the next 100 years (Kattsov et al. 2005). South and West Greenland will observe even higher precipitation changes compared with the rest of Greenland (Kiilsholm et al. 2003; Rysgaard et al. 2003).

The thickness and extent of arctic sea ice have decreased over the last 30 years and in recent years, the reduction rate has accelerated (Cavalieri et al. 2003). Even though the effects of increased temperature in the Arctic seem to occur fast, the accumulation and thinning processes of the Greenland Ice Sheet are highly variable in time and space and influenced by more than just atmospheric warming (Rignot & Thomas 2002). However, recent time series of maximum summer melt of the Greenland Ice Sheet indicate a decadal trend of increased melt, in particular in West Greenland. High melt rates such as those recently reported from the glaciers in the inner parts of Godthåbsfjord (Rignot & Kanagaratnam 2006) suggest potential for not only increased sea level by 2100 (Walsh et al. 2005, Velicogna & Wahr 2006) but, also increased input of fresh water to the marine ecosystems in West Greenland. The increased melt water flux from the Greenland Ice Sheet and surrounding land to the inner parts of the fjords will greatly

affect the circulation in the fjords and the exchange with offshore regions. Increased melt water runoff will significantly enhance estuarine circulation and nutrient input to fjords and is expected to increase biological productivity.

While reduced sea ice will markedly affect light availability in the water column in high arctic areas and, thus, stimulate primary production (Rysgaard et al. 2001, Rysgaard & Glud 2007), the effect of increased melt water runoff from land will most likely be more important in controlling productivity in West Greenland waters. However, both changes in sea ice conditions and freshwater runoff will affect the energy flow through the entire food web and most likely lead to changes in ecosystem structure and function in the future.

Today, the West Greenland marine ecosystem is very productive and sustains fisheries contributing 95% of Greenland's total export value. The Greenland marine ecosystem also sustains seals and whales, which feed in the area during summer, and seabirds by the million from the entire North Atlantic find a critical winter habitat resource in the ice-free area. Human use of the West Greenland marine ecosystem presents a complex mosaic of small- and large-scale commercial fishing, as well as subsistence and recreational fishing and hunting.

The monitoring programme MarineBasic Nuuk was initiated in August 2005. In this first report, data from 2005-6 and 2007 will be reported in two separate chapters. During 2005-6, additional investigations were made to shape the marine monitoring programme. These research projects are reported later in this issue. In parallel to the monitoring and research activities, we build up laboratory facilities and logistic routines to be able to perform all



sampling and analysis routines at the Greenland Institute of Natural Resources in Nuuk. The aim of the marine monitoring programme is to obtain comprehensive data sets in order to describe the dynamics of the marine system in Godthåbsfjord, Nuuk, West Greenland (Figure 5.1). A

main sampling station was chosen in the outer part of the fjord because it represents the interaction between the fjord and the marine system at Fylla Banke. MarineBasic Nuuk monitors physical, chemical and biological parameters at the main sampling station at monthly intervals throughFigure 5.1. Map of Godthåbsfjord. x indicates the hydrographical cross and length transects, respectively. Enlarged X indicates the main station. + indicates the sediment station in Kobbefjord. Numbers indicate seabird monitoring sites (1: Qeqertannguit, 2: Nunn-







April 2006





June 2006







February 2006



March 2006

August 2006 September 2006

garussuit).

Figure 5.2. Satellite images (AQUA AMS-R) showing sea ice extent in Baffin Bay.

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February 2006



March 2006



April 2006



July 2006



October 2006



May 2006



August 2006



November 2006

out the year. Studies at the main sampling station are supplemented with two sections – a cross section from Nuuk to Akia and a longitudinal section extending



June 2006



September 2006

Figure 5.3. Pictures of Godthåbsfjord taken by the Aqua-Modis satellite (250 m resolution). No picture was taken in December 2005 due to lack of light in the darkest season.

from the outer part of Fylla Banke to the inner parts of Godthåbsfjord. Furthermore, measurements of sediment, benthic fauna and flora are conducted in Kobbefjord (a fjord branch), satellite images are obtained and seabirds and marine mammals are monitored in Godthåbsfjord.

MarineBasic Nuuk will provide long-term data

- necessary for modelling the coupling between physical oceanography and biological production and consumption
- for use in modelling the regulation of pelagic-benthic coupling (vertical flux)
- to quantify and improve understanding of the lateral coupling (land/fjord/shelf)
- to quantify the effect of changing freshwater input, sea ice cover and hydrographical conditions on biological production and consumption
- to improve current understanding of the effects of climate on species composition and adaptation in the arctic marine environment

5.1 Sea ice

The interaction between the hydrography and sea ice cover of Baffin Bay is a complex feedback system and both parameters influence the climatic conditions in the coastal regions of West Greenland and the adjacent fjord systems. Two times a day the AQUA AMSR-E satellite takes a 3-6-km resolution microwave-radiometer image of the ice cover in Baffin Bay. These images (Figure 5.2) show a seasonal cycle of ice cover with maximum extent in February and minimum extent in August. The ice cover tends to spread towards the south along with the cold southwardflowing Baffin Current during autumn and reaches the West Greenland Disko area in February. During spring, the warm northward West Greenland Current tends to force the ice back towards Baffin Island, forming polynyas along the Northwest Greenland coast, particularly around the Thule/Qaanaaq area.

In the Godthåbsfjord area satellite images were taken once every day by the AQUA-MODIS satellite (250 m resolution) (Figure 5.3). The images were supplemented by a digital camera system placed at the Greenland Institute of Natural Resources and taking photographs of the fjord every 3 hours (Figure 5.4).

The satellite images show that the Shelf and the outer parts of Godthåbsfjord are free of sea ice even during the coldest months. Sea ice is only present in the inner part of the fjord close to the Greenland Ice Sheet and in small fjord branches such as Kobbefjord. However, glacier ice is

Figure 5.4. Examples of photographs taken every third hour by digital camera at the Greenland Institute of Natural Resources. a: 4 April 2006 b: 2 September 2006.



April 2006



September 2006

Figure 5.5. Hydrographical measurements along the cross section, from Nuuk to Akia, in October 2006. a: salinity, b: temperature (°C), c: fluorescence.



released and transported out of the fjord during most of the year except during winter (December-February). Furthermore, the export of icebergs occurs in restricted periods of days to 1-2 weeks. Analyses of the spatial and temporal export have been initiated and will be presented elsewhere. Finally, the images also shows the outflow of silt-containing melt water from the Greenland Ice Sheet, which occurs even in winter. Moreover, the pictures show how the Coriolis Effect forces the freshwater plume towards the north side of the fjord as its flows towards the open sea.

5.2 Length sections and cross sections

A hydrographical study along a cross section from Nuuk to Akia (distance 5.5 km, Figure 5.1) was performed in late October 2005. The temperature (Figure 5.5) varied from 1.6 °C in the surface water to 3.2 °C near the bottom, with maximum temperatures occurring in the bottom water at the Akia side of the fjord. Salinity and fluorescence varied little along the cross section. A minimum salinity of 28 was found in the surface water while the bottom water was 33, and fluorescence – a proxy for algal biomass – displayed maximum and minimum values, respectively, of 0.7 in the surface water and 0.05 near the bottom.

The longitudinal section (distance 200 km, Figure 5.1, note that the innermost station was not accessible in 2006 due to ice) covers an area characterized by great variations in bathymetry, influence from intensive commercial fisheries, inflow of fresh water, tides, local and large-scale currents etc. Therefore, the measurements provide a good basis for comparison of

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differences in physical, chemical and biological factors. In 2006, we brought together an international team of marine scientists to initiate research activities in combination with the monitoring work at the excellent laboratory and working facilities at the Greenland Institute of Natural Resources. Results from this study are reported later in this issue.

The hydrographical measurements along the longitudinal section showed a large climate gradient (Figure 5.6). The temperature varied from a maximum of 4.57 °C at 500 m depth offshore from Fylla Banke to a minimum of -0.57 °C at 13 m water depth at Station GF13 close to the Greenland Ice Sheet (Figure 5.6a). The warm water outside Fylla Banke represents the warm, saline and dense Atlantic/ Irminger water flowing northward along the West Greenland shelf. This water mass seems to follow the bathymetry, as a side branch of this water mass can be seen on the inside of the bank close to the fjord inlet. At the inlet of the fjord, vertical mixing takes place, probably due to strong tidal forces, as all water transports in and out of the fjord system must pass the narrow inlet. More details about this transport are provided in the project Exchange, financially supported by the Danish Environmental Protection Agency. In the inner and central parts of the fjord, a freshwater plume occurs in the upper parts of the water column. Despite the fact that this water originates from melting ice and



Figure 5.6. Hydrographical measurements along the longitudinal section, from the bottom of Godthåbsfjord across Fylla Banke, in May 2006. X indicates the main sampling station. a: salinity, b: temperature (°C), c: fluorescence. Figure 5.7. Surface pCO₂ values along the length transect, in May 2006. X marks the main station.



snow, the freshwater is warmer than the seawater below due to atmospheric heating of the strongly stratified freshwater layer (Figure 5.6a). In the deeper parts of the inner fjord, saline and warm water is found, originating from exchange with deeper waters outside the fjord. This warm water (2°C) represents a strong heat capacity that may actively melt the tidal glacier, and at present, it is not known how far the fjord system penetrates inland below the glacier. Fluorescence was highest in the surface layer, and showed maxima at Fylla Banke and at the inner part of the fjord. At the mouth of the fjord, very low levels were observed, probably due to high vertical mixing distributing the algal cells throughout the water column.

Surface pCO_2 varied along the length transect, with the highest value encountered on the Bank, and a gradual decline towards the bottom of the fjord (Figure 5.7). At all times the values were well below atmospheric CO_2 .

5.3 Pelagic sampling

From October 2005 to November 2006, the main sampling station (64°07N 51°53W) was visited at approximately monthly intervals using the vessels Aage V Jensen Nuuk and Adolf Jensen. The sampling dates were 5 October 2005, 1 November 2005, 6 December 2005, 16 January 2006, 8 February 2006, 2 March 2006, 4 April 2006, 4 May 2006, 15 May 2006, 15 June 2006, 24 July 2006, 29 August 2006, 27 September 2006, 25 October 2006 and 29 November. In the following, the field campaigns will be referred to as October, November, December, etc. Note that there were two sampling campaigns in May 2006.

Casts with a Sea-Bird SBE19+ to approximately 300 m provided detailed information on temperature, salinity, density, fluorescence, turbidity and light (PAR). Water samples were obtained at 11 water depths (1, 5, 10, 15, 20, 30, 50, 100, 150, 250 and 320 m) and analyzed for nutrients (phosphate, nitrate/nitrite and silicate), dissolved inorganic carbon, total alkalinity and chlorophyll *a*. Primary production was determined in situ at 5, 10, 20, 30 and 40 m. Vertical hauls were made with 20-µm and 45-µm plankton nets for determination of abundance and composition of phytoplankton and zooplankton, respectively. The vertical transport of chlorophyll *a*, organic matter, and calcium carbonates out of the photic zone was determined using sedimentation traps. Macrozooplankton was sampled using a bongo net (335 and 500 µm).

Abiotic parameters

The hydrography of Godthåbsfjord varied considerably over the year, showing a highly dynamic system with respect to light, temperature and salinity (Figure 5.8). During the winter months light (PAR) conditions were low (Figure 5.8a), insufficient to allow any significant primary production. The sea surface temperature generally followed the air temperature, the highest temperature being 5.5°C in late summer (August and September) and the lowest temperature 0.1°C in February (Figure 5.8b). Furthermore, the daily, weekly and monthly variability was relatively high. For example, the mean temperature value of the upper 0-40 m varied from 2 to 4.6°C at the main sampling station from June to August. The longterm temperature trend from Fylla Banke,

as measured since 1950 by the Danish Meteorological Institute in cooperation with the Greenland Institute of Natural Resources, does not take this variability into account as measurements are only performed once every year (in the summer). During 2006, the average temperature as measured on Fylla Banke St. 4 was 3.01°C. Thus, our newly acquired detailed data will be used in combination with this long-term data series to evaluate the uncertainty in the long-term trend.

The time series reveal that the surface water mass was well mixed during winter and spring, but a pycnocline was present at approximately 50 m in October 2005 and again from July to October 2006, showing that the water column becomes stratified during summer and mixes again in autumn. The hydrographical measurements did not show a clear signal of freshwater input from land during the snowmelt in May. At present, we are not able to distinguish if snowmelt discharge from the surrounding land has an impact on the establishment of a pycnocline in early spring. During summer, however, salinity was markedly reduced in the surface layer, most likely due to a relatively larger freshwater discharge from the Greenland Ice Sheet. Furthermore, MODIS satellite images (Figure 5.3) show that silt-containing water from the Greenland Ice Sheet did enter the fjord even during



Figure 5.8. Annual variation at the main sampling station. a: irradiance (PAR), b: temperature (°C) and c: salinity.

Date	PAR
5 October 2005	0,1132
1 November 2005	0,1167
6 December 2005	0,0838
16 January 2006	0,0787
8 February 2006	0,0950
2 March 2006	0,1006
4 April 2006	0,1066
4 May 2006	0,1910
15 May 2006	0,1153
15 June 2006	0,0877
24 July 2006	-
29 August 2006	0,1330
27 September 2006	0,1020
25 October 2006	0,1082
29 November 2006	0,0778
Minimum	0,0778
Maximum	0,1910

the coldest months and that freshwater input occurs at all seasons of the year and is not restricted to the summer thaw. The water mass below 150 m depth showed a different seasonal pattern of generally mixed conditions with occasional intrusions (November and February) of warmer water of high salinity and density (Figure 5.8). The intruding water masses originate from the Irminger Current, which flows northward along the West Greenland shelf. Light attenuation coefficients varied from 0.09 to 0.19, and maximum attenuation was observed during the spring bloom in early May (Table 5.1).

Surface pCO_2 values varied throughout the year (Figure 5.9). In the winter of 2005/2006, surface pCO_2 was relatively constant around 150 µatm. During summer, the values varied more, from 150 to 250 µatm. In autumn 2006, the pCO_2 steadily increased reaching 300 µatm ultimo November. Note that all measured pCO_2 values are below the atmospheric concentration, indicating that Godthåbs-fjord is a CO₂ sink.

Nutrient concentrations (Figure 5.10) were highest in February, with concentrations of 1 µM phosphate, 11.7 µM nitrate and 6 µM silicate. The highest concentrations of all nutrients were found in deeper waters, resulting from inflow of nutrientrich warm water from the open sea. The nutrient levels became more uniform with depth in April due to vertical mixing, followed by depletion in the surface water in late April/May due to phytoplankton uptake and dilution by melt water. In spite of the low concentrations of nutrients in the surface water during summer, the concentrations below 250 m increased due to remineralisation and/or inflow of nutrient-rich water from the shelf.

Biotic parameters

The biomass of phytoplankton, expressed as µg chl l⁻¹ was low during winter, and increased in late April/early May as a spring bloom occurred (Figure 5.11a). At the beginning of the spring bloom, phytoplankton was well dispersed in the upper 150 m. However, in May the bloom had a distinct peak at a depth of approximately 20 m, with maximum concentration of 8.4 µg chl l⁻¹, probably because of nutrient limitation in the surface water. In mid-summer, the values decreased below 0.5 µg chl l⁻¹, due to nutrient limitation (see section 4) and grazing from zooplankton, and in July a smaller secondary bloom developed (maximum of 1.5 µg chl l⁻¹), which continued until autumn. Fluores-



Figure 5.9. Annual variation in surface pCO_2 at the main sampling station.





cence values were well correlated to chlorophyll *a* concentration ($R^2=0.78$, p<0.01, n=141) and followed the same pattern with low winter values and two distinct peaks in May and August (Figure 5.11b). The same seasonal pattern was found for primary production, with little activity in winter and two production peaks in April/May and in July (Figure 5.11c). However, primary production was relatively high in between the two production peaks despite low nutrient concentrations in the water column, suggesting that nutrient remineralisation and uptake by the phytoplankton are closely coupled. The estimated total production over a year was 75.1 g C m⁻² yr⁻¹, which is only half the production estimated by Smidt (1979) at the same location. However, using the minimum and maximum values presented by Smidt (1979), the calculated range is 50-160 g C m⁻² yr⁻¹, suggesting substantial variability in this area.

The composition of the phytoplankton community varied throughout the year (Figure 5.12). Diatoms, particularly *Thalassionema nitzschioides, Thalassiosira antarctica* and *Chaetoceros wighamii*, were present throughout the year, and contributed significantly (40-98%) to the community. In February and March, the silicoflagellate *Dictyocha speculum* occurred, contributing up to 34% of the community. In the productive period (April-August),

100% 90%

Figure 5.11. Annual variation in algal biomass and productivity at the main sampling station. a: chlorophyll a (µg I⁻¹), b: fluorescence, c: primary production (mg C m⁻² d⁻¹). Dotted lines represent sampling points.





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species of the prymnesiophyte genus *Phaeocystis* were observed, contributing up to 60% of the community. On one occasion (June) during the productive period, the chrysophyte *Dinobryon balticum* was present in large numbers, contributing 23% of the community. In autumn and throughout winter, diatoms dominated (>95%). Integrated over the year the most abundant species were *Chaetoceros wighamii, Phaeocystis* sp. and *Thalassiosira antarctica* (Table 5.2).

The zooplankton community was diverse, consisting of e.g. copepods, ciliates, rotatoria, foraminifera etc. The life cycle of copepods can be seen in Figure 5.13a, with maxima of copepod eggs in

Species	%
Chaetoceros wighamii	30,5
Phaeocystis sp.	45,5
Thalassiosira antarctica	53,0
Thalassionema nitzschioides	58,1
Dictyocha speculum	62,7
Pseudonitzschia cf seriata	66,2
Thalassiosira nordenskioeldii	69,1
Nitzschia frigida	71,7
Dinobrion balticum	74,0
Thalassiosira bioculata	76,1

May, nauplii in July and adult stages in August. Import of copepod eggs or nauplii is necessary, as the total amount of eggs is



Table 5.2. The ten most dominant species integrated over the year as their relative accumulated proportion of total cell count (in %). much less than the number of nauplii. The copepod community (Figure 5.13b) consisted primarily of *microsetella*, *oithona* and *onacea*, with several species of *calanus* present. The abundance of other groups (Figure 5.13c) varied throughout the year, with very low levels in winter, followed by two peaks in May (bivalvia, cirripedia and polychaeta) and July (decapoda, tintinnida, foraminifera and ascidiaceae).

Macrozooplankton in Godthåbsfjord was sampled both at the main station and along the longitudinal transect. Preliminary analyses indicate that they contain fish and crab larvae as well as other meroplankton. Thirty-nine out of a total of 69 vertical samples contained Pandalus borealis larvae in stages I (51%), II (48%) and III (1%). These results are in good agreement with results from a study on the reproductive cycle of P. borealis in West Greenland waters. This study describes the frequency variation of reproductive stages of female P. borealis and indicates that hatching occurs most frequently in late March to early April (Bergstrøm 2006). Since the larval intermoult period is assumed to be about 3 weeks at temperatures found in the larval habitat off West Greenland (Parsons et al. 1986), the predominance of stage I and II larvae in the mid-May samples agrees well with the suggested hatching period.

Figure 5.14. Vertical transport: Sedimentation of carbon (C) and chlorophyll a at 65 m water depth and C:N ratio of trapped material.



Vertical transport

Sedimentation traps at 60-65 m depth at the main station collected material sinking out of the photic zone. The material was analyzed for carbon content, chlorophyll a and C:N ratio (Figure 5.14). The sedimentation of carbon and chlorophyll *a* peaked during the phytoplankton bloom in April/ May 2006 and October 2005 and was low during the rest of the year. The C:N ratio was highest in March, indicating that a larger fraction of the trap material was of terrestrial origin. Accordingly, satellite images indicated a significant run-off of highly turbid water from land in this period, which was confirmed by measurements of high water turbidity in the surface water mass.

5.4 Sediments

Organic matter from the water column reaches the sediment where it is degraded, or mineralized through a number of processes. These processes lead directly or indirectly to the consumption of oxygen, and the rate of organic matter mineralisation in the sediment can therefore be estimated by measuring the flux of oxygen into the sediment.

Intact sediment cores were sampled during spring, summer, autumn and winter conditions in the nearby Kobbefjord at 125 m water depth. The O₂ flux was measured by core incubations measuring the total oxygen uptake (TOU) of the sediment and by O₂ microelectrode profiles measuring the diffusive oxygen uptake (DOU). Oxygen was generally depleted within 1 cm from the sediment surface, and oxygen consumption was highest in the upper 2 mm, indicating that the O₂ consumption is due mainly to fresh organic matter arriving at the sediment (Figure 5.15a). TOU and DOU varied seasonally (Figure 5.15b), the highest O₂ fluxes occur in autumn (DOU and TOU).

5.5 Benthic fauna and flora

Samples of benthic fauna from 2006 are currently being analyzed. Experience from MarineBasic Zackenberg (Northeast Greenland) shows that careful consideration is required when monitoring benthic fauna. The data from 2006 will be combined with studies in 2007 to form the basis for selection of future sites and monitoring parameters.

The annual production of macroalgae can be determined by measuring the new leaf production of Laminaria saccharina, a technique developed in Young Sund and used in the MarineBasic Zackenberg programme. Macroalgal sampling was done in the Kobbefjord at a shallow location in late October 2006. However, when the algae were brought to the laboratory, we realized that the algae were not L. saccharina but rather the very similar species Laminaria longicruris, which occurs throughout the Northwest Atlantic. The species is larger than L. saccharina with a proportionally longer stipe, and it was not possible to recognize growth patterns. The growth of macrophytes will be further investigated next year with participation of experts on this field. If Laminaria saccharina cannot be located, another monitoring parameter for macroalgae in Godthåbsfjord will be determined.

5.6 Seabirds

Two major seabird colonies in the vicinity of Nuuk are included in the MarineBasic programme. The seabird counts from MarineBasic are reported each year to the Greenland Seabird Colony Database.

Qeqertannguit (colony code: 64035) in the interior parts of Godthåbsfjord (Figure 5.1) is a low-lying island and holds the largest diversity of breeding seabirds in the Nuuk District. Especially surface feeders (gulls, kittiwake and arctic tern) are well represented at the site (Table 5.3). Counts were conducted on 7 and 8 June (the incubating period) using direct counts of Apparently Occupied Nests (AON) or territorial behaviour as a parameter of

Species	Numbers	Unit	
Black-legged Kittiwake	45	AON	
Iceland gull	118	AON	
Great black-backed gull	46	Р	
Lesser black-backed gull	10	Р	
Glaucous gull	10	Р	
Arctic tern	150-220	I.	
Arctic skua	2	Р	
Black guillemot	615	I.	
Red-throated diver	1	Р	

Table 5.3. Breeding seabirds at Qeqertannguit 2006 (P = Pairs, I = Individuals, AON = Apparently Occupied Nests).



breeding pairs. The steep north-eastern cliff side (kittiwake and Iceland gull) was counted from the sea using a boat as platform while all other counts were conducted on foot.

Other breeding birds included mallard, red-necked merganser, snow bunting, Lapland bunting and northern wheatear.

A similar (period, method) count was conducted in 2003 at Qeqertannguit (Figure 5.1), resulting in significantly higher numbers of kittiwake (125 AON) and lesser black-backed gull (28 pairs). The reason for this difference is unknown. However, a rope hanging in the kittiwake/ Iceland gull colony indicates that illegal egg collection took place in 2006. It is possible that egg harvesting early in the breeding season may have influenced the number of breeding kittiwake pairs at the site in June.

Nunngarussuit (colony code: 68010) is located ca. 40 km south of Nuuk town (Figure 5.1). The northern steep cliff wall of the small island holds the only colony of Brünnich's guillemot (deep diver after fish and large zooplankton) in Nuuk District. Counts (both direct and photo counts) of birds present on the cliff wall were conducted from the sea (boat) on 4 July. The number of Brünnich's guillemot present at the site in 2006 (Table 5.4) is in the same order of magnitude compared with similar counts (direct, only) from 2001 and 2003 when 700 and 1000 birds, respectively, were recorded on the cliffs. Fulmars were observed on the steep northern cliff for the first time in 2006. The breeding status of this species is unknown at the site.

Figure 5.15. a: Vertical concentration profiles of oxygen (black dots) and modelled consumption rates (bars) in the sediment at 125 m water depth in Kobbefjord May 2006. b: Sediment-water exchange rates of oxygen. Black bars indicate total oxygen uptake (TOU) and white bars indicate diffusive oxygen uptake (DOU) modelled from microelectrode profiles. Error bars indicate standard error of the mean (n = 3).

Species	Numbers	Unit
Brünnich's guillemot	694	
Glaucous gull	20	I.
Great black-backed gull	5	I.
Northern fulmar	23	I.

Table 5.4. Breeding seabirds at Nunngarussuit 2006 (P = Pairs, I = Individuals).

In order to address a larger number of seabirds in the annual counts it is suggested that the colony 63019 (south of Lille Narsaq) and the colony 64015 should be included in future assessment (for details see Greenland Seabird Colony Database). These "new" sites are situated close to the two existing sites in the MarineBasic programme, and including them does not represent a significantly higher workload.

5.7 Marine mammals

Observations of marine mammals were made during March to September 2006 from an observation post on "Radiofjeldet" located in the middle of Nuuk town. The observation post provides an extensive view over Godthåbsfjord. Observations were done over periods of 20 minutes, and the number of observed marine mammals was noted. For each observed humpback whale the time between each blow was noted, as was the position and angle of the whale when it dived. The position of the whales was determined using a theodolite, and the measured angles were converted to geographical coordinates by referring the angles to a fixed reference point determined by Asiaq - Greenland Survey. From

Figure 5.16. a: Percentage of surveys in which humpbacks were observed per month. N shows the total number of surveys per month. b: Percentage of observations of humpbacks during daylight. N shows the total number of surveys in the given time period. March to September, a total number of 74 20-minute surveys were performed, resulting in a total of 25 hours of observation. Twenty sightings of humpbacks were made (as single individuals or in groups of two).

No humpback whales were observed in March and April. The first whale was observed on 9 May 2006, the day before the first capelin was sold at the local fish market ("Brættet"). Subsequently, the percentage of sightings per survey increased during June and July with a maximum value of 72% in July (Figure 5.16a). It should be noted that these estimates are preliminary, as the sample size/number of surveys is not high enough to make well-founded conclusions and should thus be increased in future studies.

There was no clear pattern as to which time of the day the probability of whale sightings was highest, but again it should be noted that the sample size/number of surveys should be higher in the future (Figure 5.16b). The distribution of humpbacks whales may be influenced by tidal amplitude, because the tidal water exchange may control food availability, and this will be further investigated in 2007.

In spite of the low sample size in this first-year study of humpbacks whales in Godthåbsfjord, the study provides important information on the occurrence of humpbacks. This data together with local knowledge, data from the MarineBasic programme and data on possible prey species will provide important information for understanding the migration and life strategy of the humpbacks. Further analyses of the theodolite data will show whether the humpbacks used the study



areas for feeding or as a transit area. Most observations from "Radiofjeldet" were of humpbacks moving relatively fast through the area, suggesting that this area is a transit area for whales feeding in other areas of the fjord. This hypothesis should be tested by setting up theodolite posts in other areas of the fjord.

6 NUUK BASIC

The MarineBasic Programme 2007

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This is the report from the second year of the MarineBasic monitoring programme in Godthåbsfjord. MarineBasic aims to describe and understand a sub-arctic marine ecosystem, by establishing longterm data series of key parameters in the marine environment. The data series will further help detect and document climaterelated changes. Physical, chemical and biological parameters are measured in a main research area near Nuuk and combined with studies of the entire fjord system and Fylla Banke (Figure 6.1).

The monitoring programme consists of satellite and digital images of sea ice cover, studies of benthic fauna and flora as well as monitoring of marine mammals and colony-breeding seabirds. The pelagic programme consists of frequent sampling of physical, chemical and biological parameters throughout the year at a main station, supplemented by annual hydrographical measurements along a cross and a length section. In addition, sediment cores are obtained on several occasions for determination of oxygen profiles and measurements of flux between sediment and water. Methods are briefly described in each section, for detailed methodology consult the MarineBasic Nuuk Manual (available online ultimo 2008).

6.1 Sea ice

Satellite and digital images of Baffin Bay and Godthåbsfjord are obtained on a daily basis throughout the year. The satellite dataset consist of AMS-R images of Baffin Bay as well as MODIS images of Godthåbsfjord (Figures 6.2 and 6.3). In addition, digital images overlooking the fjord are acquired every three hours at the Greenland Institute of Natural Resources (Figure 6.4).

Analyses of the satellite data are currently conducted as collaboration between Greenland Institute of Natural



Figure 6.1. Map of Godthåbsfjord. x show the hydrographical cross and length sections, respectively. Enlarged X represents the main station. + show the sediment station in Kobbefjord, while numbers show the seabird monitoring sites (1: Qeqertannguit, 2: Nunngarussuit). 1st Annual Report, 2007

Resources and Denmark Meteorological Institute. Thorough consideration is given to establishing monitoring parameters, ensuring optimal use of this extensive dataset. The monitoring parameters are expected to include seasonal transport of glacial ice, freshwater input to the inner parts of the fjord and the extent of sea ice cover.

6.2 Length sections and cross sections

Hydrographical measurements were performed along a cross section (Figure 6.5) from Nuuk to Akia in late May 2007. The salinity showed little horizontal variation but vertical variation was observed from 33 in the surface water to a maximum salinity of 33.5 in the bottom water. The temperature showed a similar pattern, with 2.2 °C in the surface water



decreasing to 0.7°C in the bottom water. Fluorescence – a proxy for algal biomass – was highest in the upper 60 m, with a maximum of 11 on the Nuuk side of the fjord, decreasing to less than 1.25 in waters deeper than approximately 125 m.

In May 2007, a length section spanning the outer Fylla Banke to the inner part of Godthåbsfjord (distance approximately

Figure 6.2. Satellite images (AQUA AMS-R) showing sea ice extent in Baffin Bay in January, May, July and November 2007.



Figure 6.3. Satellite images (Aqua-MODIS) showing sea ice conditions in Godthåbsfjord in February, July and August 2007.









Figure 6.4. Digital images overlooking Godthåbsfjord in January, April, August and November 2007, acquired from Greenland Institute of Natural Resources.

Figure 6.5. Cross section, from Nuuk to Akia, of a: salinity, b: temperature (°C), c: fluorescence, in May 2007.



200 km, Figure 6.6) was conducted from R/V Adolf Jensen. The cruise provided an opportunity to study several trophic levels, their connectivity and spatial variability, and an international team of marine scientists and students supplemented the MarineBasic programme with research on e.g. copepods and humpback whales. The majority of the results will be presented elsewhere, mainly as peerreviewed scientific papers. For this report, focus is on the hydrographical measurements (Figure 6.6).

The warmest and most saline water was found at depth at the outer Fylla Banke. This water is brought to the area by the northward flowing West Greenland Current. Some of this water entered the shelf and was observed sweeping the inner slope of Fylla Banke. Above the Irminger Water, temperature and salinity decrease towards the surface. Homogeneous temperatures and salinities were found over Fylla Banke. In outer Godthåbsfjord salinity varied between 33.2 and 33.6. Nearer to the head of the fjord, freshwater runoff and glacier melt created a fresh surface layer. In May 2007, this layer was observed to have a minimum salinity of 30. The temperature in Godthåbsfjord peaked at 2°C at a depth of 100-200 m near the head of the fjord, while water temperatures were below 1°C in both the surface and bottom waters. At the mouth of the fjord, vertical variation in both temperature and salinity was small indicating a well-mixed water column. The biomass of primary producers, expressed as fluorescence, was highest in the surface layers, except near the mouth of the fjord where deep mixing was apparent. The highest values (maximum of 12) were encountered on the outer Fylla Banke and near to the glacier.

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The surface pCO_2 varied along the length section with the highest surface pCO_2 values encountered at the mouth of Godthåbsfjord (Figure 6.7). Towards the head of the fjord, the values decreased, reaching a minimum of 100 µatm. The values were generally higher than in 2006, where the pCO_2 values were never above 200 µatm.

6.3 Pelagic sampling

The main station (Figure 6.1) was visited approximately each month throughout the year. Using a CTD (SBE19+), vertical profiles were obtained of the following parameters: irradiance (PAR), salinity, temperature, oxygen concentration, density and fluorescence. Water samples were collected at 11 depths (1, 5, 10, 15, 20, 30, 50, 100, 150, 250 and 300 m.) for determination of chlorophyll a and nutrient (NO_x, PO₄³⁻, and SiO4) concentrations. Surface samples were collected for the determination of dissolved inorganic carbon and total alkalinity. Primary production was measured in situ, and the vertical sinking flux of organic matter, chlorophyll *a*, carbon and nitrogen was determined using sediment traps deployed at 65 m. Vertical hauls were conducted with 20 µm and 45 µm plankton nets for determination of phyto- and zooplankton composition, respectively. In addition, oblique hauls using bongo net



Figure 6.6. Length section of a: salinity, b: temperature (°C), c: fluorescence across Fylla Banke to the inner part of Godthåbsfjord in May 2007. X marks the location of the main station. Figure 6.7. pCO_2 (μ atm) in surface water along the length section. X marks the main station. May 2007.



Figure 6.8. Annual variation at the main station in 2007. a: irradiance (PAR), b: temperature (°C), c: salinity.. $(335 \ \mu m \ and \ 500 \ \mu m)$ were obtained, both at the main station and along the length section, for identification and measurements of fish larvae.

Abiotic parameters

The hydrography of Godthåbsfjord varied considerably over the year, in a pattern similar to that observed in 2006. Irradiance values (Figure 6.8a) were less than 25 µmol photons m⁻² s⁻¹ in winter. In March, irradiance levels increased, peaking in May, and then declined towards the end of the year. Irradiance above 5 µmol photons m⁻² s⁻¹ was never measured below 50 m. The annual time series of temperature and salinity revealed that the water column was well-mixed in winter, with a temperature of around 0 °C and salinity of 33. In April, water of a higher temperature and salinity was observed at depths below 150 m, connected to the inflow of Irminger water from the coast. In autumn, the water column became stratified with low salinity (minimum of 25) and high temperature (up to $6 \,^{\circ}$ C) in the upper 100 m.

Surface pCO_2 values from 2005 to 2007 are presented in figure 6.9. Surface pCO_2 values were around 125 µatm in autumn 2005, with a slight increase observed in summer values during the investigation period. Winter values were, however, much higher during 2007 (approximately 300 µatm) as compared with the previous years (approximately 200 µatm). Note that all measured pCO_2 values are below the atmospheric concentration, indicating that Godthåbsfjord is a CO_2 sink.

Nutrient concentrations (Figure 6.10) varied throughout the year; with the highest concentrations encountered late in the year at a depth of 200-300 m. Maximum concentrations were 16 μ M nitrate, 0.75 μ M phosphate and 4.5 μ M silicate (Table 6.1). In the first months of the year, the nutrients were similar throughout the water column. In May, the nutrient concentrations decreased below 2 μ M nitrate, 0.35 μ M phosphate and 1 μ M silicate, particularly in the upper 100 m. In autumn, nutrient levels began to increase due to inflow of nutrient rich water and/or remineralisation.

Biotic parameters

The biomass of phytoplankton was measured as chlorophyll *a* concentration and fluorescence. The two parameters

showed the same pattern, with minima encountered in winter. In May, the levels increased throughout the water column to a maximum chlorophyll *a* level of 2.5 µg chl l⁻¹ (Table 6.1). Two surface blooms occurred, one in July and one in early September. Primary production was at a minimum in winter, exhibiting one peak of 846 mg C m⁻² d⁻¹ in July. This is unlike the pattern observed in 2006, where two distinct peaks in primary productivity were observed. The cause of this change in productivity pattern is not fully understood, however by comparison with the fluorescence (Figure 6.11b) it seems likely that a short period of low productivity (late June/early July) was missed. The total annual primary production was 104 g C m⁻² yr⁻¹, higher than the 75 g C m⁻² yr⁻¹ measured in 2006.

The composition of the phytoplankton community varied throughout the year (Figure 6.12). In the winter and spring, the silicoflagellate Dictyocha speculum was present, contributing up to 12% of the community. A species of the prymnesiophyte genus Phaeocystis was observed in March, and again in the productive period (May-June), contributing up to 93% of the community. With the exception of May and June, diatoms, particularly species of Chaetoceros, Thalassionema and Thalassiosira, were the dominant taxonomic group, contributing 70-99% of the community. Dinobryon, which was of importance in June 2006, was only encountered in very low abundance in 2007, contributing

Figure 6.9. Annual variation in surface pCO_2 at the main station.



Table 6.1. Annual minimum and maximum values of primary production, surface pCO₂ and attenuation coefficients. Annual minimum and maximum values for salinity, temperature, nutrients and chlorophyll at the depth intervals 0-5 m, 0-50 m and 50-300 m. Minima and maxima are shown with 95% confidence intervals, number of samples (n) and sampling date (dd/mm).

		20	2006		07
Depth	Parameter	Minimum	Maximum	Minimum	Maximum
	Primary production (mg C m ⁻² d ⁻¹)	3.0 (08/02)	710.3 (04/05)	1.9 (28/11)	846.0 (17/07)
	Surface pCO_2 (µatm)	131.9 (29/08)	288.9 (29/11)	153.7 (17/07)	360.5 (29/09)
	PAR attenuation (m ⁻¹)	0.078 (29/11)	0.191 (04/05)	0.088 (28/11)	0.175 (04/05)
0-5 m	Salinity	28.18±0.035 n=5 (29/08)	33.39±0.008 n=5 (04/04)	25.88±0.672 n=5 (03/09)	33.33±0.001 n=5 (13/06)
	Temperature (°C)	0.12±0.004 n=5 (08/02)	5.48±0.033 n=5 (24/07)	-0.37±0.003 n=5 (12/04)	5.54±0.145 n=5 (03/09)
	Phosphate (µM)	0.02±0.001 n=2 (24/07)	0.54±0.046 n=2 (03/02)	0.24±0.13 n=2 (11/06)	0.60±0.047 n=2 (12/04)
	Silicate (µM)	0.29±0.086 n=2 (24/07)	4.73±0.340 n=2 (04/04)	0.79±0.341 n=2 (03/090)	4.17±0.289 n=2 (28/11)
	Nitrate (µM)	0.64±0.099 n=2 (24/07)	11.38±3.725 n=2 (08/02)	0.73±0.301 n=2 (11/06)	9.65±2.38 n=2 (26/10)
	Chlorophyll a (µg l-1)	0.01±0.00 n=2 (08/02)	8.34±1.172 n=2 (04/05)	0.032±0.01 n=2 (17/12)	2.695±0.204 n=2 (04/05)
0-50 m	Salinity	30.49±0.157 n=50 (29/08)	33.40±0.002 n=50 (15/06)	29.82±0.216 n=50 (03/09)	33.35±0.001 n=50 (13/06)
	Temperature (°C)	0.27±0.007 n= (16/01)	4.50±0.057 n=50 (29/08)	0.05±0.004 n=50 (22/03)	4.30±0.074 n=50 (03/09)
	Phosphate (µM)	0.06±0.031 n=7 (24/07)	0.57±0.020 n=7 (03/02)	0.34±0.06 n=7 (11/06)	0.59±0.024 n=7 (12/04)
	Silicate (µM)	0.80±0.390 n=7 (24/07)	4.99±0.194 n=7 (04/04)	1.02±0.127 n=7 (11/06)	4.12±0.151 n=7 (28/11)
	Nitrate (µM)	1.46±0.717 n=7 (24/07)	12.49±1.639 n=7 (16/01)	1.41±0.450 n=7 (11/06)	11.65±2.861 n=7 (28/11)
	Chlorophyll a (µg l-1)	0.011±0.001 n=7 (08/02)	9.463±0.67 n=7 (04/05)	0.033±0.001 n=7 (17/12)	2.527±0.157 n=7 (04/05)
50-300 m	Salinity	32.80 ± 0.039	33.78 ± 0.030	32.80 ± 0.038	33.66±0.018
	Temperature (°C)	0.55±0.006 n=248 (04/04)	n=250 (08/02) 2.94±0.022 n=251 (29/11)	0.14±0.005 n=251 (22/03)	3.53±0.012 n=247 (25/10)
	Phosphate (µM)	0.35±0.057 n=5 (15/06)	0.88±0.053 n=5 (08/02)	0.50±0.144 n=7 (04/05)	0.72±0.055 n=7 (26/10)
	Silicate (µM)	2.13±0.545 n=5 (25/10)	5.41±0.365 n=5 (08/02)	1.58±0.388 n=7 (11/06)	4.55±0.783 n=7 (27/09)
	Nitrate (µM)	4.77±0.711 n=5 (04/05)	12.79±1.652 n=5 (16/01)	3.89±1.446 n=7 (11/06)	15.78±1.4 n=7 (28/11)
	Chlorophyll <i>a</i> (µg l ⁻¹)	0.01±0.00 n=5 (08/02)	3.136±0.28 n=5 (04/04)	0.026±0.003 n=5 (17/12)	1.344±0.068 n=5 (04/05)

maximum 0.3% of the community. Integrated over the year the most abundant genera were *Chaetoceros*, *Phaeocystis*, *Thalassiosira* and *Thalassionema* (Table 6.2).

The zooplankton community was diverse, with the same taxonomic groups present as in 2006. However, the temporal pattern was different for several parameters. The abundance of copepod eggs (Figure 6.13a) increased gradually peaking in July, with much higher abundance (6000 eggs m⁻³) than observed in 2006 (where a peak of 800 eggs m⁻³ was observed). The increase is due to a much larger abundance of *Microsetella* eggs, which were not observed in 2006. The abundance of nauplii peaked in July. Nauplii abundance was also higher than in 2006 due to the presence of Microsetella (which was present in lesser numbers in 2006). The abundance of copepods was low throughout the year, with a peak in September (70000 cells m⁻³). Unlikely the abundance of eggs and nauplii, the copepod abundance was similar to the values observed in 2006. The copepod community (Figure 6.13b) was dominated by *Microsetella*, with a relative contribution up to 90%. Other species of numeric importance were *Oithona*, *Onacea* and *Pseudocalanus*.

The abundance of other zooplankton groups varied during the year, with cirripedia and foraminiferans dominating in spring, and bivalvia in June. In July-September, rotatoria and tintinnida became dominant, and the abundance increased to a peak in early September (Figure 6.13c), then decreased.

To assess the ichthyoplankton in Godthåbsfjord, double oblique sampling with bongo net (335 µm and 500 µm) was conducted during the length section in May 2006 and 2007 (presented station numbers begin on the outer Fylla Banke, figure 6.1). Thirteen stations were sampled in May 2006. Based on this, four stations were chosen for the monitoring programme, and sampled in May



Figure 6.10. Annual variation in nutrient concentrations at the main station in 2007. a: nitrate and nitrite (µM), b: phosphate (µM), c: silicate (µM). Dots represent sampling points. Figure 6.11. Annual variation in algal biomass and productivity at the main station in 2007. a: chlorophyll a (µg l-1), b: fluorescence, c: primary production (mg C $m^{-2} d^{-1}$). Dots represent sampling points.

100

75

50

25

0

composition (%)



2007. Additional sampling was undertaken at the main station throughout the year.

The highest concentration of ichthyoplankton was found at the inlet of the fjord where vertical mixing of offshore and inshore waters takes place. The ichthyoplankton was mainly dominated by sand eel (Ammodytes sp.) larvae and arctic shanny (Stichaeus punctatus) larvae. Changes in the species composition of ichthyoplankton were found along the length section (Figure 6.14). Sand eel larvae were dominant at Fylla Banke, whereas arctic shanny larvae were only found within the fjord. Cod larvae (Gadus morhua) where found on both Fylla Banke and inside Godthåbsfjord, although in low concentrations. A single Greenland halibut larva (Reinhardtius hippoglossoides) was found at Fylla Banke in May 2006.

2006		2007	
Species	%	Species	%
Chaetoceros wighamii	30,5	Chaetoceros spp. (ex debilis)	20,1
Phaeocystis sp.	45,5	Phaeocystis sp.	36,3
Thalassiosira antarctica	53,0	Thalassiosira spp.	52,3
Thalassionema nitzschioides	58,1	Chaetoceros debilis	65,5
Dictyocha speculum	62,7	Thalassionema nitzschioides	78,6
Pseudonitzschia cf seriata	66,2	Fragilariopsis oceanica	82,2
Thalassiosira nordenskioeldii	69,1	Dictyocha speculum	83,6
Nitzschia frigida	71,7	Aulacoseira sp.	84,9
Dinobrion balticum	74,0	Cocconeis spp.	86,1
Thalassiosira bioculata	76,1	Ceratulina sp.	87,0

A temporal shift in species composition occurs during the summer months (Figure 6.15). The highest number of species was found in May in both 2006 and 2007. Sand eel is a dominating species of ichthyoplankton from March to July. Although in low concentration, larvae of cod (*Gadus* Table 6.2. The ten most dominant species integrated over the year as their relative accumulated proportion of total cell count (%) in 2006 and 2007.



Figure 6.13. Annual variation in zooplankton at the main station in 2007. a: abundance of copepod eggs, nauplii and adult stages, b: copepod community composition, c: abundance of other groups.

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of ichthyoplankton along the length section in May 2006 (a) and May 2007 (b).





tion other spp. Figure 6.15. Temporal variation in ichthyoplankton composition and abundance (fish larvae per m³) from March to May 2006

and May to October 2007.



morhua) were found from April to July. Large capelin larvae (*Mallotus villosus*) were found in October.

Vertical sinking flux

Sedimentation of particulate material was measured below the euphotic zone at the main station using free-drifting sediment traps deployed at 60-65 m. The collected material was analyzed for total particulate material, carbon, nitrogen and chlorophyll a (Figure 6.16).

The vertical sinking flux of total particulate material showed no clear seasonal pattern at the main stations in 2007 (averaging 80 g m⁻² d⁻¹; Figure 6.16a). The carbon content of the sinking particulate material remained low throughout the year (averaging 1.4%), indicating a high lithogenic component. The vertical sinking flux of carbon and chlorophyll *a* displayed similar seasonal trends in 2007 (Figure 6.16b), and the maximum sedimentation of carbon and chlorophyll *a* in May coincided with the highest recorded suspended algal biomass (Figure 6.11a). Furthermore, the seasonally higher sedimentation of algal material, i.e. chlorophyll *a*, from May to October corresponded with the higher

Depth	Parameter	2006	2007
65 m	Total flux	21,4	24,9
	(x1000 g dry weight m ⁻² yr ¹)		
	Carbon	253,9	364,1
	(g C m ⁻² yr ¹)		

Table 6.3. Integrated annual vertical sinking flux of total particulate material and carbon at 65 m in 2006 and 2007.

64

pelagic primary production (Figure 6.11c). A significant algal-based carbon component of the sinking material in summer is also supported by carbon to nitrogen ratios resembling the ratio expected for healthy algal cells (Redfield ratio 6.6 mol:mol).

The annually sedimentation of total particulate material was similar in 2006 and 2007 (Table 6.3), thus reflecting an area of high vertical export of particulate material. The significantly higher annual vertical sinking flux of carbon in 2007, than in 2006 (43% higher; Table 6.3), reflect inter-annual differences in the sedimentation of carbon below the euphotic zone.

6.4 Sediments

Mineralisation of organic matter in the sediment occurs through a number of processes, which all lead directly or indirectly to consumption of oxygen. The mineralisation rate can therefore be estimated by the flux of oxygen into the sediment. Intact sediment cores were obtained in winter and summer, at a depth of 125 m, and oxygen flux was measured by incubation and microprofiling (Figure 6.17). In both summer and winter, oxygen was depleted less than 1 cm from the sediment surface, and maximum oxygen consumption was around 0.5 cm.

The exchange between sediment and water was determined (Table 6.4). In comparison to last year, the total oxygen uptake minima were comparable, while the maxima differed with a much higher oxygen uptake in autumn 2006.

6.5 Benthic fauna and flora

Benthic fauna and flora are reported in more detail in the following as it was discovered in 2005-06 that more basic knowledge was needed to provide the optimal monitoring parameters for these components.

Benthic fauna

Macrobenthos has traditionally been considered useful for monitoring the ecological status of marine ecosystems. They are sessile, long-lived and key components of the carbon cycling in coastal ecosystems and therefore useful as



indicators of biological and physical change at a specific location. Because our knowledge of the macrobenthos in Godthåbsfjord system is very limited no specific predictions exists regarding responses to changes in climate. Therefore, the aim during the first two years of MarineBasic Nuuk (2006 and 2007) was to conduct a number of studies providing baseline information on the macrobenthos in Godthåbsfjord enabling us to identify Figure 6.16. Annual variation in vertical sinking flux of a: total particulate material, b: carbon (C), chlorophyll a (chl) and carbon to nitrogen ratio (C:N) of the sinking particulate material.



Figure 6.17. Vertical concentration profiles of oxygen (dots) and modelled consumption rates (bars).

	2006		2007	
Parameter	Minimum	Maximum	Minimum	Maximum
Total oxygen uptake (TOU) (mmol O_2 m ⁻² d ⁻¹)	5.59±3.2 n=3 (21/07)	15.67±8.1 n=4 (10/10)	5.28±0.7 n=3 (21/02)	6.50±0.9 n=7 (08/08)
Diffusive oxygen uptake (DOU) (mmol $O_2 m^{-2} d^{-1}$)	5,8 (16/05)	12,97 (10/10)	3,53 (21/02)	3,88 (08/08)
TOU/DOU	0.82 (21/07)	1.21 (10/10)	1.51 (21/02)	1.68 (08/08)
Phosphate (mmol PO4 m ⁻² d ⁻¹)	-	-	-0.01±0.08 n=6 (21/02)	0.03±0.02 n=6 (08/08)
Silicate (mmol SiO4 m ⁻² d ⁻¹)	-	-	-0.65±0.3 n=6 (21/02)	-0.83±0.2 n=7 (08/08)

Table 6.4. Sediment-water oxygen and nutrient exchange. Data are shown with 95% confidence interval (when applicable), number of samples (n) and date (dd/mm). monitoring parameters. Changes in the macrobenthic community can occur at several levels. At the community level, species composition, biomass, diversity and abundance can change. At species level, population characteristics such as growth, reproduction, settling and mortality can change.

The aim of this study was to identify one or two species that contributed significantly to the carbon flow in the area and were suitable for monitoring population changes in growth and reproduction. Approximately 300 photos of the sea floor (Figure 6.18) were obtained at several shallow stations in Kobbefjord (0-60 m). In terms of biomass, the two dominant species were identified as the bivalve Chlamys islandica and the sea urchin Strongylocentrotus droebachiensis. Abundance was estimated from pictures (Figure 6.19a) and converted to biomass (Figure 6.19b) based on relationships between size and biomass (Figure 6.19c and d).

A fundamental aspect of a population's role in ecosystem carbon flow is the ingestion of food and subsequent allocation into somatic growth and reproduction. The aim was to identity what variables to measure in order to identify future changes in 1) growth rate, 2) reproductive output, and 3) energetic conditions of the two key species in Kobbefjord.

Kobbefjord.

Growth of a population is traditionally quantified by size-age plots as illustrated for C. islandica and S. droebachiensis (Figure 6.19 e and f). Although this gives a good overall description of the average growth of the population, it is not a very sensitive measure for detecting short-term changes in growth rate. Two alternative measures were calculated for each species; 1) the average age of a specified size interval and 2) the average size of a specific age (Table 6.5). For both species the average size of a specific age showed the lowest coefficient of variation and was thus selected as the best measure of growth. However, for *S*. droebachiensis the age of which a sufficient number of individuals could be collected was 9-10 years. This is not a very useful measure for identification of year to year change.

Thus, we recommend that only the average size of five- and six-year-old individuals of *C islandica* are estimated annually in MarineBasic Nuuk. This means that approximately 50 individuals of *C. islandica* with a shell size of 35-45 mm should be collected.

To quantify the reproductive output, gonads of both species can be dissected out and weighted. Since reproductive output is highly dependent on size, we constructed a gonad index for both species. The index still showed a significant correlation to size. For both species the coefficient of variation could be reduced by calculating the gonad index for a limited size interval, > 50 mm for *S*. droebachiensis and >60 mm for C. islandica (Table 6.5). For both species, the sample size for size-specific gonad index should be increased to 30 individuals. The energetic condition of an individual can be expressed as an index relating the soft tissue biomass to size. As for the gonad index, the coefficient of variation can be reduced when defining a limited size interval. For both species, a sample size of

Figure 6.18. Photo showing the sea floor in Kobbefjord (at approximately 45 m depth). The two key species, the clam Chlamys islandica (black arrows) and the sea urchin Strongylocentrotus droebachiensis (white arrows) are indicated.

 $\uparrow \qquad \uparrow \qquad \downarrow$

30 individuals within the specified size interval (40-60 mm for *C. islandica*, and 40-50 mm for *S. droebachiensis*) is recommended (Table 6.6).

We thus recommend that each year in May specimens of *S. droebachiensis* and *C. islandica* are collected at the station in Kobbefjord (position N 64^e 07.651' W51^e 38.587', 50-60 m depth) and analysed for gonad and condition indices. For *C. islandica* the average size of the five and six-year age class is also estimated.

Benthic flora

The brown kelp Saccharina latissima (previously called Laminaria saccharina) is common in northern temperate waters but also forms dense stands in arctic regions (Borum et al. 2002). Growth of this species has been used to estimate annual production of the macroalgal community of Young Sund (Borum et al. 2002), and it has been found to reflect changes in the duration of sea ice cover and light climate (MarineBasic – Young Sund). In arctic areas, new tissue of S. latissima can clearly be distinguished from the old, as 1-2 year old blades of this species often remain attached to the new blade separated by clear constrictions (Dunton 1984, Borum et al. 2002). Therefore, assessments of annual growth can be made from just one annual sampling of *S. latissima*. For these reasons annual growth of S. latissima was originally included in MarineBasic Nuuk. However, since the 2006-survey located Laminaria longicruris, but not S. latissima, a more thorough algal survey was conducted from 17 to 21 September 2007 with the following aims:

- Assess the horizontal and vertical extension of the macroalgal community, and identify the dominant kelpspecies
- In case *S. latissima* is absent, assess growth rate as well as carbon and nutrient status of *L. longicruris*
- Provide recommendations for future monitoring

Horizontal and vertical extension of the macroalgal community of Kobbefjord and identification of characteristic species

In order to assess the horizontal and vertical extension of the macroalgal community and identify the characteristic species, 20 section lines distributed along

Parameter	Criteria	N	Average	S.d.	Coefficient of variation
S. droebachiensis	• ••••••		•••••••		••••••
Condition index	all	74	1,821	0,234	12,87
Condition index	35-45 mm	29	1,742	0,205	11,76
Condition index	40-50 mm	24	1,851	0,126	6,82
Gonad index	all	74	0,070	0,055	79,25
Gonad index	35-45 mm	29	0,057	0,039	67,83
Gonad index	>50 mm	18	0,128	0,057	44,89
Average age	35-45 mm	29	10,207	1,590	15,57
Average age	40-45 mm	16	10,875	1,821	16,75
Average size	9 years	10	38,825	2,858	7,36
Average size	10 years	12	40,508	2,919	7,2
C. islandica	• •••••	• • • • • • • • • •	••••••	•••••	••••••••••••••••••••••
Condition index	all	60	0,107	0,022	20,34
Condition index	<40 mm	40	0,096	0,015	15,89
Condition index	40-60 mm	20	0,112	0,015	13,66
Gonad index	>40 mm	40	0,020	0,023	116,33
Gonad index	>60 mm	20	0,022	0,007	33,12
Average age	45-60 mm	20	8,1	1,483	18,31
Average age	20-40 mm	17	5,06	0,966	19,1
Average size	5 years	9	34	3,359	9,91
Average size	6 years	9	40,16	4,306	10,72

the northern and southern fjord side were examined using echo sound and sampling by anchor. Vegetation at depths shallower than 4-5 m was not surveyed.

Intertidal or eulittoral macroalgae were abundant across the fjord. They formed a dense light-brown belt visible along most of the shoreline of the fjord at low tide. The community of intertidal macroalgae was dominated by *Fucus* spp. and *Ascophyllum nodosum*. Though we examined the intertidal algal community closely only in the inner part of the fjord, it seemed quite uniform across the fjord as evaluated from a distance.

Sub-littoral macroalgae were most abundant in the outer part of Kobbefjord, where dense stands completely dominated by large kelps occurred interspaced with bare bottom. The densest stands occurred along exposed shores. *L. longicruris* was the most dominant kelp. Other characteristic kelp species were *Agarum cibrosum* and *Alaria esculenta*. We also found a small Table 6.5. Comparison of average values and variability of proposed monitoring parameters for the two species S. droebachiensis and C. islandica in Kobbefjord (50-60m depth).

Table 6.6. Proposed sample size and size intervals of the two selected species in Kobbefjord for MarineBasic.

	Average size at age	Gonad index	Condition index
C. islandica			
Size interval	30-45 mm	>60 mm	40-60 mm
Sample size	50	30	30
S. droebachiensis			
Size interval		> 50 mm	40-50 mm
Sample size		30	30





specimen of Laminaria solidongula, but no S. latissima. Along with the kelps of the outer fjord, we found specimens of the coarse filamentous brown alga Desmarestia aculeata, the red alga Membranoptera dentriculata, and the green foliose Ulva lactuca. Towards the middle and inner parts of the fjord, the abundance of large kelps declined markedly. Macroalgal stands became scattered or rare and were much less dense and composed of smaller, mainly filamentous species. Many sections were completely devoid of conspicuous sub-littoral macroalgal communities. The dominant algae of the middle and inner parts of the fjord were the filamentous brown macroalgae D. aculeata, Dictyosiphon foeniculaceus and Chordaria flagelliformis. Finer branched filamentous brown algae, most probably Ectocarpus sp. were also

present and so were the filamentous green macroalgae *Chaetomorpha linum* and *C. capillaris*.

The sub-littoral macroalgae extended to maximum depths of 13-15 m - deepest in the outer part of the fjord. With an average annual attenuation coefficient of 0.11 m⁻¹, 19-24% of surface irradiance is available at 13-15 m depth. Laminaria forests at e.g. Helgoland extend to water depths receiving 4% of surface light and individuals may extend to water depths receiving only 0.7% of surface light (Lüning 1990, p. 285), indicating that the macroalgae of Kobbefjord have high light demands at the depth limit. Kobbefjord has a relatively steep slope and extends to maximum depths of >100 m and the sub-littoral macroalgal community consequently constitutes only a narrow belt of the fjord.



Blade biomass (g dw)

Figure 6.20. Length of blades (solid column) and stipes (open column) and width of blades (solid circles) of Laminaria longicruris at a protected and an exposed site of Kobbefjord and at Kolonihavnen. Nuuk.

Growth of Saccharina latissima/ Laminaria longicruris

A literature survey revealed that Laminaria longicruris and Saccharina latissima share many morphological characteristics and some scientists have suggested they should be considered one species (Chapman 1974). Both species possess an undivided blade, which grows like a continuous band from the base and gradually erodes at the tip. However, the stipe of L. longicruris is generally considerably longer and broader, and becomes hollow at the distal region at the end of the first year or during the second year of growth (Egan and Yarish 1988), while stipes of S. latissima are solid. Blade growth rates of the two species are similar (Egan and Yarish 1990), and growth rates of L. longicruris in Kobbefjord were assessed as a substitute for S. latissima. The absolute increase in length of L. longicruris in a given site is roughly the same for all size classes but in young specimens with thin blades, the annual blade is gradually eroded so that the length of the blade does not represent a full year's growth. Annual biomass production, by contrast, is largest for old specimens since they have broader and thicker blades than young specimens (Mann 1972).

Laminaria longicruris (fully grown) was sampled at three locations, two sites in Kobbefjord (a protected (64°08,6N; 51°35,3W) and an exposed (64°07,9N; 51°37,0W)) and at an exposed site in the old harbour of Nuuk (Kolonihavnen, 64°10,6N; 51°44,9W). Sampling was performed by diver and using a small anchor, with 5-14 specimens collected from each site. Length, width and wet weight were measured on the fresh algal material, and the algae were then frozen for later analysis. After drying to constant weight at 60°C, dry weight was determined. The specimen collected for assessment of annual growth did not have intact blades, and assessment of annual growth based on these blades therefore provides minimum estimates. Blade size and, thus, annual blade production increased from the protected site of Kobbefjord (length: 148 cm, width: 40 cm, biomass: 82 g dw) to the exposed site of Kobbefjord (length: 182 cm, width: 70 cm, biomass: 118 g dw) and Kolonihavnen (length: 224 cm, width: 62 cm, biomass: 121 g dw) (Figures 6.20 and 6.21). This difference is most likely due to the difference in sea ice cover and nutrient availability between the sites. The inner part of the fjord is sea ice covered 3 to 5 months per year whereas no sea ice is present in the outer part.



Figure 6.21. Dry weight of Laminaria longicruris at a protected and an exposed site of Kobbefjord and at Kolonihavnen, Nuuk.

Carbon and nitrogen content of Laminaria longicruris

For determination of carbon and nitrogen content, cross sections of the dried material were grinded and measured on an elemental analyzer. The carbon content of Laminaria longicruris was relatively similar among sites, varying from 34% at the exposed site of Kobbefjord to 37% at the protected site of Kobbefjord. The nitrogen content, by contrast, varied considerably among sites, showing an increasing trend from the protected Kobbefjord site (0.7% of dw) over the exposed Kobbefjord site (1.0% of dw) to Kolonihavnen (1.9% of dw) (Figure 6.22a). It is likely that the nitrogen values measured in this study represent annual minimum values, since other studies have shown that the nitrogen content of Laminarians varies markedly on an annual basis and typically shows a minimum in September and a maximum in March (Sjøtun 1993). Similarly low annual minimum values of September are reported from an Icelandic population of Laminaria saccharina (Sjøtun 1993). However, compared to a global survey of nitrogen content of macroalgae, which reported a mean N-content of 1.9% of dw (Duarte 1992), the values found in Kobbefjord were very low, and suggest that the algae were nitrogen limited. Because of the increasing nitrogen content

Figure 6.22. N-content (upper panel) and C/Nratio (lower panel) of Laminaria longicruris at a protected and at an exposed site of Kobbefjord and Kolonihavnen, Nuuk.



towards the more exposed sites, the C/N-ratio (molar) of the algae declined from 67 at the protected Kobbefjord site over 43 at the exposed Kobbefjord site to 22 at Kolonihavnen (Figure 6.22b). The increase in tissue nitrogen content and the decline in C/N ratio correlate with the increase in blade length and biomass, and thus annual blade production from the protected site in Kobbefjord to Kolonihavnen.

The recommendation for MarineBasic Nuuk is thus to monitor annual growth and C/N content of *Laminaria longicruris*, using the procedure established for *Saccharina latissima*, at both the exposed and the protected site in Kobbefjord. Growth rates of *L. longicruris* at the two sites in Kobbefjord represent growth under sea ice covered and -free conditions, and can be used to compare geographic and inter-annual variability as well as controlling environmental factors.

6.6 Seabirds

Two major seabird colonies near Nuuk are included in the MarineBasic program. In addition, other seabird colonies in the Nuuk area were visited in 2007. Amongst them, the five kittiwake colonies of Godthåbsfjord were censuses and the results are included in this report. The seabird counts from MarineBasic are reported annually to the Greenland Seabird Colony Database.

Qegertannguit (colony code: 64035), in the interior parts of Godthåbsfjord (Figure 6.1), is a low-lying island and holds the largest diversity of breeding seabirds in the Nuuk District. Especially surface feeders (gulls, kittiwake and arctic tern) are well represented at the site (Table 6.7). Counts of the entire island were conducted early in the incubating period, on 5 June, using direct counts of Apparently Occupied Nests (AON) or territorial behaviour as a parameter of breeding pairs. The steep cliff in the middle of the southeast facing side of the Island, holding Kittiwake and Iceland gull, and a smaller cliff on the north side, holding Iceland gull, were counted from the sea using a boat as platform. All other counts were conducted on foot.

Other birds observed on 5 June, not considered breeding or not censuses,

included one adult mew gull, two adult ring-billed gulls, one adult herring gull, one to two pairs of ptarmigan, one adult great cormorant, a few ravens, snow bunting, northern wheatear, Lapland bunting and common redpoll. A redthroated diver was seen at the coast of the island, but the lake – where a nest is usually seen – was dry this year.

The count numbers in general are similar to the numbers of 2006. The differences are likely to be within the range of various counting errors, seasonal and daily variation.

The southeast facing cliff with breeding kittiwakes and Iceland gulls was visited about once a week during most of the breeding season for reproduction biology studies (April-July). Both species attended the cliff by end of April/early May. On 26 May they did not appear to have eggs yet. By 4 June most nests had eggs but the last new registered eggs were laid between 12 and 16 June. By 22 June the first chicks of Iceland gulls were seen. The first hatched kittiwake eggs were observed on 28 June. By 8 July most eggs were gone and chicks of Iceland gulls were observed at most of the registered nests but only a few kittiwake chicks (of 43 kittiwake nests 34 were empty but the adults were still attending the nests). No kittiwake chicks survived past the pullus stage. At least 47 chicks of Iceland gull were still alive at 30 July. At this time they were large and very mobile but they were still not flying.

Illegal egg harvesting at the bird cliff was prevented on two occasions (5 June and 22 June). We did not see clear/observe any signs of egg harvesting in the studied nests, but it may have occurred. Egg harvesting is allowed until 31 May and only on great black-backed gull and Glaucous gull.

The arctic tern colony was visited four times. No nests were found on 5 June. Nests with eggs were found on 9 July. Four nests with chicks and a few more with eggs were found on 20 July, but no chicks were found on 29 July.

Nunngarussuit (colony code: 63010) is located app. 40 km south of Nuuk town (Figure 6.1). The north facing cliff wall of the small island holds the only colony of guillemot in Nuuk District (the colony includes both Brünnich's and common guillemot). These alcids are deep divers for fish and large zooplankton. Counts

Species	Numbers	Unit
Black-legged Kittiwake	45	AON
Iceland gull	82	AON
Great black-backed gull	38	Р
Lesser black-backed gull	11	Р
Glaucous gull	14	Р
Arctic tern	150	I
Arctic skua	2	Р
Black guillemot	562	I
Red-breasted merganser	4	Р

(both direct and photo counts) of birds present on the cliff wall were conducted from the sea (boat) on 10 July (Table 6.8). About 450 guillemots were estimated on the water at the time of observing. The number of guillemot present at the site in 2007 (Table 6.8) is higher than in 2006 (694 on the cliff and 2-300 on the water, including both common and Brünnich's guillemot), but in the same order of magnitude and possibly within the range of various counting errors, seasonal and daily variation.

In order to address the proportion of boreal (common guillemot) versus arctic (Brünnich's guillemot) species in the colony, an analysis from digital images photographs was performed. This is interesting in the context of climate change where the proportion of common guillemot could be expected to increase in a warmer climate. Of 526 guillemots where identifications were possible only 11% were common guillemot.

Other seabird observations near Nunngarussuit on 10 July

Simiutat (colony codes 63011, 63012 and 63013): The birds observed at these small islands just north of Nunngarussuit were summed to about 70 puffins, about 90 razorbills, 7 black guillemots, 40 great cormorants (non-breeding), several glaucous gulls and great black-backed

Species	Numbers	Unit
Brünnich's guillemot (89%)	705	I
Common guillemot (11%)	87	I.
Glaucous gull	14	I.
Great black-backed gull	5	I
Northern fulmar	13	I.

Table 6.8. Breeding seabirds at Nunngarussuit 2007 (I = Individuals).

Table 6.7. Breeding seabirds at Qeqertannguit 2007 (P = Pairs, I = Individuals, AON = Apparently Occupied Nests). gull, 1 pair of arctic skua (light morph) and 8 seemingly breeding female eiders.

Qarajat qeqertaat (colony code 63019) – This site consists of two islands: West Island: 29 eider nests found (10 empty, 1 with chicks, average of 3.42 eggs in the remaining) and 170 eiders on the water. 20 great black-backed gull, 1 ring-billed gull, 1 glaucous gull/herring gull hybrid, 6 herring gull, 12-15 lesser black-backed gull, 3 glaucous gull, 2 arctic skua (dark morph) and 70 black guillemot – all potential breeders. No breeding arctic terns this year.

East Island: 18 eider nests found (9 empty, none with chicks, average of 4.22 eggs in nests with eggs). 5 great blackbacked gull, 1 lesser black-backed gull, 2 arctic skua (light morphed), and 270 black guillemot. No breeding arctic terns this year.

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

Innaarsunnguaq (colony code 64015): 342 pairs of Iceland gull (28 June), 62 pairs of kittiwake (13 July) and 49 razorbills (9 July). This site is close to Qeqertannguit and was visited several times. However, different species were counted at different visits due to time pressure.

Kangiussaq (colony code 64018): 217 pairs of kittiwake and a larger but unknown number of Iceland gull (27 June).

Alleruussat (colony code 64022): 276 pairs of kittiwake, 45 pairs of Iceland gull and 23 nests of great cormorant (27 June).

Innajuattoq (colony code 64019): 302 pairs of kittiwake, maybe twice as many Iceland gulls and 46 nests of great cormorant (13 July).

6.7 Marine mammals

Observations of marine mammals were done during June to October 2007 from an observation post overlooking a cross section of the entrance to Godthåbsfjord. Observations were performed over periods of 30 minutes three times a day (beginning at 8:00, 14:00 and 19:00) and the number of observed marine mammals, ships, boats and observation conditions were noted. For each observed humpback whale, the surface behaviour was noted and divided into travelling, feeding or other. The time between each blow was noted, as was the horizontal and vertical angles from the theodolite to the whale when it dived. The position of the whales was determined by measuring the angles to the whale with the theodolite and subsequently converts them into geographical coordinates by referring the angles to a fixed reference point determined by Asiaq - Greenland Survey. The accuracy of the theodolite positioning was calibrated at different distances using a small boat taking GPS positions at the same point as the theodolite measured the angles to the boat. A total number of 166 30-minute surveys were performed, resulting in a total of 83 hours of observation. Twenty-eight sightings of humpback whales were made (as single individuals or in groups of two to three).

The first whales were observed on 21 May 2007 in Qorqut during the MarineBasic Nuuk length transects. Sightings were at a maximum in June, where whales were seen in 23.9% of the 30-minute surveys (Figure 6.23a). The chance of a whale sighting was highest in the afternoon, where whales were present in 20.3% of the





Figure 6.23. a: Percentage of surveys in which humpback whales were observed per month. N shows the total number of surveys per month. b: Percentage of observations with humpback whales during daylight. N shows the total number of surveys in the given time period.
surveys. Whale sightings declined during the evening with sightings in only 11.8% of the surveys (Figure 6.23b). The distribution of humpback whales may be influ-

enced by tidal amplitude, because the tidal water exchange may control food availability. This will be further investigated in 2008.

7 Research projects

7.1 Changes in sea ice algal composition and productivity throughout a sea ice season

Ditte Marie Mikkelsen, Søren Rysgaard and Ronnie N. Glud

Sea ice is recognized as a highly variable habitat, exhibiting changes in e.g. temperature, salinity, light and nutrient availability. Organisms are incorporated during sea ice formation, and some are able to adapt to the conditions in the brine network. Most taxonomic groups have been encountered, with pennate diatoms considered dominant. In 2005-6, from sea ice formation to sea ice melt, the sea ice microalgal community in Kobbefjord, West Greenland, was examined. Temporal variation in physical (irradiance, temperature, brine volume) and chemical (salinity, nutrient concentration) properties confirmed that sea ice is a very dynamic habitat. Still, a viable sea ice algal community was present throughout the entire season. Changes were observed in the species composition with flagellates (cryptophyceae and gymnodinoid dinophyceae) in winter, a bloom of the centric diatom Chaetoceros simplex in March and dominance by invasive pennate diatoms in May. Such shifts in dominance between taxonomic groups have implications for e.g. specific productivity rendering extrapolation of short-term measurements uncertain. The sea ice primary production (which mirrored the biomass dynamics) showed two distinct peaks of similar magnitude in March (21 mg C m⁻² d⁻¹) and May (15 mg C m⁻² d⁻¹), primarily regulated by irradiance (Figure 7.1). The decrease in productivity in April was attributed to heavy snow cover which impeded irradiance. The annual sea ice primary



Figure 7.1. Sea ice algal primary production.



Figure 7.2. A sea ice alga – Rhodomonas sp.

production was 0.78 g C m⁻². Sea ice algae contributed 30% of the total (sympagic plus pelagic) primary production during the sea ice season, but <1% annually (Figure 7.2). Changes in sea ice conditions are expected to affect the primary production, with consequences for the marine pelagic ecosystem.

7.2 A laboratory study on pH dynamics and photosynthesis by sea ice algal communities and an in situ study of the autotrophic versus heterotrophic activity in Kobbefjord, West Greenland

Dorte Søgaard, Morten Kristensen, Ronnie N. Glud and Søren Rysgaard

The presence of sea ice is a characteristic feature of most polar marine ecosystems. Sea ice acts as an important barrier between the atmosphere and ocean. It has recently been shown that sea ice may affect the transfer of CO_2 from the atmosphere and ocean (Rysgaard et al. 2007, Semiletov 2007). Rysgaard et al. (2007) suggest that besides the solubility and biological carbon pump; a physical driven sea ice carbon pump may also exist. The surface water which freezes in the winter extrude salt as well as dissolved inorganic carbon (DIC) through brine rejection to the underlying water that eventually may sink to deeper water layers. During the summer thaw when sea ice melts, sea ice enriched in calcium carbonates increases the pH of the surface melt water resulting in an increased uptake of CO_2 from the atmosphere.

Few investigations exist on total alkalinity (TA) and dissolved inorganic carbon (TCO₂) in sea ice. However, evidence has been presented that TA:TCO₂ ratios may be well above 1, showing the equilibrium: Carbon Dioxide (CO₂) $\leftarrow \rightarrow$ Bicarbonate (HCO₃⁻) $\leftarrow \rightarrow$ Carbonate (CO₃²⁻) is shifted toward CO₃²⁻.Three possible mechanisms has been suggested which may explain the TA:TCO₂ ratios measured in sea ice and the elevated pCO_2 concentrations in the water below: 1. Calcium carbonate (CaCO₃) formation and CO₂ rejection to the underlying water, 2. Bacterial activity that affects the TA:TCO₂ ratio through mineralization of dissolved organic carbon, 3. Sea ice algae may affect the TA:TCO₂ ratio within sea ice through photosynthetic utilization of CO₂ and HCO₃. Unlike freshwater ice, the sea ice forms a semisolid matrix which is permeated by a network of channels and pores, varying in size from a few micrometers to millimetres. This network is usually filled with brine, i.e. highly saline water, formed when salt is expelled during freezing. It is within these brine channels and pores that sympagic organisms can be found (Light et al. 2003). Numerous internal conditions (salinity, pH, light, temperature etc.) influence the sea ice environment, and affect the micro-organisms. pH is an important parameter when studying biogeochemical processes due to its major influence on the organisms within the sea ice (Rysgaard et al. 2007). Furthermore, heterotrophic respiration, chemoautotrophic activity and photosynthesis are likely to influence the sea ice carbonate system by affecting the precipitation and dissolution of calcium carbonate.

The aim of our Master Project is to compare the amount of carbon that biological producers remove from the sea ice with the amount removed by physical processes. There will be an investigation and comparison of the total biological production, i.e. primary- and heterotrophic-production, in sea ice during two periods, i.e. in February when low light levels inhibits primary production and in April when light levels increases. The sampling area will be located in Kobbefjord, West Greenland.

In another study we will investigate the influence of pH and salinity on sea ice algae by culture experiments in the laboratory. Furthermore, in order to compare the quantities of carbon utilized and removed by micro-organisms, with that removed by CO_2 precipitation and $CaCO_3$ formation, we will in the laboratory examine the strictly physical driven dynamics of sea ice, the removal of carbon in growing ice and its effect on the carbonate dynamics in artificial made sea ice.

7.3 Feeding of carnivorous zooplankton in West Greenland waters

Kajsa Tönnesson, Torkel Gissel Nielsen and Kristine Engel Arendt

Important and common predatory groups, such as the chaetognaths and carnivorous copepods are particularly understudied in the Arctic. Invertebrate predators have been found to have a substantial impact on zooplankton communities, especially in cold waters and selective predation by zooplankton may influence the trophic structure of the zooplankton community. Studies on the selectivity by predators (e.g. chaetognaths) are rare due to lack of simultaneous data on vertical distribution and co-occurrence of prey and predators, a necessary piece of information to show selectivity and estimate predation impact. This project will study carnivorous zooplankton and their trophic role in the arctic pelagic ecosystem, with emphasis on their predation on Calanus spp. A field investigation was carried out in May 2006 and 2007 at 14 stations along transects from offshore waters at Greenland's west coast along the Godthåbsfjord to the inland regions close to the Greenland Ice Sheet. The transect is characterised by large variations in bathymetry, inflow of fresh water, tide, local and large-scale currents and thus, the measurements provide a good basis for evaluating the impact of the physical and chemical properties on the food web structures. The diet and vertical and horizontal distribution of the carnivorous copepods and chaetognaths were investigated. Feeding by the carnivorous copepod Pareuchaeta norvegica was assessed by measuring faecal pellet production and the chaetognaths were analysed for gut contents.

Prey organisms (i.e. copepods) can be identified to species level by analysis of the mandibles (Figure 7.3). SimultaneFigure 7.3. Mandible plates used for identification.



ously, prey composition, prey production and vertical distribution were determined.

Pareuchaeta norvegica was at all times restricted to the deeper parts of the water column while the chaetognaths Sagitta elegans and Eukrohnia hamata were found at all depths. S. elegans was the dominate chaetognath in the fjord while E. hamata dominated in offshore waters. Copepods and their nauplii dominated the prey composition at all stations, Microsetella sp. dominated the prey composition in the fjord, while Oithona sp. and Calanus spp. dominated in offshore waters.

The results show that small copepods dominated the gut contents, with the addition of the appendicularian Fritillaria sp. and chaetognaths. Comparing prey abundance and gut content for E. hamata shows that Pseudocalanus sp. was selectively preyed. Selective feeding was also observed in S. elegans. Number of prey per chaetognath ranged from 0.2 to 0.4 prey ind⁻¹ and is among the highest values reported for this species. Feeding of the carnivorous copepod P. norvegica was assessed by measuring egestion of faecal pellets, since experimental studies have shown a linear relationship between food intake and the number of pellets defecated. We assumed 1 pellet = 1 small copepod prey. The gut content of P. norvegica ranged from 2 to 6.3 pellets ind-1 and the calculated feeding rate from 1.8 to 5.6 prey d⁻¹. To estimate the fraction of the prey population available to each predator, a prey size spectrum was assumed

based on literature data. Using the feeding rates and ambient predator and prey abundances and production, daily predation impact rates based on prey production were estimated. The mean specific egg production rate (SEP) for Calanus finmarchicus was low (0.5-4.0%) and the weight-based predation impact of Pareuchaeta norvegica 0.19% d⁻¹ (maximum) which is 19% of the copepod production, if the female egg production is representative of the copepod population. The study therefore shows that invertebrate predation is an important population regulating factor in West Greenland waters that should be included in future investigations.

7.4 Consequences of climate change on the community structure and productivity of arctic mesozooplankton

Kristine Engel Arendt

Climate models predict dramatic changes in the arctic areas during the next decade. Such changes in the arctic climate and sea currents will have remarkable consequence on the West Greenland marine ecosystems, and will therefore affect the economical important fisheries and traditional hunting patterns which is the basis of the Greenlandic society today.

The copepods constitute a key trophic group, with a central role in the pelagic



Figure 7.4. Community composition of copepods, as % of total biomass.

ecosystem. They connect the autotrophic organisms with the heterotrophic organisms, as they transfer energy from the phytoplankton to the higher trophic levels. The copepod community structure and species composition is largely dependent on physical parameters. The question is therefore whether changes in the physical parameters will affect the energy flow through the food web and if these changes of energy flow through the food web would lead to changes in the ecosystem structure and function in the future. The understanding of the lower food chain organisms and their interactions is therefore important for predictions of consequences of global warming.

The project will focus on plankton community structure and carbon cycling in the pelagic and the study will be conducted in areas with various physical conditions and vary in time and space. Godthåbsfjord provides a good basis for evaluating the impact of the physical and chemical properties on the food web structure. The discharge from the Greenland Ice Sheet in the inner parts of the fjord creates a noticeable gradient of the physical factors as it meets the warm and saline West Greenland Current in the offshore region. There is a huge difference in plankton community structure along the fjord and this study will focus on the various communities of copepods, their efficiency of transferring energy from lower to higher trophic levels, and their adaption to physical factors. The project is connected to the existing marine climate monitoring programmes, Nuuk Basic in West Greenland and Zackenberg Basic in North-east Greenland, since results from these programs will be integrated in this project.

The project has been economically supported by KVUG (The Commission for Scientific Research in Greenland), the Danish Agency for Science, Technology and Innovation and the Greenland Home Rule.

7.5 Differences in plankton community structure along a climate gradient from offshore waters to the Greenland Ice Sheet

Kristine Engel Arendt, Torkel Gissel Nielsen, Søren Rysgaard and Kajsa Tönneson

West Greenland marine ecosystems present a complex interaction between the full marine areas along the West Greenland banks and the innumerable fjords draining the Greenland Ice Sheet into the sea. The discharge from land creates a noticeable gradient of the climate factors as it meets the warm and saline West Greenland Current. The complexity of these systems is poorly described and it is not yet fully understood how the plankton community adapts to these noticeable physical gradients. The aim of this study is to describe how the plankton community structure, its productivity and the carbon cycling in the pelagic adapt to changes in the physical gradients. The study was conducted along transects from the offshore parts of the Fylla Banke along Godthåbsfjord to the inner fjord close to the Greenland Ice Sheet.

Our study revealed huge differences in plankton community structure (Figure 7.4) and chemical and physical gradients between the offshore West Greenland Current system and inland regions close to the Greenland Ice Sheet. The offshore region had pronounced vertical mixing in the upper 50 m of the water column. Centric diatoms and Phaeocystis spp. dominated the phytoplankton community, chlorophyll a (0.3-3.9 µg Chl a l⁻¹) was evenly distributed and nutrients depleted in the upper 50 m. Ciliates and dinoflagellates constituted an equal part of the heterotrophic protozooplankton, and the copepod biomass was dominated by Calanus spp. Primary production (> 1200 mg C m⁻² d⁻¹) as well as secondary copepod production (5-261 mg C m⁻² d⁻¹) was high offshore.

Figure 7.5. Salinity distribution along the length axis of Kobbefjord in April 2007. The mouth of the fjord to the left with the head of the fjord to the right.

The water column became gradually more stratified when moving from the offshore region into the fjord. In contrast to the offshore region, this caused Chl *a* to be concentrated in a narrow sub-surface band in the inner parts of Godthåbsfjord with high concentrations (up to $11.8 \text{ µg } \text{l}^{-1}$). Nutrients were depleted above the pycnocline, and Thalassiosira spp. dominated the phytoplankton community close to the Greenland Ice Sheet. In most of the fjord, naked heterotrophic dinoflagellates accounted for most of the protozooplankton biomass, whereas the copepod biomass was dominated by Pseudocalanus spp., Metridia longa. Primary production was lower in the outer part of Godthåbsfjord but considerably higher in the inner parts of the fjord (> $3100 \text{ mg C} \text{ m}^{-2} \text{ d}^{-1}$). Protozooplankton biomass and grazing were high in the fjord, and there, carbon turnover exceeds that of copepods in the fjord, since biomass of the copepod community was low in the fjord.

Analysis of the plankton community structure suggests a separation of the offshore and the inner fjord systems. It is therefore suggested that differences in plankton community structure are determined by the physical gradients due to run off from the ice sheet and the inflow of the West Greenland Currents. Consequently the plankton community structures are exposed to dramatic changes as climate change is predicted to restructure the physical conditions in both the offshore region, in terms of changes in



currents patterns, and in the fjord system in terms of increased run off from the ice sheet. The results of this study will be presented in a separate paper.

7.6 Hydrographic work and mooring development in Kobbefjord

Kunuk Lennert, Søren Rysgaard and John Mortensen

As a part of the Exchange project, hydrographical measurements were initiated in Kobbefjord near Nuuk. Kobbefjord is a small fjord with a well defined hydrologic catchment area, no connection with the Greenland ice sheet, an interesting bathymetry with a number of separate basins (Figure 7.5) and therefore an ideal developing platform for numerical model studies. Furthermore, Kobbefjord is study area for the Nuuk Basic programme, financially supported by the Danish Environmental Protection Agency, and, hence, numerous biological and physical data will be available to support the hydrographical data and vice versa. The freshwater influx from land to the fjord have been measured by Asiaq - Greenland Survey during a part of 2007 and several CTD surveys have also been performed during 2007.

Parallel with the hydrographic work there have been an ongoing work on developing different types of moorings. The purpose of these moorings is to obtain long continuous time series of different hydrographic properties in different water masses or layers. In fjord research focus is on the thin freshwater layer at the surface. In Kobbefjord this layer varies between 1 m and 10 m. To collect data from this thin surface layer we developed the "GN freshwater 1" mooring equipped with a Sea-Bird Electronics SBE 37SMP "Micro-CAT", figure 7.6. In Kobbefjord the "GN freshwater 1" has proven to work well.

"GN freshwater 1" works well in waters not influenced by ice from glaciers. In Godthåbsfjord, a fjord with a number of calving glaciers, we have used a mooring developed by Institut für Meereskunde, Universität Hamburg. The "GN Tube 1" moorings which will be deployed in the beginning of 2008 will be made up by an approximately 15 m long polyethylene tube containing buoyancy and one SBE







Figure 7.6. GN freshwater mooring ("GN freshwater 1") and smoothed (14 days running mean) time series of salinity and temperature in 2007. The moorings from north and south side of the fjord are indicated by green and black respectively. 37SMP "MicroCAT" with the tube connected to a bottom weight at 30 meter depth by a Meteor line.

7.7 Population dynamics of marine macrobenthos in Greenland – ecological role and effects of climate variation

Martin E. Blicher

The project is connected to existing marine climate charge effect monitoring programmes, Nuuk Basic and Zackenberg Basic, and focuses on the population dynamics of marine macrobenthos and their role in carbon cycling in Greenland in general, and in the Nuuk area in particular. The benthic fauna is an important food source for many predators including commercial fish species. In an attempt to build up knowledge about potential effects of climate change on marine benthic communities the effect of different biotic and abiotic factors on growth and production of benthic macroinvertebrates will be studied. From a broad ecological perspective the focus will be on the direct and indirect effects of reduced sea ice cover and variations in food level, temperature and salinity on growth at geographical, annual and seasonal scale. In several benthic species in the Arctic, the average individual growth pattern of populations can be

described by studying annually formed growth increments in the skeletal parts. This method will be used to describe spatial and annual variation in growth, which can be compared to environmental variations on similar scales and thus reveal couplings between physical and biological parameters and give indications of ecosystem processes on scales, which are very informative but only studied infrequently elsewhere. The coupling between environment and population dynamics of macrobenthos on a seasonal scale will be studied through detailed monitoring of relevant biotic and abiotic parameters in situ and growth and reproduction cycles of caged specimens at sites off Nuuk. The project will focus on species which are common in most parts of Greenland and thus achieve high ecological relevance and also make it possible to compare sub-arctic and high arctic populations. Currently it is expected to involve the bivalves, Chlamys islandica and Clinocardium ciliatum, and the sea urchin, Strongylocentrotus droebachiensis.

Further, the project aims at producing detailed descriptions of macrobenthic communities in areas in Greenland differing in climatic conditions. The overall aim is to increase the understanding of the existing marine ecosystem structure in Greenland and through this knowledge to be able to predict potential effects of future climate variation.



Figure 7.7. Sea urchin skeletal plate showing annually formed growth increments (Photo Martin E. Blicher).



7.8 Faster growth and higher production of benthic fauna in sub-arctic compared to high arctic Greenland

Martin E. Blicher, Mikael K. Sejr and Søren Rysgaard

This study was based on the idea that an existing spatial climate gradient from high arctic to sub-arctic areas will reflect the predicted temporal development in arctic climate and thus give an indication of the scale of ecological changes to be expected in the future. In 2005-6 we investigated individual growth of sea urchin *Strongylocentrotus droebachiensis* at several locations between Nuuk in the southern part of West Greenland and Qaanaaq in the northern part of West Greenland. Age of individuals was estimated from growth increments in the skeletal plates (Figure



Figure 7.8. D-tag and humpback whale.

Figure 7.9. Diving behaviour of a humpback whale recorded on a D-tag. 7.7) and average growth patterns of populations were determined by fitting growth functions to size-at-age data. This revealed a decline in growth performance of sea urchins along a southnorth climate gradient in Greenland (64-77°N). The length of open-water periods explained more than 80% (p < 0.01) of the observed variability in growth between populations. In two fjords, the sub-arctic Kobbefjord off Nuuk and the high arctic Young Sund, densities and size frequencies of sea urchins have been determined using underwater camera equipment. By supplementing these data with size-mass relationships and estimates of reproductive output, the annual production at population level can be estimated. Preliminary results indicate that annual secondary production at population level in the sub-arctic fjord is up to ten times higher than in the high arctic fjord. This difference is proportional to differences in primary production, which is strongly reduced by sea ice in high arctic areas. In combination these findings indicate that future reductions in arctic sea ice cover, through its effect on marine primary production, is important for carbon cycling in marine ecosystems in the Arctic and that secondary production in the high arctic might be positively affected by a future warming.

Figure 7.10. Multidimensional scaling plot of benthic community structure in Godthåbsfjord and on Fylla Banke, West Greenland. Results are for square root transformed data on abundance. Ovals surrounding points refer to the 20% similarity value determined by cluster analysis.

7.9 Humpback whale foraging mechanisms and ecology

Malene Simon and Peter T. Madsen

Humpback whales (*Megaptera novaean-gliae*) migrate to the Arctic to feed in Godthåbsfjord, West Greenland, from



May to October. Rorquals feed on zooplankton and fish by engulfing up to 70 tonnes of prey-laden water in a single mouthful, a process that has aptly been coined the largest biomechanical action in the animal kingdom. The currently held view on this so-called lunge feeding is that whales accelerate to rush towards a prey patch, reaching speeds of up to 4 m/s just before opening the mouth (Goldbogen et al 2006). Speeds of over 3 m/s are believed to be required to generate the hydrodynamic force that inflates the ventral buccal pouch (Orton and Brodie 1987; Goldbogen et al 2007). The increased drag from the mouth opening appears to decelerate the whale to a near stop at the end of the lunge (Goldbogen et al 2006). This acceleration-deceleration hunting strategy seem oxygen expensive and inefficient for an air breathing animal that depends on finding and capturing prey on several hundred meters depth. We investigate this hypothesis by tagging humpback whales in Godthåbsfjord with D-tags.

D-tags are digital non-invasive, inertialsensing tags containing tri-axial accelerometers, magnetometers and depth sensors sampled at 50 Hz recording sounds and 3-D movements of the tagged animal. D-tags have been used on a number of whale species, including deep sea species like sperm whales and beaked whales and have revealed new and detailed information on the foraging behaviour (Johnson et al. 2004; Madsen et al. 2005).

We tagged three humpback whales with D-tags in Godthåbsfjord in July 2007 using a handheld carbon fibre pole to deploy the D-tags onto the whales with suctions cups (Figure 7.8). The tags release after a pre-programmed time period and the tag is retrieved using VHF tracking. The data is downloaded from the tag through an IR port (Figure 7.9) (Johnson and Tyack 2003).

The D-tagging will continue in June 2008 in Godthåbsfjord where a 14 m cantilevered carbon fibre pole will be used. In 2008 we aim to investigate the humpback whales ecological influence and importance in the Godthåbsfjord ecosystem by looking at the foraging frequency of these apex predators.

7.10 Diversity, abundance and biomass of the macrobenthic community in Godthåbsfjord

Mikael K. Sejr and Martin E. Blicher

Exceptionally high diversity was found along the sampled transect from the inner part of Godthåbsfjord to the outer slope of Fylla Banke. A total of 340 different species were identified in the samples representing just 2.7 m² of sea floor. The high species richness is a result of very different habitats was sampled.

Analysis of sediment characteristics such as grain size and chlorophyll content showed very distinct differences which combined with depth was able to explain 91% of the variation in diversity (P<0.05) by the following linear model:

Diversity (ES₁₀₀) = $0.027D - 6.670C - 0.121G_{<63} + 0.355G_{125-250} + 21.210$

Where *D* is water depth (m), *C* is chlorophyll *a* (μ g m⁻²). *G*_{<63} and *G*₁₂₅₋₂₅₀ refer to size fractions of sediment particles in the intervals <63µm and 125 to 250µm, respectively. From the species composition four distinct macrobenthic communities was identified corresponding to 1) the Continental Shelf, 2) the central Fylla Banke, 3) the outer fjord and 4) the central fjord (Figure 7.10). Species diversity at each station changed along the sampled transects (Figure 7.11). Highest diversity, as estimated by the number of species per 100 individuals (ES₁₀₀), was found at FB4, FB3 and GF5. Approximately 20% of the variation in diversity could be correlated to depth (P<0.01, df =26). Abundance and biomass also varied significantly between stations (Figure 7.12). A detailed analysis of the results will be presented in a separate paper in 2009. The present study demonstrated the complexity of the coastal ecosystem of Southwest Greenland. The identification of several distinct communities highlights the need for additional studies of the basic structures and carbon flow within the coastal ecosystem before predictions can be made regarding the effect of future changes in climate. Based on this study and a study carried out at Store Hellefiske Banke (MarinID 1978), available



data suggest that the physical heterogeneity of the Southwest Greenland coast with deep fjords, and shallow banks combined with relatively high primary production create an environment which favours the existence of a very species rich benthic fauna where the total number of species exceeds what is found on the Norwegian shelf, Svalbard and northern Canada.

7.11 Ecosystem metabolism in Kobbefjord

Mikael K. Sejr, Dorte Krause-Jensen, Tage Dalsgaard, Sergio Ruiz, Mathias Middelboe, Ronnie N. Glud and Søren Rysgaard

In September 2007 scientist from the National Environmental Research Institute at the University of Aarhus, the University of Copenhagen, the Mediterranean



Figure 7.12. Mean abundance ± S.E (bars) and biomass (scatter points) of macrobenthos in Godthåbsfjord and on Fylla Banke areas.



Institute for Advanced Studies in Spain and from the Dunstaffnage Marine Laboratory in Scotland joined scientist from GN (Greenland Institute of Natural Resources) in a two week field campaign in Kobbefjord as part of a project funded by KVUG (The Commission for Scientific Research in Greenland).

The aim was to study what controls marine productivity at the beginning of the food chain where microscopic algae and bacteria are involved and to identify how the lower trophic levels could be susceptible to climate change. To do this the project focused at quantifying the ecosystem metabolism in Kobbefjord. The metabolism of an ecosystem is the sum of heterotrophic and autotrophic processes. A system is thus classified as net autotrophic when production of organic carbon is higher than consumption. Despite its fundamental role in terms of carbon, very little is known about the metabolic state of coastal waters especially in the Arctic. Whereas considerable effort has been invested in understanding what controls the autotrophic processes much less is know about what regulates the heterotrophic processes in the coastal ecosystem surrounding Greenland. Information of the carbon flow at the lower trophic levels is essential if we are to identify impacts of climate change in the future. One of the predicted effects of climate change is increased input of freshwater into the Greenland fjords due to increased precipitation and melting of the Greenland Ice Sheet. The increase in riverine input of nutrients and organic carbon affects the balance between heterotrophic and autotrophic processes. Therefore, a specific aim of the project was to study how freshwater influences the metabolism in Kobbefjord. Another important aspect of

measurements in light and
dark bottles incubated for
24 hours in Kobbefjord
in 2007. "NPP" denotes
oxygen production in light
bottles and "Resp" oxygen
roduction in dark
bottles. The gross primary
production ("GPP") was
calculated by adding
respiration rates to net
primary production.inc
Gr
tat
bal
bal
bal
bal
bal
bottles.

Figure 7.13. Water

column productivity estimated from oxygen



ecosystem metabolism is that it affects the oceans capability to take up atmospheric CO₂. Net heterotrophic systems will release CO₂ to the atmosphere whereas autotrophic systems will take up CO₂ from the atmosphere. At present, the oceans take up a large fraction of the anthropogenic CO₂ emissions. But this buffer capacity is not unlimited and more information on how biological activity influences the oceans uptake of CO₂ is needed. In this study, the primary aim related to CO₂ was to determine if Kobbefjord on an annual timescale is a source or a sink of atmospheric carbon and to identify some of the physical and biological processes that influence air-sea CO₂ flux.

During the two week field campaign detailed studies of all the different carbon pools in Kobbefjord were conducted; particulate organic carbon, dissolved organic carbon and volatile organic carbon. The net ecosystem metabolism was also determined on several occasions at the main sampling station in Kobbefjord. This was done by measuring the production and consumption of oxygen in closed dark and light bottles incubated in situ for 24 hours in Kobbefjord. The preliminary results of a single deployment are shown in figure 7.13. The water column respiration (labelled "resp") was highest at the surface. The gross primary production (labelled GPP) also showed a maximum at the surface and decreased with depth most likely reflecting light availability. The resulting net primary production ("NPP") was only positive at 5 and 10 m depth indicating that, when integrating, the entire water column the pelagic ecosystem in Kobbefjord was heterotrophic at that sampling date. When all data are available from the lab, concurrent data on concentration of nutrients, different carbon pools, bacterial activity and density will give us the possibility to determine what factors are important for determining levels of the heterotrophic and autotrophic processes and thus determine the net ecosystem metabolism. Although the ecosystem was net heterotrophic on that particular sampling date and thus produced CO₂, the surface water during the sampling period was under-saturated with CO₂ and served as a sink for atmospheric CO₂. This demonstrates the temporal complexity of air-sea CO₂ flux and highlights the

importance of conducting seasonal studies in order to understand what drives the exchange of CO_2 and to determine the net flux at an annual scale. In the project, this is accomplished through the collaboration and synergy with the Nuuk Basic monitoring program that provides seasonal measurements of the physical and biological processes in the area.

In 2008 two more field campaigns are planned in Kobbefjord to study the seasonal difference in ecosystem metabolism. Also, field campaigns are planned to the high arctic Young Sund to compare ecosystem metabolism between subarctic and high arctic fjords in Greenland.

7.12 Capelin ecology in Godthåbsfjord

Rasmus Berg Hedeholm

The capelin is the most important pelagic fish in the marine ecosystem along the coast of Greenland. Due to its ubiquity, capelin is a key species in the ecosystem and is hypothesized to affect all levels of the arctic marine food chain. Not only does it consume large amounts of zooplankton, but it is also a major prey species for commercially important species such as cod, halibut and baleen whales. Since capelin in this way affects energy flow throughout the system, changes in capelin distribution and abundance can have major ecological consequences. In spite of this, knowledge on capelin as a component in the Greenlandic ecosystem is scarce and has not been built on in many years. This makes it impossible to predict the consequences of environmental changes which, in light of the dramatic climatic changes observed in the Arctic in recent years, are becoming increasingly relevant. In order to comprehend and quantify the effects of such changes, an understanding of capelin ecology is essential. Capelin ecology forms the focus of this study, which is a part of the arctic monitoring programme Nuuk Basic.

To quantify the influence of capelin on pelagic energy flow, knowledge on feeding behaviour, energy consumption and abundance must be obtained. In Godthåbsfjord, fish have been sampled from various locations, and the stomach content has been identified. Preliminary results show that copepods and krill are the major prey items. Since stomach content only provides a snapshot of feeding at a given time, a more comprehensive picture of feeding behaviour has been obtained through stable isotope analysis, confirming the results from the stomach analysis. The energy consumed within the fjord system by capelin can then be estimated, when this knowledge is combined with acoustic surveys determining the total abundance of capelin in the fjord system. This survey is to be conducted in May 2008. To give a broader ecological perspective, this knowledge on energy consumption is used to estimate the flow of energy from phytoplankton to whales.

The environmental changes in the Arctic could affect capelin growth, and thus the entire ecosystem, through for example altered temperature and shifts in prey distribution.

Growth patterns in capelin from the west coast of Greenland have been determined through otolith studies (Figure 7.14). Capelin grows progressively faster moving north along the coast with the average size of three year old fish increasing from 9 to 15 cm (Figure 7.15). Since the environment also changes along the latitudinal gradient, this could be used to gain insight into the effect of altering environmental conditions. Figure 7.14. Otoliths from five year old capelin from Disko Bay.



7.13 Exchange (Exchange between Godthåbsfjord and the coast)

Søren Rysgaard, Morten Frederiksen, Kunuk Lennert and John Mortensen

The overall goal of the Exchange project is to increase our understanding and provide basic information on the hydrography of Godthåbsfjord with special attention on the exchange between the fjord and the coast. Several approaches were used to obtain this information: Hydrographical surveys with CTD casts along a length transect from the inner parts of the fjord to the open sea were performed during spring and autumn 2006, time series of temperature, salinity and pressure were continuously sampled by moorings in the outer part of the fjord and, finally, water exchange and water flow patterns was determined by an Acoustic Doppler Current Profiler (ADCP). The part including mooring work had the highest priority.

In addition to provide basic hydrographical information on Godthåbsfjord, the knowledge obtained from the Exchange project can be used in future mooring constructions and deployments and the time series obtained are important for the development and validation of hydrodynamic models of the fjord. Furthermore, the Exchange project in combination with the Danish Environmental Protection Agency funded Nuuk Basic monitoring programme makes it possible to link physical oceanography to biological production of Godthåbsfjord, which is essential for predicting future climate changes influence on the marine ecosystem.

Two moorings were deployed in Godthåbsfjord on 23 March 2006 at the sill outside the city of Nuuk. This position is ideal for measuring the exchange between



Figure 7.15. Average size of three year old capelin at different latitudes along the West Greenlandic coast.

Godthåbsfjord and the coast as water from all branches of Godthåbsfjord passes this point. The sill is relatively deep and the moorings were placed at 297 m depth and near the shore at 27 m depth, respectively, to monitor both deep and surface water masses.

The deep mooring deployed in the middle of the fjord was without problem recovered on 17 April 2007.

7.14 Biogeochemistry in sediments of West Greenland

Søren Rysgaard and Nils Risgaard-Petersen

During a three week expedition with the R/V Maria S. Merian (Cruise MSM 05/03) various samples were collected from Nuuk (including Godthåbsfjord) to Uummannaq to study deglaciation history, coastal development, and environmental change during the Holocene in West Greenland. Sediment cores were collected from shallow water down to 1.300 m water depth. The upper sediment layers were used to describe present-day carbon and nutrient cycling in arctic sediments. Rate measurements covered oxygen respiration, denitrification, anammox and carbon mineralization as well as fluxes of dissolved inorganic carbon and nutrients across the sediment-water interface. Furthermore, sampling in the upper sediment layers for identification and activity measurements of benthic foraminifera was made on various stations. In addition, the depth distribution of O_{2} , NH₄⁺, NO₃⁻, dissolved inorganic carbon, CH₄, organic carbon and nitrogen as well as ¹³C and ¹⁵N in the sediment will form basis for interpretation and modelling biogeochemical transformations in the sediment. Experimental and analytical work is expected to be completed early 2008. Preliminary results of microbial activity in a 6 m long sediment core collected at station # 343340 in Disko Bay show that DIC increases with depth from app 2 mM in the surface to more than 10 mM at 5 m depth. The profile indicates DIC production in the upper metres and DIC consumption at 4-6 meters depth, the latter being due to methanogenesis. Direct measurements of DIC production and consumption confirm this pattern. Yet, the activity estimates are still based on few data and more will be provided during the next months together with data for distribution and turnover of methane. The depth integrated DIC production (estimated as DIC efflux from incubated cores of surface sediment), is 100% balanced by the oxygen consumption of the sediment indicating complete re-oxidation of reduction equivalents produced during organic matter decomposition (e.g. H₂S, Fe⁺⁺, NH₄⁺). Oxygen consumption is confined to the upper 2 cm of the sediment, while we can measure DIC net production down to at least 60 cm. Nitrate respiration, measured as denitrification (i.e. the respiratory pathway that succeeds oxygen respiration) is probably confined to the upper 2-4 cm of the core (which will be confirmed by data from NO₃⁻ profile measurements) and accounts for less than 1% of DIC production.

7.15 Surface *p*CO₂ in the seas around Greenland

Søren Rysgaard, Kunuk Lennert, Ditte Marie Mikkelsen and John Mortensen

It has recently been suggested (Rysgaard et al. 2007) that sea ice may act as carbon pump in polar seas. During sea ice formation in polar seas, brine rejection increases the density in the underlying water column and thereby contributes to the formation of deep and intermediate water masses in the oceans. Evidence has been presented that dissolved inorganic carbon (TCO₂) is rejected together with brine from growing sea ice and that low temperatures may result in a significant change in the ratio of TCO₂ and alkalinity in arctic sea ice compared with surface waters. Previous model calculations show that the sea ice-driven carbon pump affects surface water partial pressure of CO₂ significantly in polar seas and potentially sequesters large amounts of CO_2 to the deep ocean.

Participation on several cruises (R/VMerian, Agdlek) enabled surface water sampling from Upernavik along the West Greenland coast, crossing over to Iceland. Along this route, numerous transects were performed in the fjords and on the shelf. In short, surface samples from the water column were taken for the determination of dissolved inorganic carbon (TCO₂), total alkalinity (TA), ¹⁸O, nutrients and chlorophyll contents. Care was taken when filling the gas tight glass bottles (250 ml) for TCO₂, TA and ¹⁸O determination to avoid bubble trapping and to ensure sufficient overflow. Samples were preserved with 50 µl HgCl₂ (saturated solution) and kept cold (2°C) until analysis. Water samples for nutrients and chlorophyll determination were frozen (-18°C), and analyzed in the laboratory at Greenland Institute for Natural Resources, Nuuk. This comprehensive dataset will be published elsewhere.

7.16 Photo-identification of humpback whales in Godthåbsfjord

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

Photo-identification of wild animals uses natural markings such as scars, nicks and coloration patterns to identify individuals within the same species. The technique can in combination with mark-recapture techniques be used for estimating abundance of marine mammals in specific areas. Secondly photo-ID can be used to address how long the animals stay in a given area (residence time) but also to verify whether or not, it is the same individuals that return to an area year after year, known as site fidelity (Bejder & Dawson, 2001). In humpback whales (Megaptera novaeangliae) the underside of the fluke is used for identification as the tail contains individual colour patterns which are as different as our fingerprint.

Every summer Godthåbsfjord is visited by humpback whales that come to the fjord to forage. However, very little is known about the whales in West Greenland, and nothing is known about site fidelity or residence time in Godthåbsfjord, which in turn reflects on the biomass turnover of the foraging whales. This project aims to alleviate this lack of data by using photo-identification to study site fidelity and residence time in the Godthåbsfjord humpback whales as well as providing a minimum estimate of the number of whales foraging in the fjord.

From April to October 2007 a total of 45 days was spent at sea collecting id-photos using a 350 EOS Canon camera with a 300 mm Canon lens. Local people along with guides on the whale safari boats also kindly contributed with photos. During the field season of 2007, 54 photos were collected, leading to the identification of 20 different individuals in Godthåbsfjord.

To determine residence time we used the id-photos to clarify which whales were present in a given time period. Most whales were present during June (31%) whereas May and September had the lowest number of individuals (4%). On average the whales stayed in the fjord for 2 weeks (SD=1.8). However, a single individual remained in the fjord throughout the entire season. One individual was present in July and returned to the fjord in mid-October around the time where the humpback whales start their southward migration.

Id-photos collected during the summer

of 2007 were compared to an already existing catalogue of id-photos collected from 1988-93 (Larsen & Hammond, 2004) to determine site fidelity. Year to year site fidelity was verified in 20% of the identified individuals. Two individuals observed in Godthåbsfjord in 2007 were matched to id-photos dating back to 1991 and 1992. Two individuals also observed in Godthåbsfjord in 2007 were matched to id-photos taken in 2006. Positive id-matches of different years were also seen amongst photos in the catalogue.

The open fjord system allows the whales to migrate in and out throughout the season. Despite this, some individuals return to this specific fjord system, which strongly indicates year to year site fidelity



Figure 7.16. Two whales that spent the summer of 2007 in Godthåbsfjord.



Figure 7.17. Photos of the same whale visiting Godthåbsfjord in 1991 and 2007, respectively.

in the West Greenlandic humpback whales foraging in Godthåbsfjord.

In the field season of 2008 we will continue to collect id-photos that will be part of an id-catalogue along with photos from previous years. We will continue to identify individuals to determine further site fidelity and aim to give a minimum estimate of foraging humpback whales in Godthåbsfjord with implications for habitat use and biomass turnover.

8 Nuuk Basic – A conceptual framework for monitoring climate effects and feedback in arctic ecosystems

Mads C. Forchhammer, Morten Rasch and Søren Rysgaard

This chapter presents a conceptual framework for implementing the longterm ecosystem monitoring programme Nuuk Basic in low arctic Greenland. The overall purpose of Nuuk Basic is to collect long-term data quantifying seasonal and inter-annual variations and long-term changes in the biological and geophysical properties of the terrestrial, freshwater and marine ecosystem compartments in relation to local, regional and global climate variability and change. The overall aim of Nuuk Basic is to establish a data platform which enables (i) a thorough description and analysis of climatic effects on the structure, function and feedback dynamics of a low arctic ecosystem, (ii) together with its existing high arctic counterpart, Zackenberg Basic, a more complete spatial coverage of the general climate-ecosystems interactions across the Arctic, and (iii) an understanding of the interactions between human utilization of natural resources and climate effects. The successful implementation and continued operation of Nuuk Basic will be secured by the internationally unique operational expertise Denmark/Greenland has gained through ten years operation of Zackenberg Basic.

8.1 Background

The arctic climate displays dramatic changing. During the last 50 years temperature increases of 2-3°C have occurred throughout the Arctic (Chapmann and Walsh 2003), and projections for future arctic climate predict temperature increases of 5-7°C by the end of the 21st century (Kattsov et al. 2005). Indeed, pronounced climate changes are also expected for Greenland during the next 100 years with temperature increases of up to 6-8°C in Northeast Greenland following the expected retreat and reduction in the Polar Sea Ice (Storis) (Rysgaard et al. 2003). In contrast, temperatures are only expected to increase to 2-5°C in West Greenland. Similarly, precipitation in Greenland, in particular winter precipitation, has been predicted to increase 20-30% (minus evaporation) in the forthcoming 100 years (Kattsov et al. 2005).

It is also well-established that the Arctic during the past 3 decades has experienced considerable and rather dramatic changes in the Cryosphere and in ultraviolet (UV) radiation compared to previous time periods (Walsh et al. 2005, Weatherhead et al. 2005). For example, there has been an average reduction of up to 11% of ozone over the last 25 years and since 1990 episodic reductions between 25-45% during spring. Future changes predict continuous low concentrations of ozone over the Arctic with concomitant high levels of UV radiation with increased negative impact on the arctic ecosystems which is most vulnerable for radiation in the spring (Weatherhead et al. 2005).

Similarly, the observed changes in the Cryosphere portray future dramatic changes. For example, associated with the behaviour of large-scale ocean-atmosphere fluctuations such as the Arctic Oscillation or the North Atlantic Oscillation, the thickness and the extent of arctic sea ice have been reduced over the last 30 years, indicating 20% acceleration in the rate of the decrease of sea ice in the Northern Hemisphere (Cavalieri et al. 2003). Concomitantly, the terrestrial snow cover in the Northern Hemisphere has been reduced by 10% and with the expected temperature increase of 5-7°C further significant reduction in snow cover is expected (Walsh et al. 2005). Coinciding with the measured increase in ground

temperature in the Arctic, a significant degradation of permafrost has been observed. This is expected to continue with up to further 10-20% degradation during the 21st century resulting in a displacement of the southern range of permafrost hundreds of kilometres northward (Walsh et al. 2005). Notwithstanding the effects of increased temperature in the Arctic, the accumulation and thinning processes of the Greenland Ice Sheet are highly variable in time and space and are influenced by more than just atmospheric warming (Rignot & Thomas 2002). However, recent time series of maximum summer melt extent of the Greenland Ice Sheet do indicate a decadal trend of increased melt, in particular in West Greenland. Indeed dramatic melt rates such as those recently reported from the glaciers in the inner parts of Godthåbsfjord (Rignot & Kanagaratnam 2006) - suggest potentials for not only increased sea level rise by the 2100 (Walsh et al. 2005, Velicogna and Wahr 2006) but, equally important, an increased input of freshwater to the marine ecosystems in West Greenland.

Evidently, such changes in the climate, the Cryosphere and UV radiation will impose tremendous constraint on the terrestrial, limnic and marine environment of the Arctic with significant consequences for the structure, function and feedback of arctic ecosystems (Callaghan et al. 2005, Wrona et al. 2005, Weatherhead et al. 2005). Indeed, the consequences may be anything but simple. For example, following the projected increase in temperature considerably shifts in ecotypes are expected where the high arctic polar deserts will be replaced by low arctic tundra, which, in turn, will be invaded by forest like habitats (Callaghan et al. 2005). Such changes in the terrestrial vegetation will affect the feedback dynamics of gasses, where increased vegetation cover will increase net storage of carbon but increase the terrestrial flux of methane to the atmosphere (Callaghan et al. 2005). Similarly will the effects UV on individual metabolic rates perpetuate to ecosystem level and increased UV radiation is expected influence the entire cycle of nutrients.

To what extent complex climatic effects may be equally important across the low and high arctic ecosystems is currently unknown and a multidisciplinary approach to ecosystem monitoring is required to illuminate this. Indeed, this is the lesson learned from over ten years of monitoring of a high arctic ecosystem at Zackenberg in Northeast Greenland. Through the monitoring program Zackenberg Basic, we have come to acknowledge that although large-scale trends in climate changes in the Arctic display clear trends of, for example, increased temperature and retreating sea ice cover, such changes are not necessarily observed in local climate. In fact, what have been observed at Zackenberg over the last ten years are weather conditions varying tremendously from year to year. More importantly, the ecosystem at Zackenberg is highly responsive to this with significant consequences for the function of organisms as well as the annual dynamics of gas fluxes (Meltofte 2002). In addition to the high variability in local weather and ecosystem responses, the research and monitoring at Zackenberg has also demonstrated that similar climate changes perpetuate across physical barriers causing similar responses in physical separated and evolutionary distinct organisms. For example, long-lived organisms such as the willow on land and marine mussels display similar annual growth responses to changes in snow and ice cover, respectively, mediated by large-scale climatic systems like the North Atlantic Oscillation (Schmidt et al. 2006).

Central to the scientific establishment of Nuuk Basic is the multidisciplinary knowledge of climate-ecosystem interaction gained through Zackenberg Basic including the aforementioned presence of local spatiotemporal variability as well as the potential numerating effects of climate. However, it is equally important to realise that the establishment of Nuuk Basic in low arctic Greenland comprise unique and urgently needed additions (ACIA 2005) to our understanding of climate impacts in the Arctic, which cannot be achieved through Zackenberg Basic alone. First, Nuuk Basic will enable a thorough description and analysis of climatic effects in a low arctic ecosystem. Second, together with Zackenberg Basic, Nuuk Basic will provide a more complete spatial coverage of the general climate-ecosystem interactions across the Arctic and, third, Nuuk Basic will provide us with a far better understanding of the interactions between human utilization of natural resources and climate effects.

8.2 Recommendations by ACIA and beyond

As exemplified above, persistent climatic changes are likely to cause rather complex and in many cases unexpected indirect changes in the arctic ecosystems (Forchhammer 2002, Forchhammer & Post 2004). Indeed, our ability to understand, monitor, evaluate and model the consequences requires a comprehensive synthesis of current knowledge of all available information on the observed and projected climatic effects across the Arctic. Recently, Climate Impact Assessment (ACIA), which has provided us with an unparalleled and comprehensive assessment of climate impacts based on previous observed concomitant changes in climate, terrestrial, freshwater and marine systems in the Arctic (ACIA 2005). Founded upon the large amount of information provided by the assessment, ACIA has specified a range of recommendations pivotal for future climate change research in the Arctic (Table 8.1). These together with those proposed by the Arctic Monitoring Assessment

this challenge was taken up by the Arctic

Table 8.1. ACIA recommendations of relevance to Nuuk Basic. Adopted from Forchhammer et al. 2008.

Recommendations	Programme	Action
Cryosphere and hydrology	•••••	
Sea ice: Fine resolution studies of sea ice cover in coastal waters	Μ	Satellite and photo surveillance
Sea ice: Seasonal, inter-annual and interdecadal measurements of sea surface albedo	Μ	Satellite surveillance (optional)
Snow cover: In situ measurements of snow water equivalents in high latitude areas	CG	Manual snow depth and density measurements
Snow cover: Measurements of snow albedo over northern terrestrial regions	CG	Point measurements, satellite surveillance (optional)
Snow cover: Establishment of models to simulate snow melt process	CG	Point and spatial through camera and satellite surveillance
Glaciers and ice sheets: Mass balance studies from regions where data are sparse	M/GEUS	None in programmes. Link to GEUS ice margin monitoring
Permafrost: Long-term field data on permafrost-climate interactions and on permafrost- hydrology interactions	G	CALM
River and lake ice: Improve understanding of hydrological and meteorological control of freeze-up and break-up	CBG	Hydrological monitoring, camera surveillance
Freshwater discharge: Increase the network of gauge stations for monitoring discharge rates	С	Hydrological monitoring
Freshwater discharge: Better estimation of subsurface flow		None
Arctic Tundra and Polar Desert ecosystems	••••	•
Biodiversity changes: Monitor currently widespread species that are likely to decline under climate change	В	Systematic monitoring of species
Relocation of species: Measure and project rates of species migration	В	Systematic transect monitoring (local/regional)
Vegetation zone redistribution: Improve information about current boundaries of veg- etation zones	BG	NDVI monitoring (cameras, satel- lite)
Carbon sinks and sources: Long-term, annual C monitoring throughout the Arctic	G	Not whole year but summer and 'shoulder' periods (CO ₂ and CH ₄)
Carbon sinks and sources: Models capable of scaling ecosystem processes from plot experiments to landscape scale	BG	Spatial modelling
Carbon sinks and sources: Develop observatories to relate disturbance to C dynamics	BCG	Monitoring platform and database
Carbon sinks and sources: Combine ecosystem carbon flux estimates with C flux from thawing permafrost	G	Irrelevant to Nuuk Basic. No permafrost
Ultraviolet-B radiation and CO_2 impacts: Long-term impact on ecosystem of increased CO_2 concentrations and UV-B radiation	BCG	UV-B and CO_2 monitoring
Increasing and extending the use of indigenous knowledge: Expand use of indig- enous knowledge	G	None
Monitoring: More networks of standardised, long-term monitoring are required	BCG	It is the ambition that Nuuk Basic participate in all such networks
Monitoring: Integrated cross-disciplinary monitoring of co-varying environmental variables	BCG	The concept for this is developed in Zackenberg- and NuukBasic
Monitoring: Long-term and year-round eddy covariance sites and other long-term flux sites for C flux measurements	G	Seasonal, CO_2 by eddy correlation, CH_4 by chamber measurements
Long-term and year-round approach: Long-term observations are required	BCG	ClimateBasic year round, Bio- and GeoBasic seasonal
Long-term and year-round approach: Year-round observations are necessary to under- stand importance of winter processes	BCG	ClimateBasic year round, Bio- and GeoBasic seasonal

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Recommendations	Programme	Action
Freshwater Ecosystems and fisheries	•••••	• •••••••••••••••••••••••••••••••••••••
Freshwater ecosystems: Increase knowledge on long-term changes in physical, chemical and biological attributes	BCG	Physical, chemical, biological monitoring
Freshwater ecosystems: Establish integrated, comprehensive monitoring programs at regional, national and circumpolar scales	BCG	It is the ambition that Nuuk Basic shall participate in all such networks
Freshwater ecosystems: Standardise internationally approach for monitoring	BCG	Standardised procedures developed for Nuuk Basic
Freshwater ecosystems: Improve knowledge of synergistic impacts of climate on aquatic organisms	BCG	Possible with existing data
Freshwater ecosystems: Increase understanding of cumulative impacts of multiple envi- ronmental stressors on fresh water ecosystems	В	Nuuk Basic mainly addresses undisturbed ecosystems in relation to climate
Freshwater ecosystems: Increase knowledge of effects of UV radiation - temperature interactions on aquatic biota	В	None
Freshwater ecosystems: Increase knowledge of linkages between structure and function of aquatic biota	BCG	Included in existing programmes
Freshwater ecosystems: Increase knowledge on coupling among physical/chemical and biotic processes	BCG	Included in existing programmes
Marine Systems		•••••••••••••••••••••••••••••••••••••••
Observational techniques: Increase application of recently developed techniques	Μ	Yes, state-of-the-art equipment and techniques in use
Surveying and monitoring: Undertake surveys that are poorly mapped and whose resident biota has not been surveyed	Μ	No investigations like this before the Zackenberg and Nuuk Basic
Surveying and monitoring: Continue and expand existing monitoring programs	Μ	It is the ambition that Nuuk Basic shall participate in international cooperation
Surveying and monitoring: Evaluate monitoring data through data analysis and modelling	Μ	Included
Data analysis and reconstruction: Reconstruct twentieth century forcing field		None
Data analysis and reconstruction: Establish database with all available physical and biological data	Μ	Included - data can easily be pro- vided to other databases
Data analysis and reconstruction: Recover past physical and biological data	Μ	Included
Data analysis and reconstruction: Past climate events to understand physical and biological responses to climate forcing	М	Included
Field programs: Undertake field studies to quantify climate-related processes	Μ	Major purpose
Modelling: Develop reliable regional models	MB	Included
Approaches: Prioritize ecosystem based research by integrating multiple ecosystem components in models concerning climate effects	MB	The concept in both Nuuk and Zackenberg Basic
Ozone and Ultraviolet Radiation		•••••••••••••••••••••••••••••••••••••••
Ultraviolet radiation: Address the impact of increased UV irradiance	BCG	Included

B: BioBasic, G: GeoBasic, C: ClimateBasic, M: MarineBasic, GEUS: Geological Survey of Denmark and Greenland

c, G: Geobasic, C: Climatebasic, M: Marinebasic, GEUS: Geological Survey of Denmark and Greenlan

Programme (AMAP) in their Climate Change Effects Monitoring Programme (AMAP 2000) and in their follow-up of ACIA (AMAP 2005) and by the International Conference on Arctic Research Planning II (ICARP II), specifically Working Groups 7, 8 and 9 (Prowse et al. 2005, Callaghan et al. 2005, Bengtsson et al. 2005) inherently form the objective core of the monitoring in Zackenberg Basic and Nuuk Basic. Indeed, most of the monitoring actions taken by the monitoring sub-programmes, ClimateBasic, GeoBasic, BioBasic and MarineBasic (Rasch et al. 2003), confine with the recommendation issued by ACIA embracing the long-term monitoring of Cryosphere and hydrology, arctic tundra systems, freshwater systems, marine systems and ultraviolet radiation (Table 8 1). In contrast to Zackenberg Basic, which monitors an untouched pristine high arctic ecosystem, Nuuk Basic monitors a low arctic ecosystem in which natural resources are utilized by the indigenous human population. Hence the implementation of Nuuk Basic are in accordance with a central issue addressed by ACIA, namely the role of resource utilization and climate change affecting arctic ecosystems (ACIA 2005).

Table 8.1. Continued.

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The recommendations provided by ACIA are formulated in a general context, that is, actions to be taken in future climate change monitoring are not specifically addressed to be carried out within a single ecosystem. Indeed, inherent to ACIA's (2005) notion on the need for increased spatial coverage of climate impacts, actions to be taken may be performed at different locations on selected organisms or communities without specifically monitoring the entire system in which these are embedded. In contrast and indeed as a unique additional feature, Zackenberg Basic and Nuuk Basic address ACIA recommendations within a selected ecosystem in the high arctic and low arctic region, respectively. Specifically, both programmes perform monitoring on all physical and biological levels of the ecosystem so all observed changes can be functionally connected and, hence, summarized and conveyed as ecosystem response to climate changes. In this perspective, the monitoring in Zackenberg Basic and Nuuk Basic not only complies with most of the recommendations by ACIA but also move beyond by providing as recommended by ICARP II (Prowse et al. 2005, Callaghan et al. 2005) new pivotal knowledge of (i) how an entire arctic ecosystem respond to climate changes and (ii) how these are perpetuated through the system as direct and indirect impacts (Forchhammer & Post 2004). The knowledge gained from system monitoring at Zackenberg Basic and Nuuk Basic therefore constitute a major and unique contribution to forthcoming revisions of the ACIA recommendations.

Figure 8.1. Conceptual visualization of the interactions between climate and ecosystem response (i, ii), ecosystem feedback (iii) and human resource utilization (iv). Adopted from Forchhammer et al. 2008.

8.3 The concept of climate change and feedback

The interactions between climate and ecosystem can basically be regarded as a two-way process (Figure 8. 1). First, any changes in climate such as increased variability in large-scale atmosphericocean systems will cause changes in the physical characteristics of ecosystems like snow and ice cover (Figure 8.1, arrow i). For example, the atmospheric fluctuations described by the Arctic Oscillation are closely associated with the last 35 years of inter-annual variability in snow onset, snow melt, and number of snow free days observed in the Northern Hemisphere (Bamzai 2003). Any climate-mediated changes in the physical characteristics will, in turn, affect the function of organisms and their interactions in the system. These effects may be divided into direct and indirect effects (Forchhammer & Post 2004). Direct climatic effects on the organisms themselves are easily observed with no time lags. For example, from the monitoring in Zackenberg Basic, we have learned that even small annual changes in the amount and extension of snow and sea ice have dramatic influence on for example seasonal growth, distribution and production of terrestrial vegetation as well as marine and freshwater plankton the following summer (Christoffersen & Jeppesen 2002, Mølgaard et al. 2002, Rysgaard et al. 1999, Tamstorf & Bay 2002). Indirect climatic effects, on the other hand, involve multi-organism interactions often between several trophic levels and are therefore more difficult to monitor using



single-organism monitoring approach alone (Forchhammer & Post 2004). This has been recognised in several temporal ecosystem communities but also at Zackenberg. For example, we know that following winters with much snow and prolonged ice cover on lakes, the seasonal production of freshwater zooplankton decreases dramatically as a result of the low abundance of their food, phytoplankton, and not ice cover per se (Christoffersen & Jeppesen 2002).

The second aspect of the two-way interaction between climate and ecosystem is the reciprocal feedback from ecosystem to climate through changes in e.g. carbon, water and energy balances (Figure 8.1, arrows ii and iii). Documented from the work at Zackenberg and other studies, we know that changes in the physical characteristics of ecosystems are highly correlated with changes in for example the annual flux of carbon from system to atmosphere (e.g. Nordstrøm et al. 2001, Grøndahl et al. 2006). However, to what extent the climate-mediated changes in the biological diversity, function and structure of natural ecosystems affect the feedback induced exchange of carbon has not been described previously. In this context, the

integration of GeoBasic, BioBasic and MarineBasic in Zackenberg Basic and Nuuk Basic offers a unique and unprecedented opportunity to bridge this gap of knowledge.

Specific integration of human resource utilization in the conceptual approach to monitoring climatic effects is rare although utilization of natural resources occurs throughout most arctic regions (Nuttall et al. 2005). In contrast to Zackenberg Basic, the monitoring of Nuuk Basic is performed in a system exposed to resource utilization (Figure 8.1, arrow iv) mainly through hunting and fisheries. Although Nuuk Basic is not planned to embrace specific monitoring of resource utilization, the programme is operated in a way that enables analytic comparisons with annual hunting statistics in West Greenland. The Greenland Institute of Natural Resources and the National Environmental Research Institute has taken the first steps in establishing and maintaining databases to be used in context with Nuuk Basic. The difference between Zackenberg Basic and Nuuk Basic with respect to the influence of indigenous peoples presents a new and unique comparable aspect of climatic effects on arctic ecosystems.

Basis Programme	Aim	
ClimateBasic and GeoBasic	 Provide long-term data that are: Necessary for describing all aspects of the regional climate at Zackenberg and Nuuk. To be used to quantify and model the variation in snow cover at Zackenberg and Nuuk. To quantify the freshwater, sediment and nutrient transport from the terrestrial system to the marine system. To quantify, together with BioBasic and MarineBasic, the carbon balance of the terrestrial part of low and high arctic ecosystems. To improve current understanding of the effect of climate variability on the physical land-scape dynamics. 	
BioBasic	 Provide long-term data: To establish ecological base-line data for evaluating and modelling how climatic changes, directly and indirectly, sum up and affect an entire low and high arctic ecosystem, respectively. For the fundamental knowledge of the spatio-temporal dynamics of a low and high arctic ecosystem in a changing climate. To describe and quantify intra- and intertrophic processes. To describe and quantify short- and long-term changes in UV radiation effects, species composition and the communities in which they are embedded. To describe and quantify short- and long-term changes in individual life history of central floral and faunal species. 	
MarineBasic	 Provide long-term data: Necessary for modelling the coupling between physical oceanography and biological production and consumption. For use in modelling the regulation of pelagic-benthic coupling (vertical flux). To quantify and improve understanding of the lateral coupling (land/fiord/sea). To quantify the effect of changing freshwater input, sea ice cover and deepwater formation on biological production and consumption. To improve current understanding of the effect of climatic changes on selected species composition and adaptation in the arctic marine environment. 	Tal ain gra Ba: Clii Bic Ad al.

Table 8.2. The specific aims of the four sub-programmes of Zackenberg Basic and Nuuk Basic: ClimateBasic, GeoBasic, BioBasic and MarineBasic. Adopted from Rasch et al. 2003.



Figure 8.2. Schematic landscape representation of the major scientific themes in Zackenberg Basic and Nuuk Basic and how these are related to the four sub-programmes: ClimateBasic (C), GeoBasic (G), BioBasic (B) and MarineBasic (M). Under each theme title is given the capital letters for the sub-programmes involved. Adopted from Forchhammer et al. 2008.

8.4 The scientific structure

The ecosystem monitoring programmes Zackenberg Basic and Nuuk Basic each consist of four sub-programmes related to the different physical and biological compartments representative of the ecosystem: ClimateBasic, GeoBasic, BioBasic and MarineBasic (Rasch et al. 2003), each focusing on providing longterm data within their compartments (Table 8.2). However, it must be emphasized that the four sub-programmes are established and operated in a highly integrative manner (Table 8.1) to secure the overall goal of Zackenberg Basic and Nuuk Basic: collect long-term data quantifying seasonal and inter-annual variations and long-term changes in the biological and geophysical properties of the terrestrial, freshwater and marine ecosystem compartments in relation to local, regional and global climate variability.

The sub-programmes of Zackenberg Basic and Nuuk Basic have been purposely constructed to be similar in order to enable a much more complete spatial coverage of the general climate-ecosystems interactions embracing both low and high arctic regions. ClimateBasic, Geo-Basic, BioBasic and MarineBasic have been described in details elsewhere (Rasch et al. 2003) and will not be presented here. Instead, extending on these basis-specific descriptions, we present a thematic overview of their integrative associations across the major scientific physical and biological themes embraced by both Zackenberg Basic and Nuuk Basic. The scientific structure of the monitoring in Zackenberg Basic and Nuuk Basic embrace a total of 14 central themes covering the climatic (Climate), physical (Snow, Soil, Ice, Sea Ice, Lakes, Hydrology, Oceanography, UV radiation) and biological (Soil, Vegetation, UV radiation effects, Gas flux, Lakes, Arthropods, Mammals,

Scientific theme	Description
Climate	Temperature (air, surface and soil), wind, humidity, precipitation
Snow	Cover, thickness, distribution
Hydrology	Water balance, nutrient cycling
Glacier ice	Iceberg export to Godthåbsfjord
Sea ice	Cover, thickness, distribution
UV radiation	Strength, seasonal, inter-annual variations and ecosystem effects
Soil	Water balance, chemistry, soil arthropods, decomposition
Vegetation	Species diversity, growth, reproduction, phenology, parasitism, distribution of vegeta- tion types, UV radiation effects
Gas flux	Carbon dioxide, methane, interactions with structure and function of herbivore-plant interactions
Lakes	Chemistry, carbon balance, abundance and production of plankton and fish
Arthropods	Insect abundance, reproduction and phenology
Mammals & Birds	Selected terrestrial, freshwater and marine species, species diversity, Abundance, distribution, reproduction, phenology
Water phase	Temperature, salinity, currents, chemistry, carbon balance, plankton, crustacean, fish.
Sea bottom	Chemistry, carbon balance, growth, abundance and distribution of benthic animals

Table 8.3. Summary of the central scientific themes embraced by the four sub-programmes in Zackenberg Basic and Nuuk Basic. Birds, marine pelagic- and benthic fauna and infauna) ecosystem compartments (Figure 8.2). What is obvious from figure 8.2 is that both Zackenberg Basic and Nuuk Basic display highly integrated monitoring across the four sub-programmes. A scientific summary of themes is given in table 8.3.

The operational structure of Nuuk Basic is outlined in figure 8.3. Nuuk Basic is the low arctic equivalent to Zackenberg Basic, and the different sub-programmes (Climate Basic, GeoBasic, BioBasic and MarineBasic) involved in Zackenberg Basic will also be responsible for the run of Nuuk Basic. As previously with Zackenberg Basic, the Nuuk Basic Working Group will be established with representatives from the different sub-programmes, logistics and relevant scientific key-supervisors with Danish Polar Centre as the secretariat. Nuuk Basic will be the monitoring component of the research programme Ecogreen in the same way as Zackenberg Basic is the research component of Zackenberg Ecological research Operations (ZERO).

It is the ambition to coordinate Nuuk Basic and Zackenberg Basic with other climate related monitoring activities in Greenland in a centre without walls, tentatively called the Greenland Climate Change Effects Monitoring Programme (Figure 8.3). One such example could be integration with the glaciological monitoring in Greenland funded by the Danish Environmental Protection Agency and operated by Geological Survey of Denmark and Greenland.

8.5 The geographic and logistic settings of Nuuk Basic

The study areas of Nuuk Basic embrace two localities; a main locality in Kobbefjord and a satellite locality in Nordlandet (Figure 8.4). Whereas Nordlandet focus on climate-related interactions between reindeer and their forage and how these influence the flux of carbon between land and atmosphere, Kobbefjord embrace an entire drainage basin (Figure 8.4). Specifically, the Kobbefjord study area consists of: (i) A well-confined fjord without branches and with a surface area of approximately 25 km², a maximum depth of approximately 145 m and a sill at the mouth at a depth of approximately



40 m, and (ii) a drainage basin with an area of 32 km² situated at the head of the fjord.

The local climate is low arctic with a mean annual temperature of -1.4 °C and a mean annual precipitation of 752 mm (1961-90). The drainage basin is situated in an alpine landscape with mountains rising up to 1400 m a.s.l. and with glacier coverage of approximately 2 km². Geologically, the area is homogenous with Precambrium gneisses as basement throughout the drainage basin. A well defined cross profile near the mouth of the local river enables easy measurements of drainage basin output, while the high mountains in the area allows for easy installation of digital cameras for snow cover monitoring. The terrestrial setting is diverse and includes the most typical vegetation types of a low arctic ecosystem within a very confined area. The area is well suited for monitoring the seasonal and inter-annual dynamics, carbon balance, biodiversity, zonal migration and

Figure 8.3. Operational structures for Nuuk Basic. **GCCEM:** Greenland Climate Change Effects Monitoring. **ZERO:** Zackenberg Ecological Research Operations. **UofC:** University of Copenhagen. **NERI:** National Environmental Research Institute. **GINR:** Greenland Institute of Natural Resources. **DPC:** Danish Polar Centre.



Figure 8.4. a: Locations of Zackenberg Basic and Nuuk Basic. b: The entire Godthåbsfjord system in which Nuuk Basic with the field stations at Kobbefjord and Nordlandet is located. c: The entire drainage bassin and associated terrestrial, freshwater and marine environments at Kobbefjord. structural and functional changes of terrestrial and freshwater communities.

In the fjord, the upper approximately 15 m of the water masses is affected by freshwater input from the local rivers during spring and summer. In the photic zone, the sea floor is characterised by a high diversity of fauna. Well oxygenated bottom waters are present in the fjord but, low oxic conditions can occur locally in bays with low water exchange. In the deeper parts of the fjord oxygen penetrates approximately 1 cm into the sea floor during winter, but only a few millimetres during summer.

A small field station with accommodation facilities for four persons will be established in the drainage basin at Kobbefjord. Nordlandet will have two cabins, one for the accommodation of two persons and one for storage. These facilities will be used only for piecewise intensive field campaigns through out the entire annual season. The Greenland Institute of Natural Resources will accommodate Danish scientists during longer campaigns, and will provide office and laboratory facilities for programme staff and visiting scientists.

8.6 Outreach and public foundation

Due to the proximity of the Nuuk Basic field site to Nuuk, the Capital of Greenland, the programme has an excellent opportunity to involve the local population in the monitoring activities and as such in climate change related issues. Several perspectives are important. First, there is generally a very high level of interest in environmental research, and especially climate change research, among the Greenland population due to their high dependence on natural resources. With Nuuk Basic, it will be possible eventually to involve a nature interpretation and management services focussing on knowledge transfer and interactive education for local school and high school pupils. In practise, it will be possible to invite school classes on one-day educational trips to the field stations at either Kobbefjord or Nordlandet introducing new generations in Greenland for the important aspects of climate effect monitoring. This is an excellent opportunity for Nuuk Basic which has not been possible with Zackenberg Basic due to its remote and isolated location in the heart of Northeast Greenland. Secondly, it is the clear intention of Nuuk Basic that as much of the work as possible shall be carried out by local staff. Specifically, the programme aims at employing local staff for operating the programmes under the supervision of Danish specialists. The logistics (i.e. maintenance of field stations at Kobbefjord/Nordlandet, transportation of scientists to and from field localities etc.) will be carried out by local labour employed at The Greenland Institute of Natural Resources.

As with Zackenberg Basic, the reporting of Nuuk Basic will be by annual reports with basic coverage of the annual results from the monitoring programmes and in popular journals and newspapers. However, in order to maintain the highest quality of the monitoring programmes, the publication in peer reviewed international journals is of highest priority to Nuuk Basic. Annual workshops will secure the optimal integration between the four sub-programmes as well as the between Zackenberg Basic and Nuuk Basic.

Finally, a website for Nuuk Basic will be established. This website will contain information about the programme, a bibliography of programme publications, a database with free access to data from the monitoring and a collection of the most recent popular articles stored as PDF-files. This website will be hosted by Danish Polar Centre, and attempts will be made to visualise on the internet the close link between Zackenberg Basic and Nuuk Basic.

8.7 International framework

In recent years, several attempts have been made to internationally coordinate monitoring in the Arctic by either establishing umbrella organisations, as for example the Circumarctic Environmental Observatories Network (CEON) and the Coordination of Observation and Monitoring of the Arctic for Assessment and Research (COMAAR), to encompass and coordinate existing international monitoring networks, projects and programmes, or by establishing, in different climate settings, a limited number of 'Flagship Observatories' or 'Supersites' such as those at Abisko Scientific Research Station, Svalbard, Toolik Research Station, Point Barrow, Cheerskii and Zackenberg Research Station, all with extensive, long-term, integrated and cross-disciplinary monitoring (Prowse et al. 2005, Callaghan et al. 2005, Study of Environmental Arctic Change 2005, Committee on Designing an Arctic Observatory Network 2006). The Zackenberg Research Station and Zackenberg Basic have been intensively involved in these international networks, as will Nuuk Basic. As flagship observatories, both Zackenberg Basic and Nuuk Basic will be at the forefront of already existing projects, programmes and networks (Table 8.4).

Acronym	Name	Reference / Web page
ABBCS	Arctic Birds Breeding Conditions Survey	http://www.arcticbirds.ru/
ACD	Arctic Coastal Dynamics	http://www.awi-potsdam.de/acd/
CALM	Circumpolar Active Layer Monitoring Pro- gramme	http://www.geography.uc.edu/~kenhinke/CALM/
CEON	Circumpolar Environmental Observatories Network	http://www.ceoninfo.org/
ENVINET	European Network of Arctic-Alpine Environ- mental Research	http://envinet.npolar.no/
GRDC	Global Runoff Data Centre	http://grdc.bafg.de/servlet/is/Entry.987.Display/
ITEX	International Tundra Experiment	http://www.geog.ubc.ca/itex/
SCANNET	Scandinavian / North European Network of Terrestrial Field Basses	http://www.scannet.nu
CHASM	The Committee for Holarctic Shorebird Monitoring	http://www.caff.is/sidur/uploads/Shorebirds.pdf

Table 8.4. Projects, programmes and networks in which Zackenberg Basic is and Nuuk Basic will be involved.

9 Disturbance in the study area

Peter Aastrup

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

Based on experiences from 2007, public disturbances falls mainly in the following categories:

- Visits by boats at the head of the fjord no landing.
- Visits by boats at the head of the fjord

 the persons take a short walk inland and returns within a couple of hours or less.
- Visits by boats at the head of the fjord

 the persons go on land and spend the
 night in a tent close to the coast.
- Hiking through the area
- During winter people visit the area by snow scooter or by ski from Nuuk.
- Ordinary flights by fixed wing aircrafts pass over the study area at cruising altitude or in ascent or descent to or from Nuuk.
- Helicopter pass at cruising altitude
- The electrical power transmission line between Nuuk and the hydro power plant in Buksefjord, runs through the area

There have been no difficulties in relation to the visits in the area. Nothing has been touched; neither in the camps nor in study plots.

Except for the risk of damage or vandalism to study plots or camps, the human disturbances are unlikely to have any influence on the present monitoring programmes.

The implementation of the monitoring programmes have brought increased disturbance to the area in Kobbefjord. These disturbances fall into the following categories:

- Transportation of Nuuk Basic personnel by boat to and from the study area.
- A base camp in the study area.

- Walks between study sites and study plots.
- Physical impact by marking plots, pegs for marking vegetation transect etc.
- Physical impact by trampling around study plots.

Transportation between Nuuk and the study site in Kobbefjord was generally on a daily basis with transportation out into the study area in the morning and back to Nuuk in late afternoon, if weather conditions permitted.

The base camp was used temporarily by two to 10 persons and consisted of two to six sleeping tents and a kitchen tent. The kitchen tent was replaced two times, because high wind pressure destroyed the tents. The base camp was an advantage as it allowed longer working days and reduced the number of boat transportations between Nuuk and Kobbefjord.

Local transportation in the study area between study sites and plots was by walking. During the first season in 2007 the impact on vegetation and terrain was low. When the programme has become fully implemented it should be considered to mark permanent trails between study sites and study plots.

Marking of study plots and the vegetation transect with pegs is visible in the terrain. The most important visual impacts are the structures, including a solar panel, which have been erected in relation the measuring of carbon and methane flux.

At a longer time perspective trampling along trails and around study plots will impose wearing of the vegetation cover and the upper layer of soil. The wearing can be reduced by use of portable boardwalks, but it should be considered to establish permanent boardwalks around flux measuring plots.

In conclusion, it is estimated that the first years' monitoring and establishing activities only had a minor impact on the vegetation and terrain.

10 Logistics

Josephine Nymand

The logistics related to Nuuk Basic is handled by The Greenland Institute of Natural Resources. Most monitoring activities were established in 2007, but the logistics facilities will not be fully established before 2008 when it is planned to build a hut with accommodation, laboratory and storage facilities at Kobbefjord.

In 2007 activities relating to Nuuk Basic in Kobbefjord were carried out from the end of May to end of December. The main field activity with establishment of most of the programmes was in August. Marine-Basic was operating in Kobbefjord and Godthåbsfjord throughout the year.

All transportation between Nuuk and the research area in Kobbefjord, and between Nuuk and Godthåbsfjord (Akia) was carried out with the boats "Aage V. Jensen II" and "Erisaalik" belonging to The Greenland Institute of Natural Resources. Both boats are financed by Aage V. Jensen Charity Foundation.

Visiting scientists in 2007 were primarily accommodated in the Annex of the

Greenland Institute of Natural Resources (more than 200 overnights stay), but also at the Seamen's home in Nuuk. In Kobbefjord a camp with tents was established and served as accommodation facilities for overnight stays in the field.

When needed, power was generated with a 900 W generator. Water supply came from a small river running through the camp. This water is suitable as drinking water without any processing.

Communication between Kobbefjord and mainly Nuuk was carried out by Iridium satellite telephones, while local communication between research teams was carried out with VHF-radios.

Apart from the scientist working in Kobbefjord an unknown number of locals have been visiting the area. On a weekly basis several smaller boats stayed in the fjord for a few to several hours per day and people from these boats took shorter or longer hiking trips in the area. It has not been possible to put a number on these visits.

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- Klaus Andersen, Head of Section, the Environment and Regional Planning Committee
- Svend Auken, MP, member of the Presidium

- Berit Brørby, Vice President, the Nordic Council
- Ole Vagn Christensen, MP, member of the Environment and Regional Planning Committee
- Jørn Dohrmann, MP, member of the Environment and Regional Planning Committee
- Vibeke Grave, MP, member of the Environment and Regional Planning Committee
- Torben Hansen, MP, member of the Environment and Regional Planning Committee
- Connie Hedegaard, Minister for the Environment and Minister for Nordic Cooperation
- Gunna Heidemann, Head of Division, Ministry of the Environment
- Anne Grete Holmsgaard, MP, member of the Environment and Regional Planning Committee
- Erik Jacobsen, Permanent Secretary, Ministry of the Environment

Kuupik Kleist, MP, member of the Environment and Regional Planning Committee

Søren Korsholm, Private Secretary to the Minister, Ministry of the Environment

- Per Movritsen, Head of Section, the Environment and Regional Planning Committee
- Bjørn Medom Nielsen, MP, member of the Environment and Regional Planning Committee
- Leif Skov, chairman of Aage V. Jensen Charity Foundation
- Niels Skov, member of Aage V. Jensen Charity Foundation
- Frank Sonne, head of section, Ministry of the Environment
- Ole Stavad, member of the Presidium, the Nordic Council
- Christian Wedell-Neergaard, MP, member of the Environment and Regional Planning Committee,
- Jytte Wittrock, MP, member of the Environment and Regional Planning Committee

13 Publications

Compiled by Lillian Magelund Jensen

Scientific papers 2005-2007

- Berg, P., Swaney, D., Rysgaard, S., Thamdrup, B. & Fossing, H. 2007. A fast numerical solution of the general mass-conservation equation for solids and solutes in aquatic sediments. Journal of Marine Research 65:317-343.
- Blicher, M.E., Rysgaard, S. & Sejr, M.K. 2007. Growth and production of the sea urchin, Strongylocentrotus droebachiensis (O.F. Müller, 1776), in a high arctic fjord and growth along a climate gradient (64-77°N). Marine Ecology Progress Series 341:89-102.
- Cook, P., Wenzhöfer, F., Rysgaard, S., Galaktionov, O., Eyre, B., Cornwell, J., Huettel, M. & Glud, R.N. 2006. Quantifying denitrification in permeable sediments: Insights from a two-dimensional simulation analysis and experimental data. Limnology and Oceanography Methods 4:294-307.
- Mikkelsen, D. & Rysgaard, S. 2008. Annual variation in algal composition, primary production and nutrient dynamics of an arctic sea ice community. Marine Ecology Progress Series 368:65-74.
- Roeselers, G., Norries, T.B., Castenholz, R.W., Rysgaard, S., Glud, R.N., Kühl, M. & Muyzer, G. 2006. Diversity of phototrophic bacteria in microbial mats from arctic hot springs (Greenland). Environmental Microbiology doi:10.1111/j.1462-2920.2006.01103.x
- Rysgaard, S., Glud, R.N., Sejr, M.K., Bendtsen, J. & Christensen, P.B. 2007. Inorganic carbon transport during sea ice growth and decay: A carbon pump in polar seas. Journal of Geophysical Research 112: C03016. doi: 10.1029/2006jc003572.
- Rysgaard, S., Glud, R.N., Sejr, M.K., Blicher, M.E. & Stahl, H.J. 2007. Denitrification activity and oxygen dynamics in arctic sea ice. Polar Biology 31:527-537.
- Schmid, M.C., Risgaard-Petersen, N., van de Vossenberg, J., Langezaal, S., Kuypers, M.M.M., Lavik, G., Brandsma, J., Damsté, J.S., van der Zwaan, B., Hulth, S., Thamdrup, B., Canfield, D., Dalsgaard, T., Rysgaard, S., Sejr, M.K.,

Strous, M., op den Camp, H.J.M. & Jetten, M.S.M. 2007. Anaerobic Ammonium Oxidizing Bacteria in Marine Environments: Widespread Occurrence but low Diversity. Environmental Microbiology 9(6), 1476-1484.

Sejr, M.K., Nielsen, T.G., Rysgaard, S., Risgaard-Petersen, N., Sturluson, M.E. & Blicher, M. 2007. The fate of pelagic organic carbon and importance of the benthic-pelagic coupling in a shallow cove in Disko Bay, west Greenland. Marine Ecology Progress Series 341:75-88.

Reports 2005-2007

- Risgaard-Petersen, N. & Rysgaard, S. 2007. Biogeochemistry and microbiology. Report on R/V Maria S. Merian Cruise MSM 5/03 15 June to 4 July. 169 pp.
- Rysgaard, S., Frandsen, M. & Arendt, K. 2007. "Exchange" – udveksling mellem Godthåbsfjord og hav. Report to DANCEA (the Danish Cooperation for the Environment in the Arctic) under the Danish Ministry of Environment. 10 pp.
- Rysgaard, S., Frederiksen, M. & Arendt, K. 2007. Nuuk Basic: The MarineBasic programme. Report 2005-06. Report to DANCEA (the Danish Cooperation for the Environment in the Arctic) under the Danish Ministry of Environment. 60 pp.

Presentation at symposiums, workshops, meetings and conferences 2005-2007

- Frederiksen, M.S., Rysgaard, S. & Arendt, K. 2007. Monitering af klimaændringer i Arktis. Indlæg ved 14. Danske Havforskermøde. Syddansk Universitet Odense, Danmark 23-25 January.
- Hansen, J., Sejr, M.K. & Rysgaard, S. 2007. Studies of benthic macrofauna and macroalgae. Meeting on "Ice climate and environment in the DISKO west area. Copenhagen, Denmark, 6 December.
- Mikkelsen, D.M., Rysgaard, S., Glud, R.N.

2007. Årsvariation af mikroalger, primærproduktion og næringssaltdynamik i og ved havis. Poster ved 14. Danske Havforskermøde. Syddansk Universitet Odense, 23-25 January.

- Nielsen, T.G. & Rysgaard, S. 2007. Ecogreen – økosystem Vestgrønland. Polarforskerdagen, København, Danmark, 23 November.
- Rysgaard, S. 2005. Nuuk Basic workshop on climate change and sub-arctic ecosystems. Greenland Institute of Natural Resources, Nuuk, Greenland, 22-26 August.
- Rysgaard, S. 2005. Arctic initiatives on sea ice research in Greenland. European Science Foundation ESF LESC exploratory workshop on "New perspectives on sea ice research for the next 10 to 20 years". Demenhorst, Germany 12-16 December.
- Rysgaard, S. 2006. Biogeochemical processes in arctic sediments. Presentations at GREENLAND *07 Workshop in preparation of an expedition using R/V "Maria S. Merian" Leibniz Institute for Baltic Sea Research Warnemünde, Germany. October 23-24, 2006.
- Rysgaard, S. 2006. Marine aktiviteter: Igangværende arbejde og anbefalinger vedrørende den fremtidige indsats. National Workshop om klimaændringer i Arktis. Miljøstyrelsen, København, Danmark 10 May.
- Rysgaard, S., Christensen, J.H. & Kliem, N. 2006. Climate change meeting on a regional circulation model for Greenland and adjacent waters. Greenland Institute of Natural Resources, Nuuk, Greenland, 5 February.
- Rysgaard, S. 2007. Carbon uptake in the Nordic Seas is controlled by sea ice conditions in the Arctic Ocean. Workshop on sea ice and climate. Greenland Institute of Natural Resources. Nuuk, Greenland 29 October to 2 November.
- Rysgaard, S. 2007. Impact of changes in the Ice Sheet. Kick-off workshop for Cryosphere sub-project 2 "The Greenland Ice Sheet in a changing climate" 4-5 December. Copenhagen. Denmark.
- Rysgaard, S. 2007. MarineBasic Nuuk og nye aktiviteter ved Grønlands Naturinstitut. Klimaforum på Danmarks Meteorologiske Institut, Denmark 16 May.
- Sejr, M.K., Hansen, J. & Rysgaard, S. 2007. Studies of benthos in coastal habitats and ecological key areas. Meeting on

"Ice climate and environment in the KANUMAS area". Copenhagen, Denmark 5 December.

General information 2005-2007

- Bernarroch, J. 2007. Sydlig overvågning. Polarfronten 4/2007.
- From, L. 2007. Smeltet is truer klimaet. Jyllandsposten 16 January.
- Glud, R.N. & Rysgaard, S. 2007. CO2 i de arktiske oceaners dyb" i serien "Videnskabens Verden". Danmarks Radio P1 og P2. 17, 19 and 22 March.
- Jastrup, M. 2007. Det kolde Nord ind i varmen. Politiken, 1 March.
- Manabe, H. 2006. Receding glaciers and global warming. Asahi Shinbun Newspaper, Japan. 28 May, 2, 3, 4, 5, 6, 7, 8 and 9 June.
- Mikkelsen, D.M. 2007. Havisens alger. Urt 31 (2): 64-67.
- Person, M. 2006. Ons ijs is jullie probleem. de Volkskrant Holland, 23 December.
- Philbert, P. 2006. En vestgrønlandsk aflægger. Polarfronten 4/2006.
- Rysgaard, S. 2006. Klimap nunat immallu issittut avannarlerni allanngorarnera. Climate change in the Arctic. INUTEK – Katuaq 19 January.
- Rysgaard, S. 2006. Klimap nunat immallu issittut avannarlerni allanngorarnera. Climate change in the Arctic. KNR Radio 20 January, 21 January and 16 February.
- Rysgaard, S. 2006. Videnskabens Verden: Klima, ferskvand og marinbiologisk produktion. KNR Radio Greenland 4 June.
- Rysgaard, S. 2006. Climate change and Greenland. Finnish Broadcasting Company (YLE) 19 June.
- Rysgaard, S. 2007. Viaje historica llega de Dianamarca Chilenos se suman al viaje. La Estrella, Chile, 9 February.
- Rysgaard, S. 2007. Det internationale Polarår (IPY). KNR Radio Greenland 14 February.
- Rysgaard, S. 2007. Det internationale Polarår (IPY). KNR Radio, Greenland, 22 February.
- Rysgaard, S. 2007. Kuldioxid og havis. Videnskabernes verden, KNR radio, Greenland, 22 May and 3 June.
- Rysgaard, S. 2007. Information to US public about climate change, melting Ice Sheet and reduced sea ice conditions in Greenland. The Peter Greenberg show, New York, USA, 2 June.
Rysgaard, S., Mikkelsen, N., Kuipers, A., Jensen, J.B. & Risgaard-Petersen, N. 2007. Forskere på jagt i havbunden efter fortidens klima. Atuagadliutit 19 July.

Rysgaard, S., Mikkelsen, N., Kuipers, A., Jensen, J.B. & Risgaard-Petersen, N. 2007. Fortidens klima hentes op fra havet. Ingeniøren 17 August. Struck, D. 2007. Climate change in Greenland; positive and negative effects. The Washington Post, 20 May.

14 References

- ACIA, 2005. Arctic Climate Impact Assessment. Cambridge: Cambridge University Press, 1042 pp.
- AMAP, 2000. AMAP Trends and Effects Programme 1998-2003. AMAP Report 99:7. Section C. 23-33.
- AMAP, 2005. AMAP Workshop on Follow-up of ACIA June 15-17, 2005, Oslo, Norway. 106 p.
- Bamzai, A.S. 2003. Relationship between snow cover variability and Arctic Oscillation index on a hierarchy of time scales. International Journal of Climatology 23, 131-142.
- Bay, C. 2001. The ZERO-line, pp. 21-22 in Caning, K. & Rasch, M. (Eds.). Zackenberg Ecological Research Operations. 6th Annual Report 2000. Danish Polar Centre, Ministry of Research and Information Technology.
- Bay, C. 2006. The ZERO line and northern species, pp 42-44 in Meltofte, H., Sigsgaard, C. and Rasch, M. (Eds.).
 Zackenberg Ecological Operations. 11th Annual Report 2005. Danish Polar Centre, Ministry of Research and Information Technology.
- Bejder, L. & Dawson, S. 2001. Abundance, Residency and Habitat Utilization of Hector's Dolphins (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand. New Zealand Journal of Marine and Freshwater Research 35: 277-287.
- Bengtsson, L. 2005. ICARP II: Working Group 9 Modelling and Predicting Arctic Climate and Ecosystems. Draft Science Plan. 21 p.
- Bergstrøm, B. 2006. A note on the timing of hatching of Northern Shrimp, (*Pandalus borealis* Krøyer, 1861) off West Greenland (NAFO Area 1D, 1C and 1B) October/November 2006, NAFO SCR Doc. 06/60 Serial No.N5308, mimeo.
- Borum, J., Pedersen, M.F., Krause-Jensen,
 D., Christensen, P.B. & Nielsen, K. 2002.
 Biomass, photosynthesis and growth of Laminaria saccharina in a high arctic fjord, NE Greenland. Marine Biology 141: 11-19.
- Callaghan, T.V. et al. 2005. Arctic Tundra and Polar Desert Ecosystems. In: Arctic Climate Impact Assessment (Eds: Symon, C., Arris, L. & Heal, B.), pp. 243-352. Cambridge: Cambridge University Press.

- Callaghan, T.V. et al. 2005. ICARP II: Working Group 8 Terrestrial and Freshwater Biosphere and Biodiversity. Draft Science plan. 16 p.
- Cavalieri, D.J. et al. 2003. 30-year satellite record reveals contrasting Arctic and Antarctic decadal sea ice variability. Geophysical Research Letters 30, 1970.
- Chapman, A.R.O. 1974. The genetic basis of morphological differentiation in some Laminaria populations. Marine Biology 24: 85-91.
- Chapman, W.L. & Walsh, J.E. 2003. Observed climate change in the Arctic, updated from Chapman and Walsh 1993. Recent variations of sea ice and air temperatures in high latitudes. Bulletin of the American Meteorological Society 74(1): 33-47.
- Christoffersen, K. & Jeppesen, E. 2002. Isdækkets varighed har stor indflydelse på livet i søerne. In: Meltofte, H. (Ed.) 2002. Sne, is og 35 graders kulde. Hvad er effekterne af klimaændringer i Nordøstgrønland? p. 79-84. Tema rapport 41. Danmarks Miljøundersøgelser.
- Committee on Designing an Arctic Observing Network 2006. Arctic Observing Network. The National Academies Press. Washington D.C. 116 p.
- Duarte, C.M. 1992. Nutrient concentration of aquatic plants: Patterns across species. Limnology and Oceanography 37: 882-889.
- Dunton, K.H. 1984. An annual carbon budget for an arctic kelp community. In Barnes, P.W., Schell, D.M. & Reimnizt, E. (Eds). The Alaskan Beaufort Sea: ecosystems and environments. Academic, Orlando, pp 311–326.
- Egan, B. & Yarish, C. 1988. The distribution of the genus Laminaria (Phaeophyta) at its southern limit in the Western Atlantic Ocean. Botanica marina 31: 155-161.
- Egan, B. & Yarish, C. 1990. Productivity and life history of Laminaria longicruris at its southern limit in the Western Atlantic Ocean. Marine Ecology Progress Series 67: 263-273.
- Forchhammer, M.C. 2002. Analyser og modeller i relation til forandringer i klimaet. In: Meltofte, H. (Ed) 2002. Sne,

is og 35 graders kulde. Hvad er effekterne af klimaændringer i Nordøstgrønland?, p. 15-24. Tema rapport 41. Danmarks Miljøundersøgelser.

- Forchhammer, M.C. & Post, E. 2004. Using large-scale climate indices in climate change ecology studies. Population Ecology 46, 1-12.
- Forchhammer, M.C., Schmidt N. M., Høye, T.T., Berg, T.B., Hendrichsen, D.K. & Post, E. 2008. Population Dynamics Responses to Climate Change. In: Meltofte, H., Christensen, T.R., Elberling, B., Forchhammer, M.C. & Rasch, R. 2008. Advances in Ecological Research. Volume 40. High Arctic Ecosystem Dynamics in a Changing Climate. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland.
- Fredskild, B. & Mogensen, G.S. 1996. ZERO line. Final report 1997. Greenland Botanical Survey & Botanical Museum, University of Copenhagen 1997, 36 pp.
- Glud, R.N., Risgaard-Petersen, N., Thamdrup, B., Fossing, H & Rysgaard, S. 2000. Benthic carbon mineralization in a high arctic sound (Young Sound, NE Greenland). Marine Ecology Progress Series 206: 59-71.
- Goldbogen, J.A., Calambokidis, J., Shadwick, R.E., Oleson, E.M., McDonald, M.A. & Hildebrand, J.A. 2006. Kinematics of foraging dives and lunge-feeding in fin whales. The Journal of Experimental Biology 209:1231-1244.
- Goldbogen, J.A., Pyenson, N.D. & Shadwick, R.E. 2007. Big Gulps require high drag for fin whale lunge feeding. Marine Ecology Progress Series 349: 289-301.
- Grøndahl, L. et al. 2006. Temperature and snow melt controls on inter-annual variability in carbon exchange in the High Arctic. Theoretical and Applied Climatology, in press.
- Hinkler, J., Pedersen, S.B., Rasch, M. & Hansen, B.U. 2002: Automatic snow covers monitoring at high temporal and spatial resolution, using images taken by a standard digital camera. International Journal of Remote Sensing 23: 4669-4682.
- ISO 1100-2 1998. Measurement of liquid flow in open channels – Part 2: Determination of stage-discharge relation, ISO 1100-2, International Organization for Standardization, Switzerland 1998.
- Johnson, M.P. & Tyack, P.L. 2003. A Digital Acoustic Recording Tag for Measuring

the Response of Wild Marine Mammals to Sound. IEEE Journal of Engineering 28 (1): 3-12.

- Johnson, M., Madsen, P.T., Zimmer, W.M.X., Aguilar de Soto, N. & Tyack, P.L. 2006. Foraging Blainvilleís beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. The Journal of Experimental Biology 209: 5038-5050.
- Kattsov, V.M. et al. 2005. Future Climate Change: Modelling and Scenarios for the Arctic. In Symon, C., Arris, L. & Heal, B. (Eds). Arctic Climate Impact Assessment pp. 99-150. Cambridge: Cambridge University Press.
- Keylock, C.J., 2005. Simpson diversity and the Shannon-Wiener index as special cases of a generalized entropy. Oikos 109, 203-207.
- Kiilsholm, S., Christensen, J.H., Dethloff, K. & Rinke, A. 2003. Net accumulation of the Greenland Ice Sheet; modelling arctic regional climate change. Geophysical Research Letters 30: 1485, doi:10.1029/2002GL015742.
- Larsen, F. & Hammond, P.S. 2004.Distribution and Abundance of West Greenland Humpback Whales (*Megaptera novaeangliae*). Journal of Zoology, London 263: 343-358.
- Light, B., Maykut, G.A & Grenfell, T.C. 2003. Effects of temperature on the microstructure of first-year Arctic sea ice. Journal of Geophysical Research-Oceans 108 (C3).
- Lüning, K. 1990. Seaweeds their environment, biogeography and ecophysiology. John Wiley & Sons Inc. New York.
- Madsen, P.T., Johnson, M., Aguilar de Soto, N., Zimmer, W.M.X. & Tyack, P.L.
 2005. Biosonar performance of foraging beaked whales (*Mesoplodon densirostris*). The Journal of Experimental Biology.
 208: 181-194.
- Mann, K. H. 1972. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. II. Productivity of the seaweeds. Marine Biology 14: 199-209.
- MarinID, 1978. Bundinvertebrater på store og lille Hellefiskebanke og i Holsteinsborgdybet. Rapport til Ministeriet for Grønland.
- Meltofte, H. & Rasch, M. (Eds.) 1998: Zackenberg Ecological Research Operations. 3rd Annual Report 1997. Danish Polar Centre, Ministry of Research and Information Technology.

- Mølgaard, P. et al. 2002. Blomsterne må vente på at sneen smelter og på varme. In: Meltofte, H. (Ed.) (2002) Sne, is og 35 graders kulde. Hvad er effekterne af klimaændringer i Nordøstgrønland?, pp. 43-46. Tema rapport 41. Danmarks Miljøundersøgelser.
- Nordström, C. et al. 2001. Seasonal carbon dioxide balance and respiration of a high arctic fen ecosystem in NE-Greenland. Theoretical and Applied Climatology 70, 149-166.
- Nuttall, M. et al. 2005. Hunting, herding, fishing, and gathering: indigenous peoples and renewable resource use in the Arctic. In: Arctic Climate Impact Assessment (Eds: Symon, C., Arris, L. & Heal, B.), pp. 649-690. Cambridge: Cambridge University Press.
- Orton, L.S. & Brodie, P.F. 1987. Engulfing mechanics of fin whales. Canadian Journal of Zoology 65(1212): 2898-2907.
- Parsons, D.G., Lilly, G.R. & Chaput, G.J. 1986. Age and growth of northern shrimp *Pandalus borealis* off north-eastern Newfoundland and southern Labrador. Transactions of the American Fisheries Society 115:872-881.
- Prowse et al. 2005. ICARP II: Working Group 7 Terrestrial Cryospheric and Hydrological Processes and Systems. Draft Science Plan. 26 p.
- Rasch, M., Rysgaard, S., Meltofte, M. & Hansen, J.B. 2002. Zackenberg Basic.
 Climate change effects in a high arctic ecosystem at Zackenberg, Northeast Greenland. The Concept. In: Caning, K. and Rasch, M. (Eds.) 2003. Zackenberg Ecological Research Operations, 8th Annual Report, 2002, p. 70-80. – Danish Polar Centre, Ministry of Research and Information Technology.
- Rignot, E. & Thomas, R.H. 2002. Mass balance of the polar ice sheets. Science 297: 1502-1506.
- Rignot, E. & Kanagaratnam, P. 2006. Changes in the Velocity Structure of the Greenland Ice Sheet. Science 311: 986-990.
- Rysgaard, S., Nielsen, T.G. & Hansen, B. 1999. Seasonal variation in nutrients, pelagic primary production and grazing in a high arctic coastal marine ecosystem, Young Sound, Northeast Greenland. Marine Ecology Progress Series 179, 13-25.
- Rysgaard, S. et al. 2003. Physical conditions, carbon transport, and climate

change impacts in a north-east Greenland Fjord. Arctic, Antarctic and Alpine Research 35(3): 301-312.

- Rysgaard, S., Glud, R.N., Sejr, M.K., Bendtsen, J. & Christensen, P.R. 2007. Inorganic carbon transport during sea ice growth and decay: A carbon pump in polar seas. Journal of Geophysical Research-Ocean. 11:(C3).
- Rysgaard, S. & Glud, R.N. 2007. Carbon cycling in Arctic marine ecosystems: Case study – Young Sound. Medd. Greenland, Bioscience 58. 216 pp.
- Schmidt, N.M. et al. 2006. Common climatic signature in long-lived species from physically separated environments. Manuscript.
- Semiletov, I.P., Pipko, I.I., Repina, I. & Shakhova, N.E. 2007. Carbonate chemistry dynamics and carbon dioxide fluxes across the atmosphere-ice-water interfaces in the Arctic Ocean: Pacific sector of the Arctic. Journal of Marine Systems 66: 204-226.
- Study of Environmental Arctic Change (SEARCH) 2006. Study of Environmental Change: Plans for Implementation During the International Polar Year and Beyond. Arctic Research Consortium of the United States (ARCUS). 104 p.
- Tamstorf, M.P. & Bay, C. 2002. Snedækket bestemmer plantesamfundenes udbredelse og production. In: Meltofte, H. (Ed) 2002. Sne, is og 35 graders kulde. Hvad er effekterne af klimaændringer i Nordøstgrønland? pp. 35-41. Tema rapport 41. Danmarks Miljøundersøgelser.
- Velicogna, I. & Wahr, J. 2006. Accelerating of Greenland ice mass loss in spring 2004. Nature doi:10.1038/nature05168.
- Walsh, J.E. et al. 2005. Crysphere and Hydrology. In: Symon, C., Arris, L. & Heal, B. (Eds.) Arctic Climate Impact Assessment, pp. 183-242. Cambridge: Cambridge University Press.
- Weatherhead, B. et al. 2005. Ozone and Ultraviolet Radiation. In: Symon, C., Arris, L. & Heal, B. (Eds.) Arctic Climate Impact Assessment, pp. 151-182. Cambridge: Cambridge University Press.
- Wrona, F.J. et al. 2005. Freshwater ecosystems and fisheries. In: Symon, C., Arris, L. & Heal, B. (Eds.) Arctic Climate Impact Assessment, pp. 353-453. Cambridge: Cambridge University Press.