

ZERO



ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

17th Annual Report 2011



Aarhus University
DCE – Danish Centre for Environment and Energy

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

17th Annual Report 2011



AARHUS
UNIVERSITY

DCE - DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Title: Zackenberg Ecological Research Operations
Subtitle: 17th Annual Report 2011

Editor: Lillian Magelund Jensen
Department of Bioscience, Aarhus University

Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy
URL: <http://dmu.au.dk>

Year of publication: 2012

Please cite as: Jensen, L.M. (ed.) 2012. Zackenberg Ecological Research Operations, 17th Annual Report, 2011. Aarhus University, DCE – Danish Centre for Environment and Energy. 120 pp.
Reproduction permitted provided the source is explicitly acknowledged

Layout and drawings: Tinna Christensen, Department of Bioscience, Aarhus University
Front cover photo: Kirstine Skov at the methane station at Zackenberg, October 2011. Photo: Jørgen Skaftø
Back cover photos: Sunset over Clavering, October 2011. Photo: Jørgen Skaftø

ISSN: 1904-0407
ISBN: 978-87-92825-79-7

Number of pages: 120

Internet version: The report is available in electronic format (pdf) on www.zackenberg.dk/Publications and on www.dce.au.dk

Supplementary notes: Zackenberg secretariat, Department of Bioscience, Aarhus University
P.O. Box 358
Frederiksborgvej 399
DK-4000 Roskilde, Denmark

E-mail: zackenberg@dmu.dk
Phone: +45 87158734

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

Department of Bioscience, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
Greenland Institute of Natural Resources: MarineBasis programme
Asiaq – Greenland Survey: ClimateBasis programme
University of Copenhagen: GeoBasis programme
Geological Survey of Denmark and Greenland: GlacioBasis programme

The programmes are coordinated by a secretariat at Department of Bioscience, Aarhus University and financed through contributions from:

The Danish Energy Agency
The Environmental Protection Agency
The Government of Greenland
Private foundations
The participating institutions

Contents

Summary for policy makers 5

Lillian Magelund Jensen

Executive summary 6

Mikkel P. Tamstorf, Michele Citterio, Niels Martin Schmidt, Mikael Sejr and Lillian Magelund Jensen

1 Introduction 10

Lillian Magelund Jensen

2 Zackenberg Basic: The ClimateBasis and GeoBasis programme 12

Maria Rask Pedersen, Torben R. Christensen, Julie Maria Falk, Per Hangaard, Birger Ulf Hansen, Aart Kroon, Morten Larsen, Anders Lindroth, Magnus Lund, Mikhail Mastepanov, Dorthe Petersen, Lau Gede Petersen, Laura Helene Rasmussen, Charlotte Sigsgaard, Kirstine Skov, Kisser Thorsøe and Mikkel P. Tamstorf

3 Zackenberg Basic: The GlacioBasis programme 30

Michele Citterio, Signe Hillerup Larsen and Andreas Ahlstrøm

4 Zackenberg Basic: The BioBasis programme 39

Lars Holst Hansen, Jannik Hansen, Kirsten Christoffersen, Kristian Albert, Magnus Lund, Noémie Boulanger-Lapointe, Lars O. Mortensen, Line Anker Kyhn, Eric Steen Hansen and Niels Martin Schmidt

5 Zackenberg Basic: The MarineBasis programme 65

Mikael K. Sejr, Thomas Juul-Pedersen, Egon Frandsen, Martin Blicher and Ivali Lennart

6 Research projects 77

6.1 Climate change and glacier reaction in the Zackenberg region 77

Bernhard Hynek, Daniel Binder, Gernot Weyss, Gernot Resch and Wolfgang Schöner

6.2 Mercury (Hg) transport from the terrestrial to the marine environment 78

Frank Rigét, Mikkel P. Tamstorf, Martin M. Larsen, Gert Asmund, Julie Maria Falk, Kirstine Skov and Charlotte Sigsgaard

6.3 Plant-soil-herbivore interactions in the Arctic – feedback to the carbon cycle 79

Julie Maria Falk and Lena Ström

6.4 Effects of climate manipulations on soil organic matter under *Cassiope tetragona* dominated heath in Zackenberg, Greenland 80

Ji Young Jung, Yoo Kyung Lee, Anders Michelsen and Niels Martin Schmidt

6.5 The role of plant interactions on plant recruitment along a snow depth gradient 81

Oriol Grau and Josep M. Ninot

6.6 Arctic bell-heather – annual growth in the *Cassiope* heath 82

Claudia Baittinger and Noémie Boulanger-Lapointe

6.7 Pollination networks and climate change 83

Claus Rasmussen, Jesper Bruun Mosbacher and Jens Mogens Olesen

6.8 A high Arctic food web – phase II: The core web expanded 84

Tomas Roslin, Tapani Hopkins, Malin Ek, Bess Hardwick and Gergely Várkonyi

6.9	Pelagic carbon cycling under influence of a melting ice cap	86
	<i>Mikael K. Sejr, Thomas Juul-Pedersen, Anette Bruhn, Colin Stedmon, Martin E. Blicher, Tage Dalsgaard, Nikolaj From Petersen, Daniel F. McGinnis and Diana Krawczyk</i>	
6.10	Ecological function of aquatic mosses in Arctic lakes	89
	<i>Tenna Riis, Birgitte K. Tagesen and Kirsten S. Christoffersen</i>	
6.11	Winter ecology of lakes	90
	<i>Kirsten S. Christoffersen</i>	
6.12	Three-spined stickleback <i>Gasterosteus aculeatus</i> L. recorded for the first time at Zackenberg – short description and comparative analysis with Arctic char food biology	92
	<i>Anders Birk Nielsen, Ladislav Hamerlik and Kirsten S. Christoffersen</i>	
6.13	Brood mixing in Sanderling <i>Calidris alba</i>	95
	<i>Jeroen Reneerens, Laura Kooistra, Jacques de Raad and Pieter van Veelen</i>	
6.14	MANA Project	96
	<i>Philippe Bonnet, Kirsten Christoffersen, Javier Gonzalez, Joel Granados, Mohammed Aljarrah and Jesper Aagard Christensen</i>	
6.15	Virtual Instrumentation	96
	<i>Philippe Bonnet, Javier Gonzalez and Joel Granados</i>	
7	Disturbances in the study area	98
	<i>Jannik Hansen</i>	
8	Logistics	100
	<i>Henrik Spanggård Munch and Lillian Magelund Jensen</i>	
9	Personnel and visitors	101
	<i>Compiled by Lillian Magelund Jensen</i>	
10	Publications	104
	<i>Compiled by Lillian Magelund Jensen</i>	
11	References	106
	<i>Compiled by Lillian Magelund Jensen</i>	
	Appendix A	111
	Appendix B	118

Summary for policy makers

Lillian Magelund Jensen

The year 2011 was another busy year at Zackenberg Research Station with a field season from 30 April to 7 November, 53 scientists visiting the station and the number of bed nights totalling 1857.

Zackenberg Ecological Research Operation is involved in several larger international research projects. Greenland Ecosystem Monitoring (GEM) is co-leading the project and coordinating two work packages in the EU project 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT), leading a task concerning international cooperation in the EU project 'Svalbard Integrated Arctic Earth Observing System' (SIOS) and playing an active role in the terrestrial component of the Circumpolar Biodiversity Monitoring Programme (CBMP).

INTERACT has a transnational access component, which from 2011 is allowing foreign scientists to visit the stations involved in the network free of charge. Zackenberg Research Station has been allocated approximately 1000 bed nights for transnational access during the period 2011-14. In 2011, five projects received support from INTERACT transnational access.

Results from the Zackenberg Basic monitoring programme are continuously published in scientific papers and popular science articles. Furthermore, data from the Zackenberg Basic programme is freely available and was in 2011 used for reporting purposes in a number of international fora and by a number of externally funded research projects.

In 2011, more than thirty-three scientific papers were published by the researchers from the Zackenberg Basic programme and from externally funded research projects.

In 2011, the Greenland Ecosystem Monitoring Coordination Group has produced a strategy and working programme for Greenland Ecosystem Monitoring 2011-15 describing in details how the goals of the strategy will be achieved. Among the overall changes were inclusion of upscaling of climate change effects to Greenlandic scale

and two new stations – Arctic Station and Sermilik Station.

Economy at Zackenberg Research Station

In 2011, the monitoring programme Zackenberg Basic received approximately 10 million DKK from the Danish Energy Agency and the Environmental Protection Agency for the five programmes – ClimateBasis, GeoBasis, GlacioBasis, BioBasis and MarineBasis. The funding includes means for long-term monitoring as well as analytical and strategic initiatives. On top of this the five Zackenberg Basic monitoring programmes co-funded the monitoring with approximately 3 million DKK.

Zackenberg Research Station received 3.2 million DKK from the Danish Agency for Science, Technology and Innovation for the Zackenberg secretariat, running and maintaining the station, salaries and logistics support.

Information on the total amounts of funding within the individual research projects at Zackenberg has not been available, and therefore only funding related to travels and accommodation is presented below. Hence, funding for e.g. salaries and laboratory analyses within the research projects are not included.

The total number of bed nights during the 2011 season at Zackenberg and Daneborg was 1857 (1416 related to scientists and 441 to logisticians). Of the 1416 bed nights related to scientists, 889 bed nights were primarily monitoring while 527 were used by individual research projects.

The five Zackenberg Basic monitoring programmes spent 1.9 million DKK on logistics handled by the station (travel, accommodation, cargo and subsistence) while the externally funded research projects spent 1.3 million DKK on logistics handled by the station. Five externally funded research projects were supported by INTERACT Transnational Access with 872.000 DKK (which includes 237 bed nights).

Executive summary

Mikkel P. Tamstorf, Michele Citterio, Niels Martin Schmidt, Mikael Sejr and Lillian Magelund Jensen

Introduction

The year 2011 was another busy year at Zackenberg Research Station with a field season from 30 April to 7 November, 53 scientists visiting the station and the number of bed nights totalling 1857.

ClimateBasis and GeoBasis

The winter 2010/2011 did not have as much snow as the previous year. The snow cover was 40 cm thick 30 April when GeoBasis personnel arrived at the station. Snow thickness was less than average, with timing of snow melt differing from the average depending on location in the Zackenberg valley. By 16 June, the snow had disappeared from the area around the meteorological station.

2011 was an average year for most climatic parameters. The first positive temperatures in 2011 was measured 28 April and the maximum temperature was 19.7°C (1 August). Mean monthly summer temperatures in 2011 were very close to 2010 mean monthly temperatures while it was being several degrees warmer during the winter months. In August, a large rainfall occurred 17 August resulting in a significant peak in discharge in the river Zackenberg.

Episodes of frost were observed in August but diurnal average temperatures below 0°C were not registered before 4 September and only after 22 September did the diurnal average temperatures stay below 0°C.

A thin snow cover started to build up in the Zackenberg valley from 6 October 2010 (3-5 cm lasting snow on the heath) and a continuous snow cover above 0.1 m did not happen before the end of January 2011.

The river Zackenberg started running 8 March when the glacier dammed lake at A.P. Olsen Land bursted. This resulted in running water during a week in March hereafter the river refroze. Due to build

up of water from A.P. Olsen Land in Store Sødal the river broke up already in the beginning of May with water starting to flow on top of the frozen river 8 May. However, contribution from the main streams Lindeman and Store Sødal due to snow melt was not significant until late May. Another flood from the glacier lake was observed 22 July. By the end of September, the river was again covered by ice and only a limited base flow persisted. The total runoff for river Zackenberg was 197 million m³ which is slightly above the average probably caused by the flood in July. During the same period, the suspended sediment transport amounted to 38337 tonnes, which is also close to the average for the past 15 years.

In Young Sund/Tyrolerfjord the fjord ice broke up around 13 July, and by 15 July, ice was no longer present in the fjord. The timing of the break up is close to the average of previous years. New ice started to form on the fjord end of September and by 28 September, a thin layer of fast ice covered the fjord.

The soil thaw in the two CALM plots (ZEROCALM 1 and ZEROCALM 2) took place from the moment the snow disappeared and the active layer reached a maximum in the end of August. At both sites, the thickness of the active layer was the highest ever measured.

Gas flux measurements between land and atmosphere were continued in the fen and on the well-drained heath area. At the heath site measurements of exchange rates of CO₂ was initiated 3 May and lasted until 16 August. During the days following 16 August, the setup was changed due to collaboration with an EU-INTERACT project; data is now logged on a Campbell data logger instead of on a computer. Measurements of CO₂ on the heath were re-initiated shortly after and in the end of October, the system was set up to run on EFOY cells during the winter. We hope this will allow us to measure during the unmanned periods in the future. From 26

June to 15 August, there was a net uptake of CO₂ and within this period, the total accumulation of carbon amounted to 31.5 g m⁻². A maximum diurnal uptake of 0.97 g C m⁻² d⁻¹ took place 19 July. During the entire measuring period, the net CO₂ balance amounted to -23 g C m⁻², which is above the average uptake during the summer.

At the fen site, measuring was initiated 7 May and lasted until 25 October. A new house for the methane analyzer, batteries and EFOY cells was built in August. The system was changed from running on electricity to EFOY cells in the end of October. The total accumulation of CO₂ from this site amounted to 129.9 g m⁻². The maximum diurnal uptake of 4.49 g C m⁻² d⁻¹ was measured 22 July. At the fen site, the system shifted back to being a net source of CO₂ 16 August – one day later than at the heath site.

Methane emissions from the fen were measured in chambers from 27 June and lasted until 31 October. Unfortunately, there were several leakage issues, especially during the first weeks of measurements, resulting in less reliable data. However, some information from the system can be presented. Similar to earlier years, there was an increase in CH₄ emissions during the early part of the growing season. During late August through September, fluxes were low and stable. In mid-October, there was an increase in both mean fluxes and variability between chambers most likely related to frost action releasing CH₄ stored in the soil profile.

GlacioBasis

In 2011, the monitoring, processing and data management tasks carried out included:

- Measurement and re-drilling of the network of ablation and displacement stakes
- Maintenance of three automatic weather stations (AWS), two of them with satellite telemetry to Denmark
- Survey of snow depth by snow radar calibrated with manual probing and density profiles from snow pits
- Survey of surface velocity and surface elevation by dual frequency differential GPS
- Trials with the field acquisition and later precise post-processing (PPP) of dual frequency GPS data, allowing to obtain high accuracy positions of an autonomous GPS receiver
- Airborne Lidar and ground penetrating radar (GPR) surveys flown by DTU Space during summer 2011
- Scheduling of on-demand acquisitions by the US-Japan ASTER instrument onboard the Terra satellite, with custom tuning of the satellite sensor settings to avoid saturation over high albedo surfaces
- Workflow for data retrieval, validation and storage
- Production of an improved digital elevation model (DEM) over the glacier has been produced by the GEUS Aerophotogrammetric Lab

Fieldwork in 2011 was completed successfully in all planned components. All ablation and surface velocity stakes have been surveyed and maintained, with the exception of the stake in the crevassed area close to the ice dammed lake, which was not approached for safety reasons. The differential GPS survey of the stakes used baselines to a temporary reference station established at the glacier terminus. The high accuracy position of the temporary reference station has been determined using the PPP method. More than 50 km of usable snow radar and differential GPS profiles of the glacier surface have been acquired and post-processed with reference to a temporary base station established at the glacier forefront. All three AWS have been visited and maintained and the calibration plan of the sensor is up to date. The DTU airborne campaign has been successful and data is currently being post-processed. The new GlacioBasis aerophotogrammetric DEM was produced based on stereo pairs from 1984 and manual interpretation of the difficult, low contrast areas in the accumulation zone, which were not accurately mapped in the existing DEM covering the entire river Zackenberg catchment area. The new aerophotogrammetric DEM and the airborne Lidar data cover the entire Ice Cap and provide surface elevation change between 1984 and 2011.

BioBasis

The 2011 season started relatively early compared to previous years, and most plots were snow-free earlier than average. The relatively early snow melt resulted in earlier than average flowering in all plant plots when compared to all previous seasons.

However, despite the early onset, many plant plots exhibited relatively late onset of senescence. In addition, in many plots the abundance of flowers was lower or close to the average of previous seasons.

As for the flowering phenology, the vegetation greening in the permanent plots peaked relatively early in 2011. The normalized difference vegetation index (NDVI) measurements conducted along the ZERO line exhibited the same pattern as previous years. The carbon flux measured in the ITEX and UV-B experimental plots were comparable to previous years' fluxes, and the plots functioned as sinks for atmospheric CO₂ in July-August, while in June, September-October they were generally small sources of CO₂. The experimental warming in the ITEX plots generally increased the soil respiration, whereas no significant effects on the carbon flux of the UV-B exclusion plots were observed this season. Nevertheless, plants in the UV-B reduced plots performed better than plants in the control plots. In 2011, all the permanent lichen plots and stations were revisited for the fourth time since 1994, and a number of interesting changes documented.

Furthermore, the arthropod pitfalls and windows traps melted free relatively early in 2011. The total number of arthropods caught was close to the average of previous seasons, with some interesting deviations for arthropod groups such as the very common Chironomids that were caught in record low numbers. One single specimen of Psylloidea, jumping plant lice, was caught in Zackenberg in 2011 for the first time. The degree of invertebrate herbivory on *Dryas* flowers was below the average of previous seasons.

The densities of common breeding birds in the area, such as sanderling and dunlin, were relatively high compared to previous years. Breeding long-tailed skuas, however, were again found in low numbers, most likely reflecting the low abundance of lemmings (see later). Only two of the focal wader species (sanderling and ruddy turnstone) initiated nests relatively early, while the dunlin was relatively late this season. Generally, the nest success of the wader species was low in 2011, though sanderlings were quite successful this season. The mean wader clutch size was 3.84, which is above average of previous seasons. For the barnacle geese, a record low number of three broods were observed.

The low lemming abundance observed in previous years continued in 2011, and again with no observations of stoat predation. Nonetheless, breeding Arctic fox were observed in three breeding dens, though with an estimated minimum number of seven cubs only. The number of muskoxen observed in the weekly censuses was a little lower than in previous years.

The monitored lakes were both characterised by a relatively early ice-out and a warm summer. The concentrations of nutrients were around the average of previous seasons. The same was true for chlorophyll concentrations during the summer season. However, during the autumn chlorophyll concentrations doubled. Both the composition of the phytoplankton and the zooplankton communities were comparable to previous years. The abundance of zooplankton was, however, remarkably high during the autumn.

MarineBasis

The 2011 season was characterized by an ice-free period spanning from 11 July to 20 October equalling 101 days, which is close to the average observed since 2003. Continuous seasonal data from the mooring revealed several interesting things: The vertical stratification created during the summer by warm freshwater at the surface was not eradicated until February where the density differences between instruments at 28 m and 62 m approaches a minimum. Also, the salinity, in addition to displaying the seasonal pattern observed in previous years, showed a distinct reduction in salinity by 0.3 psu units during the year of sampling at 62 m. Finally, data from the sediment trap showed exceptional high sedimentation of total and organic matter especially during September 2010. The three-week field season was dominated by calm and warm weather, which resulted in increased run-off from glaciers and very low salinity in the surface water of the inner parts of Tyrølerfjord. The calm conditions also allowed the distinct pattern of the surface freshwater to exit the fjord along the coast of Clavering Ø with water from the Greenland Sea flowing in along the opposite shore. The *p*CO₂ content showed undersaturation throughout the fjord but the degree of undersaturation was lower compared to previous years whereas measurements at the main station was close average. The PAR attenuation co-

efficient at the main station was close to average for the period.

Phytoplankton species composition was dominated by the genus *Chaetoceros* to a degree not previously observed. For the zooplankton, unusual high dominance of the genus *Oithona* was found comprising 58% of all specimens in 2011 compared to on average 35% from 2003-2010. Oxygen conditions in the sediment did not show any unusual trends whereas the growth of the kelp *Saccharina latissima* was low with an average growth of only 106 cm. In addition to measurements conducted as part of MarineBasis programme, an intensive research project was conducted to increase

understanding of processes affecting the inter-annual variation in parameters measured in the MarineBasis programme, see section 6.9.

Research projects

Fifteen research projects were carried out at Zackenberg Research Station in 2011. Of these six projects were parts of the Zackenberg monitoring programmes. Fourteen projects used Zackenberg Research Station as a base for their activities and one used Daneborg.

1 Introduction

Lillian Magelund Jensen

The year 2011 was another busy year at Zackenberg Research Station with a field season from 30 April to 7 November, 53 scientists visiting the station and the number of bed nights totalling 1857.

1.1 International cooperation

In 2011, Zackenberg Research Station staff was involved in several larger international research projects. Greenland Ecosystem Monitoring (GEM) is co-leading the project and coordinating two work packages in the EU project 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT). The work packages are i) International Cooperation and ii) Station Managers Forum with station managers from 45 research stations in the Arctic and in the northern alpine areas. INTERACT has a transnational access component, which from 2011 allows foreign scientists to visit the stations involved in the network free of charge. Zackenberg Research Station has been allocated approximately 1000 bed nights for transnational access during the period 2011-14. In 2011, five projects received support from INTERACT transnational access. Furthermore, INTERACT contributes to the work at Zackenberg with three so-called joint research activities focusing on (i) development of intelligent data loggers and telemetry, (ii) improved measurements of climate change feedback mechanisms in Arctic ecosystems, and (iii) project meta database management.

GEM is leading a task concerning international cooperation in the EU project 'Svalbard Integrated Arctic Earth Observing System' (SIOS).

In both INTERACT and SIOS, GEM is responsible for international cooperation including linkage to other research and monitoring networks, programmes and projects.

GEM is playing an active role in the terrestrial component of the Circumpolar Biodiversity Monitoring Programme (CBMP), which is an international network of scientists, government agencies, Indigenous organizations and conservation groups working together to harmonize and integrate efforts to monitor the Arctic's living resources. The CBMP coordinates marine, freshwater, terrestrial and coastal ecosystem monitoring activities while establishing international linkages to global biodiversity initiatives. The CBMP emphasizes data management, capacity building, reporting, coordination and integration of Arctic monitoring, and communications, education and outreach. The CBMP is endorsed by the Arctic Council and an important Arctic input to the UN Convention on Biological Diversity. It is the biodiversity component of the Sustaining Arctic Observing Networks (SAON).

In October 2011, Professor Bo Elberling from University of Copenhagen received funding for a new Centre of Excellence - Centre for Permafrost (CENPERM). The overall objective of CENPERM is to provide new insight into the complex interactions going on between microbial activity, plant growth and soil structure when permafrost thaws. CENPERM will focus on permafrost thawing in Greenland and will take a multidisciplinary approach and investigate the bio-logical, geographical and physical effects of permafrost - in the short and in the long term. The centre will have four Greenland Ecosystem Monitoring field sites at Zackenberg, Nuuk, Sermilik and Disko Island among its most important study sites.

Aarhus University will in 2012 establish an Arctic Research Centre (ARC). The centre will be established as an interdisciplinary centre across the main academic areas, Science and Technology, and Health. The Centre is to be a partner in the Arctic Science Partnership (ASP) and to have strong

collaborative ties with the Greenland Institute of Natural Resources in Nuuk and University of Manitoba, Canada. In 2012, a winter/spring campaign will be carried out in March and April at Daneborg, Zackenberg and Scoresbysund. The winter/spring campaign will be financed ARC and ASP and will involve among others the Zackenberg Basic sub-programmes.

1.2 Greenland Ecosystem Monitoring Strategy 2011-15

In 2011, the Greenland Ecosystem Monitoring Coordination Group produced a strategy and working programme for Greenland Ecosystem Monitoring 2011-15 describing in details how the goals of the strategy will be achieved. Among the overall changes were inclusion of upscaling of climate change effects to Greenlandic scale and two new stations, Arctic Station and Sermilik Station.

The Greenland Strategy and Monitoring Strategy and Working Programme 2011-15 can be downloaded from www.zackenberg.dk and www.g-e-m.dk or a hard copy can be ordered free of charge from the Zackenberg secretariat (zackenberg@dmu.dk).

1.3 Scientific papers

Results from the Zackenberg Basic monitoring programme are continuously published in scientific papers and popular science articles. Furthermore, data from the Zackenberg Basic programme is freely available and was in 2011 used for reporting purposes in a number of international fora and by a number of externally funded research projects.

In 2011, more than thirty-three scientific papers were published by the researchers from the Zackenberg Basic programme and from externally funded research projects.

In 2010, a paper with the title 'High nitrous oxide production from thawing permafrost' was published in Nature (Elber-

ling, Christiansen and Hansen 2010). The paper showed that thawing permafrost could release nitrous oxide, also known as laughing gas, a contributor to climate change that has been largely overlooked in the Arctic. Emissions of the gas measured from thawing wetlands in Zackenberg in eastern Greenland leapt 20 times to levels found in tropical forests under thawing conditions. Unfortunately, this paper was not mentioned in the 16th Annual Report.

1.4 Further information

Further information about Zackenberg Research Station and the work at Zackenberg are collected in previous annual reports (Meltofte and Thing 1996, 1997; Meltofte and Rasch 1998; Rasch 1999; Canning and Rasch 2000, 2001, 2003; Rasch and Canning 2003, 2004, 2005; Klitgaard et al. 2006, 2007; Klitgaard and Rasch 2008, Jensen and Rasch 2009, 2010, 2011) and in a book about the first ten years of monitoring and research at Zackenberg (Meltofte et al. 2008).

Much more information is available at the Zackenberg website, www.zackenberg.dk, including the ZERO Site Manual, manuals for the different monitoring programmes, a database with freely available data from the monitoring programmes, up-to-date weather information, a Zackenberg bibliography and an extensive collection of public outreach papers in PDF-format.

The Zackenberg Research Station address is:

*The Zackenberg Secretariat
Department of Bioscience
Aarhus University
P.O. Box 358
Frederiksborgvej 399
DK-4000 Roskilde*

*Phone: +45 871 58 734
E-mail: zackenberg@dmu.dk
Web site: www.zackenberg.dk*

2 Zackenberg Basic

The ClimateBasis and GeoBasis programmes

Maria Rask Pedersen, Torben R. Christensen, Julie Maria Falk, Per Hangaard, Birger Ulf Hansen, Aart Kroon, Morten Larsen, Anders Lindroth, Magnus Lund, Mikhail Mastepanov, Dorthe Petersen, Lau Gede Petersen, Laura Helene Rasmussen, Charlotte Sigsgaard, Kirstine Skov, Kisser Thorsøe and Mikkel P. Tamstorf

GeoBasis and ClimateBasis provide long-term data of climate, hydrology and physical landscape variables describing the environment at Zackenberg. This include climatic measurements, seasonal and spatial variations in snow cover and local microclimate in the Zackenberg area, the water balance of the river Zackenberg drainage basin, the sediment and solute transport of the river Zackenberg, the carbon dioxide (CO₂) and methane (CH₄) fluxes from a well-drained heath area and a fen area, the seasonal development of the active layer, temperature conditions and soil water chemistry of the active layer, and the dynamics of selected coastal

and periglacial landscape elements. For a map of the main study sites, see figure 2.1.

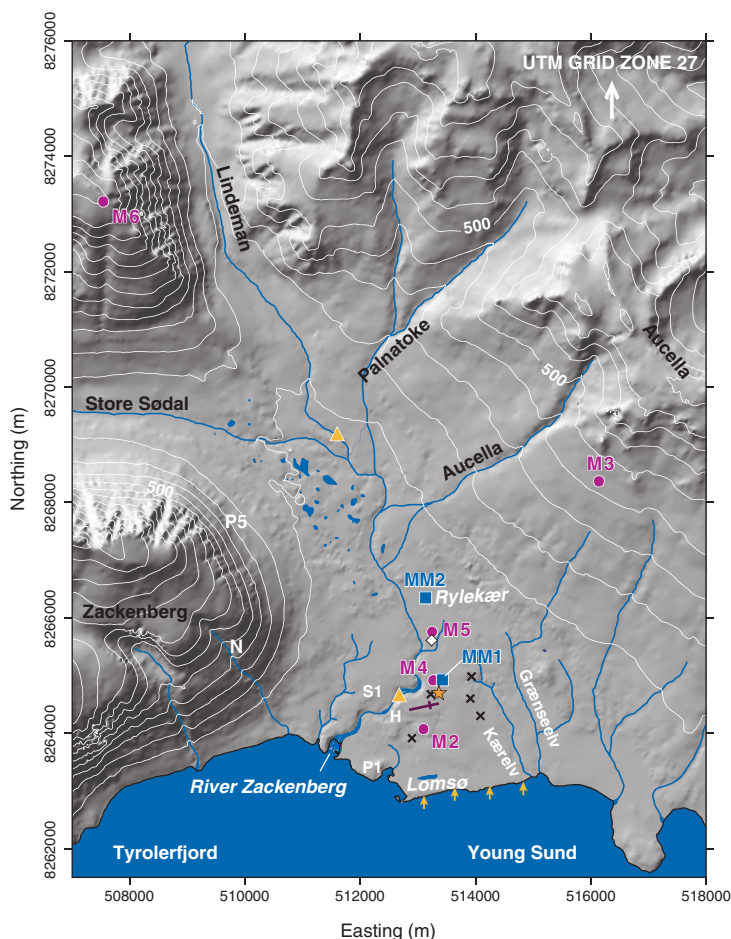
GeoBasis is operated by Department of Bioscience, Aarhus University, in collaboration with Department of Geography and Geology, University of Copenhagen. In 2011, GeoBasis was funded by Danish Ministry of Climate, Energy and Building as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. ClimateBasis is run by Asiaq - Greenland Survey who operates and maintains the meteorological station and the hydrometric station. ClimateBasis is funded by the Government of Greenland.

More details about sampling procedures, instrumentation, locations and installations are given in the GeoBasis manual and the ClimateBasis manual. Both can be downloaded from www.zackenberg.dk. Selected validated data from the monitoring programmes are also accessible from this website. For other validated GeoBasis data – please contact Charlotte Sigsgaard (cs@geo.ku.dk), Maria Rask Pedersen (mrp@geo.ku.dk) or programme manager Mikkel P. Tamstorf (mpt@dmu.dk). For matters concerning the ClimateBasis programme and data please contact programme manager Kisser Thorsøe (kit@asiaq.gl).

2.1 Meteorological data

The meteorological station at Zackenberg was installed during summer 1995. Technical specifications of the station are described in Meltofte and Thing 1996. Once a year the sensors are calibrated and checked by Asiaq - Greenland Survey. The problem with the malfunctioning satellite modem on the eastern mast was solved during the annual technical visit in August 2011 and data are again sent to Asiaq on a daily basis.

Figure 2.1 GeoBasis and ClimateBasis plots. Asterix=Meteorological station. H=Hydrometric station. Rectangles=Eddy towers. Circles=Snow and micrometeorological stations. Triangles=Water sample sites. N=Nansenblokken (photo site). Crosses=Soil water sites. Square=Methane site. Arrows= Coastal cliff recession.



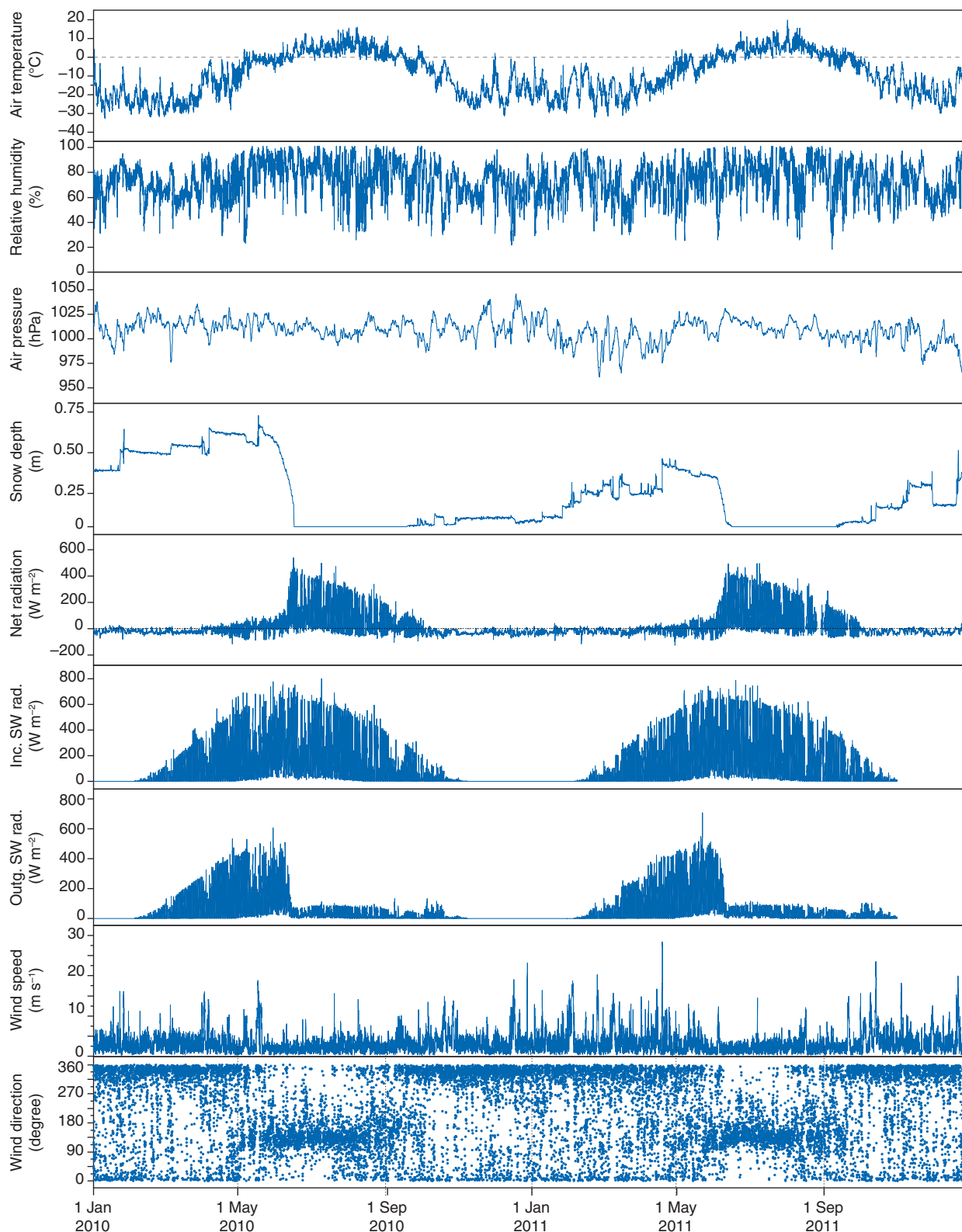


Figure 2.2 Variation of selected climate parameters during 2010 and 2011. Wind speed and direction are measured 7.5 m above terrain; the remaining parameters are measured 2 m above terrain. Data from November and December 2011 are preliminary. Outgoing and incoming SW radiation is not available.

Data was collected from the climate stations 1 November 2011, just before the research station was closed for the winter. As data for the last two month of 2011 has

not been retrieved from both stations yet, a thorough presentation of data from 2011 will be presented in the 2012 annual report. Data for 2010 and 2011 are shown in

Table 2.1 Monthly mean values of climate parameters 2010 and 2011. *Data for 2011 are preliminary.

Year	Month	Air temperature (°C)		Rel. humidity (%)	Air press. (hPa)	Net rad. (W m ⁻²)	Shortwave rad. (W m ⁻²)		Wind velocity (m s ⁻¹)		Dominant wind dir.
		2.0 m ¹⁾	7.5 m				In	Out	2.0 m	7.5 m	
2010	Jan	-20.3	-18.8	71	1007.9	-18	0	0	2.7	3.2	NNW
2010	Feb	-23.5	-21.5	69	1019.4	-26	6	5	2.4	3.0	NNW
2010	Mar	-23.9	-22.0	65	1015.3	-26	67	51	2.5	3.1	NNW
2010	Apr	-12.7	-11.6	72	1012.7	-15	156	126	2.8	3.5	NNW
2010	May	-2.8	-2.2	80	1016.5	1	236	177	2.9	3.5	SE
2010	Jun	1.9	2.1	85	1011.1	98	272	95	1.7	2.0	SE
2010	Jul	5.3	5.4	80	1004.8	123	264	40	2.2	2.6	SE
2010	Aug	5.3	5.9	74	1010.3	58	164	27	2.0	2.6	SE
2010	Sep	-0.6	0.2	80	1011.2	3	61	11	2.0	3.0	NNW
2010	Oct	-9.0	-7.8	70	1010.0	-28	14	9	3.2	4.5	NNW
2010	Nov	-20.5	-18.6	68	1013.7	-33	0	0	2.0	2.8	NNW
2010	Dec	-16.7	-15.1	65	1015.9	-33	0	0	2.8	3.9	NNW
2011	Jan	-20.2	-18.6	68	1009.2	-24	0	0	2.6	3.5	NNW
2011	Feb	-14.4	-13.1	80	998.7	-16	6	5	3.3	4.4	NNW
2011	Mar	-19.2	-17.7	64	998.7	-26	58	47	2.9	3.9	NNW
2011	Apr	-12.7	-11.9	73	995.2	-12	140	118	3.2	4.2	NNW
2011	May	-4.0	-3.1	75	1015.0	-2	254	199	2.1	2.8	NNW
2011	Jun	2.3	2.8	78	1017.0	122	300	84	1.6	2.1	SE
2011	Jul	5.8	6.1	80	1009.9	118	254	41	1.8	2.4	SE
2011	Aug	5.6	-	79	1012.2	61	147	23	2.0	2.7	SE
2011	Sep	-0.8	-	72	1002.2	2	87	14	2.0	2.8	NNW
2011	Oct	-10.2	-	71	1005.2	-23	14	10	3.7	5.0	NNW
2011*	Nov	-16.6	-	72	1000.6	-21	-	-	2.7	3.7	NNW
2011*	Dec	-19.0	-	70	995.0	-22	-	-	3.0	4.0	NNW

figure 2.2 and monthly mean values of climate parameters for 2010-2011 are shown in table 2.1. Furthermore, annual values for selected parameters for 1996 to 2010 and mean wind statistics have been updated in tables 2.2 and 2.3.

2011 was a normal year for most climatic parameters (figure 2.2), but February mean air temperature was relative high compared to previous year (figure 2.3). The first positive temperatures in 2011 were measured 28 April and by 24 June the temperature for the first time exceeded 10°C. The maximum temperature was 19.7°C (1 August). Monthly mean values of selected climate parameters for June, July and August from 1996-2011 are shown in table 2.4. The sum of positive degree-days during 2011 was a little below the average for the last 15 years (table 2.5). Episodes of night frost were registered in both July and August but the first negative diurnal mean temperature was not measured until 4 September.

2.2 Climate gradients, snow, ice and permafrost

In order to increase the spatial resolution of meteorological data and to describe the gradients (both altitudinal and coast/inland), several smaller automatic weather stations have been installed in the area. In 2003, the station M2 was installed in the Zackenberg valley and the station M3 was installed half-way up Aucellabjerg (Rasch and Caning 2004). M6 was installed at the top of Dombjerg in 2006 (Klitgaard et al. 2007) and M7 was installed in 2008 in the area just west of Store Sø in Store Sødal (Jensen and Rasch 2009). Three automatic weather stations were installed on the A.P. Olsen Glacier and data from these are reported in Chapter 3.

Monthly mean temperatures from the four weather stations are shown in figure 2.4. Here it is very clear that the lower lying stations have larger annual variations than the higher lying stations. Especially

Table 2.3 Mean wind statistics are based on wind velocity and direction measured 7.5 m above terrain in 1997, 1998, 2000 and 2002-2009. Due to re-evaluation of the figures for 2003, differences can be seen if compared to earlier publications. Calm is defined as wind speed lower than 0.5 m s⁻¹. Max speed is maximum of 10 minutes mean values. Mean of maxes is the mean of the yearly maximums. The frequency for each direction is given as percent of the time for which data exist. Missing data amounts to less than 8% of data for the entire year.

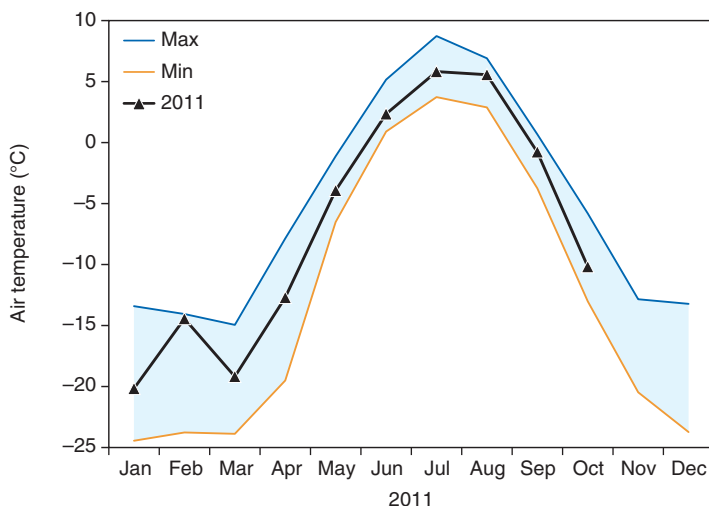
Year	Mean ¹⁾				2010		2011*				
	Direction	Frequency	Velocity (m s ⁻¹)			Frequency	Velocity (m s ⁻¹)		Frequency	Velocity (m s ⁻¹)	
			%	mean	mean of max		max	%		mean	max
N	15.8	4.5	24.2	29.6	14.3	3.9	23.2	13.6	5.0	29.7	
NNE	3.6	2.7	18.6	28.9	3.5	2.1	15.0	3.5	2.8	14.9	
NE	2.5	2.3	15.3	23.2	2.4	2.0	15.0	2.3	2.2	16	
ENE	2.7	2.4	13.1	17.4	2.7	2.0	10.1	2.6	2.4	16.4	
E	3.9	2.0	8.9	10.7	3.6	2.0	7.1	3.7	2.1	6.9	
ESE	6.7	2.2	8.9	10.3	6.7	2.3	6.9	6.9	2.3	7.2	
SE	8.7	2.4	9.6	18.1	9.9	2.6	7.9	10.6	2.5	7.5	
SSE	5.8	2.4	9.4	16.2	5.8	2.5	9.6	6.3	2.4	7.3	
S	4.1	2.5	8.1	9.9	4.1	2.3	6.9	4.4	2.5	7.6	
SSW	3.0	2.3	8.5	13.4	2.8	2.1	8.3	2.8	2.1	7.4	
SW	2.6	2.1	8.0	12.2	2.4	1.9	5.4	2.5	1.9	6.8	
WSW	3.0	2.4	9.8	15.9	2.8	2.1	6.7	3.1	2.2	9.1	
W	2.9	2.5	16.7	23.5	2.7	2.1	11.7	3.0	2.1	13.9	
WNW	3.3	2.6	16.7	20.6	3.6	2.5	15.0	3.6	2.5	13.1	
NW	6.5	3.5	19.0	25.1	7.7	3.6	15.5	7.5	3.8	19.1	
NNW	21.9	5.0	22.8	26.2	23.3	4.5	18.8	20.3	5.5	30.1	
Calm	3.1				1.8			3.2			

¹⁾Data from 1997, 1998, 2000, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009

*Data from 2011 are preliminary

during the winter months, the valley stations have much lower temperatures than the stations at higher elevations. This is mainly due to the effect of cold air sinking down and creating frequent inversions. From November 2010 to June 2011 M6 on top of Dombjerg only have sporadic measurements. Therefore data from December 2010 to May 2011 is not included in figure 2.4. Data from M7 in Store Sødal was not successfully retrieved until in April 2012.

Figure 2.3 Mean monthly air temperatures at Zackenberg during the period 1995-2011.



Winter hot spells (where the temperature suddenly rises above the freezing point) were registered at all stations except M6 (probably because of malfunctioning data logger). At the beginning of January 2011 one episode with temperatures up to three degrees celsius were registered at the climate stations, M3 and M7. Due to the limited access to M6 and the many problems arising at this station, the M6 on Dombjerg will be discontinued in 2012 and re-established on the mountain Zackenberg in 2013. This will ease the access and upgrading to CR1000 data loggers and will enable wireless data communication to the station in the future.

Snow depth

The amount of snow measured at the meteorological station during the winter 2010/2011 was below the average level. The build-up of a continuous snow cover above 0.1 m did not happen before the end of January 2011 (table 2.6). The maximum snow depth measured at the climate station was 40 cm, which was reached 26 April (figure 2.2 and figure 2.5). Snow melt started around 1 June and by 16 June the

ground was free of snow below the sensor at the meteorological station (table 2.6). This is close to the average date for snow melt in the Zackenberg valley. The winter had a very short period with continuous snow cover above 0.1 m (135 days). This was close to the shortest period ever, 108 days during the winter 2008/2009 (table 2.6). The thin snow cover is reflected in the soil temperatures that were lower than during most previous winters (figure 2.5).

Snow depth is also being measured at the automatic weather stations M2, M3 and M7 (figure 2.6). Snow depth at both M3 and M7 peaked in the end of March while M2 and the climate station did not peak until the end of April. The build-up under M2 from 19 April to 20 April is properly due to strong wind with resulting snow drifting. By 16 June, snow had disappeared from all stations.

In order to achieve a better spatial resolution of snow depths for the modelling,

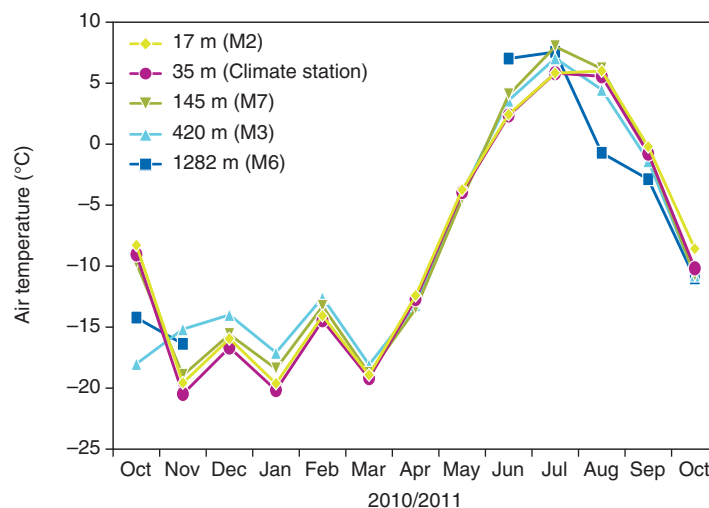


Figure 2.4 Mean monthly temperatures from automatic weather station M2 (17 m a.s.l.), M3 (420 m a.s.l.), M6 (1282 m a.s.l.), M7 (145 m a.s.l.) and climate station (35 m a.s.l.) during the period 1 October 2010 to 30 October 2011.

Table 2.4 Climate parameters for June, July and August 2002 to 2011. ¹⁾ Wind velocity, max is the maximum of 10 minutes mean values.

Year	Month	Shortwave rad. (W m ⁻²)		Net rad. (W m ⁻²)	PAR (mmol m ⁻² s ⁻¹)	Air temperature (°C)			Precipitation (mm) total	Wind velocity (m s ⁻¹)		Dominant wind dir.
		mean in	mean out			mean	min. 2 m	max. 2 m		mean 7.5 m	max ¹⁾ 7.5 m	
2002	Jun	344	151	113	–	2.6	–2.8	14.9	1	1.6	6.8	SE
	Jul	205	23	105	424	5.7	–0.9	13.8	11	2.6	9.9	SE
	Aug	129	16	51	272	4.9	–3.1	11.6	15	2.8	12.9	SE
2003	Jun	294	108	106	612	2.2	–4.8	14.7	7	1.6	5.4	SE
	Jul	210	26	96	431	7.7	1.8	16.7	6	2.8	14.2	SE
	Aug	151	20	56	313	6.6	–0.5	15.4	3	2.5	10.1	SE
2004	Jun	279	73	111	571	2.5	–3.4	19.1	3	2.3	13.6	SE
	Jul	225	30	95	464	7.2	–0.7	19.0	10	2.8	10.5	SE
	Aug	150	20	62	302	5.6	–1.4	17.2	4	2.4	12.6	SE
2005	Jun	261	53	–	519	2.7	–3.5	13.4	6	2.4	11.8	SE
	Jul	215	29	–	428	6.9	–0.6	21.8	28	2.9	13.3	SE
	Aug	154	21	51	321	4.6	–2.7	14.0	4	3.2	10.9	SE
2006	Jun	312	208	54	675	1.0	–4.4	9.5	0	1.7	6.9	SE
	Jul	256	28	131	550	6.6	–1.2	22.8	12	2.5	11.3	SE
	Aug	158	21	61	336	5.5	–4.5	16.3	2	2.6	12.0	SE
2007	Jun	287	86	116	609	3.3	–2.4	15.8	9	2.2	14.8	SE
	Jul	251	32	118	531	5.9	–1.8	16.4	8	2.2	6.5	SE
	Aug	149	20	56	320	6.6	–2.6	13.6	6	2.7	12.3	SE
2008	Jun	284	145	74	612	5.2	–1.5	12.8	3	1.9	11.7	ESE
	Jul	260	32	126	551	8.8	0.0	18.4	8	2.8	14.2	SE
	Aug	141	19	51	296	8.0	0.3	17.1	49	3.3	16.9	SE
2009	Jun	257	32	134	532	1.9	–2.4	9.3	3	2.6	11.0	SE
	Jul ²⁾	233	30	103	487	7.9	0.4	18.1	26	3.3	15.4	SE
	Aug ²⁾	145	18	48	292	4.4	–1.8	11.6	31	2.8	24.4	SE
2010	Jun ²⁾	272	95	98	548	1.9	–8.1	12.8	13	2.0	10.2	SE
	Jul ²⁾	264	40	123	529	5.3	–1.7	15.1	1	2.6	15.7	SE
	Aug ²⁾	164	27	58	325	5.3	–2.6	16.1	2	2.6	15.0	SE
2011	Jun	300	84	122	590	2.3	–5.9	13.8	–	2.1	12.3	SE
	Jul	254	41	118	503	5.8	–0.8	14.5	–	2.4	15.0	SE
	Aug	147	23	61	–	5.6	–2.4	19.7	–	2.7	12.6	SE

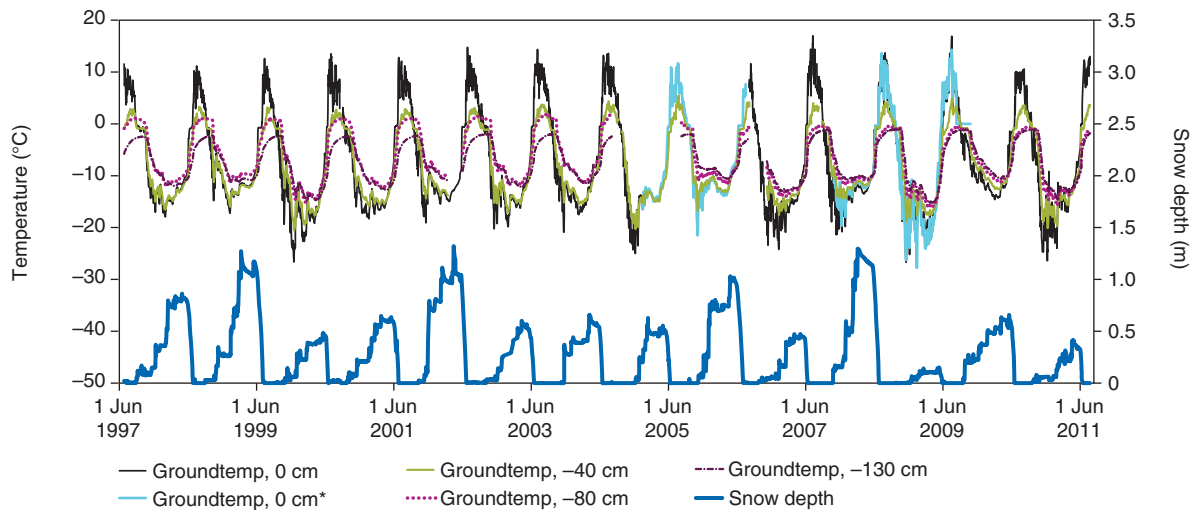


Figure 2.5 Daily mean soil temperatures and snow depth from the meteorological station 1997–2011. In August 2006 soil temperature sensors were replaced. *Data from sensor at the snow depth station.

Table 2.5 Positive degree-days calculated on a monthly basis as the sum of daily mean air temperature above 0°C. Calculations are based on air temperatures from the meteorological station.

Degree days	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
January										1.5		3.6				
February																
March																
April								0.2	1.1		2.9					
May	1.1	1.3	0.1	3.6	0.5	0.5	18.2	3.3	4.1	5.4	3.1		10.0	12.3	0.4	0.6
June	63.7	74.6	32.5	52.9	71.8	68.2	81.8	74.2	73.9	84.6	37.2	99.7	155.0	64.6	73.3	78.1
July	181.0	115.4	147.4	192.7	164.4	152.0	175.6	237.2	222.2	214.7	205.3	182.2	270.8	265.6	165.6	180.1
August	140.5	154.2	143.6	89.2	127.3	181.2	152.5	203.2	169.4	141.5	171.5	204.5	213.7	141.3	164.3	172.5
September	15.3	4.5	11.3	19.7	5.7	31.1	41.2	42.5	41.4	17.7	15.7	10.1	63.1	8.9	29.6	18.7
October		1.5				0.3	1.8									
November																
December																
Sum	401.7	351.5	334.8	358.0	369.7	433.2	471.1	560.6	514.8	466.4	435.7	500.1	712.6	492.7	433.2	450.1

Table 2.6 Key figures describing the amount of snow at the meteorological station during the last 14 winters.

Winter	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11
Max. snow depth (m)	0.90	1.30	0.50	0.70	1.30	0.60	0.70	0.70	1.10	0.60	1.30	0.18	0.66	0.45
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr	13 Apr	12 Feb	26 Apr	4 May	6 ar	17 Feb	19 May	25 Apr
Snow depth exceeds 0.1 m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	6 Dec	24 Nov	27 Dec	19 Dec	12 Jan	26 Oct	29 Jan	25 Sep	26 Jan
Snow depth below 0.1 m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul	8 Jun	24 Jun	16 May	16 Jun	10 Jun

snow depths are also being measured along two main transects, i.e. one transect (SNM) running from Lomsø into the Zackenberg valley and another (SNZ) running along the ZERO line from the old delta up to 420 m a.s.l. These snow depths will be used as input for the SnowModel covering the central

part of the Zackenberg valley and possibly compared directly to normalized difference vegetation index (NDVI) and vegetation development along the ZERO line.

By mid-October 2011, the Zackenberg valley was more or less totally covered by new snow with a bulk density of 330 kg

m⁻³. There was a lot of wind during and after the snowfall, which caused the relatively high density. The snow densities during the fall of 2011 were all relatively high compared to previous fall periods.

Snow cover

The snow cover depletion for 2011 was close to average for the 1995-2011 period (figure 2.7). Real change in snow cover started in early June with 50% snow cover occurring 15 June. In late June, the snow cover depleted fast ending up as in 2010 being one of the years where all snow within the area of the camera coverage disappeared earliest.

The snow cover 10 June, which has been chosen as a good early season indicator for biological conditions, is given for different sub-sections of the study area in table 2.7. Values for 2011 are close to average for the eastern most sections (9, 10 and 11) but significantly lower in the other sections compared to average for the period 1995-2010.

Active layer depth

Development of the active layer (the layer above the permafrost that thaws during the summer) starts when the air temperature becomes positive and snow has disappeared from the ground. The depth of soil thaw was measured throughout the field season at two grid-plots; ZEROCALM-1 (ZC-1) covering a 100×100 meter area with

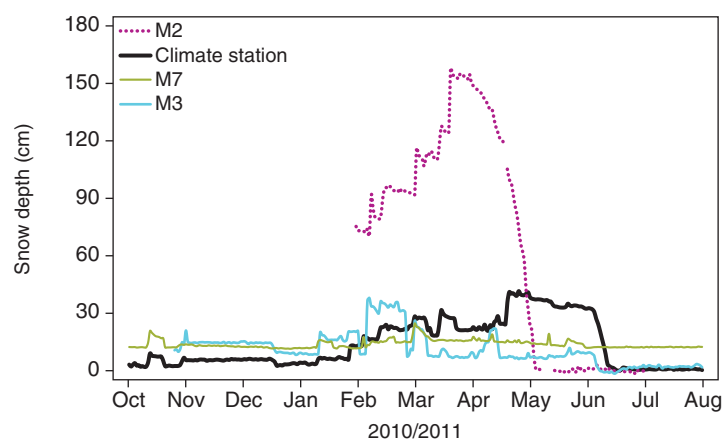


Figure 2.6 Snow depths at the automatic weather stations in 2010/2011, M2 (17 m a.s.l.), M3 (420 m a.s.l.), M7 (145 m a.s.l.) and the climate station (35 m a.s.l.).

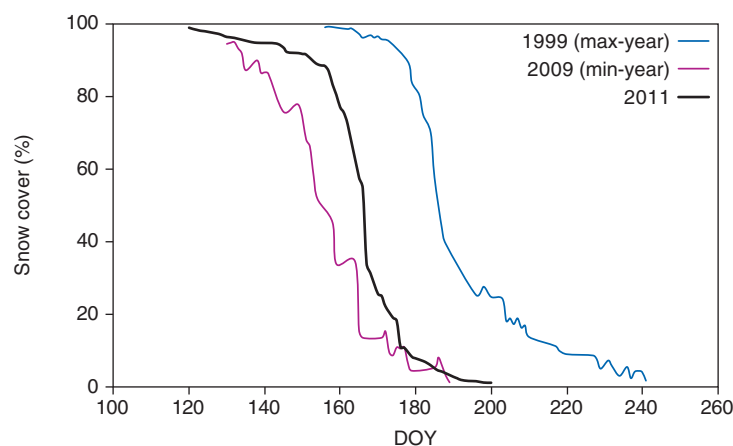


Figure 2.7 Snow cover depletion curves from the central part of the Zackenberg valley. The three years shown in the figure, is 2009 with a very early melt-off, 1999 with a late melt-off and the depletion curve for 2011. Curves exist from 1998-2011.

Table 2.7 Area size and snow cover 10 June in 13 bird and mammal study sections in the Zackenberg valley and on the slopes of Aucellabjerg 2001-2011 and mean for the period 1995-2010 (see figure 4.1 in Caning and Rasch 2003 for map of sections). Photos were taken from a fixed point 480 m a.s.l. on the east facing slope of the mountain Zackenberg within +/- 3 days of 10 June and extrapolated according to the methods described by Pedersen and Hinkler (2000). Furthermore, the proportions of the areas not visible from the photo point are given. Values in *italic* are based on only part of the given section due to missing photo coverage.

Section	Area (km ²)	Area hidden (%)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean (1995-2010)
1 (0-50 m)	3.52	3.5	73	77	68	48	31	74	38	62	13	53	53	61
2 (0-50 m)	7.97	1.2	87	87	92	49	25	81	43	77	5	61	50	68
3 (50-150 m)	3.52	0.0	89	82	83	51	35	77	40	74	11	48	32	65
4 (150-300 m)	2.62	0.0	79	56	73	39	28	65	36	54	19	32	23	53
5 (300-600 m)	2.17	0.0	56	36	49	16	25	62	25	46	17	12	15	39
6 (50-150 m)	2.15	75.3	84	78	74	56	50	80	50	59	18	49	29	66
7 (150-300 m)	3.36	69.3	84	74	90	56	46	82	58	69	34	44	27	68
8 (300-600 m)	4.56	27.5	45	52	66	30	29	67	26	45	16	25	11	45
9 (0-50 m)	5.01	6.2	96	96	100	58	23	73	49	80	18	56	72	73
10 (50-150 m)	3.84	2.9	97	93	100	56	47	92	57	85	43	55	80	78
11 (150-300 m)	3.18	0.2	97	88	100	66	61	88	54	73	77	51	79	79
12 (300-600 m)	3.82	0.0	73	65	98	53	70	85	38	53	64	43	50	65
13 (Lemmings)	2.05	1.0	83	83	89	46	25	79	41	73	4	64	54	65
Total area	45.70	12.9	82	77	83	49	37	77	43	65	28	44	46	64

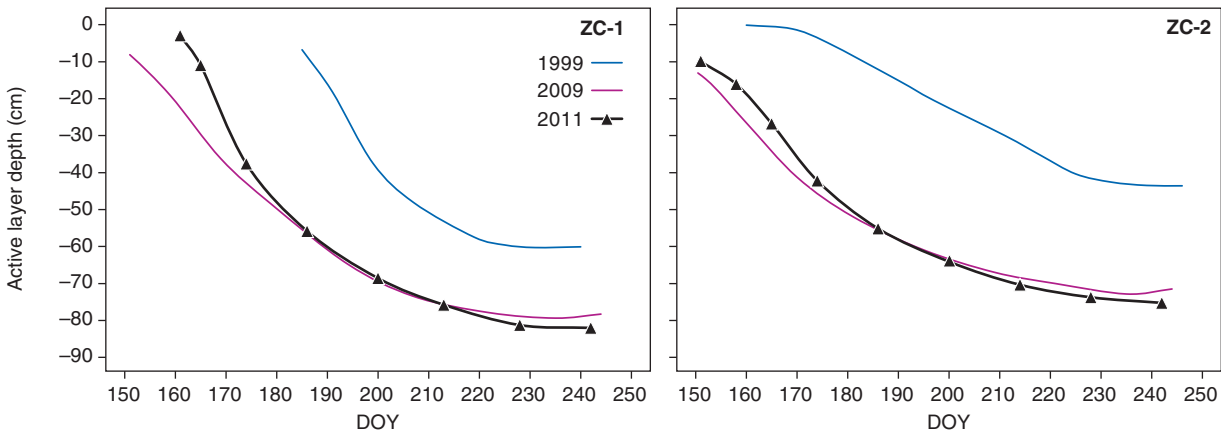


Figure 2.8 Thaw depth progression in ZEROCALM-1 and ZEROCALM-2 during summer 2011 (bold black line). Minimum and maximum thaw years (1999 and 2009, respectively) are shown as blue and red lines, respectively.

Table 2.8. Average maximum thaw depth (in cm) for grid points in ZEROCALM-1 and ZEROCALM-2 measured late August, 1997-2011.

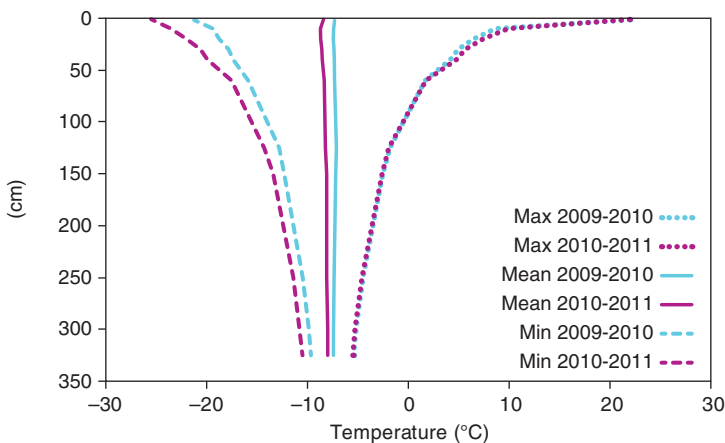
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
ZEROCALM-1	61.7	65.6	60.3	63.4	63.3	70.5	72.5	76.3	79.4	76.0	74.8	79.4	79.4	78.2	82.0
ZEROCALM-2	57.4	59.5	43.6	59.8	59.7	59.6	63.4	65.0	68.6	67.6	67.1	67.5	72.9	69.5	75.3

121 grid nodes and ZEROCALM-2 (ZC-2) covering a 120x150 meter area with 208 grid nodes.

In ZC-1, the first grid node was free of snow 7 June and within ten days all snow in this relatively homogenous grid site had melted. The maximum thaw depth was reached by the end of August and was deeper than previous maximum thaw depths measured at these grids (figure 2.8 and table 2.8).

In ZC-2, there were five grid nodes without snow cover 6 May and by 23 June all grid nodes were free of snow. The maximum thaw depth was reached at the end of August/early September and for this plot it was close to the deepest thaw that has been measured since 1997, even though the timing of the snow melt was average.

Figure 2.9 Minimum, mean and maximum temperatures from the borehole at M4. 30 October 2009 to 29 October 2010 (purple) and 30 October 2010 to 29 October 2011 (blue).



Data from the two ZEROCALM-sites are reported to the circumpolar monitoring programme CALM III (Circumpolar Active Layer Monitoring-Network 2009-2014) maintained by Centre for International Studies, the University of Delaware (www.udel.edu/Geography/calm).

Temperature in different settings and altitudes

GeoBasis operates several mini data loggers for year-round temperature monitoring in different altitudes and different geomorphologic settings in the landscape. Positions and a short description of the sites are given in the GeoBasis manual.

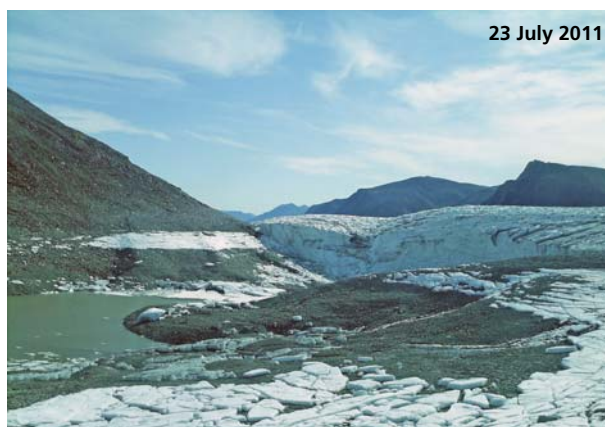
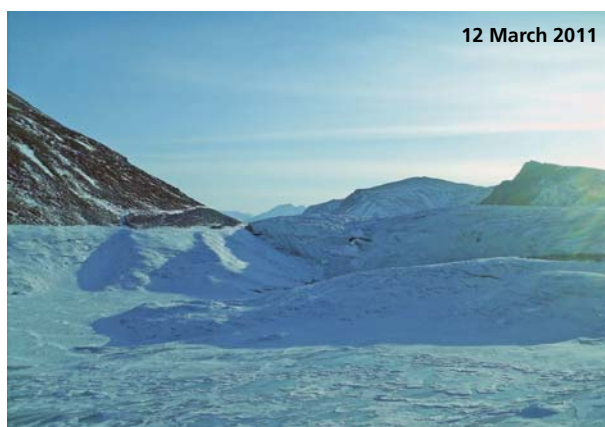
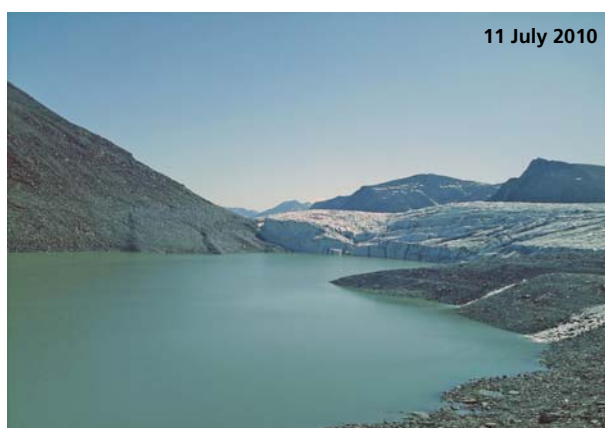
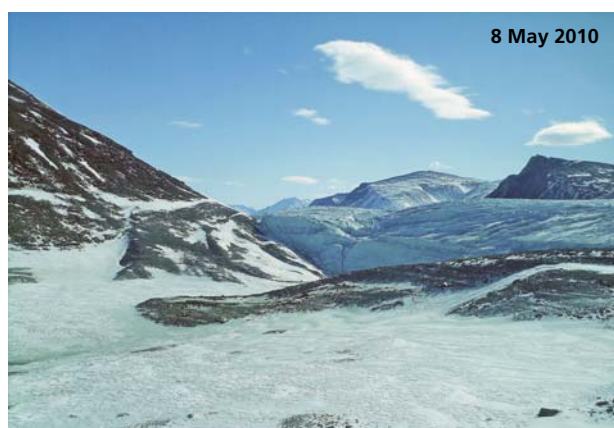
Year-round soil temperatures in the active layer are being logged at the meteorological station, at the automatic weather stations M2, M3, M4 and M5 and at the automatic chamber site in the fen (figure 2.1). At M4 a 325 cm deep borehole monitors temperatures from the upper part of the permafrost (Jensen and Rasch 2009). Now three years of data has been obtained from this borehole (figure 2.9). In 2012, we hope to be able to establish a deeper borehole to obtain more knowledge of the state of the permafrost in the Arctic. For Greenland there is a gap within data from boreholes and it would be very valuable to include a 10-20 m deep borehole with temperature loggers as part of the Zackenberg long-term monitoring programme.

Lake drainage

Photos from the digital camera at the A.P. Olsen Land glacier dammed lake was retrieved 6 May 2011. The camera was installed in April 2008 to cover fluctuations of the glacier dammed lake (figure 2.10). Daily photos had been obtained since 10 May 2008 except from a gap between October 2009 and May 2010 because of a full memory card. The photos (figure 2.10) show how the lake builds up from a minimum in spring 2010 to a maximum during late summer and fall, new ice covered the lake from 20 September. Unlike 2009 the lake did not drain in the summer 2010. In January 2011, the lake is com-

pletely covered with ice and snow patches. From 1 February to 10 March the camera was unfortunately covered by snow. The picture from 12 March shows the lake drained completely through the glacier. Ice on the banks along the river Zackenberg was observed when personnel arrived at the station in late April, which is evidence of the outburst from the glacier lake in March. From the hydrometric station and the cameras covering the Zackenberg valley it was clear that the water arrived in the lower part of the valley 8 March. The distance from the lake to the hydrometric station is approximately 35 km. Depending on the seasonal timing

Figure 2.10 Glacier dammed lake at A.P. Olsen Land. The lake builds up during the summer 2010 and is covered by ice in January 2011 before it drains early in March 2011. Then the lake builds up again and drains 22 July 2011. Photos: GeoBasis programme.



for the outburst severe erosion can take place along the river banks. If it happens during winter (as in 2008) when the landscape is covered by ice and snow the erosion is minimal whereas if it happens during summer (as in 2009) when the riverbanks are free of snow and the soil has thawed the erosion impact may be very large.

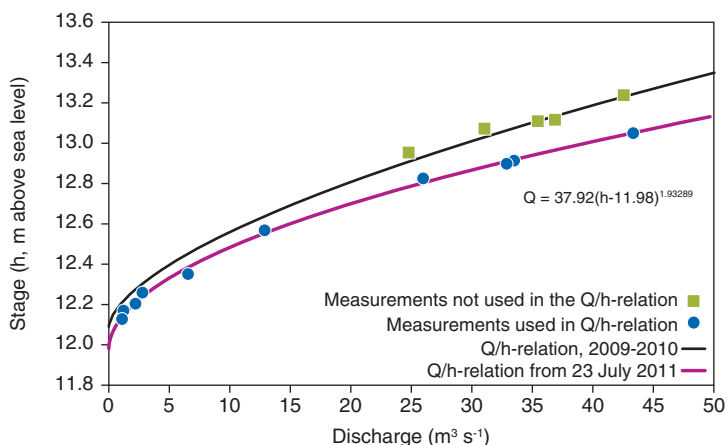
During the 2011 summer field season another flood from the glacier dammed lake at A.P. Olsen Land was observed at Zackenberg 22 July.

2.3 River water discharge and sediment transport

The river Zackenberg

The drainage basin of the river Zackenberg includes the Zackenberg valley, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of approximately 514 km² of which 106 km² are covered by glaciers. The first hydrometric station was established in 1995 on the western riverbank near the river mouth (Meltofte and Thing 1996). In 1998, the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried beneath a thick snowdrift each winter. During the years, the station has been flushed away a few times by the major floods from the ice dammed lake at the A.P. Olsen Land. The present position on the eastern river bank near the river crossing site is not perfect since large boulders at the river bottom creates some rather big waves during high flow. However, by combining different methods to decide water level fluctuations reliable data are obtained.

Figure 2.11 Stage-discharge relations (Q/h-relation) for the river Zackenberg at the hydrometric station. Purple line – relation valid from 23 July 2011, green line – relation valid before 23 July 2011 (=Q/h-relation, 2009–2010). The coefficient of correlation (R²) for the new relation is 0.986.



At the station, water level, water temperature, air temperature and conductivity are logged automatically every 15 minutes. In 2011, the water level was measured with a sonic range sensor and different pressure transducers.

Q/h-relation

After a large flood in 2005, the river cross profile changed and a new Q/h-relation had to be established. The new relation was valid until the end of the 2006 season. Unfortunately, the changed river cross profile made safe manual discharge measurements at high water levels almost impossible. This was the main reasons for the Danish Environmental Protection Agency to donate an Acoustic Doppler Current Profiler (ADCP) of the type Q-liner, which has now been used with great success since 2009. For further description, see Jensen and Rasch 2011. As the major floods make the river profile unstable a new Q/h-relation has to be established almost every year.

In 2011, twenty-nine discharge measurements were carried out. Of these, nineteen measurements were carried out under snow and ice-free conditions where the Q/h-relation is valid. In July another flood occurred, which again changed the river profile. Therefore, a new Q/h-relation has been established. The new Q/h-relation is based on 10 measurements and is valid from 23 July 2011 (figure 2.11).

River water discharge

Water passed the station 8 May 2011, when water that was dammed in Store Sødal after an outburst flood from the ice dammed lake at A.P. Olsen Land in March, made its way on top of the snow packed river bed. Water from Lindeman and other streams were significant contributors from the end of May. There was another flood 22 July, which is registered at the hydrometric station (figure 2.12).

The water discharge from 2011 is shown in figure 2.12. From the river started flowing and until 22 June the riverbed and banks were covered with ice and/or snow to such a degree that the Q/h-relation was invalid. Instead, the discharge is approximated by interpolation between 10 manual discharge measurements made during the period 11 June to 16 June. From 18 June until the Q/h-relation is valid the discharge is calculated by using a new method that was developed in 2010, see Larsen et al.

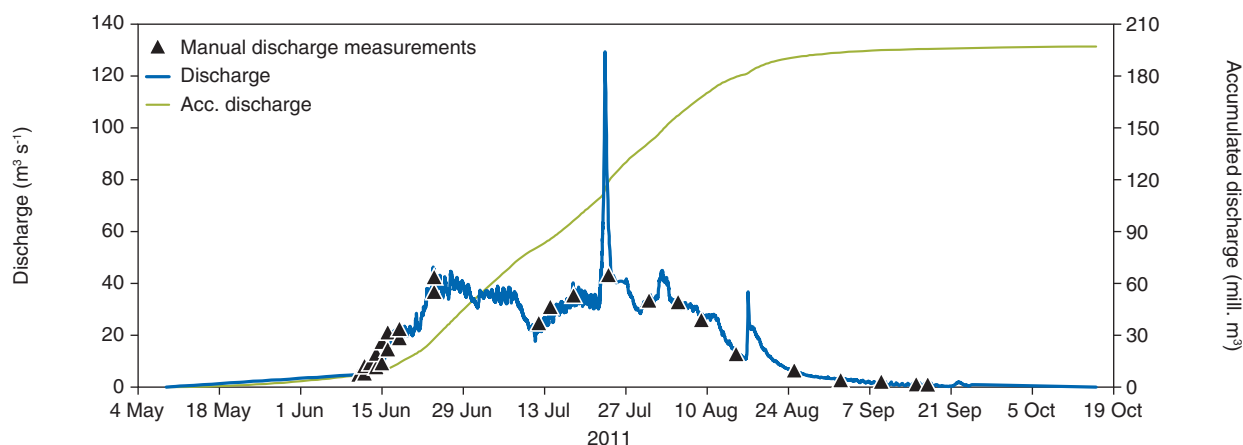


Figure 2.12 Water discharge in the river Zackenberg during 2011.

2011. From 22 June to 24 September, the discharge is calculated from the Q/h-relation (figure 2.11). After 24 September, the discharge is estimated to decrease linearly to an assumed zero discharge 15 October.

The total amount of water drained from the catchment area during the measuring period in 2011 was 197 million m³. Despite the flood 22-23 July this is only slightly above the average discharge season, which is 188 million m³ (table 2.9). The water level at the peak flood was lower than earlier seen, which probably is due to the fact that a minor outburst flood from the glacier occurred in March and that the lake at A.P. Olsen Land had not filled up to maximum level before draining again.

The peaks in the discharge all seems to be correlated with higher temperatures in

the more elevated areas of the drainage basin and likewise the significant drop in discharge observed around 1 August correlates with a drop in temperature in these areas (figure 2.13a and b). The slight increase in the end of August is a response to the rain event 17 August. This is also reflected as a peak in the conductivity. From mid-September, ice starts to form on the river and by 3 October, it is possible to cross the river on the ice. However, some water is still running below the ice – observed as late as 16 October.

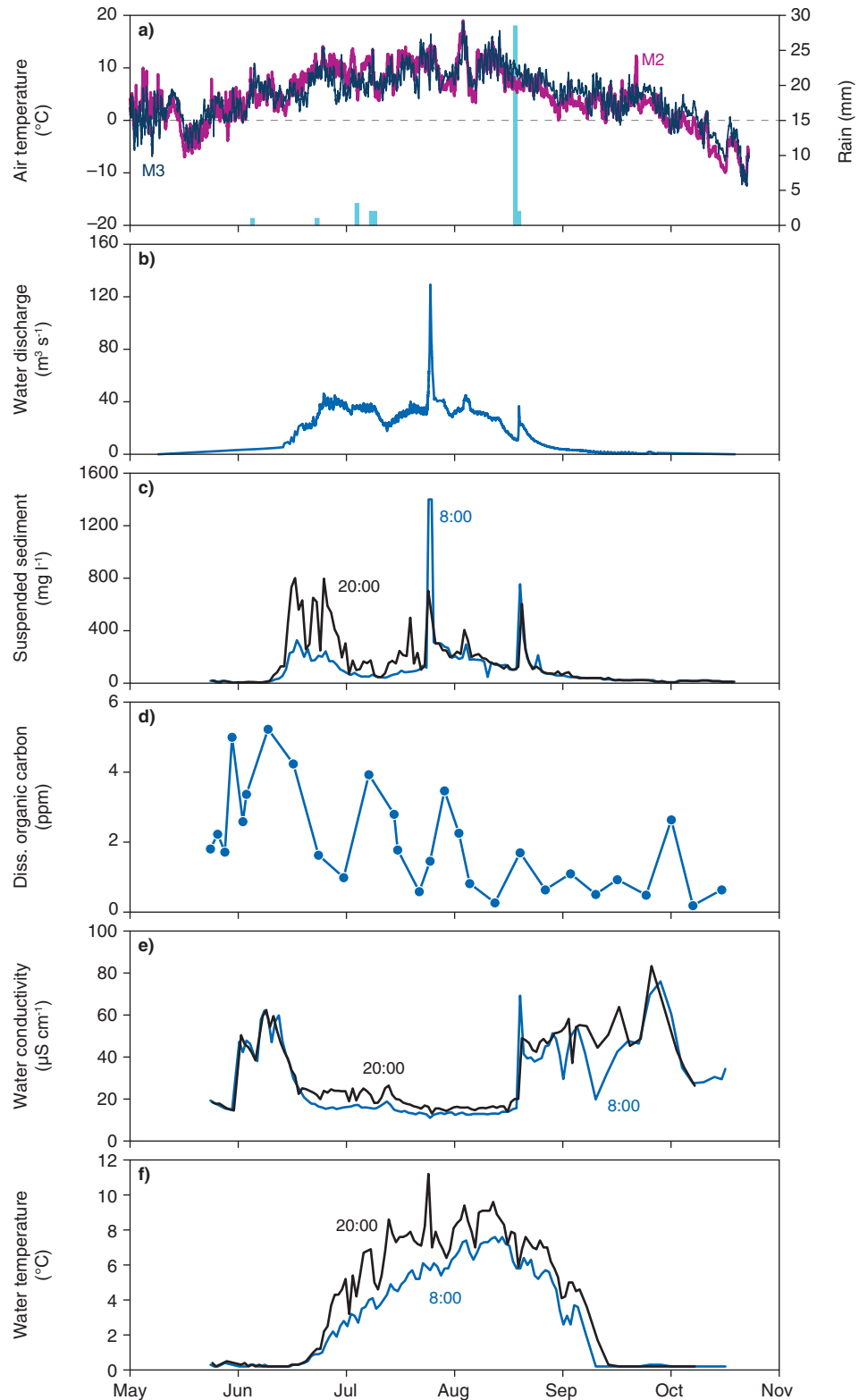
Suspended sediment and river water chemistry

Daily water samples were collected in the morning (8:00) and in the evening (20:00) in order to determine suspended sediment

Table 2.9 Total discharges in the river Zackenberg during the years 1996-2011, corresponding water loss for the drainage area (514 km²), and precipitation measured at the meteorological station and estimated suspended sediment transport. ¹⁾The hydrological year is set to 1 October previous year to 30 September present year. ²⁾For 2005, no data is available during the flood from 25 July 05:00 until 28 July 00:00. After this date and until the new hydrometric station was set up on 5 August the discharge are estimated from manual readings of the water level from the gauge. ³⁾No precipitation data available from 22 January to 7 April. No total precipitation as there is too many missing values.

Hydrological year ¹⁾	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total discharge (mill m ³)	132	188	232	181	150	137	338	189	212	>185*	172	183	201	146	173	197
Water loss (mm)	257	366	451	352	292	267	658	368	412	>360	335	356	391	284	337	383
Precipitation (mm)	239	263	255	227	171	240	156	184	279	266	206	133	219	157	>125**	–
Total annual transport																
Suspended sediment (ton)		29444	130133	18716	16129	16883	60079	18229	21860	71319	27214	51118	39039	44716	23538	38337
River break-up	late May	4 Jun	10 Jun	9 Jun	8 Jun	8 Jun	4 Jun	30 May	1 Jun	3 Jun	12 Jun	2 Jun	7 Jun	22 May	30 May	23 May

Figure 2.13 a) Diurnal mean air temperatures for 2011 at M2 (17 m a.s.l.) and at M3 (420 m a.s.l.) and rain registered at the meteorological station. Seasonal variations of selected parameters in the river Zackenberg: b) water discharge. c) suspended sediment concentrations at 08:00 and 20:00. d) dissolved organic content. e) conductivity at 08:00 and 20:00. f) water temperature at 08:00 and 20:00.



concentrations (SSC). As shown in figure 2.13c, SSC shows highest concentrations early in the season. At the same discharge rates, concentrations of suspended sediment are much lower in late July and August than in the first part of the summer – probably due to depletion of easy erodible material along the riverbanks. A distinct

diurnal variation is measured early in the season whereas no variation is measured later during the season. This correlates with diurnal discharge variations being more distinct early in the season (figure 2.13b). Usually, the SSC are highest and show larger fluctuations in the afternoon and evening than in the morning.

The highest concentration of SSC during 2011 was 2288 mg l⁻¹, which was measured in the morning 23 July as a single peak value during the flood. The summer river burst began in the evening 22 July and ended the next day.

During the entire run-off period, the suspended sediment transport amounted to 38337 tonnes (table 2.9). In order to compare values between years, the total amount of sediment given is based solely on the SSC measured in the morning, but includes measurements carried out during flood events. If evening values were included, the total transport in 2011 would amount to 48112 tonnes. This indicates that all the calculated sediment yields given in the table are underestimated.

Daily variations of conductivity and water temperature are shown in figure 2.13d and 2.13e. The very first melt water early in the season shows high conductivity; a well-known phenomenon ascribed to solutes being washed out of the snow (Rasch et al. 2000). During the dry summer, the conductivity was very stable. The conductivity increases after a big rain event 17 August, where over 500 ml of rain was collected from the open bucket collector on the heath. The conductivity in the river peaks during rainy periods due to increased surface and subsurface drainage from land and soil water that has higher conductivity than melt water from the glacier.

Throughout the entire season, samples from the river were collected for mercury analysis. Results from this work are reported separately in section 6.2.

Suspended sediment and water discharge in Lindemanselven

Fluctuations of water level was measured in Lindemanselven approximately 300 m upstream from the junction between the rivers from Lindeman and Store Sødal (UTM: 511662 E, 8269094 N, 82 m a.s.l.). A logger with a pressure transducer was installed 22 July. This is later than previous years. Data was logged continuously every 15 minutes until mid-August. On 27 August, the pressure transducer was found underneath 31 cm sand and gravel. The big rain event 17 August apparently caused a lot of sediment from the hills to be washed out in Lindemanselven. Unfortunately, the pressure sensor failed and data from 17 August to the end of the season cannot be used. There is only water level data from 22 July until 17 August.

The logger was removed 19 September due to ice formation.

The Lindeman discharge measurements will not be continued in the coming years.

2.4 Precipitation and soil water chemistry

Precipitation

Rain samples for chemical analyses were collected from an open bucket collector 3 July, 17 August and 22 September. Furthermore, snow samples were collected from a snow pit 22 September, 2, 10, 15 and 24 October. All precipitation samples were analysed for chemical composition.

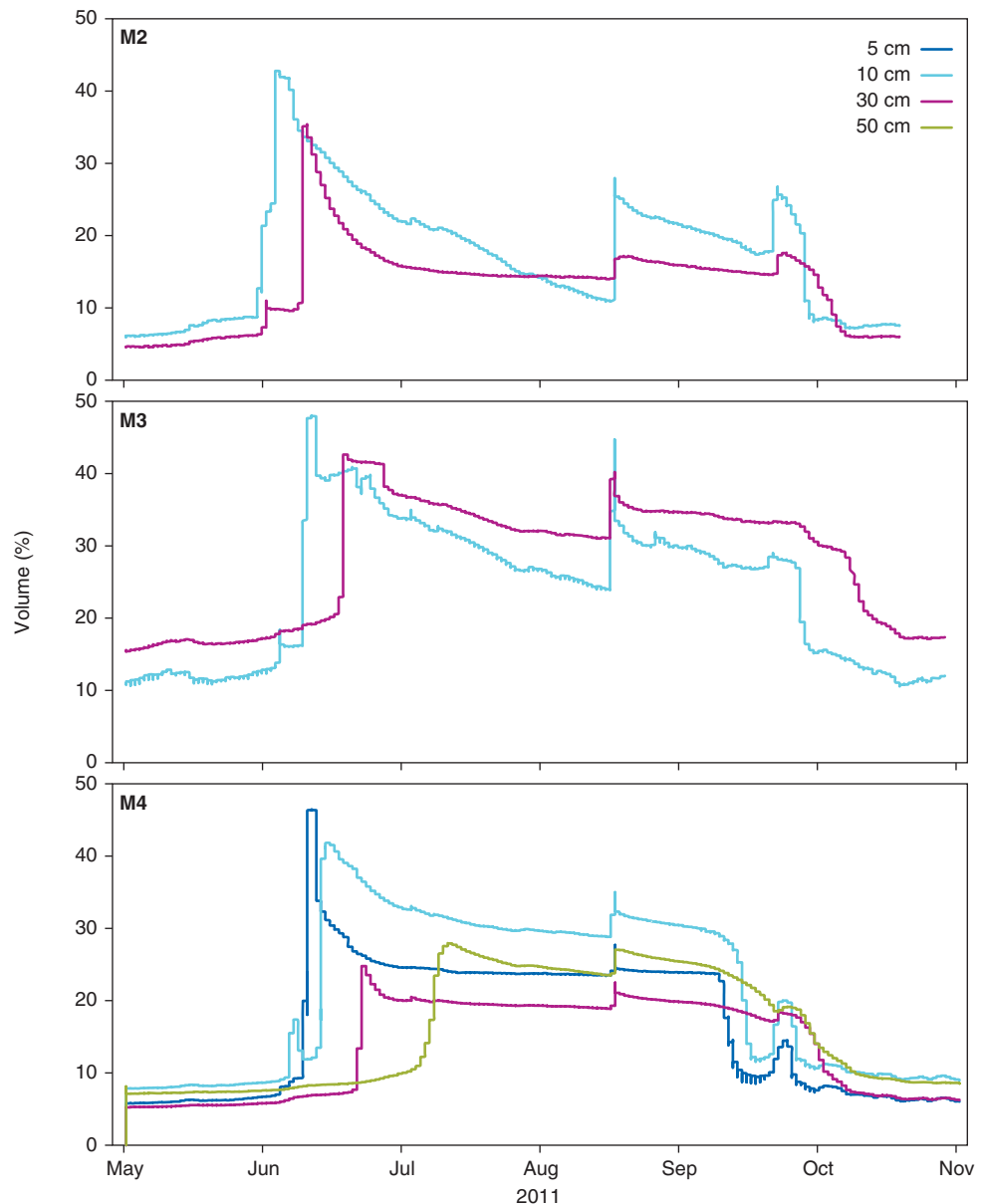
Soil moisture and soil water

Variation in soil moisture content is measured at several sites. During the field season, soil moisture was measured once a week at all soil water sites and along two transects in ZEROCALM-2 (the active layer grid site). Besides the manual measurements, soil moisture is monitored continuously at the three automatic weather stations M2, M3 and M4 (figure 2.14). M2 is located on a slope and affected by large snow accumulation but dries out quickly due to the primarily sandy material. M3 is located on a gentle slope at 420 m a.s.l. and during the early summer, this site is affected by flow of melt water from snow patches further up the mountain. Finally, M4 is located in the *Cassiope* heath just north of the meteorological station.

Except from an increase around 6 June due to a wet snow event a steady drying of the soil is observed until 17 August where a rain event increased the soil moisture content. Soil freeze in the upper part of the active layer happened almost momentarily around 6 September at all three plots whereas it happens more gradually deeper in the soil as it is not directly exposed to the air temperatures. There was a wet event at 21 September where all stations rose in moisture levels. By mid-October most of the active layer was frozen at the sites.

Three to four times during the season, soil water was collected from various depths in the active layer at three different sites covered by *Cassiope* heath, *Salix arctica*, and mixed heath vegetation, respectively. In late August a new soil water site close to the automatic chambers where installed. At this new site four lysimeters/

Figure 2.14 Soil moisture content throughout the field season 2011 at the three automatic weather stations M2, M3 and M4.



suction probes was installed in 10, 20, 30 and 50 cm depths. Collection from this site will start in 2012. The collected water from the other sites has been analysed for chemical composition.

2.5 Gas fluxes

Carbon gas fluxes are monitored on plot and landscape scale in the Zackenberg valley using two measurement techniques:

- Automatic chamber measurements of CH_4 and CO_2 exchange on plot scale in a fen site
- Eddy covariance measurements of CO_2 and H_2O exchange on landscape scale in heath and fen sites

Automatic chamber measurements

The CH_4 exchange has been monitored in six automatic chambers in a wet fen area since 2006 (Klitgaard et al. 2007). During 2011, the automatic chamber system was expanded to include two new chambers, giving eight chambers.

The temporal variation in CH_4 production is mainly associated with temperature, water table depth and substrate quality and availability. It has also been found from this site that frost action resulting in accumulated CH_4 gas squeezing out from the soil matrix can be of high importance for the annual CH_4 exchange (Mastepanov et al. 2008).

In 2011, measurements began 27 June and lasted until 31 October. Unfortunately, there were several leakage issues, especial-

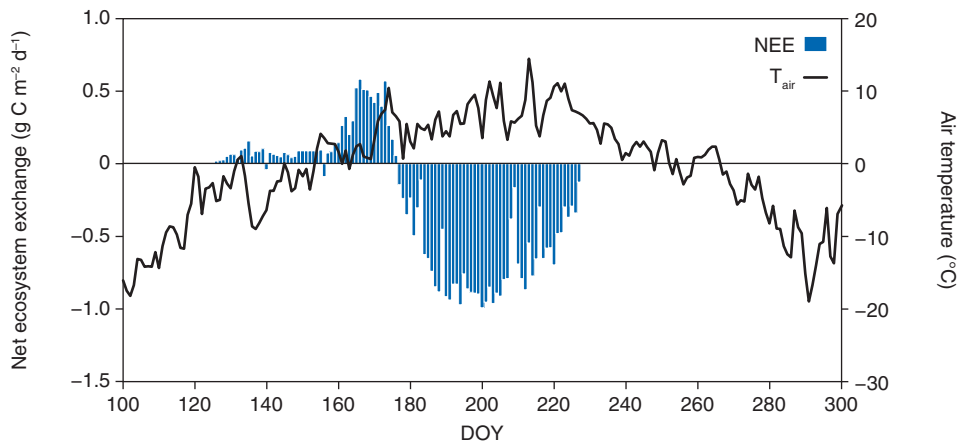


Figure 2.15 Daily net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the heath site in 2011.

ly during the first weeks of measurements, resulting in less reliable data. As these issues need to be studied in more detail to ensure high data quality, figures on the CH_4 flux from the fen during 2011 cannot be published yet. However, some information on the CH_4 dynamics during 2011 can be given: Similar to previous years, there was an increase in CH_4 emissions during the early part of the growing season. During late August through September, fluxes were low and stable. In mid-October, there was an increase in both mean fluxes and variability between chambers, with a pattern similar to those observed in some of the previous years, most likely related to frost action releasing CH_4 stored in the soil profile. There is also an overall tendency, the flux magnitudes were lower during 2011 compared with previous years.

Eddy covariance measurements

The land-atmosphere exchange of CO_2 is measured using the eddy covariance technique at two sites in Zackenberg: One located in a *Cassiope* heath site where measurements have been conducted since 2000, and one located in a wet fen area where measurements have been conducted since 2007. Both eddy covariance systems consist of a 3D sonic anemometer and a closed-path infrared CO_2 and H_2O gas analyser. For further details of the instrumentation, see Klitgaard and Rasch 2008, and Rasch and Caning 2003. Raw data from the eddy covariance systems were calculated using the software package EdiRe (Robert Clement, University of Edinburgh). For more details on the flux calculation procedures see Jensen and Rasch 2010.

During August 2011, several changes were made to both the heath and the fen measurement systems, due to the EU-IN-

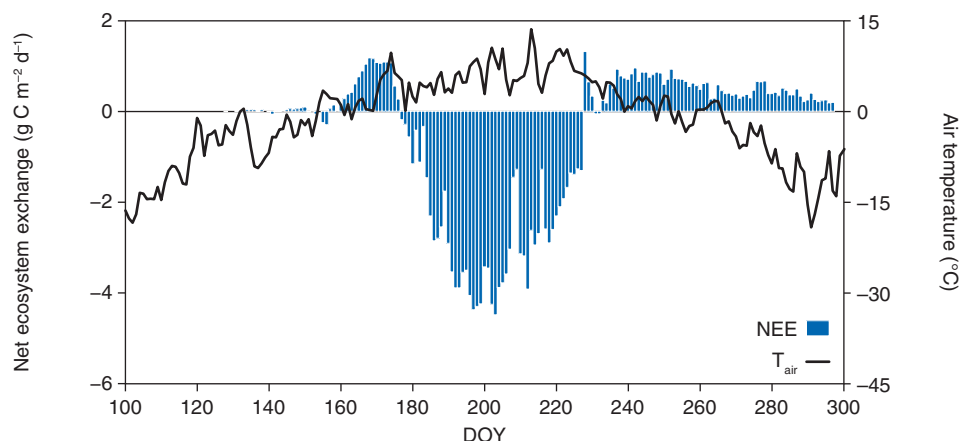
TERACT project that has funded new sensors, which increase the coverage of energy flux components. In addition, the fen site has been upgraded to a so-called ICOS (Integrated Carbon Observation System) level 2 site, with new sonic anemometer (Gill HS) and CO_2 and H_2O gas analyzer (enclosed path LI-7200). The old setup at the fen site was running in parallel with the new system during fall and early winter, and in this report, only data from the old system is presented, as new data has not yet been processed.

The temporal variation in the mean daily net ecosystem exchange of CO_2 (NEE) and air temperature during 2011 for the heath and fen sites is shown in figures 2.15 and 2.16 and tables 2.10 and 2.11. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants, plant respiration and microbial decomposition. The CO_2 exchange is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), along with the amount of biomass and soil moisture content. The sign convention used in figures and tables is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

Heath site

Eddy covariance CO_2 flux measurements at the heath site in 2011 were initiated 3 May and lasted until 16 August. During the days following 16 August, the setup was changed in relation to an EU-INTERACT project so that data was being logged on a data logger instead of a computer. Due to technical issues, data from new setup has not yet been processed. Between 3 May and 16 August, approximately 2%

Figure 2.16 Daily net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the fen site in 2011.



of the data were lost due to malfunction, maintenance and calibration.

The eddy covariance mast was placed on top of approximately 40 cm of snow and the snow cover in the fetch was 100% when measurements started. Early season CO_2 fluxes were small; however, in the period between snow melt and start of net uptake period, CO_2 emissions increased and a maximum spring daily emission of $0.6 \text{ g C m}^{-2} \text{ d}^{-1}$ was detected 15 June. As the vegetation developed, the photosynthetic uptake of CO_2 started, and 26 June the heath ecosystem switched from being a source to a sink of atmospheric CO_2 on a daily basis.

The end of net CO_2 uptake period in the heath site was not included in the data set presented here. However, based on data from the fen site (see next section) it is likely that the last day with net CO_2 uptake was 15 August. By that assumption, the heath accumulated -31.5 g C m^{-2} , which is slightly more than the mean of all measurement years (-27.2 g C m^{-2}), during a net uptake period that lasted 50 days. It is mainly the onset of the uptake period that varies from year to year as it is regulated by the timing of snow melt, while the end of the period is more stable as it is

governed by fading solar radiation. Maximum daily CO_2 uptake ($-1.0 \text{ g C m}^{-2} \text{ d}^{-1}$) measured 19 July, was however slightly less than mean of all years ($-1.1 \text{ g C m}^{-2} \text{ d}^{-1}$). During the entire measurement period (105 days) the net CO_2 balance amounted to -23.0 g C m^{-2} .

In 2012, a scientific paper will be published based on the CO_2 flux measurements at the heath site (Lund et al. 2012 in press). It was found that temperature controlled the inter-annual variation in NEE, gross primary production (GPP) and ecosystem respiration (R_{eco}). However, while R_{eco} increased linearly with temperature, the initial increase in GPP with temperature levelled off at the high end of observed temperature range, suggesting that future increases in temperature may turn the heath ecosystem into a source for atmospheric CO_2 .

Fen site

Eddy covariance CO_2 flux measurements at the fen site in 2011 began 7 May and lasted until 25 October. During this period, approximately 5% of the data were lost due to malfunction, maintenance and calibration. During the first part of the measurement period until early June, fluxes were

Table 2.10 Summary of the CO_2 exchanges 2000-2011 at the heath site. Please note that the measuring period varies from year to year. *Recalculated compared with earlier ZERO annual reports.

Year	2000*	2001*	2002*	2003*	2004*	2005*	2006*	2007	2008	2009	2010	2011
Measurements start	6 Jun	8 Jun	3 Jun	6 Jun	3 Jun	21 May	28 May	27 May	30 Mar	16 May	5 May	3 May
Measurements end	25 Aug	27 Aug	27 Aug	30 Aug	28 Aug	25 Aug	27 Aug	28 Oct	28 Oct	22 Oct	31 Oct	16 Aug
Start of net uptake period	25 Jun	7 Jul	2 Jul	29 Jun	23 Jun	8 Jun	8 Jul	16 Jun	6 Jul	13 Jun	1 Jul	26 Jun
End of net uptake period	13 Aug	17 Aug	16 Aug	15 Aug	16 Aug	16 Aug	23 Aug	19 Aug	20 Aug	15 Aug	14 Aug	15 Aug
NEE for measuring period (g C m^{-2})	-18.8	-2.1	-5.4	-13.8	-13.2	-37.9	-24.9	-28.2	-11.2	-11.1	5.0	-23.0
NEE for net uptake period (g C m^{-2})	-23.2	-17.5	-16.6	-26.7	-24.6	-38.1	-28.9	-37.8	-32.0	-23.1	-26.8	-31.5
Max. daily accumulation ($\text{g C m}^{-2} \text{ d}^{-1}$)	-1.10	-1.10	-0.89	-1.26	-1.14	-1.40	-1.11	-1.32	-1.30	-0.97	-1.14	-0.97

Table 2.11 Summary of CO₂ exchanges 2007-2011 at the fen site. Please note that the measuring period varies from year to year.

Year	2007	2008	2009	2010	2011
Measurements start	20 Sep	10 Apr	31 Jul	9 May	7 May
Measurements end	19 Oct	30 Aug	13 Oct	1 Nov	25 Oct
Start of net uptake period	–	10 Jul	–	–	26 Jun
End of net uptake period	–	22 Aug	16 Aug	16 Aug	15 Aug
NEE for measuring period (g C m ⁻²)	9.8	-65.8	3.5	-73.5	-80.5
NEE for net uptake period (g C m ⁻²)	–	-94.6	–	–	-129.9
Max. daily accumulation (g C m ⁻² d ⁻¹)	–	-4.03	–	-5.15	-4.49

close to zero. As snow began to disappear in mid-June, fluxes increased and at 17 June, the highest daily emission during pre-growing season was measured (1.2 g C m⁻² d⁻¹). The fen ecosystem switched from being a source for atmospheric CO₂ to a sink 26 June, and remained so until 15 August. During this period of net CO₂ uptake, 50 days, the fen accumulated -129.9 g C m⁻². The highest daily CO₂ uptake was recorded 22 July, amounting to -4.5 g C m⁻².

By 16 August, respiration processes exceeded the fading photosynthesis and the ecosystem returned to a net source of atmospheric CO₂. In the beginning of this period, there is plenty of fresh litter available and soil temperatures remain comparably high, allowing decomposition processes to continue at a decent rate. Autumn CO₂ emissions were approximately 1 g C m⁻² d⁻¹ until soil started to freeze in mid-September. Highest autumn daily emission was measured 16 August (1.3 g C m⁻² d⁻¹). During the entire measurement period (172 days) the net CO₂ balance amounted to -80.5 g C m⁻².

The growing season's daily uptake rates as well as shoulder seasons daily

emissions are generally higher in the fen site compared to the heath site. This is because of denser vegetation with higher leaf area index in the fen site, allowing for higher CO₂ uptake per area unit.

2.6 Geomorphology

Coastal geomorphology

In 2008, the cliff top along the northern site of the active delta lobe was measured, while the shore-line was measured in 2010 and 2011.

The shore-line at the river delta showed a rapid decrease from 2008 towards 2010. Most of the protruding glacial cliff was eroded and a small island remained on the delta plain. From 2010 to 2011, the shore-line at the delta mouth was more stable. The cliff at the northern site of the delta retreated with some metres, while the beach west of the active delta plain showed an accretion in the same order of magnitude.



Figure 2.17 Delta and coastal cliff line measured by DGPS in 2008 (yellow line), 17 October 2010 (blue line) and 12 October 2011 (purple line) on an aerial photo from 8 August 2000.

3 Zackenberg Basic

The GlacioBasis programme

Michele Citterio, Signe Hillerup Larsen and Andreas Ahlstrøm

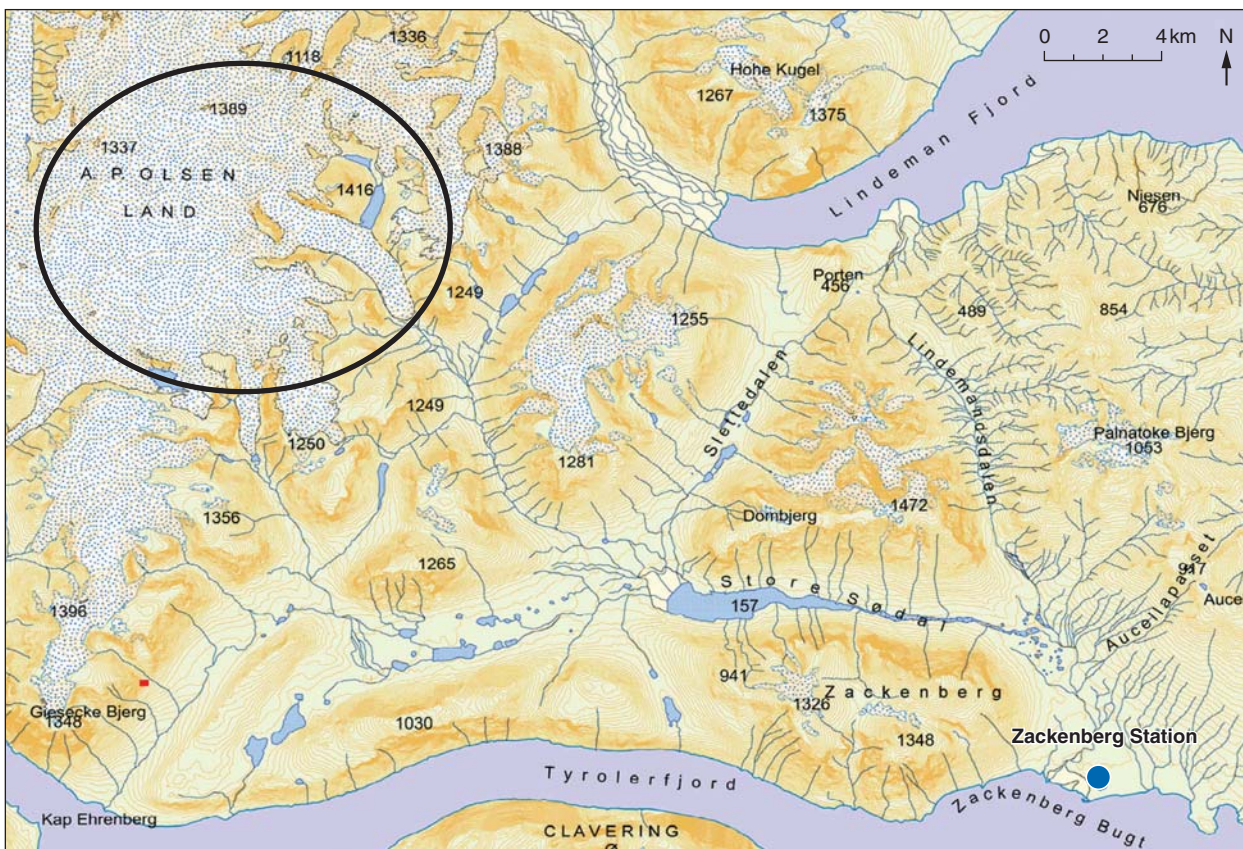
The aim of the GlacioBasis monitoring programme at Zackenberg is to produce an extended record of high quality glaciological observations from the A.P. Olsen Ice Cap and its outlet glacier in the river Zackenberg basin (figure 3.1). The A.P. Olsen Ice Cap is located at 74° 39' N, 21° 42' W. The summit of the Ice Cap reaches an elevation of 1 425 m and the terminus of the outlet glacier contributing to the river Zackenberg basin is at 525 m. Zackenberg Research Station is located SE of the site, approximately 35 km downriver from the glacier terminus. The most direct access to the glacier terminus is through Store Sødal.

The severe scarceness of glacier mass balance measurements from local glaciers and ice caps surrounding the Greenland Ice Sheet, the strong impact that such ice

masses are expected to exert on sea level rise in the present century (Meier et al. 2007), and the particularly marked warming expected to take place in the Arctic (IPCC 2007a) highlights the scientific relevance of GlacioBasis monitoring tasks. The monitoring data are suitable for modelling the surface energy balance and the glacier mass budget, and for assessing the sensitivity to future climate change scenarios of local glaciers and ice caps in this region.

In order to measure winter accumulation, fieldwork must be carried out during springtime, immediately before the onset of snow melt. This timing is also required for snowmobile use, which is the only practical mean to reach the glacier and transport the required equipment and instrumentation. Fieldwork must be car-

Figure 3.1 Map of the Zackenberg area, with A.P. Olsen Ice Cap in the northwestern corner of the map. The main investigation area is marked by the circle. Geological Survey of Denmark and Greenland (GEUS), Copenhagen.



ried out every year in order to maintain the stakes network operational, to service the automatic weather stations (AWS) on the glacier, and to carry out the differential GPS (DGPS) and snow radar surveys.

3.1 Overview of fieldwork in 2011

In 2011, the complete GlacioBasis programme was carried out successfully. The existing ablation stakes were revisited, measured and redrilled if needed. Snow pits were dug and density measured at several locations over the altitudinal range of the Ice Cap.

The three AWS have been serviced, data retrieved and the sensor recalibration plan implemented. All stations were found in fair conditions and left in full working order.

DGPS work was carried out both in static mode at the sites of the ablation stakes, and in kinematic mode for the positioning of the snow radar profiles and for the survey of surface elevation along the central flowline and several transects. The master reference station was setup at the forefront of the glacier, occupying a temporary, unsurveyed position. The precise coordinates of the reference station were later determined by precise post-processing method (PPP).

The snow depth survey using 500 MHz radar was carried out along the tracks of the DGPS work.

Arriving at Zackenberg Research Station in late April made it possible to travel to the glacier with good terrain conditions, even though the amount of snow on the ground was limited. A glacier outburst flood had occurred in early March, resulting in long stretches of the riverbed being impassable and covered by bare ice.

The actual work on the glacier was carried out 2-7 May, before snow conditions deteriorated. Easy and safe snowmobile access to the glacier was from the right side of the tongue, as in 2010. Due to the limited thickness of the snow cover, some crevasses were open and visible, particularly at, and just upflow of the ice-fall where a moderate crevassed area had been recognized during the helicopter reconnaissance in 2009. On the first day the safe route from 2010 was checked, found safe again, marked and used the following days. Running melt water from melting of

the bare ice stretches in the riverbed appeared already during the last day at the glacier both at the approach to the terminus and at the entrance of Store Sødal.

Michele Citterio and Signe Hillerup Larsen, both from Geological Survey of Denmark and Greenland (GEUS), took part in the fieldwork.

3.2 Automatic Weather Stations

The GlacioBasis programme operates one larger automatic weather station (AWS) and two smaller stations deployed on the glacier to obtain *in situ* time series of physical parameters describing the weather at the glacier surface. The main GlacioBasis AWS was deployed in late March 2008 on A.P. Olsen Ice Cap (AWS1 in this report). AWS1 has now completed the fourth year of uninterrupted operation and has proved very reliable, having only required minor maintenance in 2009 and 2010 to the mechanical construction of the station. AWS2 also required some maintenance in May 2011 to re-establish the failed frame supporting the ice ablation sonic ranger. At AWS3, a fault condition in the data logger box was repaired and satellite transmission re-established. Scheduled replacement of sensors with freshly calibrated units was carried out at all stations. GlacioBasis uses the same recalibration plan developed for PROMICE (Ahlstrøm et al. 2009). Ideally, GlacioBasis should hold a stock of spares and replacement parts in storage at Zackenberg Research Station to increase the chances that unanticipated issues can be resolved quickly, as only on trip per year is possible. Currently, no such stock exists.

All the three AWS' worked through the few, moderately strong wind episodes recorded. To date, transmission since the field visit in May 2010 indicates that the stations are working properly. During data validation and calibration, data were calibrated based on the manufacturer's calibration report. The calibration factors are traced to the corresponding units through the device serial number using the same Glaciobase database as GEUS do to handle the sensors inventory for PROMICE. Details on Glaciobase are provided by Ahlstrøm et al. 2009 and are not repeated here. Validation of the data is carried out using the same procedures established for PRO-

MICE; again, details on this are provided by Ahlstrøm et al. 2009 and are not repeated here.

Detailed information on each AWS and a selection of the observed data is shown below, where plots show the entire availability of data starting from the establishment of the first two AWS's in late March 2008.

The AWS1 station

Description: AWS1 – A.P. Olsen main AWS (centreline, lower tongue).

Coordinates: 74° 37.5' N, 21° 22.55' W, elevation (WGS84): 660 m a.s.l.

Measured parameters: Barometric pressure, aspirated T_{air} , aspirated RH_{air} , wind speed, wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, sensor T of LW radiometer, ice ablation, ice level, snow level, eight-levels thermistor string, two axes station tilt, GPS position, diagnostics, experimental sensors (variable from year to year, currently a passive radiation shield with a second Rotronics temperature and humidity probe identical to the one in the aspirated radiation shield).

Time series: Uninterrupted from 29 March 2008 until today for all sensors except the sonic rangars, which had intermittent problems.

Current availability: All transmitted data (hourly summer/three-hourly winter); 10 minutes measurements from flash card be-

tween 29 March 2008 and 5 May 2011.

AWS1 was established 29 March 2008 and 5 May 2011, normal maintenance and scheduled calibration were carried out. The support frame for the ice ablation sonic ranger had failed and had to be re-established.

As a site and station especially well suited to technical experiments and testing of new devices, a new one-year experiment has been set up. The new experiment is comparing a passive Vaisala radiation shield against the aspirated Rotronic radiation shield that is used in all other GEUS glacier AWS (figure 3.2). The experimental snow pillow installed in 2010 was recovered.

AWS1 has been working without interruption since the day it was set up, and satellite telemetry delivers near real-time data. Complete time series of barometric pressure, air temperature, relative humidity and wind speed are shown in figure 3.3a through 3.3d respectively.

The AWS2 station

Description: AWS2 – A.P. Olsen small AWS (centreline, middle tongue, just upflow of the lake and lateral glacier confluence)

Coordinates: 74° 38.6' N, 21° 28.2' W, elevation (WGS84): 880 m a.s.l.

Measured parameters: Aspirated T_{air} , aspirated RH_{air} , wind speed, wind direction, ice level, snow level, GPS position, diagnostics.

Figure 3.2 The AWS1 station in May 2011 with the addition of a Vaisala passive radiation shield for comparison with the standard Rotronics aspirated shield. Photo: Signe Hillerup Larsen, GEUS.



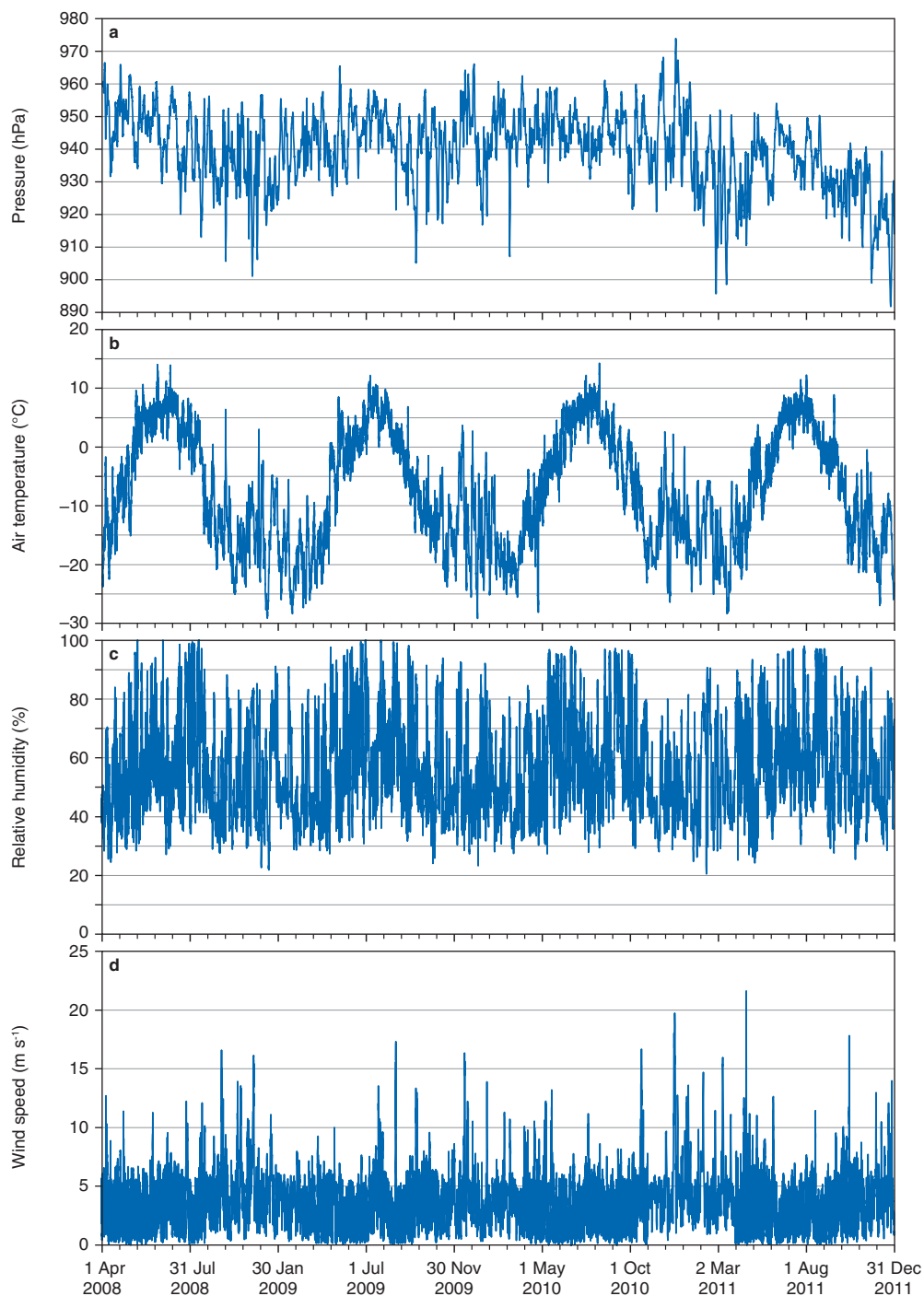


Figure 3.3 The complete available time series of selected parameters at AWS: a) barometric pressure. b) air temperature. c) relative humidity. d) wind speed.

Time series: Uninterrupted from 31 March 2008 until today for all sensors except the sonic rangers, which had intermittent problems.

Current availability: 10 minutes measurements from flash card from 31 March 2008 to 7 May 2011. There is no satellite data telemetry; therefore, data is only retrieved once a year in the field.

This AWS is a smaller version of AWS1 and it is not equipped with satellite transmission. In 2011, the metal frame support-

ing the sonic ranger measuring ice ablation had collapsed. The frame was re-established, data downloaded and the scheduled recalibration plan was implemented (figure 3.4).

Data retrieval in the field is required for this station, therefore the plots in figure 3.5 stop in early May 2011. Further data will be retrieved upon the next revisit in spring 2012. Air temperature, relative humidity and wind speed are shown in figure 3.5a through 3.5c, respectively.

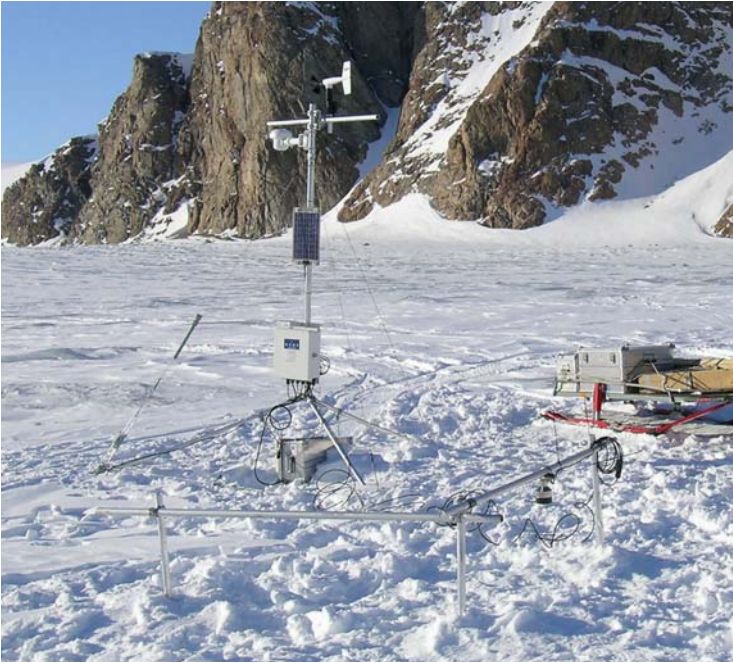


Figure 3.4 The AWS2 station in May 2011 after the repair of the sonic ranger frame.
Photo: Signe Hillerup Larsen, GEUS.

The AWS3 station

Description: AWS3 – A.P. Olsen Summit (at the wide-open flat just SSW of A.P. Olsen Summit)

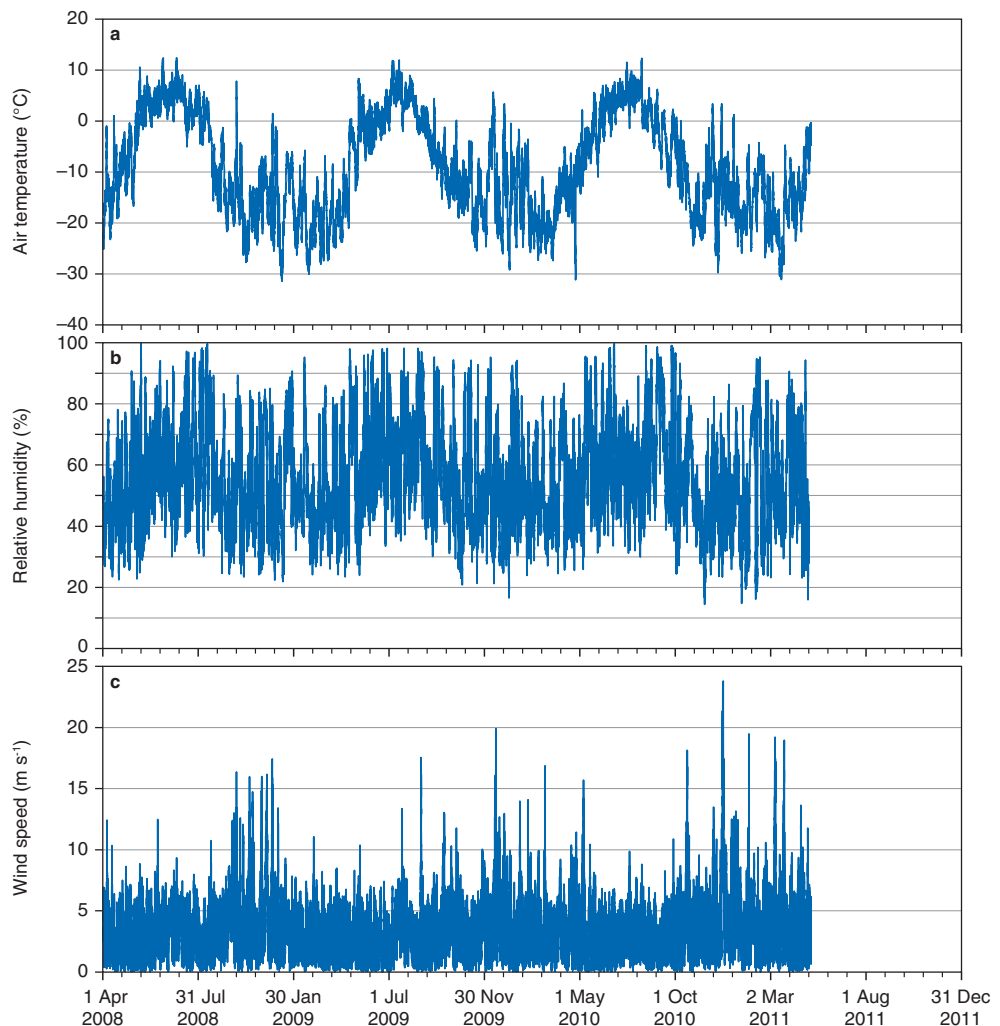
Coordinates: 74° 38.9' N, 21° 39.1' W, elevation (WGS84): 1475 m a.s.l.

Measured Parameters: Aspirated T_{air} , aspirated RH_{air} , wind speed, wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW, sensor T of the LW radiometer, ice and snow level, eight-levels thermistor string, two axes station tilt, GPS fix, diagnostics.

Time series: From 6 August 2009 to 19 October 2010, for all sensors except the sonic rangers which had intermittent problems, with a four days gap for unknown reasons just before the revisit 11 May 2010. On 19 October 2010, transmission stopped abruptly during moderately high wind conditions and resumed spontaneously 13 March 2011, resulting in a data gap during the winter.

Current availability: 10 minutes measurements from flash card from 6 August 2009 to 4 May 2011, then one- or three-hourly

Figure 3.5 The complete available time series of selected parameters at AW2. a) air temperature. b) relative humidity. c) wind speed.



transmitted data until revisit in 2011.

This AWS was setup by helicopter in August 2009. It is equipped with a subset of the sensors on AWS1 and it was found in good working condition upon revisit in May 2011. This station is equipped with an “alpine type” wind monitor instrument which features a special surface colour and designed to better cope with riming (figure 3.6, note the black wind monitor with reduced surface propeller).

Transmissions from ASW3 suddenly stopped 19 October 2010 during moderately high wind conditions. The mechanical structure of the tripod may have partly failed, most likely following failure of a guy wire, however transmissions resumed spontaneously 13 March 2011, reporting reasonable values for most sensors. The tilt metres read in excess of 20 degrees from the vertical in both directions, again suggesting that a guy wire or an aluminium tube failed. Figures 3.7a through 3.7c show air temperature, relative humidity and wind speed from AWS3.

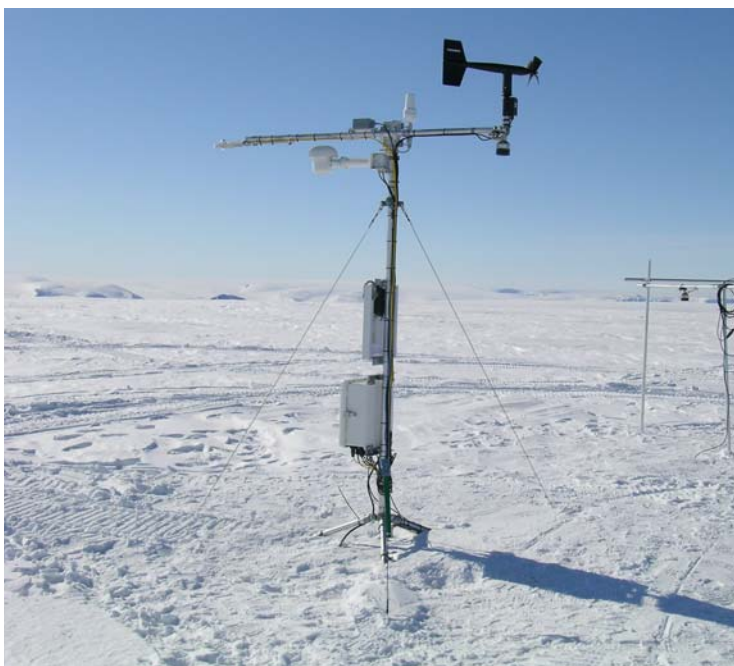


Figure 3.6 The AWS3 station near the Summit in May 2011 after minimal maintenance and the replacement of sensors due for calibration. Being in the accumulation area, the tripod is firmly frozen in the firn. Photo: Signe Hillerup Larsen, GEUS.

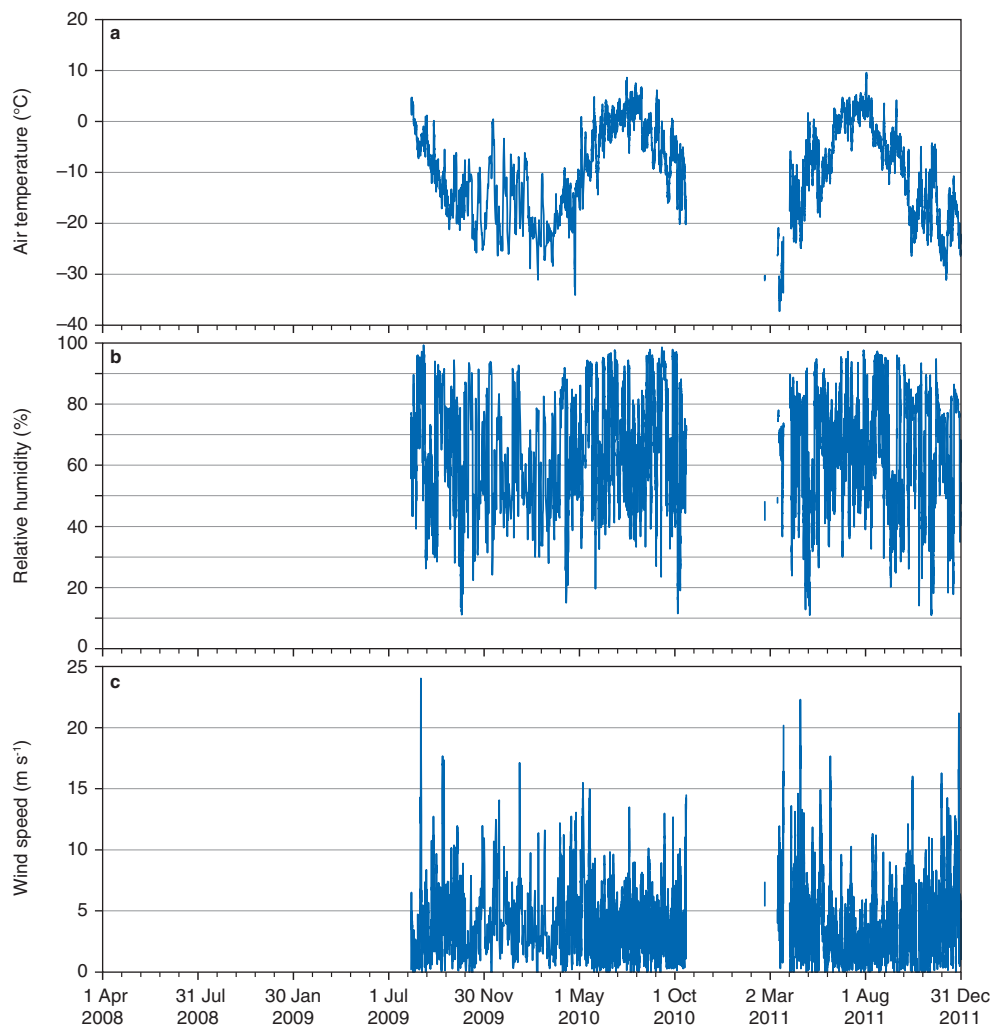


Figure 3.7 The complete available time series of selected parameters at AWS3. a) air temperature. b) relative humidity. c) wind speed.

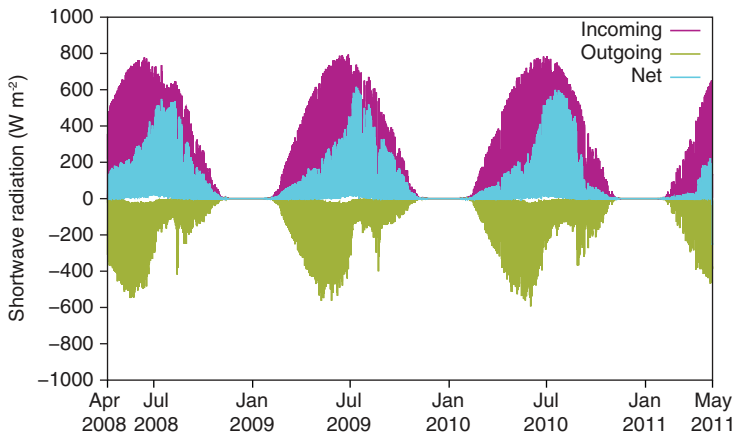


Figure 3.8 Shortwave radiation fluxes at AWS1. The significant drop in surface albedo after the seasonal snow cover has melted is clearly visible as a strong reduction of outgoing shortwave radiation.

3.3 Derived meteorological quantities

Meteorological quantities requiring post-processing after instrument calibration to produce physically meaningful values are only calculated based on the full temporal resolution data downloaded in the field. For instance, shortwave radiation fluxes need extensive corrections to account for two axes sensor tilt before global radiation, surface albedo and the radiative energy fluxes can be computed. The plot in figure 3.8 shows corrected incoming, reflected and net shortwave radiation flux at AWS1.

The pattern of wind direction at AWS1 is shown in figure 3.9a and is dominated by the katabatic NW glacier wind, with minor but clearly visible events of the wind blowing upglacier at this site close to the terminus. The daily evolution of average windspeed at AWS1 displays a minimum at about noon local time (figure 3.9b, where the time axis is labelled as UTC) in spring and, to a lesser extent, in autumn. During summertime, the lowest wind speed occurs in the late afternoon.

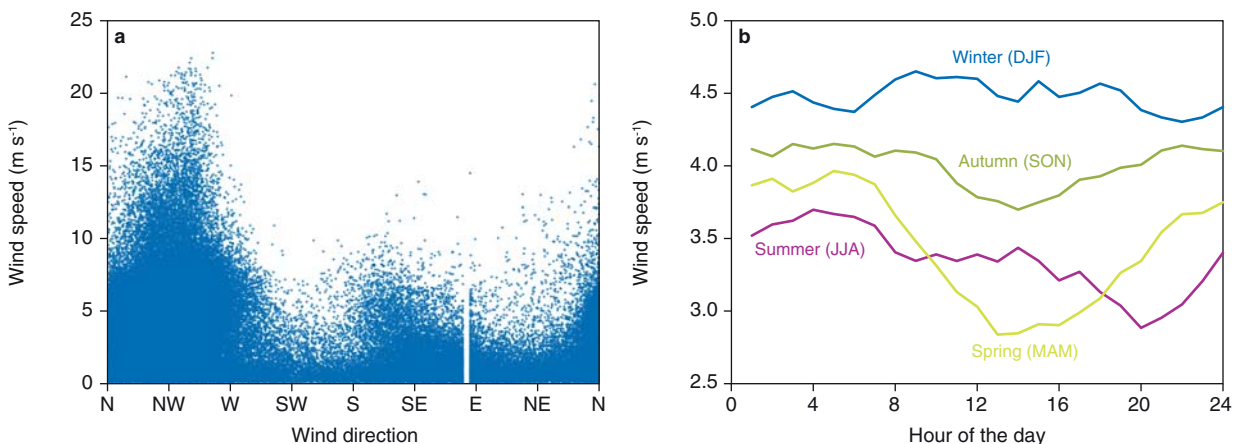


Figure 3.9 Dominant wind directions (a) and seasonality of the daily cycle of wind speed (b) at AWS 1.

3.4 Ablation stakes network

A network of ablation and surface velocity stakes distributed along the central flow line was established in spring 2008 on the outlet glacier of the A.P. Olsen Ice Cap and along three transects at elevations of approximately 675, 900 and 1300 m a.s.l. (figure 3.10). In May 2010 one more stake was established very close to the terminus (stake 1, figure 3.10) to better cover the area's strongest ablation. The location of the stakes is provided in the 2010 annual report (Jensen and Rasch 2011).

Surveying the network of ablation stakes is a core task for GlacioBasis, because it provides a direct measurement of the glacier mass balance, which is central to the entire programme. Ablation stakes are 6 m long metal rods drilled into the ice and measured periodically to quantify the amount of water lost to ablation. Stakes are distributed over the glacier surface with the primary aim to cover the entire elevation range of the glacier, because glacier mass balance shows the strongest gradient with elevation. Stakes are also arranged in transects at roughly the same elevation in order to capture the lateral variability moving out from the centreline of the glacier, due e.g. to shading and long-wave radiation from the surrounding rock walls. Figure 3.10 provides an overview and map of the investigated outlet glacier of the A.P. Olsen Ice Cap.

3.5 Snow radar and differential GPS surveys

Monitoring snow accumulation allows calculation of the winter mass balance.

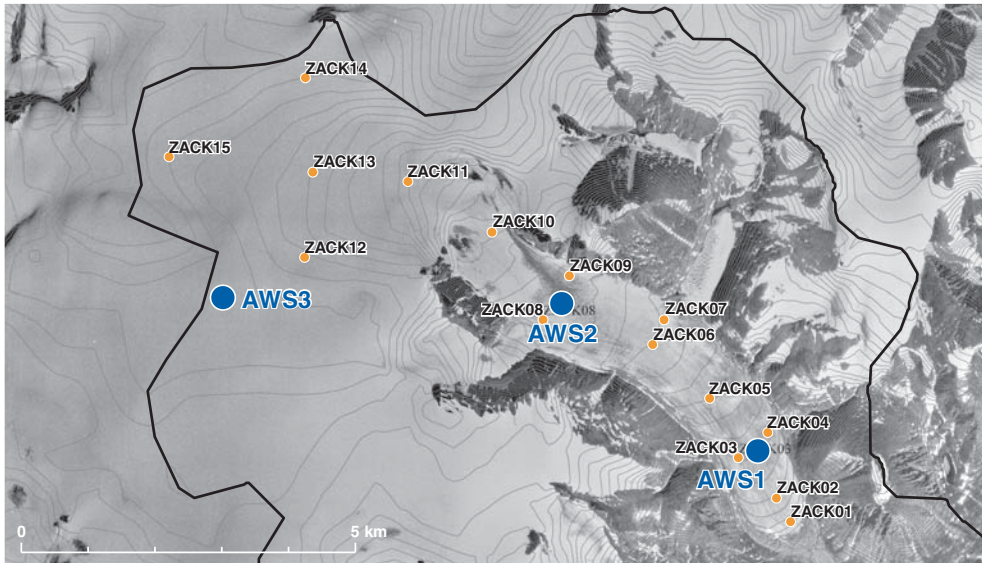


Figure 3.10 Orthophoto-graph of the investigated outlet glacier with the position of ablation stakes (yellow dots) and AWSs (blue dots).

The most effective method to map snow depth is to use snow radar towed by snowmobile and connected to a DGPS system to precisely geolocate the radar traces and simultaneously collect surface elevation profiles. A 500 MHz GPR (ground penetrating radar) available through GeoBasis was again used with success for this purpose in 2011 (figure 3.11).

Manual probing of snow depth with an avalanche probe was carried out to calibrate the radar velocity in the snow at about 100 known points along the first radar line, which extends over the entire length of the glacier. The GPR data were postprocessed and interpreted using the ReflexW software and then calibrated for radar velocity in the snow pack by least squares fitting of the radar and manual measurements. Recorded travel times of the electromagnetic signal are then scaled

by the propagation velocity calculated above. The pattern of snow depth with elevation is characteristic for this glacier, with deeper snow cover toward the terminus than at intermediate elevations. In the accumulation area the snow depth tends to increase with elevation.

Knowledge of snow density is required to convert surveyed snow thickness into water equivalent. Snow densities have been measured in 2011 by digging a number of snow pits from the elevation of the lower ablation stake (stake 1) to the Summit weather station (AWS3), and by surveying the density profile along the snow stratigraphy.

DGPS provides the accuracy needed to monitor elevation changes of the glacier surface after repeated surveys are acquired and postprocessed over the years. This information provides independent

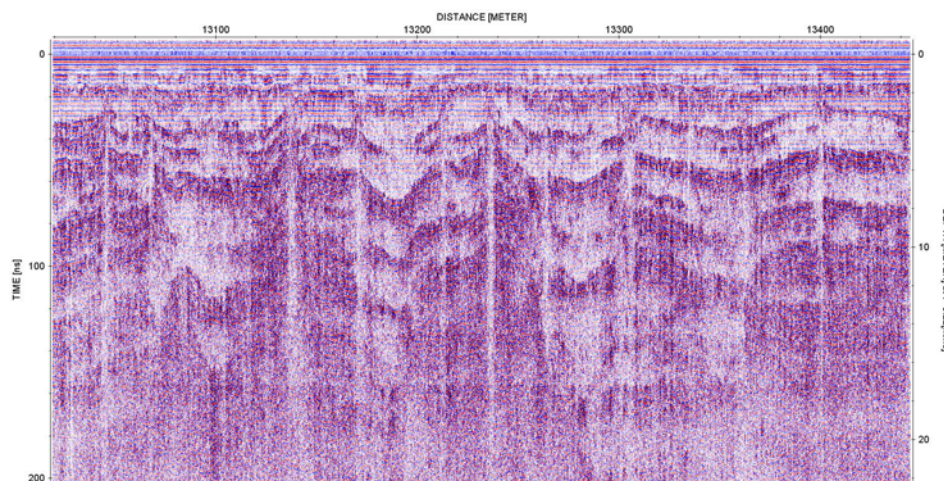


Figure 3.11 Radargram acquired in the accumulation area with a 500 MHz antenna showing up to seven annual layers.

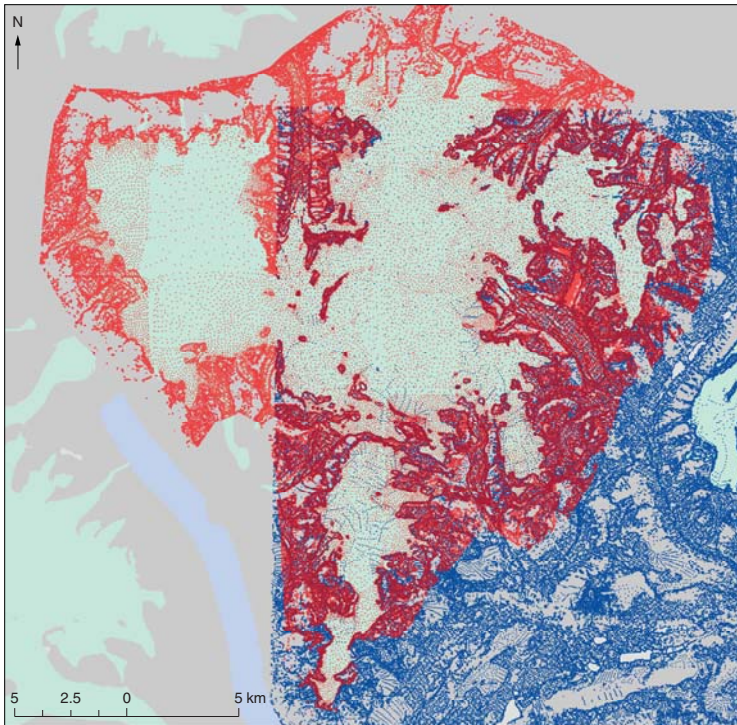


Figure 3.12 Area coverage of the new GlacioBasis aerofotogrammetric DEM of A.P. Olsen Ice Cap (red) and of the previous river Zackenberg catchment DEM (blue).

validation to any distributed mass balance modelling, and several transects have been surveyed. Finally, all ablation stakes have been re-measured in 2011 by DGPS using the same settings detailed in the 2010 annual report (Jensen and Rasch 2011). Postprocessing of the raw GPS files was carried out either in static mode for the position of the ablation stakes or in kinematic mode for the surface elevation profiles and transects. The accurate posi-

tion of the base station was determined by the precise post processing (PPP) technique, based on refined GPS orbital and clock data, which are more accurate than those broadcast in real time, using approximately 20 hours of logged observations.

3.6 New GlacioBasis DEM and airborne surveys

During 2011, a new digital elevation model (DEM) of the A.P. Olsen Ice Cap (figure 3.12) has been produced by the GEUS Aerophotogrammetry Lab based on aerial photographs from 1984. Combined with the Lidar surface elevation and ice thickness from the airborne surveys carried out by DTU Space during the summer 2011, the new DEM allows to estimate the overall volume and volume change of the Ice Cap from 1984 to 2011.

The new DEM has been carefully controlled and corrected manually to overcome the limitations of the previous DEM, which is not accurate over the snow covered areas in the accumulation zone and only covers the sector of A.P. Olsen Ice Cap draining into the river Zackenberg catchment. The new GlacioBasis DEM covers the entire A.P. Olsen Ice Cap, including large areas missing in the old DEM.

At the time of writing this report, post-processing of the Lidar and ice radar acquisitions is ongoing at DTU Space and the results will be included in the 2012 annual report.

4 Zackenberg Basic

The BioBasis programme

Lars Holst Hansen, Jannik Hansen, Kirsten Christoffersen, Kristian Albert, Magnus Lund, Noémie Boulanger-Lapointe, Lars O. Mortensen, Line Anker Kyhn, Eric Steen Hansen and Niels Martin Schmidt

This chapter reports the 2011 field season of BioBasis. The BioBasis programme at Zackenberg is carried out by the Department of Bioscience, Aarhus University, Denmark. BioBasis is funded by the Danish Environmental Protection Agency as part of the environmental support programme Danish Cooperation for Environment in the Arctic (DANCEA). The authors are solely responsible for all results and conclusions presented in this chapter, which do not necessarily reflect the position of the Danish Environmental Protection Agency.

Please refer to previous Zackenberg Annual Reports for presentation of data covering the earliest years of monitoring.

Detailed information on the BioBasis methods and updated sampling protocols are available at the Zackenberg home page (<http://www.zackenberg.dk>).

The 2011 BioBasis field team consisted of, Lars Holst Hansen (day 137-164 and 202-311), Jannik Hansen (day 150-216), Lars O. Mortensen (day 150-195), Line Anker Kyhn (day 167-195), Noémie Boulanger-Lapointe (day 209-237), Niels Martin Schmidt (day 181-195) and Eric Steen Hansen (day 188-202).

4.1 Vegetation

The weekly records of snow cover, plant flowering and reproduction were conducted by Lars Holst Hansen, Lars O. Mortensen, Line Anker Kyhn and Noémie Boulanger-Lapointe. Gas flux measurements were conducted by Lars Holst Hansen, Lars O. Mortensen and Line Anker Kyhn. Pinpoint analyses

Table 4.1 Inter- and extrapolated date of 50% snow melt cover 2001-2011 for white Arctic bell-heather *Cassiope tetragona*, mountain avens *Dryas integrifolia/octopetala*, Arctic poppy *Papaver radicum*, Arctic willow *Salix arctica*, purple saxifrage *Saxifraga oppositifolia* and moss campion *Silene acaulis*. *Denote extrapolated dates.

Plot	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
<i>Cassiope</i> 1	158	164	157	<155	143	164	155	164	138	150	147
<i>Cassiope</i> 2	172	171	164	168	158	183	167	174	145	164	153
<i>Cassiope</i> 3	171	171	158	159	148	179	158	172	140	164	159
<i>Cassiope</i> 4	172	168	158	159	158	174	164	174	148	167	161
<i>Dryas</i> 1	<151	<150	155*	<154	<140	150*	<145	147	<135	<142	<135
<i>Dryas</i> 2/ <i>Salix</i> 7	184	179	173	173	168	192	170	182	157	174	168
<i>Dryas</i> 3	157	157	157	<155	<140	151	<145	147	136	<142	<136
<i>Dryas</i> 4	158	157	151*	<153	<140	164	152	162	135	<142	150
<i>Dryas</i> 5	156	157	157	<153	<140	177	<145	152	<135	142	<136
<i>Dryas</i> 6/ <i>Papaver</i> 4	179	181	170	173	165	191	164	184	149	170	169
<i>Papaver</i> 1	171	169	163	166	152	179	162	169	139	162	146
<i>Papaver</i> 2/ <i>Salix</i> 5	172	171	172	163	158	183	161	178	149	166	160
<i>Papaver</i> 3	172	170	165	160	158	174	163	174	148	167	161
<i>Salix</i> 1	<151	<150	151*	<155	<140	145*	<145	137	<135	<142	<135
<i>Salix</i> 2	172	165	165	161	156	178	160	169	148	162	159
<i>Salix</i> 3	158	158	153*	<155	138*	160	151	163	<135	146	145
<i>Salix</i> 4	162	161	164	157	150	165	154	161	147	158	157
<i>Salix</i> 6	–	–	–	173	166	186	165	182	149	169	166
<i>Saxifraga/Silene</i> 1	<151	<150	152*	<154	<140	<146	<145	<131	<135	<142	<135
<i>Saxifraga/Silene</i> 2	<151	<150	151*	<154	<140	<146	<145	<131	<135	<142	<135
<i>Saxifraga/Silene</i> 3	147*	<150	152*	<154	128*	158	152	145	<135	<142	<136
<i>Silene</i> 4	179	176	170	170	163	186	164	176	150	167	165

were carried out by Noémie Boulanger-Lapointe assisted by Jannik Hansen and Lars Holst Hansen. Noémie Boulanger-Lapointe and Lars Holst Hansen did the leaf fluorescence measurements.

Reproductive phenology and amounts of flowering

The 2011 BioBasis field season began 17 May (day 137). Snow melt was relatively early with dates of 50% snow cover earlier than the median for previous seasons in all plant plots (table 4.1). The relatively early snow melt resulted in earlier than average 50% flowering in all 28 plots when compared to previous seasons (table 4.2). Only in two *Salix* and one *Saxifraga* plot was the flowering later than the 1st quartile of previous seasons.

Despite the relatively early snow melt and flowering, not all plant plots had earlier dates of 50% open seed capsules than average for previous seasons (table 4.3). Four of 14 plots had later than average dates. Of the 10 plots that were earlier

than average, seven (all four *Papaver*, one *Salix*, two *Saxifraga*) were earlier than the 1st quartile of previous seasons.

During the season of 2011, 22 of 43 categories of flowers or catkins had fewer or close to average peak number of flowers or catkins hitherto recorded (table 4.4). There were two new minima, one for *Eriophorum scheuzerii* in one plot and one for *Eriophorum triste* in another plot.

Vegetation greening

Table 4.5 lists the dates (as day of year) of the peak NDVI of 17 of the permanent plots. In 13 out of the 17 tabulated plant plots, peak NDVI was earlier than the average of previous seasons.

Transect NDVI was measured from snow melt and into the autumn until the ground was covered with snow. Figure 4.1 summarises the NDVI transect data across the 2011 season in three altitude categories. The different vegetation types had very similar developments in NDVI in all three altitude categories, with the lower

Table 4.2 Inter- and extrapolated date of 50% open flowers (50/50 ratio of buds/open flowers) 2001-2011 for white Arctic bell-heather *Cassiope tetragona*, mountain avens *Dryas integrifolia/octopetala*, Arctic poppy *Papaver radiculatum*, Arctic willow *Salix arctica*, purple saxifrage *Saxifraga oppositifolia* and moss campion *Silene acaulis*. *Denote interpolated dates based on less than 50 buds+flowers.

Plot	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
<i>Cassiope</i> 1	185	184	178	175	167	185	178	186	173	176	172
<i>Cassiope</i> 2	193	188	184	187	173	201	186	193	180	186	176
<i>Cassiope</i> 3	192	190	183	182	173	200	185	194	178	184	183
<i>Cassiope</i> 4	200	188	186	185	183	200	186	195	183	190	185
<i>Dryas</i> 1	173	176	181	173	164	177	173	172	170	170	170
<i>Dryas</i> 2	213	210	200	200	198	215	192	204	188	200	193
<i>Dryas</i> 3	187	179	180	175	164	180	177	174	175*	174	171
<i>Dryas</i> 4	187	179	174	174	164	187	178	186	173	172	172
<i>Dryas</i> 5	186	179	179	172	164	172	171	175	172*	172	167
<i>Dryas</i> 6	210	213	198	199	194	214	191	206	185	200	194
<i>Papaver</i> 1	193	193	186	193	185	206	188*	195	184	190*	179*
<i>Papaver</i> 2	195	194	189	190	190	208	188	204	185	194	187
<i>Papaver</i> 3	198	194	192	187	187	201	187*	199	186	193	187
<i>Papaver</i> 4	208*	214	198	194	194	214	192*	204	186*	197*	194
<i>Salix</i> 1	159	160	168	156	155	165	161	161	155	162	156
<i>Salix</i> 2	180	179	179	173	165	196	177	187	167	177	174
<i>Salix</i> 3	175	167	166	159	157	174	165	174	152*	161	159
<i>Salix</i> 4	179	177	174	173	164	180	170	174	167	174	171
<i>Salix</i> 5	–	–	186	175	164	194	174	193	168	179	174
<i>Salix</i> 6	–	–	–	197	184	200	179	194	171	184	180
<i>Salix</i> 7	–	–	–	187	187	202	182	195	179	186	185
<i>Saxifraga</i> 1	159	154	165	157	144	151	160*	159*	149*	153	144
<i>Saxifraga</i> 2	159	157	165	157	152	157	158	158	150	157	151*
<i>Saxifraga</i> 3	160	158	165	<154	146	172	165	159*	146*	161	151
<i>Silene</i> 1	179	174	182	173	165	170	173	172	174	174	172
<i>Silene</i> 2	181	178	185	181	166	182	179	173	184	179	175
<i>Silene</i> 3	185	179	185	172	166	194	179*	173	180	178	172
<i>Silene</i> 4	210	209	201	201	197	194	193	207	187	199	198

Table 4.3 Inter- and extrapolated date of 50% open seed capsules 2001-2011 for Arctic poppy *Papaver radicum*, Arctic willow *Salix arctica* and purple saxifrage *Saxifraga oppositifolia*. *Denote interpolated dates based on less than 50 flowers+open capsules.

Plot	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
<i>Papaver</i> 1	228	232	213	219	212	232	223	211*	203	223*	207
<i>Papaver</i> 2	228	229	215	219	215	234	221	226	206	221	214
<i>Papaver</i> 3	230	232	218	216	212	223	220	215	212	225	216
<i>Papaver</i> 4	236	238*	222	227	220	239*	222*	222*	214*	222*	220
<i>Salix</i> 1	214	210	214	208	201	219	218	211*	220	223	218
<i>Salix</i> 2	230	223	215	218	215	231	220	227	218	222	222
<i>Salix</i> 3	226	217	209	209	206	223	215	225	213*	218	212
<i>Salix</i> 4	225	224	215	219	210	223	219	225	220	222	221
<i>Salix</i> 5	–	–	216	220	219	>240	221	229	215	227	222
<i>Salix</i> 6	–	–	223	223	226	>240	222	234	217	228	229
<i>Salix</i> 7	–	–	225	223	226	>240	224	234	221	229	232
<i>Saxifraga</i> 1	220	216	219	205	203	217*	218	195	209*	212	218*
<i>Saxifraga</i> 2	226	213	223	209	212	217	216	205	213	214	193
<i>Saxifraga</i> 3	225	224	221	205	212	225	221	188	215*	218	207

altitude having slightly later peaks, however, absolute NDVI values for the vegetation types changed with altitude.

Due to technical problems, the 2011 greening index data (NDVI) inferred from satellite images cannot be presented in this report, but will be presented in the 2012 annual report.

Carbon flux in ITEX temperature chamber and UV-B exclusion plots

The ITEX experimental warming plots were established in June and removed in October 2011 at the two heath sites dominated by *Salix arctica* and *Cassiope tetragona*. During this period, treatment responses were monitored fortnightly by measurements of ecosystem CO₂ exchange using the closed chamber technique. The net ecosystem exchange (NEE), ecosystem respiration (R_{eco}) and gross primary production (GPP) are presented in figure 4.2. The *Salix* heath was more productive than the *Cassiope* heath, which is in line with re-

sults from previous years. Both sites functioned as sinks for atmospheric CO₂ in July-August, while in June, September and October they were generally small sources of CO₂. Warming generally increased R_{eco} at both sites; however the difference between control plots and warmed plots was only significant in July for both sites ($\alpha=0.05$). For NEE and GPP, no significant differences between treatments and control plots were detected on a monthly basis, but the difference in NEE during July was close to significant ($p=0.0506$) for *Cassiope* heath. When comparing temporal flux averages throughout the whole measuring period for each plot, there were significant differences in R_{eco} at both the *Cassiope* heath ($p=0.0376$) and *Salix* heath sites ($p=0.0325$). In general, these results are similar to previous years.

The experimental UV-B exclusion plots, located close to the ITEX *Salix* site, were established in June and taken down in October. The experimental UV-B exclusion re-

Figure 4.1 Mean NDVI from the four main vegetation types (fen, grassland, *Salix* heath, *Cassiope* heath) along an altitudinal gradient in Zackenberg during the 2011 season, averaged for three altitude intervals; 0-140, 140-280 and 280-420 m above sea level.

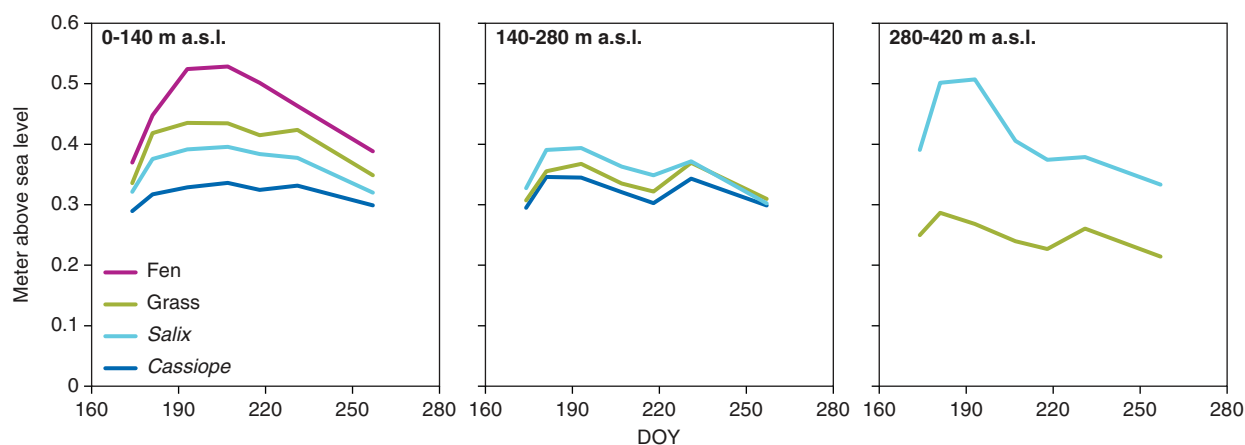


Table 4.5 Peak NDVI recorded in 17 plant plots 2001-2011 together with date of maximum values. NDVI values from 2000-2006 are based on data from hand held Ratio Vegetation Index (RVI) measurements, and have been re-calculated to account for varying incoming radiation that otherwise affects the measurements. Note that the greening measured accounts for the entire plant community, in which the taxon denoted may only make up a smaller part. Data from 2004 are not included due to instrumental error.

Plot	2001		2002		2003		2005		2006		2007		2008		2009		2010		2011	
	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY	NDVI	DOY
Cassiope 1	0.4	203	0.40	224	0.37	210	0.37	217	0.36	220	0.35	218	0.36	239	0.33	238	0.32	224	0.31	189
Cassiope 2	0.41	203	0.39	210	0.39	217	0.40	217	0.38	220	0.37	218	0.39	239	0.36	205	0.39	216	0.37	208
Cassiope 3	0.37	203	0.34	210	0.34	217	0.38	210	0.35	224	0.41	218	0.34	239	0.31	213	0.33	217	0.3	217
Cassiope 4	0.41	203	0.38	217	0.40	210	0.44	210	0.41	220	0.39	218	0.45	239	0.39	238	0.38	211	0.35	217
Eriophorum 1	0.61	203	0.61	210	0.59	189	0.60	196	0.60	220	0.51	190	0.57	219	0.54	205	0.55	203	0.49	196
Eriophorum 2	0.56	203	0.54	210	0.53	203	0.52	196	0.52	220	0.47	218	0.51	206	0.49	213	0.51	203	0.52	196
Eriophorum 3	0.52	203	0.53	210	0.50	203	0.47	196	0.47	220	0.43	218	0.50	206	0.53	213	0.51	203	0.47	182
Eriophorum 4	0.69	203	0.70	217	0.71	189	0.72	210	0.72	220	0.68	197	0.64	206	0.67	196	0.69	203	0.63	210
Papaver 1	0.42	203	0.45	210	0.42	203	0.42	217	0.41	220	0.41	218	0.42	239	0.40	213	0.42	203	0.39	189
Papaver 2/ Salix 5	0.44	203	0.45	210	0.43	203	0.46	210	0.44	220	0.45	218	0.44	239	0.42	213	0.43	217	0.41	217
Papaver 3	0.43	203	0.42	210	0.42	203	0.45	210	0.41	212	0.40	218	0.46	239	0.38	238	0.39	211	0.36	196
Salix 1	0.56	203	0.56	210	0.57	189	0.52	196	0.51	220	0.51	197	0.53	206	0.50	213	0.56	183	0.5	196
Salix 2	0.54	203	0.55	210	0.53	189	0.52	196	0.53	220	0.48	197	0.50	211	0.47	205	0.53	203	0.48	196
Salix 3	0.46	203	0.46	210	0.43	189	0.41	210	0.41	220	0.38	197	0.41	206	0.37	213	0.39	189	0.38	182
Salix 4	0.51	203	0.52	210	0.50	189	0.49	196	0.49	220	0.47	218	0.48	206	0.44	213	0.47	196	0.44	196
Salix 6	-	-	-	-	0.48	212	0.48	210	0.46	220	0.47	218	0.44	239	0.42	213	0.46	211	0.42	210

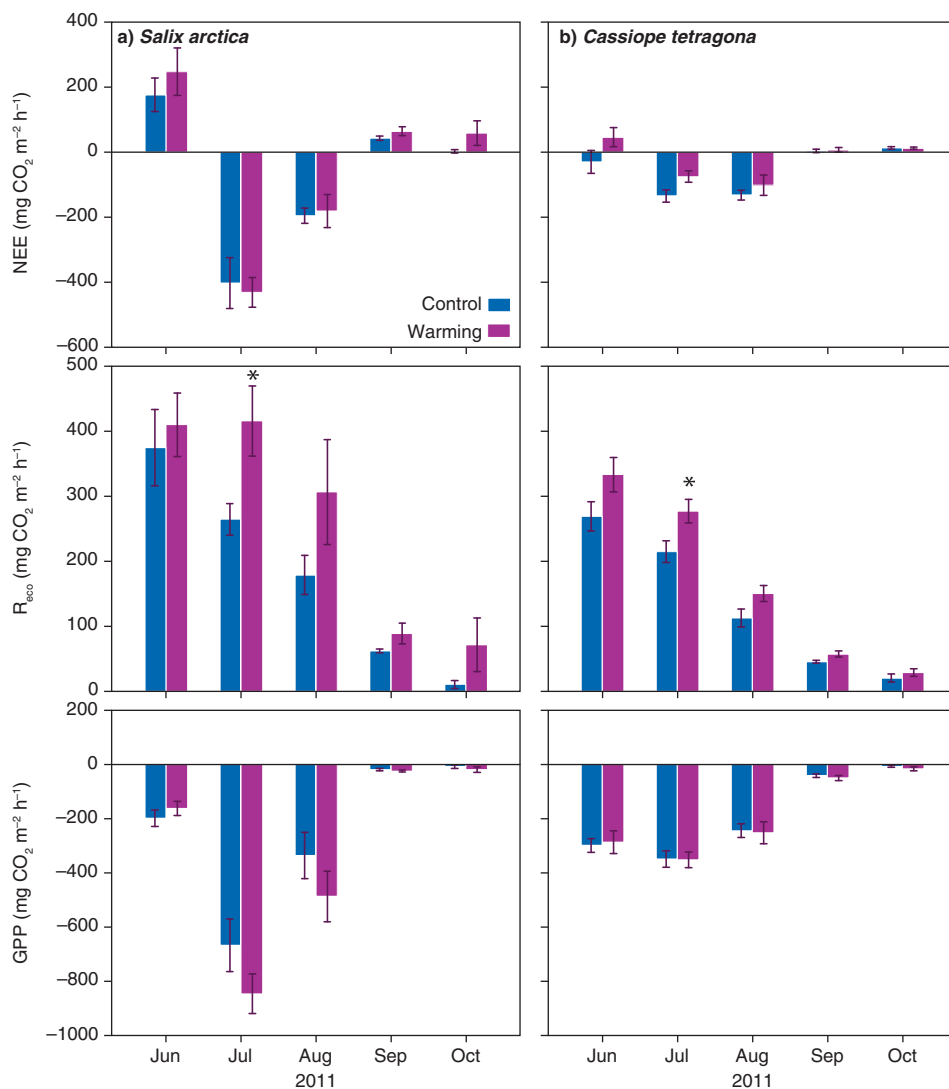


Figure 4.2 Ecosystem CO₂ exchange in ITEX and control plots during June-October 2011. Measurements were carried out fortnightly on (a) Salix arctica dominated heath sites and (b) Cassiope tetragona dominated heath. Flux is positive when CO₂ is released from the ecosystem and negative when CO₂ is accumulated by the ecosystem. Depicted are means ± standard error of net ecosystem exchange (NEE), ecosystem respiration (R_{eco}) and gross primary production (GPP). Treatment effects were analysed using ANOVA. Stars indicate significant differences at = 0.05 level.

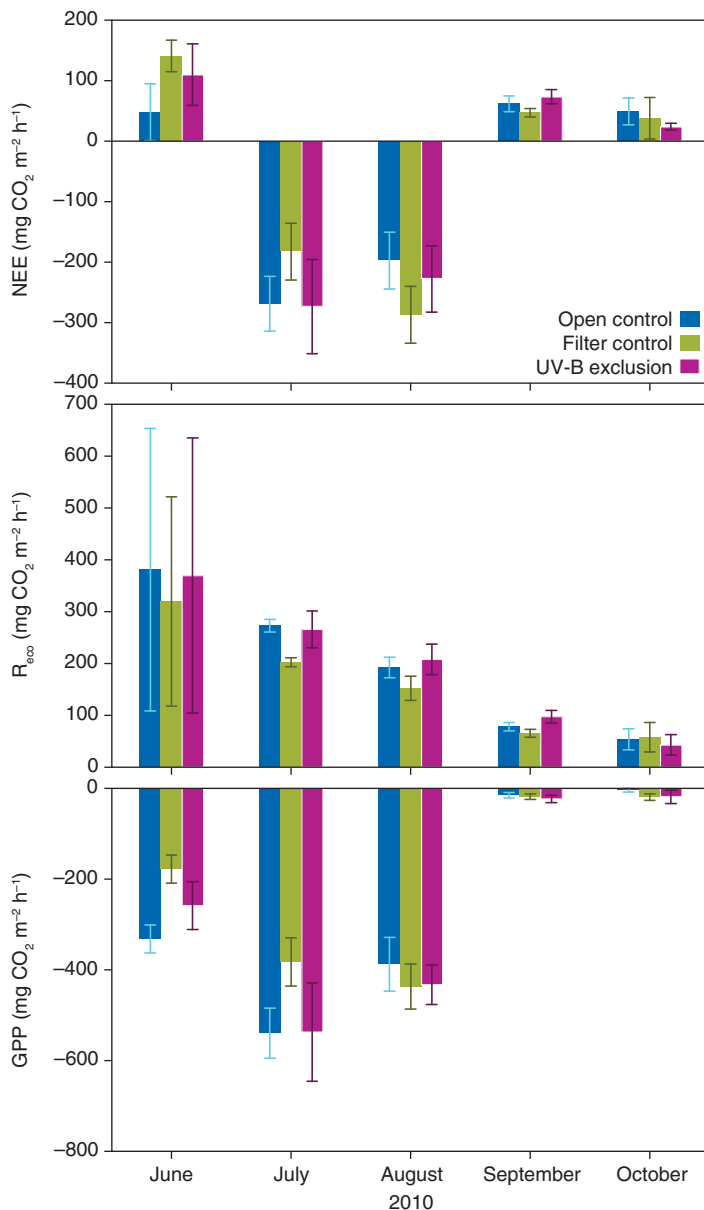


Figure 4.3 Ecosystem CO_2 exchange in UV-B exclusion plots, filter control and open control during fortnightly measurements in June-October 2011. Flux is positive when CO_2 is released from the ecosystem and negative when CO_2 is accumulated by the ecosystem. Depicted are means \pm standard error of net ecosystem exchange (NEE), ecosystem respiration (R_{eco}) and gross primary production (GPP). Treatment effects were analysed using ANOVA.

moves a large proportion of ambient UV-B irradiance and was compared with transparent filter control and an open control, and the responses were monitored fortnightly by measurements of ecosystem CO_2 exchange using the closed chamber technique (figure 4.3) and chlorophyll fluorescence (figure 4.4 and table 4.6). The seasonal development and magnitudes of NEE, R_{eco} and GPP were similar to those recorded at the ITEX *Salix* site (figure 4.2). During 2011, no significant differences, at $\alpha=0.05$ level, were detected for NEE, R_{eco} and GPP on a monthly basis. However, for June GPP, July R_{eco} and September R_{eco} differences between treatments and controls were close to significant ($0.05 < p < 0.10$). Also for temporal flux averages throughout the whole measuring period differences in R_{eco} were close to significant ($p=0.0839$).

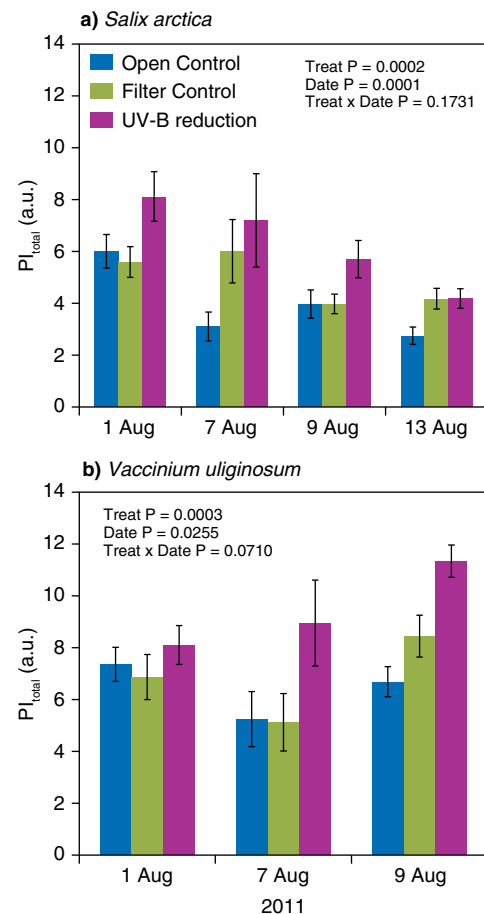


Figure 4.4 Seasonal variation in total performance index (PI_{total}). The PI_{total} integrates the responses of antenna, reaction centre, electron transport and end acceptor dependent parameters [$PI_{\text{total}} = (RC/ABS) \times [\phi P_o / (1 - \phi P_o)] \times [\psi E_o / (1 - \psi E_o)] \times [\delta R_o / (1 - \delta R_o)]$]. The presented values are the seasonal mean \pm standard error for open control (no filter), filter control (transparent filter, Mylar) and UV-reduction (UV-B absorbing filter, Teflon). Three campaigns were conducted on *Salix arctica* (a) and *Vaccinium uliginosum* (b).

Leaf fluorescence in UV-B exclusion plots

The total performance index (PI_{total}), integrating responses of antenna, reaction centre, electron transport and end acceptor dependent parameters, were the most sensitive parameter in both *Salix* and *Vaccinium*. The PI_{total} were reduced by around 29% in *Vaccinium* and around 24% in *Salix* when comparing the filter treatment to reduced UV-B (table 4.6). The PI_{total} were significantly decreased 1, 7 and 9 August (days 213, 219 and 221) in *Salix* and for *Vaccinium* 1 and 7 August (days 213 and 219) when filter treatment were compared to reduced UV-B (figure 4.4). No measurements were conducted on *Vaccinium* 13 August (day 225).

Table 4.6 Seasonal response in the UV-B exclusion plots. Parameters are the ratio of PSII reaction centre's (RC) and absorbance flux, [RC/ABS]. The maximum quantum yield, [$\Phi_{Po} = F_V/F_M$] which corresponds to the efficiency an absorbed photon will be trapped by PSII RC leading to QA reduction. The fraction of electrons transported beyond QA per exciton trapped by the open reaction PSII RC, [$\Psi_{E_o} = ET_o/TR_o$]. The efficiency with which an electron can move from the reduced intersystem electron acceptors to the PSI end acceptors, [$\delta_{R_o} = RE_o/ET_o$]. The total performance index integrating the responses of antenna, reaction centre, electron transport and end acceptor dependent parameters [$PI_{Total} = (RC/ABS) \times [\Phi_{Po}/(1-\Phi_{Po})] \times [\Psi_{E_o}/(1-\Psi_{E_o})] \times [\delta_{R_o}/(1-\delta_{R_o})]$]. The presented values are the seasonal mean \pm standard error for open control (no filter), filter control (transparent filter, Mylar), UV-reduction (UV-B absorbing filter, Teflon). The relative effect of ambient UV-B are given as the difference in percent for filter minus UV reduction ($\Delta\%F-UV = [(F-UV)/F*100]$). Statistical significant differences F vs. UV are in bold ($p < 0.05$).

Species	Parameter	Open control (C)	Filter control (F)	UV-B reduction (UV-B)	$\Delta\% F-UV-B$
<i>Salix arctica</i>	RC/ABS	0.682 \pm 0.013	0.770 \pm 0.015	0.774 \pm 0.011	-0.5
	$\Phi_{Po} = F_V/F_M$	0.741 \pm 0.007	0.761 \pm 0.007	0.777 \pm 0.004	-2.0
	$\Psi_{E_o} = ET_o/TR_o$	0.526 \pm 0.010	0.566 \pm 0.010	0.587 \pm 0.009	-3.6
	$\delta_{R_o} = RE_o/ET_o$	0.572 \pm 0.013	0.542 \pm 0.012	0.548 \pm 0.011	-1.1
	PI_{Total}	4.043 \pm 0.293	4.670 \pm 0.262	5.827 \pm 0.418	-24.8
<i>Vaccinium uliginosum</i>	RC/ABS	0.668 \pm 0.012	0.714 \pm 0.017	0.779 \pm 0.018	-9.1
	$\Phi_{Po} = F_V/F_M$	0.757 \pm 0.009	0.765 \pm 0.010	0.789 \pm 0.008	-3.1
	$\Psi_{E_o} = ET_o/TR_o$	0.684 \pm 0.006	0.671 \pm 0.009	0.688 \pm 0.008	-2.5
	$\delta_{R_o} = RE_o/ET_o$	0.563 \pm 0.007	0.559 \pm 0.007	0.571 \pm 0.007	-2.2
	PI_{Total}	6.766 \pm 0.407	7.473 \pm 0.556	9.680 \pm 0.502	-29.5

Lichens

All plots and permanent stations established in 1994 and 2000 were inspected by Eric Steen Hansen from 7-21 July. The aluminium tubes at station 144 had been lost since inspection in 2005 probably due to the loose attachment in the basaltic gravel. It was decided to drop this station, which monitor changes in snow melt just as plot L1 situated near the top of Aucellabjerg do. Three new stations, L20, L21 and L22, were established on boulders manured by birds in the area between Zackenberg Research Station and Ulvehøj. Records from stations (outside the ZERO line) that were surveyed in 1994, 2000, 2005 and 2011 are presented in Appendix A.

I. Permanent plots L1-L22

A. Epilithic lichens

Two species, viz. *Usnea sphacelata* and *Pseudephebe minuscula*, have disappeared, and two lichens belonging to *Placynthium* and *Stereocaulon*, respectively, could be noted as new in L1 near the top of Aucellabjerg (altitude approximately 1000 m a.s.l.). The lichen vegetation in this plot has been fairly constant between 1994 and 2005.

Lecidea atrobrunnea has increased its size, and the number of thalli of *Umbilicaria virginis* has increased as well, but the maximum diameter of the last-mentioned has remained constant in L6 situated at 600 m a.s.l.

The number of thalli has increased since 2005 by the following lichens in L2-L5 situated on four gneissic boulders just above Oksebakkerne: *Pseudephebe minuscula*, *Rhizoplaca melanophthalma*, *Umbilicaria decussata*, *U. lyngei* and *Xanthoria candelaria*.

The lichenicolous species, *Caloplaca epithalina*, was recorded as new in L5. *Pseudephebe minuscula*, which was recorded as disappeared from L 10 in 2005, has colonized the boulder at the top of Ulvehøj again.

No important changes of the lichens in L7 near the old Zackenberg trapping station were observed, but the thalli of *Umbilicaria decussata* has disappeared from L 8 on the big gneissic boulder since 2005. However, the number of thalli of this species has increased considerably in L15 near the old trapping station. The lichens do not show important changes in L16 situated at 170 m a.s.l. on the mountain Zackenberg.

B. Epigaeic lichens

An increase in the number of thalli was recorded for the following lichens in L 11 on Ulvehøj: *Cetrariella delisei*, *Flavocetraria nivalis*, *Peltigera leucophlebia*, *P. rufescens* and *Stereocaulon alpinum*. The growth of *Peltigera leucophlebia* is particularly strong. Two species, viz. *Candelariella canadensis* and *Psoroma hypnorum*, could be recorded as new in L11. The moisture supply from melting snow during spring, and rain during summer and autumn is evidently optimum for the lichens occurring in this plot.

Apart from a big increase in the number of thalli of *Peltigera rufescens*, L12 and L13 have remained rather constant since 2005. The snow cover during winter is thinner at these stations than at L11. This also applies to the *Dryas-Carex rupestris* heath with L14. Here the number of thalli has increased by *Flavocetraria nivalis* and *Hypogymnia subobscura*, while *Peltigera rufescens* and *Phaeorhiza nimbosa* have disappeared.

The most important change in L17, L18 and L19 is the increased cover of *Cladonia mitis*, which evidently is favoured by a sufficient snow cover during winter in these *Cassiope* heath patches. The following lichens were recorded as new in these plots: *Nephroma expallidum* and *Psoroma hypnorum* (L17), *Buellia papillata* and *Cladonia borealis* (L18), *Cladonia macroceras* and *Pertusaria geminipara* (L19). The greyish brown colouring of the tips of the podetia of *Cladonia amaurocraea* and *C. mitis* has not developed to the worse since 2005. The colouring is believed to be caused by UV-radiation.

II. Permanent stations along the ZERO line 0-155

A. *Dryas-Carex rupestris* heaths

Numerous changes as regards to the lichen vegetation were recorded in the following stations: 2, 36, 47, 51, 81, 83, 92a and 92b. Many lichens have disappeared from one or more plots and even whole stations since 2005, and during the same period (2005-2011), numerous lichens have migrated to new plots at the stations. The changes indicate that the microclimate that influences the stations generally has become drier since 2005. The soil in station 83 evidently has been disturbed mechanically by strong winds and/or muskoxen.

B. *Cassiope* heaths

Many lichens have also disappeared and others arrived at one or more plots in the following stations in the *Cassiope* heaths: 14, 20, 32, 34, 38 and 82. Totally, the changes indicate that the moisture conditions are more favourable for the lichen vegetation in the *Cassiope* stations than in the *Dryas-Carex rupestris* stations. However, a number of lichens appear to have been overgrown by the expanding dwarf shrubs. Like station 84, station 34 apparently has been disturbed by wind and/or animals.

C. *Salix arctica* snow patch heaths

As in the A and B stations, many changes of the lichen vegetation were recorded in the following C-stations: 13, 28, 31, 60 and 96. Apart from station 28, where the microclimate apparently has become slightly drier, the moisture conditions are still optimal for most lichens in these snow patch heaths. Station 60 has been disturbed by wind and/or animals since 2005.

D. Mixed *Vaccinium uliginosum* heaths

The vegetation changes in station 10 and 57 indicate that the soil conditions have become drier since 2005.

E. Fell fields

Comparatively few changes as regards to the lichen vegetation were noted in station 100, and *Xanthoria sorediata* was still very conspicuous with its bright reddish orange colour at station 144.

4.2 Arthropods

All five pitfall trap stations and the one window trap station (four trap chambers) were open during the 2011 season. Sampling procedures were concurrent with previous seasons. Field work was carried out by Lars Holst Hansen, Noémie Boulanger-Lapointe and Jannik Hansen. Samples were sorted by personnel from Department of Bioscience, Aarhus University, Denmark. The material is stored in 90% ethanol (before 2008, in 70% ethanol) at the Museum of Natural History, Aarhus. Please contact the BioBasis manager, Niels Martin Schmidt (nms@dmu.dk), regarding access to the collection. The total number of arthropods collected in 2011 was 31 258. Ice and snow at the arthropod trap stations melted relatively early in 2011 (table 4.7).

Table 4.7 Day of year (DOY) of 50% snow cover in the arthropod stations 2001-2011. a) 0% snow, b) <1% snow, c) 7% ice cover, d) 3% snow, e) 31% snow, f) 2% snow.

Station	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Arthropod 1	157	154	163	<153 ^c	<140	156	148	154	144	151	141
Arthropod 2	<151 ^a	<151 ^a	152	<153 ^a	<140 ^a	<147	<146 ^a	147	135	<142 ^a	<136 ^a
Arthropod 3	170	165	171	156	154	174	158	172	147	162	156
Arthropod 4	172	171	162	158	156	179	161	174	138	163	153
Arthropod 5	159	154	156	<153 ^a	<140	154	<176 ^b	150	138	145	<136 ^e
Arthropod 7	<150	<151 ^a	153	<153 ^a	<140	<147	<176 ^b	144	134	<142 ^d	<136 ^f

Table 4.9 Weekly totals of arthropods etc. caught at the five pitfall stations and the window trap station during autumn 2011. Values from each date represent catches from the previous period. Totals from previous seasons are given for comparison.

DOY / Year	Window traps							Pitfall traps							
	245	252	259	264- 266	2011	2010	2009	245	252	259	266	273	2011	2010	2009
No. of active stations	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5
No. of trap days	16	14	14	12	56	48	56	160	140	140	140	140	720	700	600
COLLEMBOLA					0	35	2	98	58	14	14	6	190	416	56
HEMIPTERA															
<i>Nysius groenlandicus</i>					0	0	0	8	37	6			51	1	3
Aphidoidea					0	0	0	6	9				15	8	0
Coccoidea					0	1	0						0	2	0
THYSANOPTERA					0	0	0		1				1	1	1
LEPIDOPTERA															
Lepidoptera larvae					0	0	0			1			1	0	2
<i>Clossiana</i> sp.					0	0	0						0	0	2
DIPTERA															
Chironomidae	117	27	1	2	147	20	6	1	4	1		1	7	1	7
Ceratopogonidae					0	1	0						0	0	0
Mycetophiliidae	1				1	0	2	2		1			3	4	5
Sciaridae					0	0	0		1				1	1	2
Syrphidae					0	1	0						0	1	2
Phoridae					0	21	0	14	4				18	316	0
Agromyzidae					0	1	0	1	4	2	2	1	10	9	2
Tachinidae					0	0	0	1					1	1	0
Calliphoridae					0	0	3	1					1	0	12
Scatophagidae	1	9			10	16	4		3		1	1	5	7	12
Anthomyiidae	2	20			22	13	6	13	19	12	2	1	47	10	31
Muscidae	5	1	3		9	5	0	1	1	2	2		6	9	2
HYMENOPTERA															
Ichneumonidae	1	2			3	4	1	9	19	6	2		36	61	9
Braconidae					0	0	0		1		1		2	0	5
Chalcidoidea					0	18	0	3	3				6	12	11
Ceraphronoidea	1				1	0	0		1				1	1	0
ARANEA															
Thomisidae					0	0	0	3	5	3			11	11	11
Lycosidae					0	19	1	36	42	6	4	1	89	30	30
Lycosidae egg sac					0	0	0	1	3				4	1	5
Dictynidae					0	2	1	1	9			3	13	3	3
Linyphiidae				2	2	17	2	61	43	22	24	26	176	212	48
ACARINA					0	31	2	109	60	12	38	9	228	303	34
Total	128	59	4	4	195	205	30	369	327	88	90	49	923	1421	295

group, Muscidae, were caught in high numbers again after some low seasons. Ichneumonid wasps, Ichneumonidae, were caught in a new record high number. Wolf spiders, Lycosidae, were caught in relative low numbers, whereas dwarf spiders, Linyphiidae, had the hitherto highest number caught. Mites and ticks, Acarina, were caught in very low numbers, although higher than the record low of 2008.

Table 4.9 summarises the 2011 window trap captures in the extended fall season until 23 September (day 266) with totals for 2009 and 2010 for comparison.

Pitfall traps

The first pitfall traps were established 18 May (day 138), and all traps were in use from 10 June (day 161) and until 30 September (day 273). In 2011 until 25 August (day 237), the number of trap days was 1785 and the total number of specimens caught was 20852. Weekly totals were pooled for all five stations from May through August and are presented in table 4.10 with totals from previous seasons for comparison.

Collembola, spring tails, were caught in moderate numbers. Thysanoptera were caught in higher numbers than in previous seasons, while fritillaries, *Clossiana* sp., were caught in lower numbers than in most previous seasons. Continuing the

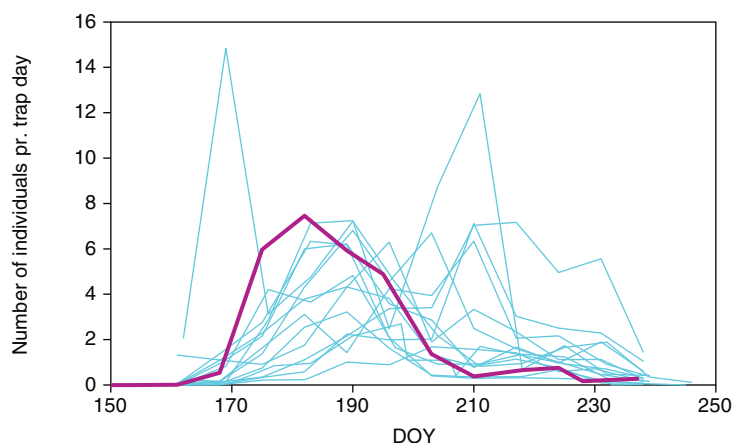


Figure 4.5 Numbers of houseflies, *Muscidae*, caught per trap day every week in the pitfall traps in 2011 (purple line) compared with 1996-2009 (blue lines). Only part of the samples from the 2010 season is available, and 2010 is hence not included in the figure.

trend from the latest years, no Nematocera larvae were caught. Mosquitos, *Culicidae*, were caught in moderately low numbers and midges, *Chironomidae*, were caught in new record low numbers.

Mycetophiliidae (belonging to fungus gnats) were caught in very low numbers, whereas dark-winged fungus gnats, *Sciariidae*, were caught in high numbers. Scuttle flies, *Phoridae*, were caught in a new record high number, and tachinid flies, *Tachinidae*, also had high numbers. Houseflies, *Muscidae*, were caught in moderately low numbers with a single early peak (figure 4.5). Ichneumon wasps, *Ichneumonidae*, were caught in average numbers compared with all previous seasons. Mites and ticks, *Acarina*, were caught in relatively low numbers.

Table 4.9 summarises the 2011 pitfall trap captures in the extended fall season until 30 September (day 273) with totals from 2009 and 2010 for comparison.

Table 4.11 Peak ratio (per cent) of mountain avens *Dryas integrifolia/octopetala* flowers depredated by larvae of "black moth" *Sympistris zetterstedtii* in mountain avens plots in 1996-2011.

Plots	<i>Dryas</i> 1	<i>Dryas</i> 2	<i>Dryas</i> 3	<i>Dryas</i> 4	<i>Dryas</i> 5	<i>Dryas</i> 6
1996	2	0	11	17	2	0
1997	6	5	18	1	8	0
1998	3	0	3	7	2	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	15	1	7	11	9	0
2003	2	0	1	5	2	0
2004	15	4	33	39	3	1
2005	1	1	10	3	0	0
2006	27	3	6	18	2	6
2007	0	2	8	4	0	5
2008	34	25	67	32	2	8
2009	8	5	27	14	33	5
2010	7	7	16	11	6	47
2011	3	3	6	2	2	4

New taxa to Zackenberg

One single specimen of Psylloidea, jumping plant lice, was caught in Zackenberg in 2011 for the first time (table 4.8).

Insect predation on *Salix arctica* and *Dryas* flowers

The percentage of *Dryas* flowers marked by predation from "black moths" *Sympistris zetterstedtii* was below average compared to previous seasons for all plots (table 4.11). The BioBasis programme does no longer include registrations of the sawfly *Symphyla* sp. on Arctic willow.

4.3 Birds

Bird observations were carried out by Lars Holst Hansen, Jannik Hansen, Line A. Kyhn, Lars O. Mortensen and Niels Martin Schmidt. Other researchers and staff – not least Jeroen Reneerkens and colleagues – provided much valued observations throughout the season. Local site names can be found in Schmidt et al. 2011.

Breeding populations

During five days – between 11 June (day 162) and 23 June (174) – a complete, initial census was carried out. That is a normal start, but a slightly delayed last day of census. The weather prevented census work on a number of days during the period. The completion of the survey took 35 "man-hours", which is average.

The entire census was carried out on days with good weather conditions. In addition, large parts of the census area were covered regularly during June, July and most of August, exceptions being the closed goose moulting area along the coast and the Aucellabjerg slopes above 350 m a.s.l. The latter were covered on six occasions only, in addition to the many visits by Jeroen Reneerkens and colleagues.

The total effort in June and July 2011 was average (135 hours in June and 70 hours in July) compared to recent years.

The results of the initial census, supplemented with records during the rest of the season (see Schmidt et al. 2011), are presented in tables 4.12 and 4.13, and compared with the estimates of previous seasons.

The first red-throated diver *Gavia stellata* pair settled in a fen near the research station 1 June (day 152), only a day after the first observation of the species. Three

Table 4.12 Estimated numbers of pairs/territories in the four sectors of the 15.8 km² census area in the Zackenberg valley 2011.

Species/sectors	<50 m a.s.l. 7.77 km ²	50-150 m a.s.l. 3.33 km ²	150-300 m a.s.l. 2.51 km ²	300-600 m a.s.l. 2.24 km ²	Total
Red-throated diver	3-4	0	0	0	3-4
King eider	0	0	0	0	0
Long-tailed duck	5-6	0	0	0	5-6
Rock ptarmigan	0	1	1-2	0	2-3
Common ringed plover	8	3	5-6	8	24-25
Red knot	9-13	21-22	1	0	31-35
Sanderling	32-33	6	18-20	6-7	62-66
Dunlin	74-80	22-23	0	0	96-103
Ruddy turnstone	18-23	28-29	0	0	46-52
Red-necked phalarope	0	0	0	0	0
Long-tailed skua	8-10	5	2-3	0	15-18
Glaucous gull	1	0	0	0	1
Arctic redpoll	1-2	0	0	0	1-2
Snow bunting	38	27	6	2	73

Table 4.13 Estimated numbers of pairs/territories in the 15.8 km² census area in Zackenberg valley 2011 compared with the 1996-2010 averages.
¹Within the census area

Regular breeders				
Species	No. of territories	Average min. and max. no. of territories 1996-2010	No. of nests found ¹	Comments
Red-throated diver	3-4	2.4-2.8	0	
Common eider	0	0.3-0.4	0	
King eider	0	1.2-2	0	
Long-tailed duck	5-6	5.3-6.3	1	
Rock ptarmigan	2-3	2.5-3.5	0	
Common ringed plover	24-25	28.9-35.4	0	
Red knot	31-35	24.7-31.5	3	
Sanderling	62-66	50.6-58.6	22	
Dunlin	96-103	74.9-84.9	13	
Ruddy turnstone	46-52	40.9-46	8	
Red-necked phalarope	0	0.8-1.6	0	
Long-tailed skua	15-18	17.8-21.9	6	
Glaucous gull	1	0.5	1	
Common raven	2	-	-	Nests outside the census area
Snow bunting	73	42.4-47.3		Nests of passerines are only found opportunistically
Irregular breeders				
Pink-footed goose	0	0.13	0	Min. 3324 immatures migrated northwards over the area
Eurasian golden plover	0	0.06	0	
Red phalarope	0	0.6-0.75	0	
Snowy owl	0	0.06	0	
Northern wheatear	0	0.08-0.16	0	Nests of passerines are only found opportunistically
Arctic redpoll	1-2	0.6-1.0	0	Nests of passerines are only found opportunistically
Lapland bunting	1-2	0.06	0	Nests of passerines are only found opportunistically

pairs attempted to breed within the census area and two nests were found. All fell victim to predation.

The number of common ringed plover *Charadrius hiaticula* territories was a little below average.

Sanderling *Calidris alba* territories were recorded at comparatively high numbers (table 4.13). After a few years with slightly falling numbers, 2011 saw a rise.

Dunlin *Calidris alpina* territories were found in high numbers again this year (cf. Hansen et al. 2012). In earlier years, dunlin territory numbers might have been underestimated (Meltotte 2006).

Ruddy turnstone *Arenaria interpres* territories were found in numbers just above average, as were red knot *Calidris canutus* territory numbers (tables 4.12 and 4.13).

No phalarope nests (red-necked phalarope *Phalaropus lobatus*; red phalarope *P. fulicarius*) were found in 2011.

Long-tailed skua *Stercorarius longicaudus* territories were found in numbers below average within the census area, although higher than the last few years (table 4.13). Six pairs nested in the census area (see below). Another three nests were found in adjacent areas.

A glaucous gull *Larus hyperboreus* pair has had a nest on an islet in the same stretch of river Zackenberg since at least 2004. 2011 was no exception. No chicks were seen, and the nest is thought to have fallen victim to flooding. This species was seen daily throughout the season. A very large flock, 43, were seen as early as 11 May (day 131). The species were still recorded in late September.

The number of rock ptarmigan *Lagopus muta* territories was average. Two broods were found, both on the slopes of Aucella-bjerg 11 June (day 192).

The numbers of snow bunting *Plectrophenax nivalis* territories were the highest since 2005 (table 4.13). Juveniles of snow

bunting were seen both within the census area and in adjacent areas in fair numbers. Fledgling success seemed quite high, although no systematic efforts were made to estimate this.

One to two Arctic redpoll *Carduelis hornemanni* territories were recorded this year (table 4.13).

It is likely that Lapland bunting *Calcarius lapponicus* bred in the study area. One pair and another singing male were recorded this season. Zackenberg had the northernmost breeding record in Greenland in 2010 (Hansen et al. 2012; cf. Boertmann 2008).

Reproductive phenology in waders, Charadriiformes

7.7% of all wader nests were initiated before 10 June (day 161), and 61.5% before 20 June (day 171) (table 4.14).

The snow cover 6 June (day 161) was 78% and nest initiation was relatively late for dunlin compared to previous seasons, although slightly earlier than average for sanderling and ruddy turnstone (table 4.15).

Reproductive success in waders, Charadriiformes

The all-wader nest success was low in 2011, and among the lowest during the BioBasis programme. Using the modified Mayfield method (Johnson 1979), 14.4% of the wader nests were successful.

Dunlin nests were hit less hard than other wader species, with 21.1% nest success. However, this is the lowest success rate through the years of the BioBasis programme. The sanderling nest success was the highest since 2004 (table 4.17). Two red knot nests were found in 2011 both suffered predation. The ruddy turnstone nests were generally unsuccessful; 2.9% success only.

After years of low numbers of fox encounters, 2011 had 20 encounters, which is close to average. Pups were recorded in three dens this season (table 4.16). Three dens with pups combined with the low number of lemming winter nests (table 4.22) could possibly be part of the reason for the high predation on wader eggs.

The mean wader clutch size was 3.84 in 2011, which is above the weighted mean for all years (table 4.17). Nests containing fewer than four eggs were: Sanderling; two nests of two eggs. Ruddy turnstone: one nest of three eggs. Dunlin, one nest of one egg.

Table 4.14 Median first egg dates for waders at Zackenberg 2011 as estimated from incomplete clutches, egg floating, hatching dates, as well as weights and observed sizes of pulli.

Species	Median date	Range	N	Average 1996-2010
Common ringed plover	–	–	–	166.4
Red knot	163	162-175	5	166.6
Sanderling	166	159-183	35	168.3
Dunlin	173	159-179	14	166.5
Ruddy turnstone	162	157-179	11	164.6

Table 4.15 Snow cover 10 June together with median first egg dates (day of year) for waders at Zackenberg 1995-2011. Data based on less than 10 nests/broods are marked by asterisks, less than five are omitted. The snow cover is pooled (weighted means) from section 1, 2, 3 and 4 (Sigsgaard et al. 2011) from where the vast majority of the egg laying phenology data originate.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Snow cover	84	82	76	80	91	53	84	79	83	48	28	85	48	71	4	72	78
Sanderling		168*	169	169	174.5	168	173.5	168	164	160	166*	181	166	169	167	163	166
Dunlin	169*	163.5	164	167.5	173	163.5	176	159	163	164	163	178	166	169	162	165.5	173
Ruddy turnstone	163*	170.5	164	163.5	175	163	174	160	159	160	162	172*	158	170	154	165	162

Table 4.16 Mean nest success (%) 1996-2011 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked by asterisks. Data from species with less than 50 nest days have been omitted. If no nest was found, it is indicated by "-". Nests with at least one piped egg or one hatched young are considered successful. Also given are total numbers of adult foxes observed by the bird observer in the bird census area during June-July (away from the research station proper) along with the number of fox dens holding pups.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Common ringed plover				60*		38*				-	0*	-	2*	-		-
Red knot	-	-			-		-			-	-	100*				3*
Sanderling	72*	33-100*	88*	40	46*	19	33*	45	71-85		7*	3	5	7.5	3	17
Dunlin			28-47	65	68	75*		63	93	43*	47	48	17	80*	62*	21.1*
Ruddy turnstone	21-68	67-100	16	23-28	29	60*	52	21-27	83			36	22*	27*	34*	2.9*
Red-necked phalarope	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Red phalarope	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
All waders	33-63	52-100	32-37	42-44	44	43	43	42-44	87-90	22	37	18	16	14	9	14.4
N nests	17	31	44	44	47	32	21	51	55	15	28	60	58	66	46	47
N nest days	163	228	334	520.8	375	328.4	178.9	552	700	104	332.2	532.7	423.5	508.5	306.5	349
Fox encounters	14	5	7	13	11	14	21	11	16	18	22	23	20	11	9	20
Fox dens with pups	2	0	1	0	2	2	0-1	2	3	0	2	3	5	3	3	3

Table 4.17 Mean clutch sizes in waders at Zackenberg 1995-2011. Samples of fewer than five clutches are marked by asterisks. ¹Weighted mean (species)

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	W. mean ¹	
Common ringed plover	4.00*	4.00*	3.50*	4.00*	3.50*	4.00*	3.50*	4.00*	4.00*	4.00*	-	3.75*	-	3.75*	-	4.00*	-	3.77	
Red knot	-	-	-	4.00*	4.00*	-	4.00*	-	4.00*	4.00*	-	-	4.00*	4.00*	4.00*	4.00*	4.00*	4.00*	3.43
Sanderling	4.00*	4.00	3.86	4.00	3.67	4.00	3.43	3.83	4.00	4.00	3.75	3.63	3.73	3.77	3.91	3.92	3.85	3.84	
Dunlin	-	4.00*	3.75*	3.90	3.70	3.93	3.63	4.00*	4.00	3.92	4.00	3.13	3.79	3.67	4.00	4.00	3.70	3.80	
Ruddy turnstone	-	3.71	3.79	3.82	3.58	3.80	3.75	4.00	3.77	3.92	3.86	3.00*	4.00*	3.71	3.78	3.92	3.90	3.79	
Weighted mean	4.00	4.00	3.76	3.90	3.65	3.89	3.63	3.95	3.94	3.94	3.89	3.33	3.76	3.74	3.91	3.80	3.84	3.78	

In July and early August, alarming parents and later juveniles were found in the fens and marshes (dunlins and sanderling), on the slopes of Aucellabjerg and in the dry lowlands (common ringed plovers, red knots, sanderlings, dunlins, and turnstones).

Data on chick survival is almost negligible, and as early as 28 June (day 179), flocks of long-tailed skuas roamed the lower slopes of Aucellabjerg and the lowlands fens and heath. The largest flocks held 21 individuals.

Reproductive phenology and success in long-tailed skuas *Stercorarius longicaudus*

Three long-tailed skua nests were found initiated before the census period, the others during the census period (the average of preceding years; table 4.18). No northern collared lemming *Dicrostonyx groenlandicus* was observed by the bird observers, reflecting another season with very low numbers of lemming winter nests found (table 4.22). As mentioned above, roaming flocks of long-tailed skuas were seen early this season.

Table 4.18 Egg-laying phenology, breeding effort and success in long-tailed skuas *Stercorarius longicaudus* at Zackenberg 1996-2011. Median egg laying date (day of year) is the date when half the supposed first clutches were laid. Number of clutches found includes replacement clutches. Mean hatching success according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked by asterix. Nests with at least one piped egg or one hatched young are considered successful.

Long-tailed skua breeding	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Median 1 st egg date	–	158	163	168	170	166	160	166	160	159	170	163	164	168	172	165
No. of clutches found	8	17	23	8	5	21	14	7	21	8	2	15	9	2	1	6
No. of young hatched	1	25	16	2	2	18	14	5	36	6	1	11	3	1	0	0
Nest success % (Mayfield)	–	80.6*	26.7	18.1*	17.5*	39.5	44.1	76.2*	94*	51.8*	100*	23	33	25.9	0	0
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22	1	0	1	2	1	0	0

One observation of a 3rd calendar year bird 22 June (day 173) was the only observation of immatures this season.

Barnacle geese *Branta leucopsis*

Activity was seen at the barnacle goose colony on the southern face of the mountain Zackenberg, with three individuals seen flying to and from the colony. For further recent details on the colony, see Hansen et al. 2009.

The first barnacle goslings in the Zackenberg valley, were seen 16 July (day 197), which is late. A record low three broods were seen this season (table 4.19), and a maximum number of two goslings (per family) seen at any one time. That is the lowest number of barnacle goslings on record at Zackenberg. The percentage of young in wintering flocks was relatively high on Isle of Islay, Western Scotland, (table 4.19; M. Ogilvie, pers. comm.).

Southward migrating barnacle geese were seen from 11 August (day 223), when 16 flew south. 192 barnacle geese were seen migrating southwards in 2011. The last barnacle goose was seen flying 2 October (day 275).

Immature barnacle geese moulted in numbers far below average (1995-2010 average: 200; table 4.20).

Common birds, not breeding in the census area

Between 11 June (day 162) and 8 July (day 189), 3324 individual immature pink-footed geese *Anser brachyrhynchus* were recorded (unsystematically) on their north-bound moult migration. This is a quite high number compared to recent years, but as these data have been collected unsystematically, we are cautious to make any concrete comparisons.

With only 21 immature pink-footed geese found moulting in the Zackenberg area in 2011, the numbers are still low and the trend of pink-footed geese avoiding the Zackenberg valley seem to continue (table 4.20). Immature pink-footed geese on southward migration were recorded from mid-July to 4 October (day 247). A total of 784 pink-footed geese were recorded (unsystematically) on southward migration.

Only few common eiders *Somateria mollissima* were recorded in the study area during the 2011 season. The first observation was 14 June (day 165), when a pair was seen flying over the lower slopes of Aucellabjerg. No eider ducklings were seen at or near Zackenberg in 2011. The first king eiders *Somateria spectabilis* was a pair 5 June (day 156). No nesting attempts were recorded, and no ducklings were seen in 2011. For both eider species, flocks

Table 4.19 Average brood sizes of barnacle geese in the Zackenberg valley during July and early August 1995-2011, together with the total number of broods brought to the valley. Samples of fewer than 10 broods are marked by asterix. Average brood size data from autumn on the Isle of Islay in Scotland are given for comparison, including the percentage of juveniles in the population (M. Ogilvie pers. comm.).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Primo July	–	3.0*	3.1	2.9*	1.9	3.2*	1.8*	2.4	1.8*	2.6	1.7*	2.0*	1.3	4*	1*	1.5*	0
Medio July	–	2.3*	2.7	2.3	1.8	3.1*	1.7*	2.4	1.2*	2.3	2.7	1.5*	1.5	1.6	1.33*	1.8*	1*
Ultimo July	2.0*	3.0*	2.6	2.2	1.7	3.1	–	2.3	1.1*	2.3	2.2*	1.1*	3.3*	1.5*	1*	1.4*	0
Primo August	2.3*	2.3*	2.4	–	1.8	–	2.0*	2.2	1.2*	1.9*	–	1.5*	–	1*	1.5*	1.6*	0
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26	14	9	28	15	9	18	3
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59	2.35	1.67	1.15	2.14	1.9	1.9	2.26	2.1
Percent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4	15.9	6.3	3.23	9.8	8.2	3.8	11.2	11.2

Table 4.20 Numbers of immature pink-footed geese and barnacle geese moulting in the study area at Zackenberg 1995-2011. The closed area is zone 1c (see http://www.zackenberg.dk/fileadmin/Resources/DMU/GEM/Zackenberg/pdf/mapzoner_stor_opl.jpg).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Pink-footed goose																	
Closed moulting area and further east	310	246	247	5	127	35	0	30	41	11	17	27	0	0	1	10	17
Coast west of closed area	230	40	~60	0	29	0	0	0	0	10	0	3	2	0	0	0	0
Upper Zackenberg valley	0	0	15	0	0	0	0	0	0	0	0	1	0	2	1	0	6
Pink-footed goose total	540	286	322	5	156	35	0	30	41	21	17	31	2	2	2	10	23
Barnacle goose																	
Closed area at Lomsø and Kystkærene	21	0	29	21	60	84	137	86	120	81	87	148	66	106	70	80	48
Coast east of closed area	>120	~150	96	55	66	0	109	80	45	0	2	218	46	125	77	13	0
Coast west of closed area	0	0	0	0	0	30	0	0	0	0	29	29	106	65	34	0	66
Upper Zackenberg valley	41	85	2	75	<57	27	60	0	14	0	25	30	6	41	51	0	0
Barnacle goose total	>182	~235	127	151	<183	141	306	166	179	81	143	425	224	337	232	93	114

were seen from June, and for king eiders until ultimo July. Common eiders were seen in flocks (up to 35 individuals) into late August, except for a very late flock of 35 common eiders, seen as late as 22 September (day 265).

Long-tailed ducks *Clangula hyemalis* were seen from 4 June (day 155), after which pairs were seen almost daily until mid-July. One nest was found (suffered predation), but no ducklings were seen in 2011. In late July, August and September, only few birds, often females, were recorded. The last two long-tailed ducks were seen 5 September (day 248) at Lomsø.

As in recent years, the home range of two common raven *Corvus corax* pairs overlaps with our census area. Nesting is believed to take place outside our study area. The first three juvenile birds were seen as early as 25 June (day 176) at Sydkærene. The three young ravens were recorded twice since then. The last day was 11 July (day 192) on the lower slopes of Aucella-bjerg. However, a flock of six were seen as late as 17 September (day 260).

Visitors and vagrants

In table 4.21, we present data on avian visitors and vagrants. On 27 and 28 May a lesser yellowlegs *Tringa flavipes* was seen at a pond near the research station. This is only the fourth record of lesser yellowlegs in Greenland, and the first one in east Greenland (D. Boertmann, pers. comm.). This was the only actual rarity in 2011.

Two observations of single Canada geese *Branta canadensis* both in flocks of either barnacle geese or pink-footed geese were

seen this year. The latest observation was a small goose from the Canada goose *Branta canadensis*/*B. hutchinsii* complex, as opposed to all other, large bodied Canada geese having been observed at Zackenberg (Hansen et al. 2009 and J. Hansen unpublished).

Sandøen

BioBasis only had a short visit to Sandøen during the breeding season in 2011. There were no signs of successful breeding or breeding attempts among Arctic terns *Sterna paradisaea* and Sabine's gull *Larus sabini*. Common eiders *Somateria mollissima*, however, seemed to have some successful clutches.

Daneborg

At Daneborg, the common eider colony between the sledge dog pens had above average numbers of nests: 2986 (Sirius Patrol, pers. comm.; 2002-2010 average nest numbers: 2259). This is the highest number recorded in the BioBasis time series. In 1975, the colony held a little more than 1262 nests (Meltofte 1978). In 2011, there was an estimated average of four eggs in the nests.

Validation of sightings

The Rarities Committee for Denmark, Faroe Islands and Greenland (under BirdLife Denmark) has officially recognised this season's observation of the lesser yellowlegs described above.

All submitted rarities from Zackenberg over the years are now officially recognised sightings.

Table 4.21 Numbers of individuals and observations of avian visitors and vagrants at Zackenberg 2011, compared with the numbers of individuals observed in previous seasons, 1995-2010. Multiple observations reasonably believed to have been of the same individual have been reported as one individual.

Species	Visitors and vagrants																No. individuals	No. observations	
	Previous records															2011			
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010			
Great northern diver	0	0	0	0	0	0	1	0	0	0	0	0	2	2	0	1	0	0	
Whooper swan	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	
Greylag goose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
Snow goose	0	0	0	0	0	2	11	0	23	0	0	0	1	0	0	0 ^a	0	0	
Canada goose	0	0	0	0	0	0	0	0	0	0	0	4	3	0	1	0	2	2	
Merlin	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
Gyr falcon	1	1	1	3	0	4	5	1	3	4	2	0	3 ^b	2 ^c	4	3	3	2	
Pintail duck	0	0	0	1 ^d	0	0	0	0	0	0	0	0	3 ^d	0	0	3	0	0	
Common teal	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
Eurasian golden plover	0	3	1	3	1	0	3 ^e	1	0	1	1	1	1	1	2	2	0	0	
White-rumped sandpiper	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	
Pectoral sandpiper	0	0	0	1	0	0	0	2	0	0	0	1	1	0	1	1	0	0	
Purple sandpiper	0	0	0	0	0	0	0	1 ^f	0	0	0	0	0	0	0	0	0	0	
Red phalarope	0	0	0	4-5 ^e	0	0	4 ^e	0	1	0	2 ^e	11 ^e	0	2	0	2	0	0	
Common snipe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
Whimbrel	0	0	0	0	0	1	1	0	0	2	1	0	1	2	0	0	0	0	
Eurasian curlew	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Redshank	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	
Lesser yellowlegs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1 ^g	2	
Pomarine skua	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	
Arctic skua	0	0	11	6	0	2	7	4	3	2	0	1	0	0	0	0	0	0	
Great skua	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
Lesser black-backed gull	0	0	0	0	0	0	1	0	1	2	1	4	0	0	0	0	1	1	
Iceland gull	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	
Great black-backed gull	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	
Black-legged kittiwake	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	
Arctic tern	~200	2	1	2	0	14	0	0	32	0	0	0	0	57	0	0	0	0	
Snowy owl	0	0	2	1	1	1-2	≥4 ^e	0	0	0	0	0	1 ^b	0	0	0	0	0	
Meadow pipit	0	0	0	1	0	0	0	0	0	0	1 ^d	1 ^d	0	0	0	0	0	0	
White wagtail	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
Northern wheat-ear	4	8 ^e	4	3 ^e	1-2 ^e	0 ^h	0	0	0	0	2	1	4 ^b	2	2	5 ⁱ	1	1	
Lapland longspur	0	0	0	0	1-2	0	1	0	0	0	1	0	0	0	0	2 ^e	3 ^e	10	

^aTwo outside census area • ^bSee Hansen et al. 2010 • ^cAfter regular season, four observations of 1-3 birds • ^dNorthernmost records in East Greenland (cf. Bortmann 1994) • ^eAt least one territory, possible territory or breeding found • ^fJuvenile • ^g4th record in Greenland, first in N.E. Greenland • ^hOne dead individual found • ⁱThree juveniles, all from pair(s) outside the census area

4.4 Mammals

The mammal monitoring programme was conducted by Lars Holst Hansen, Lars O. Mortensen, Jannik Hansen, Line Anker Kyhn, Noémie Boulanger-Lapointe and

Niels Martin Schmidt. The station personnel and visiting researchers supplied supplemental observations during the entire field season.

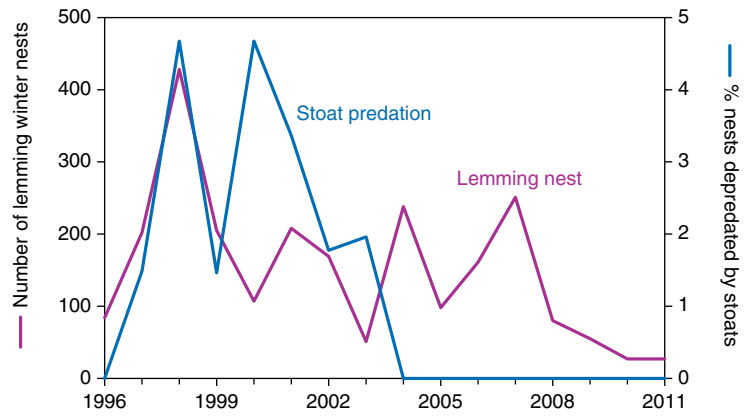
The collared lemming *Dicrostonyx groenlandicus* census area was surveyed for

Table 4.22 Annual numbers of collared lemming winter nests recorded within the 1.06 km² census area in the Zackenberg valley 1996-2011 together with the numbers of animals encountered by one person with comparable effort each year within the 15.8 km² bird census area during June-July.

Year	New winter nests	Old winter nests	Animals seen
1996	84	154	0
1997	202	60	1
1998	428	67	43
1999	205	36	9
2000	107	38	1
2001	208	13	11
2002	169	20	4
2003	51	19	1
2004	238	15	23
2005	98	83	1
2006	161	40	3
2007	251	21	1
2008	80	20	4
2009	55	9	0
2010	27	23	0
2011	27	3	0

winter nests during July and August. During the entire season, when weather permitted, Arctic hares *Lepus arcticus* in the designated monitoring area on the south-east and east facing slopes of the mountain Zackenberg were censused during 7 July (day 188) – 15 September (day 258).

The total numbers of muskoxen, including sex and age from as many individuals as possible, were censused weekly within the 47 km² census area during the period July - October. The 16 known Arctic fox *Vulpes lagopus dens* (number 1-10 and 12-17) within the central part of the Zackenberg valley



were checked approximately once a week for occupancy and breeding. The 29 fixed sampling sites for predator scats and casts were checked in late August and early September. Observations of other mammals than collared lemming, Arctic fox, musk ox, Arctic hare and seal sp. are presented in the section "Other observations" below.

For the sixth year in a row, BioBasis collected Arctic fox scats for the analysis of parasitic load.

Figure 4.6 Number of collared lemming winter nests registered within the 1.06 km² designated lemming census area (red line), along with the percentage of winter nests taken over by stoats (blue line) 1996-2011.

Collared lemming *Dicrostonyx groenlandicus*

In 2011, a total of only 27 collared lemming nests from the previous winter were recorded within the 1.06 km² census area (table 4.22). This is the same low number as in 2010. All previous years have had higher numbers.

As in the seven previous seasons, not a single nest was found depredated by stoat in the 2011 season (figure 4.6). No lemmings were seen by bird observers, researchers or staff.

Figure 4.7 The sex and age composition of muskoxen registered during the weekly field censuses within the census area during the 2011 season (for the counts from 5 September (day 248) onwards, only a part of the area was censused due to length of daylight). F=female, M=male.

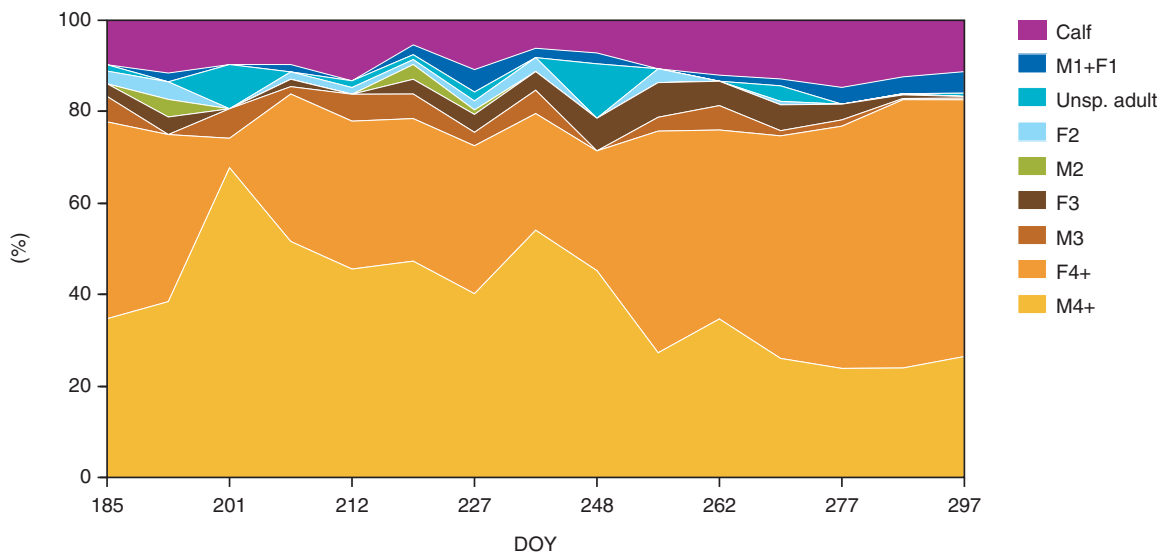


Table 4.23 Sex and age composition of muskoxen based on weekly counts within the 47 km² census area in the Zackenberg valley from July – August 1996-2011.

Year	M4+		F4+		M3		F3		M2		F2		1M+1F		Calf		Unsp. adult		No. of weekly counts
	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	
1996	98	14	184	27	7	1	31	5	54	8	17	3	146	22	124	18	15	2	9
1997	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1998	97	29	97	29	22	7	19	6	30	9	27	8	14	4	22	7	1	0	8
1999	144	38	106	28	21	6	21	6	9	2	12	3	5	1	30	8	32	8	8
2000	109	30	118	32	11	3	15	4	2	1	7	2	31	8	73	20	3	1	8
2001	127	30	120	29	8	2	19	5	26	6	19	5	43	10	55	13	4	1	7
2002	114	20	205	36	20	3	24	4	38	7	43	8	51	9	77	13	0	0	8
2003	123	23	208	39	24	5	23	4	16	3	19	4	44	8	72	14	0	0	8
2004	122	22	98	18	13	2	28	5	5	1	8	1	32	6	124	23	119	22	7
2005	212	23	260	28	11	1	46	5	43	5	21	2	116	13	200	22	6	1	9
2006	205	29	123	17	29	4	55	8	62	9	34	5	102	14	94	13	0	0	7
2007	391	25	341	22	73	5	152	10	80	5	83	5	202	13	246	16	8	1	9
2008	267	34	189	24	38	5	57	7	44	6	58	7	58	7	63	8	18	2	8
2009	269	42	176	28	32	5	38	6	32	5	23	4	30	5	18	3	21	3	8
2010	246	49	101	20	40	8	26	5	29	6	21	4	8	2	18	4	15	3	9
2011	267	46	181	31	24	4	16	3	6	1	12	2	11	2	53	9	8	1	8

Musk ox *Ovibos moschatus*

The muskoxen counts from a fixed position are no longer undertaken.

Based on the weekly field censuses, table 4.23 lists the sex and age composition over the seasons during July and August. In 2011, again males of four years or older constituted the highest proportion recorded. After two years with very few calves observed, this group has now increased

in both absolute values and relatively. On the other hand, both male and female two-year-olds did show a decrease compared to recent years. The mean number of animals per count was 72.3. This is just below average for all previous seasons. Figure 4.7 illustrates the temporal development in the proportions of the different sex and age classes during the 2011 season. A similar trend to previous seasons was seen with the proportion of males of four years of age or older showing a decrease over the course of the season and females of the same age class showing an increase.

Three fresh musk ox carcasses (one male and two females) were found within the musk ox census area during the 2011 season (table 4.24). In addition, two carcasses (two males) thought to have been overlooked in 2010 were found inside the survey area and two fresh carcasses were found outside the survey area. Remains of muskoxen calves were found at some of the fox dens.

Arctic fox *Vulpes lagopus*

In 2011, breeding was verified in three dens and a combined minimum of seven fox pups (all white colour phase) were observed at the known dens (table 4.25). Late in the season, one adult dark colour phase fox was observed in the field on one occasion.

Table 4.24 Fresh muskoxen carcasses found during the field seasons of 1995-2011. F=female, M=male.

Year	Total carcasses	4+ yrs F/M	3 yrs F/M	2 yrs F/M	1 yr F/M	Calf
1995	2	0/1				1
1996	13	7/1	0/1	0/2	1/1	
1997	5	0/2		1/0	1/0	1
1998	2	0/2				
1999	1	0/1				
2000	8	0/6	1/0			1
2001	4	0/4				
2002	5	1/2	1/0			1
2003	3	0/2				1
2004	2	1/1				
2005	6	2/3				1
2006	5	0/2			0/1	2
2007	12	3/4	1/0		1/0	3
2008	11	3/1	2/0			5
2009	15	4/5				8
2010	6	2/1	0/1			2
2011	3	2/1				

Table 4.25 Numbers of known fox dens in use, numbers with pups and the total number of pups recorded at their maternal dens within and outside the central part of the Zackenberg valley 1995-2011. W=white phase, D=dark phase.

Year	No. of known dens inside/outside	No. of dens in use inside/outside	No. of breeding dens inside/outside	Total no. of pups recorded
1995	2/0	0/0	0/0	0
1996	5/0	4/0	2/0	5W+4D
1997	5/0	1/0	0/0	0
1998	5/0	2/0	1/0	8W
1999	7/0	3/0	0/0	0
2000	8/0	4/0	3/0	7W
2001	10/2	6/1	3/1	12W+1D
2002	10/2	5/1	0-1/0	0
2003	11/2	8/1	3/0	17W
2004	12/2	12/2	4/1	18+W
2005	14/2	6/0	0/0	0
2006	15/1	6/1	3/0	17W
2007	14/1	12/1	3/1	23W
2008	15/1	14/1	4/1	24W
2009	15/1	13/1	3/0	10W
2010	16/1	14/1	2/0	11W
2011	16/1	9/0	3/1	7W

Table 4.26 Numbers of Arctic hares within the designated census area per observation day counted during July and August 2001-2011.

Year	Counts	Average	SD	Range
2001	22	1.2	1.3	0-5
2002	16	0.4	0.6	0-2
2003	20	2.4	1.8	0-6
2004	23	0.9	1.1	0-3
2005	48	5.5	5.1	0-26
2006	39	5.9	3.7	1-19
2007	18	4.8	3.0	0-11
2008	17	2.5	2.3	0-7
2009	16	4.8	2.8	1-12
2010	18	3.1	1.9	0-7
2011	14	2.7	1.7	1-7

Arctic hare *Lepus arcticus*

In 2011, fourteen counts with good visibility were made during July and August with a mean of 2.7 hares per census (table 4.26). This is very close to average for all available previous seasons (3.2). An additional four counts were carried out in September with a mean of 6.0.

Other observations

Polar bears *Ursus maritimus* were observed during the 2011 season on several occasions. From 2-8 June one adult male and one adult female was continuously obser-

ved on the ice of Young Sund as close as 3 km from the station. It was presumably a mating couple although no copulations were observed with certainty. In addition, 8 June, an adult female with two cubs were observed walking SW on the ice of Young Sund about 5-6 km from the station. They turned and disappeared in a southerly direction. On 12 June an adult male and a female (presumably the same as the couple mentioned above) was observed on the ice of Young Sund walking towards Tyrolerfjord about 6 km from the station. At the same time 12 June a lonely adult, presumably male, was observed on the ice of Young Sund walking towards the station. It turned NW following the coastline until the Old Delta about 1.2 km from station where it again turned and left in a SW direction towards Clavering Ø. Lastly, 16 June a single adult (presumably same as the single individual observed 12 June) was seen, again on the ice of Young Sund about 4-5 km from the station, first lying and later standing in wait for a seal at two different seal breathing holes. Presumably this same bear was again observed 17 June. This is by far the season with most polar bears observed. Contrary to previous observations of polar bears at Zackenberg, none of them was observed on land.

In 2011, no stoats *Mustela erminea* were observed, and none of the new lemming

Table 4.27 Wildlife specimens collected for tissue samples in 2011 and all seasons, respectively.

Species	2011	1997-2010
Arctic char	0	6
Arctic fox	1	11
Arctic hare	12	13
Collared lemming	0	6
Common raven	1	1
Dunlin	1	5
Glaucous gull	0	1
Gyr falcon	0	1
Muskoxen	10	73
Northern wheatear	0	1
Rock ptarmigan	0	2
Ruddy turnstone	1	1
Seal (sp.)	0	1
Three-spined stickleback	0	6
Fourhorn sculpin	5	5

winter nests found in the census area were depredated by stoats. During the standardised collection of scats and casts, seven stoat scat was found (table 4.28).

Walrus *Odobenus rosmarus* was observed in Young Sund from boats on several occasions. BioBasis did one landing on Sandøen 23 July, where 12 walrus hauling out were observed. On 12 September, Sandøen was surrounded by drifting ice and one walrus was seen on the ice near the island.

Censusing of the seals hauling out on the ice of Young Sund is no longer part of the monitoring programme. On 21 August a single adult bearded seal was observed resting on an ice floe just outside the old river delta.

Table 4.28 Numbers of casts and scats from predators collected from 29 permanent sites in the Zackenberg valley. The samples represent the period from mid/late August the previous year to mid/late August in the year denoted.

Year	Fox scats	Stoat scats	Skua casts	Owl casts
1997	10	1	44	0
1998	46	3	69	9
1999	22	6	31	3
2000	31	0	33	2
2001	38	3	39	2
2002	67	16	32	6
2003	20	1	16	0
2004	16	3	27	0
2005	24	0	7	6
2006	29	0	15	4
2007	54	4	13	3
2008	30	1	16	0
2009	22	2	11	1
2010	22	1	3	0
2011	28	7	15	1

Collection of wildlife samples

Tissue samples from dead vertebrate species encountered in the field were collected (table 4.27). In addition, scats and casts were collected at 29 permanently marked sites in the Zackenberg valley (table 4.28).

4.5 Lakes

The two lakes, Sommerfuglesø and Langemandssø, situated in Morænebakkerne, were sampled six times during the period 10 July to 23 October 2011. This represent both the summer period (July and August), which has been sampled since 1997, and the autumn period (September and October), that has been sampled during a number of extended seasons. The reason for the latter is that results from our research projects during the last few years clearly have shown biological activity in the lakes after the ice-over in early/mid-September (see Jensen and Rasch 2009 and 2010). Hence, an extension of the standard sampling period was carried out to allow for verification of the findings.

It appears that the 2011 season was comparable to the 2010 season, both characterized by a fairly early ice-off and a warm summer (tables 4.29, 4.30 and 4.31). July and August represent the standard sampling period (i.e., the period sampled every year) while September and October represent the autumn/early winter situation.

An automatic camera was set up at Langemandssø in October 2010 and it has been taking pictures of the lake weekly until May 2011 and thereafter daily until the ice was melting at the end of June 2011.

Ice and snow

Based on visits to the lakes and visual inspections by binoculars from the slopes of Aucellabjerg it was estimated that both lakes were 50% ice free in late June (25 June for Sommerfuglesø and 28 June for Langemandssø). The ice conditions at Langemandssø were verified by the automatic camera (figure 4.8), although it was not possible to estimate the ice coverage as the entire lake is not included in the camera view.

The lakes became ice covered again from mid-September (table 4.29). This implies the so-called growing season lasts approximately 75 days. The ice-out and ice-in dates were within the range found for previous years (tables 4.30 and 4.31).

Table 4.29 Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July-October 2011.

Lake	SS	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
DOY 2011	191	213	232	260	275	296	191	213	232	260	275	296	
Ice cover (%)	0	0	0	100	100	100	0	0	0	100	100	100	
Temperature (°C)	9.9	14.1	8.4	3.7	3.1	1.9	10.3	15.3	8.5	2.4	3	0.3	
pH	6.6	6.7	6.4	6.7	6.5	6.7	6.8	6.9	6.5	6.7	6.5	6.5	
Conductivity ($\mu\text{S cm}^{-1}$)	19	21	26	31	34	39	27	29	36	50	45	64	
Chlorophyll a ($\mu\text{g l}^{-1}$)	0.57	0.46	0.42	0.55	0.77	1.01	0.69	0.67	0.55	0.77	1.26	1.76	
Total nitrogen ($\mu\text{g l}^{-1}$)	190	230	240	230	190	290	210	270	200	200	160	220	
Total phosphorous ($\mu\text{g l}^{-1}$)	10	6	8	4	3	4	4	4	4	8	4	4	

Table 4.30 Average physico-chemical variables in Sommerfuglesø (SS) in 1999-2011 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data.

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Date of 50% ice cover	ND	192	199	177	183	184	175	176	169	186	166	181	179	165	176
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	11	8.7	9.8	10.1	10	10.6	9.5	10.4	10.8
pH	6.5	7.4	6.7	5.8	6.6	6	6.5	6.3	6	6.2	6.6	5.9	6.7	6.7	6.6
Conductivity ($\mu\text{S cm}^{-1}$)	15	13	10	18	18	8	12	15	22	11	10	16	22	18	22
Chlorophyll a ($\mu\text{g l}^{-1}$)	0.84	0.24	0.41	0.76	0.67	1.27	1.84	1.62	1.59	0.65	1.49	0.57	0.89	1.26	0.50
Total nitrogen ($\mu\text{g l}^{-1}$)	ND	130	210	510	350	338	277	267	263	293	323	238	298	248	220
Total phosphorous ($\mu\text{g l}^{-1}$)	4	9	11	10	19	11	11	7	9	8	10	6	7	5	8

Table 4.31 Average physico-chemical variables in Langemandssø (LS) in 1999-2011 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data.

Lake	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Date of 50% ice cover	ND	204	202	182	189	187	183	178	173	191	167	182	172	174	178
Temperature (°C)	6.8	6.4	4	9.5	8.4	8.1	11.1	9.1	10.5	9.8	10.6	8.8	9.1	9.2	11.4
pH	6.5	7	6.3	5.5	6.4	5.5	6.1	6.1	6	6.3	6	5.7	6.5	6.6	6.7
Conductivity ($\mu\text{S cm}^{-1}$)	8	9	7	9	8	6	6	8	14	5	7	7.8	18	15	31
Chlorophyll a ($\mu\text{g l}^{-1}$)	1.04	0.32	0.38	0.9	1.46	2.72	3.14	0.98	1.62	0.56	1.54	0.92	1.06	1.20	0.60
Total nitrogen ($\mu\text{g l}^{-1}$)	ND	80	120	290	340	387	237	230	247	203	268	138	172	208	227
Total phosphorous ($\mu\text{g l}^{-1}$)	8	7	7	11	20	13	10	11	11	6	8	6	9	10	4



Figure 4.8 Photo taken by the automatic camera of the 50% ice covered Langemandssø 28 June 2011.

Figure 4.9 Photo of an ice and partly snow covered Langemandssø in mid-May 2011. Photo: Kirsten S. Christoffersen.



Table 4.32 Biovolume ($\text{mm}^3 \text{ l}^{-1}$) of phytoplankton species in Sommerfuglesø and Langemandssø during July-October 2011.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
DOY 2011	191	213	232	260	275	296	191	213	232	260	275	296
Nostocophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Dinophyceae	0.160	0.761	0.850	0.052	0.055	0.016	0.114	0.017	0.150	0.125	0.058	0.026
Chrysophyceae	0.058	0.110	0.099	0.066	0.064	0.119	0.244	0.186	0.121	0.094	0.163	0.163
Diatomophyceae	0.001	0	0	0	0	0	0	0	0.002	0.001	0.001	0.001
Chlorophyceae	0.001	0	0	0.014	0.000	0	0.004	0.058	0.051	0.020	0.026	0.008
Others	0	0	0	0.008	0.000	0.002	0	0	0	0	0	0
Total	0.220	0.871	0.948	0.139	0.119	0.137	0.363	0.261	0.324	0.240	0.248	0.199

The snow conditions of both lakes were inspected in mid to late May as part of a research project (see section 6.11). It appeared that approximately 15% of the ice surface of Langemandssø had no snow (figure 4.9) and the rest of the lake had a snow layer of 2 to 20 cm. By contrast, Sommerfuglesø was totally covered by a thick (20-45 cm) layer of snow in May.

Physical and chemical conditions

The early ice melt and a warm summer lead to water temperatures of 14-15°C in early August (tables 4.29). The mean temperatures for the entire summer period were 10.8 and 11.4°C in Sommerfuglesø and Langemandssø, respectively (table 4.29). This implies that the season on average followed the general trend of warm-

Table 4.33 Average biovolume ($\text{mm}^3 \text{ l}^{-1}$) of phytoplankton species in Sommerfuglesø during summer (July and August) from 1997 to 2011 (note that some years are missing).

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011
Nostocophyceae	0	0.005	0	0	0	0	0	0	0	0	0	0
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.185	0.068	0.113	0.184	0.053	0.248	0.590
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.554	0.145	0.386	0.092	0.261	0.303	0.089
Diatomophyceae	0.002	0	0.001	0	0	0	0.007	0	0	0.003	0.005	0.001
Chlorophyceae	0.005	0.002	0	0	0.002	0.009	0.004	0.001	0	0	0	0.001
Others	0	0	0.004	0	0	0	0	0	0	0.002	0	0
Total	0.06	0.15	0.38	0.07	0.27	0.75	0.22	0.50	0.28	0.32	0.56	0.68

Table 4.34 Average biovolume ($\text{mm}^3 \text{ l}^{-1}$) of phytoplankton species in Langemandssø during summer (July and August) from 1997 to 2011 (note that some years are missing).

Lake	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	1997	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011
Nostocophyceae	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinophyceae	0.291	0.185	0.305	0.04	0.156	0.123	0.03	0.068	0.05	0.222	0.095	0.118	0.094
Chrysophyceae	0.066	0.187	0.048	0.592	0.377	0.358	0.296	0.318	0.192	0.262	0.424	0.48	0.184
Diatomophyceae	0.002	0	0	0.002	0	0	0	0.009	0	0	0	0	0.002
Chlorophyceae	0.016	0	0.002	0.002	0	0.003	0.019	0.008	0.017	0.004	0.013	0.099	0.038
Others	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0.38	0.37	0.35	0.64	0.53	0.48	0.35	0.40	0.26	0.49	0.53	0.70	0.32

Table 4.35 Density (no l^{-1}) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) during July-October 2011.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
DOY 2011	191	213	232	260	275	296	191	213	232	260	275	296
Cladocera	0.8	7.9	1.4	0.1	0.9	0.4	0.1	0	0.1	0.1	0	0
Copepods	16.1	5.9	3.2	1.9	2.4	1.6	21.5	0	12.4	7.9	6.0	8.4
Rotifers	6.7	16.3	14.0	21.2	19.5	0.3	15.0	23.2	14.0	23.0	9.2	0.1
Others	0	0	0.1	0	0.3	0	1.0	0.7	0	0	0	0
Total	23.6	30.1	18.7	23.1	23.8	2.3	37.6	23.9	26.5	31.0	15.2	8.5

ing that has been observed for several years (tables 4.30 and 4.31).

The basic water chemistry measurements included concentration of total nitrogen and total phosphorus as well as conductivity and pH (table 4.29). The average concentrations calculated for the summer period for all parameters were within the levels recorded during previ-

ous years (tables 4.30 and 4.31). The nutrient concentrations (TP and TN) and pH remained at the same levels during the autumn while the conductivity increased from mid-September in both lakes (table 4.29). This is probably an effect of freezing as the ions are concentrated in the unfrozen water.

Table 4.36 Average density (no l^{-1}) of zooplankton species in Sommerfuglesø during summer (July and August) from 1997 to 2011.

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Cladocera																
<i>Daphnia pulex</i>	0.3	10.5	0.3	6.7	8.2	6.8	7.7	0.7	6.4	7.07	3.8	6.33	2.87	7.8	3.4	
<i>Macrothrix hirsuticornis</i>	0.1	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	
<i>Chydorus sphaericus</i>	0.05	0	0	0	0.06	0	0	0	0.13	0	0	0	0	0.1	0	
Copepoda																
<i>Cyclops abyssorum alpinus</i> (adult+copepodites)	0.8	0.5	0.5	0.3	0.5	0.2	0.9	0.3	0.07	0.27	2	1.27	0.47	2	1.5	
Nauplii	5.7	1.3	6.5	1.1	1.4	2.3	0.3	0.3	0.2	1.67	0.13	1.93	0.07	3.7	6.9	
Rotifera																
<i>Polyarthra dolicoptera</i>	171	90	185	97	74	11	0.5	1.87	7.67	42.2	108	49.8	150.18	45	12.3	
<i>Keratella quadrata</i> group	4.5	3	17	0	0	0.4	0.1	0	0	0.33	0	0	0	0	0	
<i>Conochilus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Euchlanis</i> sp.	0	0	0	0	0	0	0	0	0.33	0.07	0	0	1.78	0	0	

Table 4.37 Average density (no l⁻¹) of zooplankton species in Langemandssø during summer (July and August) 1997 to 2011.

Lake	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cladocera															
<i>Daphnia pulex</i>	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
<i>Macrothrix hirsuticornis</i>	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chydorus sphaericus</i>	0	0.1	0	0.5	0.1	0.07	0	0	0.13	0.07	0.07	0	0	0	0.1
Copepoda															
<i>Cyclops abyssorum alpinus</i> (adult+copepodites)	3.3	2.9	4.1	22	13.4	6.8	8.6	4.9	5.8	11.74	8.93	2.27	14.11	15	13.6
Nauplii	5.2	3.8	6.4	3.1	4.5	4.5	4.2	0	2.2	5.13	1.07	3.07	2.27	5.3	5.4
Rotifera															
<i>Polyarthra dolicoptera</i>	316	330	274	168	248	22	78	71	99	181.33	40	185.3	32.67	46.3	9.9
<i>Keratella quadrata</i> group	4.5	28	34	0	0	0.3	0	1.3	0	41.33	0	2.6	0	1.3	0
<i>Conochilus</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Euchlanis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Phytoplankton and zooplankton

The pelagic chlorophyll *a* concentration reflects the phytoplankton biomass and was 0.5 and 0.6 µg l⁻¹ in Sommerfuglesø and Langemandssø, respectively during summer and were within the levels recorded in previous years (tables 4.30 and 4.31). However, the chlorophyll concentrations doubled in both lakes late in the season (table 4.29). The increased concentration of chlorophyll *a* in the late autumn is a consequence of the raised nutrient concentrations as indicated by the increased conductivity mentioned earlier.

The phytoplankton communities were dominated by dinophytes and chrysophytes (table 4.32) during most of the season in Sommerfuglesø and Langemandssø. The remaining biomass in both lakes was chlorophytes, chrysophytes and occasionally diatoms. Typical genera were *Gymnodium*, *Peridinium*, *Uroglana*, *Mallomonas* and *Ochromonas*. The results are comparable to findings from previous years (tables 4.33 and 4.34). The phytoplankton diversity and biomass was lowest in the beginning of the season, peaked during August and remained surprisingly high during September-October, where the light climate is rapidly declining.

The zooplankton community in Sommerfuglesø included cladocerans (*Daphnia pulex*), copepods (*Cyclops abyssorum*) and rotifers. The average abundance for the summer period was 24 individuals l⁻¹ (table 4.35). Langemandssø had average zooplankton densities up to 30 individuals l⁻¹ but the community consisted only of copepods and rotifers. The difference in species composition is caused by fish as Langemandssø holds a population of dwarf-sized Arctic char. The recorded species composition as well as densities in the summer period (July and August) was within the range found in previous years (tables 4.36 and 4.37). The zooplankton abundances were surprisingly high in the autumn but match the higher food concentrations (chlorophyll).

Overall, the results from the standard sampling programme showed similar trends as several previous warm seasons with fairly high water temperatures and high densities of phyto- and zooplankton. The extended sampling programme revealed that phyto- and zooplankton are active long after the ice-over has started and probably as long as there is light. This implies that evaluations of e.g. lake carbon budgets need to include more than just the ice-free season.

5 Zackenberg Basic

The MarineBasis programme

Mikael K. Sejr, Thomas Juul-Pedersen, Egon Frandsen, Martin Blicher and Ivali Lennart

This chapter presents results from the 9th year of the MarineBasis programme. The programme conducts long-term monitoring of physical, chemical and biological parameters of the coastal marine ecosystem at Zackenberg/Young Sund. The intention is to be able to quantify any climate related changes in this high Arctic marine ecosystem. The programme is conducted during a three week field campaign in the summer combined with continuous measurements by moored instruments during the rest of the year. Summer measurements are primarily conducted in the outer part of Young Sund and supplemented with data from Tyrolerfjord and the Greenland Sea.

The sampling strategy during summer is to describe the spatial variation in hydrographic parameters by sampling a number of stations once (figure 5.1) and

also to determine the day-to-day variation at a single station. The programme includes hydrographic measurements (salinity, temperature, pressure, dissolved oxygen, fluorescence, light profiles and turbidity) combined with determination of nutrient concentrations (NO_x , PO_4^{3-} , SiO_4) and surface $p\text{CO}_2$. The species composition of phyto- and zooplankton is determined at a single station. On the sea floor, the sediment-water exchange of nutrients, DIC and oxygen is quantified. In addition, the annual growth rate of the kelp *Saccharina latissima* is estimated. To supplement data collected in summer, a mooring is established in the outer part of Young Sund where continuous measurements of temperature and salinity are conducted at two depths and the vertical flux of sinking particles are estimated throughout the year using a sediment trap.



Figure 5.1 Map of the sampling area. The dots represent the hydrographic sampling stations from the innermost Tyrolerfjord on the left to the East Greenland Shelf on the right.



Figure 5.2 Examples of images used to monitor ice conditions in 2010-2011 in Young Sund. Photos: MarineBasis programme.

5.1 Sea ice

The sea ice conditions in Young Sund are monitored by daily satellite photos, observation made by the Sirius Patrol and by cameras mounted on the coast (figure 5.2). In 2011, the sea ice broke up in Young Sund approximately 11 July (figure 5.3). Permanent ice formed again 20 October resulting in an open-water period of 101 days close to the average observation during the programme. Snow thickness, measured by the Sirius Patrol, was low with just 20 cm and maximum sea ice thickness was measured to 144 cm (table 5.1).

5.2 Water column

Annual data from mooring

The mooring was deployed 8 August 2010 and retrieved 5 August 2011. The two CTDs positioned in 28 and 62 m depth recorded temperature and salinity every 20 minutes. Unfortunately, a malfunctioning battery resulted in premature termination of measurements at 28 m 18 May 2011. Data from 62 m depth show the typical seasonal variation (figure 5.4a). Temperature increased from August through October as warm surface water is gradually being mixed down. At around November a maximum temperature of -1.4°C is reached after which temperature decreased steadily to -1.75°C corresponding to heat loss to the atmosphere and eventually sea ice formation. At around 1 May temperature started to increase continuously until the mooring was retrieved in August. The seasonal variation of the salinity is slightly different. A steady decrease from 32.35 to 32.00 was observed from August to February. From February until late May an increase was observed reaching 32.15. Then salinity decreased through June and July. The result is that when measurement started in 2010 salinity was above 32.3 but one year later was reduced to 32. When plotting the difference (62 m-28 m) between values obtained at the two CTDs (figure 5.4b) it is possible to quantify the degree of vertical stratification in the water column. When measurement started temperature was lower and salinity and density higher at 62 m. Surprisingly, the difference between the two depth increases during September most likely as a result of the warm and low sa-



Figure 5.3 Satellite image showing condition 11 July 2011 when ice broke up in the outer part of Young Sund.

Table 5.1 Summary of sea ice and snow conditions in Young Sund.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
Ice thickness (cm)	120	150	125	132	180	176	155	148	144
Snow thickness (cm)	20	32	85	95	30	138	45	45	20
Days with open water	128	116	98	75	76	132	90	99	101

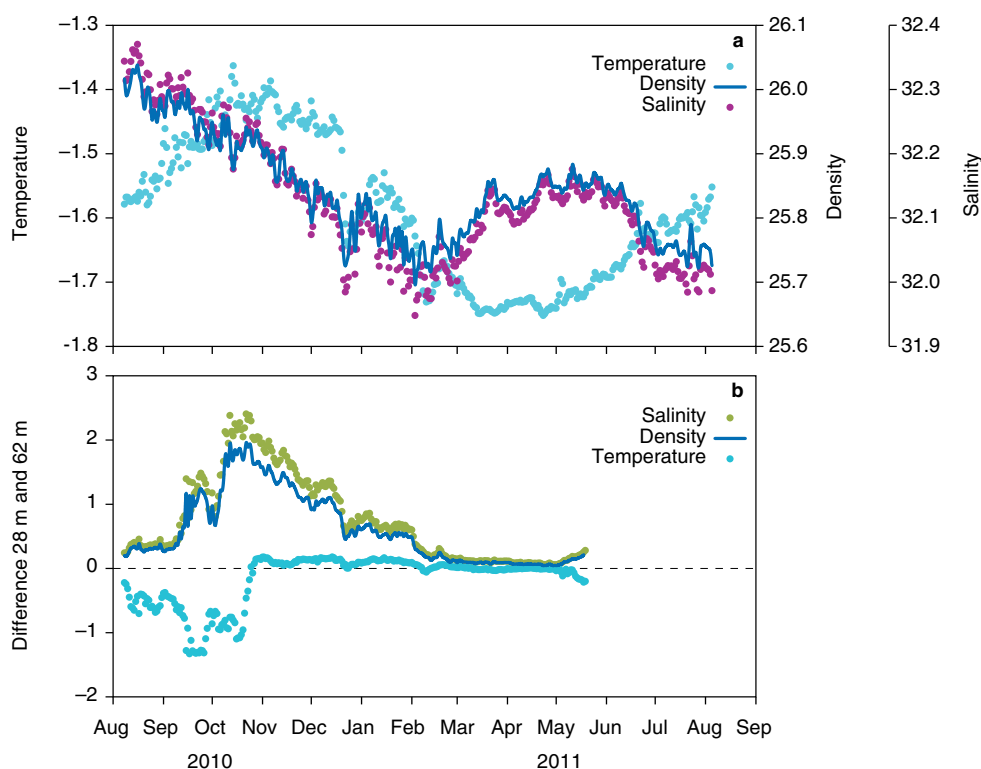


Figure 5.4 a). Time series of salinity, temperature and density at 62 m depth in central Young Sund. b) Difference (28 m-62 m) between parameters measured at two depths.

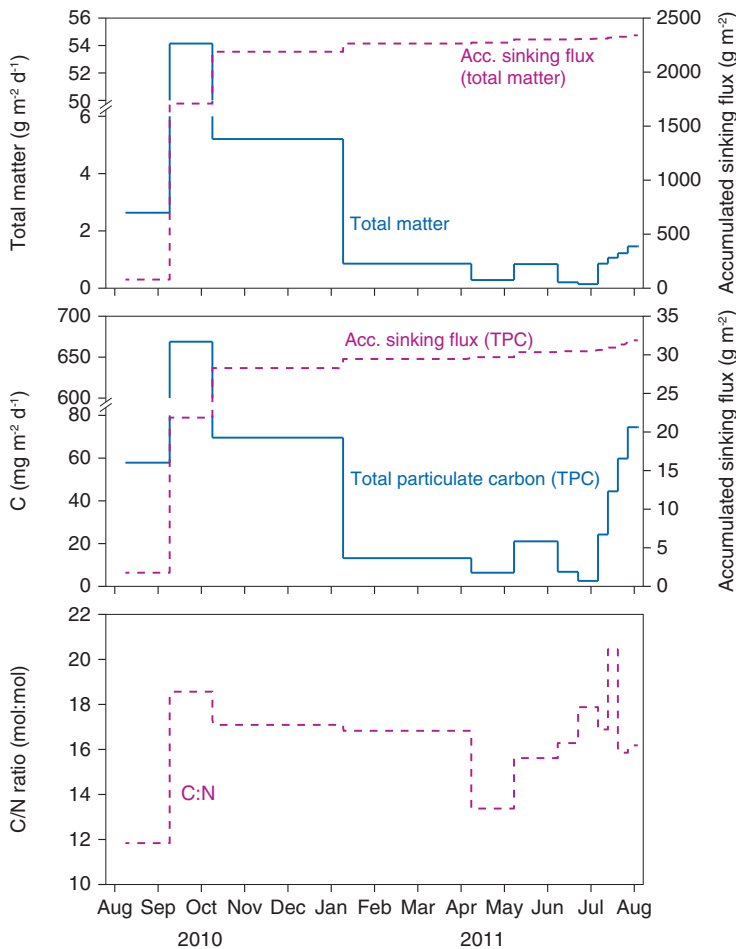


Figure 5.5 Sinking fluxes and accumulated sinking fluxes of total matter and total particulate carbon (TPC) along with C:N ratios of the material collected during 2010/11 in the outer part of Young Sund.

linity surface water gradually being mixed down and hits the CTD at 28 m first. In mid-October in about a week the temperature switched to being lowest at 28 m. This most likely reflects that cooling took place from the surface as sea ice formed. The difference in salinity reached a maximum of 2 psu units in late October and then decreased steadily as continued tidal driven mixing eradicated the vertical stratification. In late April difference in salinity and density reached a minimum and then started increasing again most likely as a result of melting of sea ice and heating of the surface water in the polynya outside the fjord.

The annual mooring included a long-term sediment trap comprised of 12 separate bottles each sampling during a pre-programmed interval. The array collected sinking particulate material during 361 days (figure 5.5). High sinking fluxes of total matter was recorded from August to January, and the highest ever recorded peak occurred in September (54.1 g m⁻² d⁻¹). During the rest of the deployment period, i.e. February to August 2011, sinking fluxes remained lower (below 1.5 g

m⁻² d⁻¹). The same seasonal trend was observed for total particulate carbon (TPC), showing a peak sinking flux of 669 mg m⁻² d⁻¹ during September 2010. The majority of the sinking particulate material occurred prior to January 2011, as illustrated by the accumulated sinking fluxes. In addition, the high overall sinking flux during October to January sampling interval was likely dominated by higher fluxes early in the sampling interval. Analysis showed that the sinking material contained a high lithogenic component (i.e. sedimentary material) of either terrestrial or resuspended origin, as the carbon content remained low throughout the sampling period (1.2 to 5.1% of total matter; data not shown) and the C/N ratio remained above 15 mol:mol in all but two sampling intervals (11.8 and 13.4 mol:mol in August 2010 and April 2011, respectively). Annual vertical sinking fluxes of total matter and TPC during the 2010-11 deployment (2337 and 31.9 g m⁻² y⁻¹, respectively) where the highest ever recorded (207 and 1420 g m⁻² y⁻¹, and 3.2 and 17 g m⁻² y⁻¹ for TPC and total matter from 2003-2010, respectively). Moreover, the high sinking fluxes were dominated by the September peak in 2010. The discharge from the river Zackenberg did not show any exceptional events in late summer 2010 that could explain the high particle load in the trap but the material could originate from other rivers in the area or from resuspension of marine sediments.

Summer distribution of hydrological parameters

The spatial variation in hydrological conditions is assessed by measuring vertical profiles along three transects in the fjord. One transect extending from Tyrolerfjord to the Greenland Sea was covered 2 August. Data show large spatial differences related to the input of freshwater in the inner parts of the fjord. Salinity (figure 5.6) showed the typical freshwater wedge at the surface with very low salinities in the top 1-2 m in Tyrolerfjord. Due to calm conditions surface salinity was below 5 psu in the inner parts of Tyrolerfjord. The freshwater wedge only extended to 5-8 m depth in the Tyrolerfjord and became gradually shallower towards the Greenland Sea. Temperatures reflected the freshwater stratification. Surface water reached a maximum of 12 °C in the central part of Tyrolerfjord as the melt water gradually warmed up. In the Greenland Sea the cooling effect of melting sea ice re-

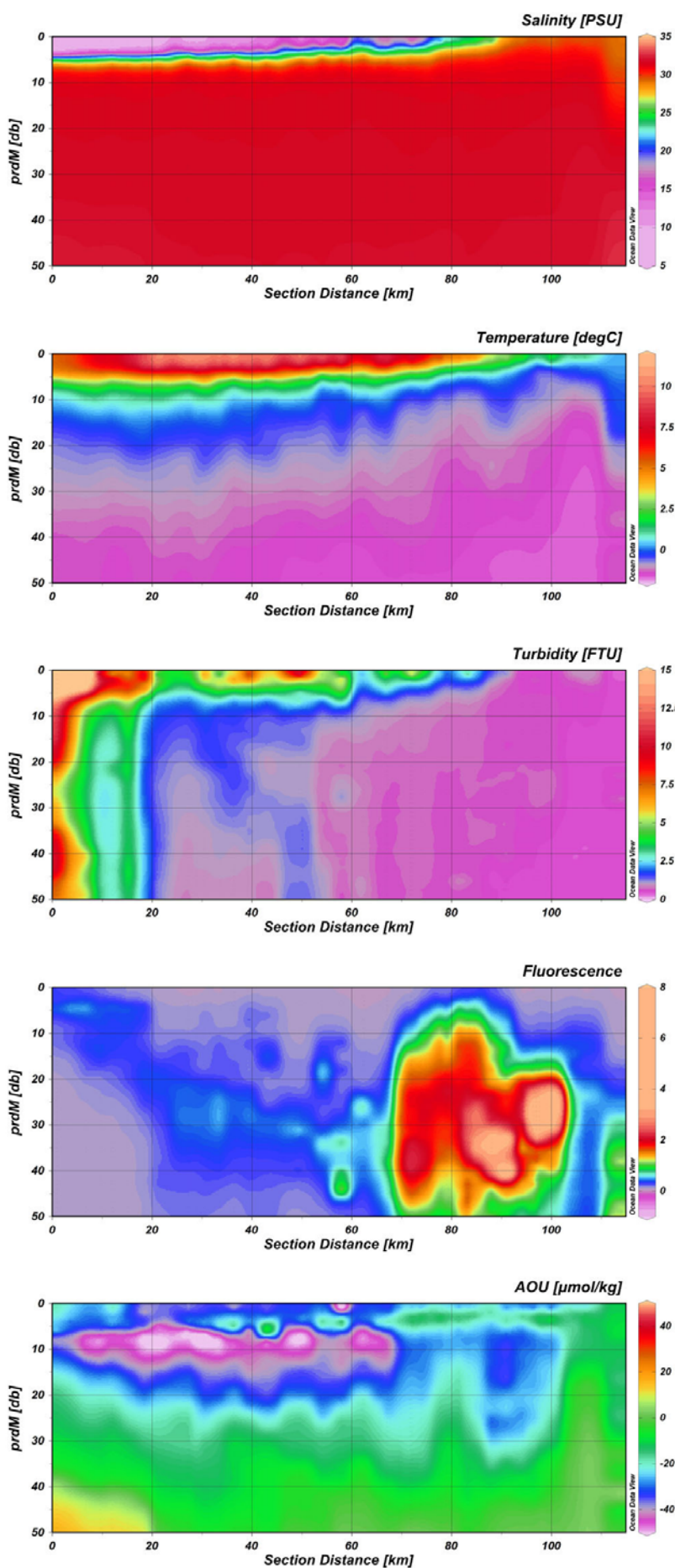
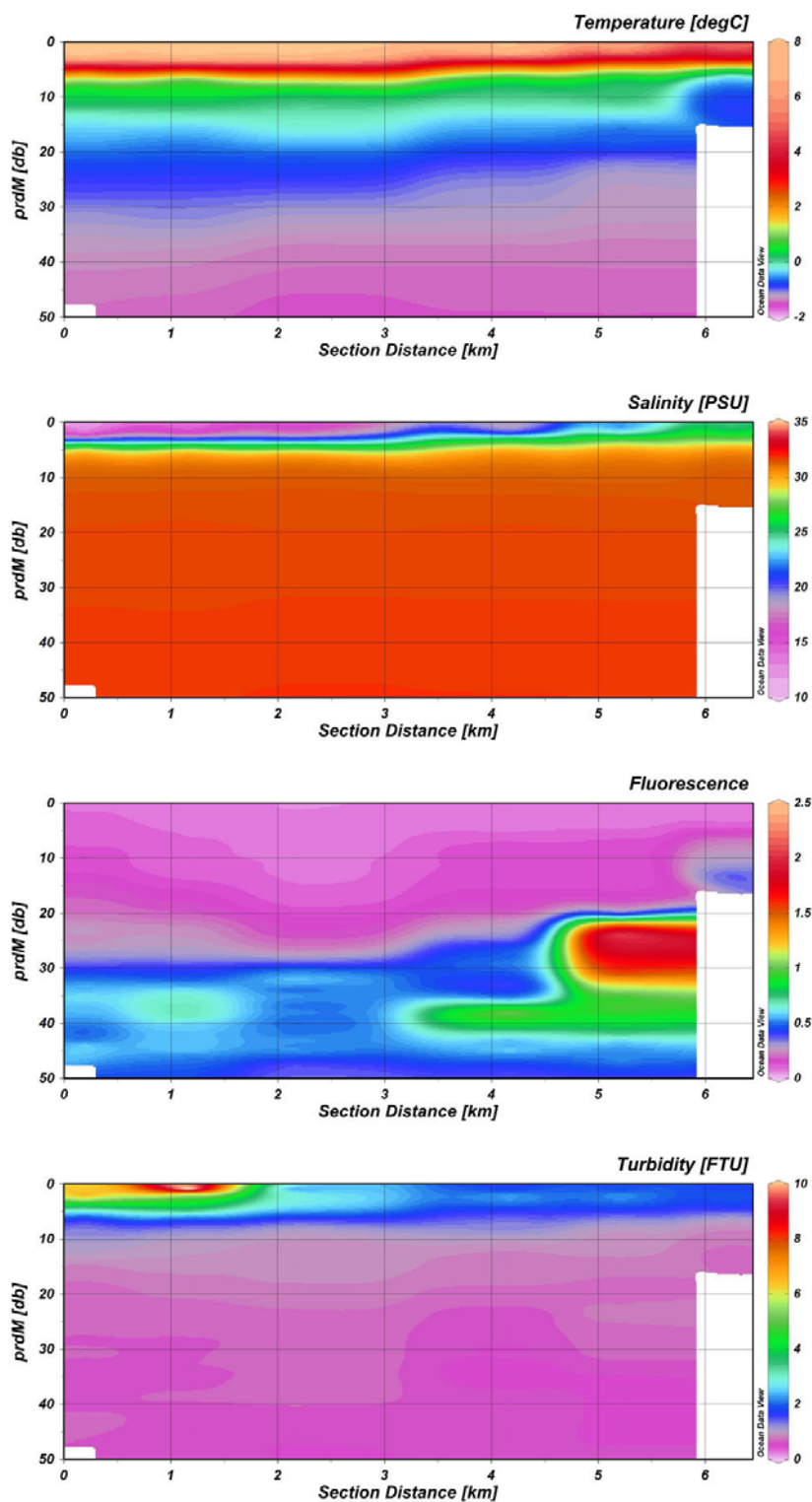


Figure 5.6 Spatial variations in oceanographic conditions along the fjord transect 2 August 2011. Data on salinity, temperature (°C), turbidity, fluorescence and apparent oxygen uptake (AOU $\mu\text{mol kg}^{-1}$). Measurements were conducted to the bottom but only the top 50 m are shown.

Figure 5.7 Spatial variation in oceanographic conditions along a transect across the fjord near Basaltø. Data on temperature, salinity, fluorescence and turbidity are presented for the upper 50 m.



duces surface temperatures to $<2^{\circ}\text{C}$. Input of terrestrial run-off also transports large quantities of particles, which influence turbidity in the water column and hence light penetration. Turbidity is very high in the innermost part of Tyrolerfjord but high turbidity is also observed near Lerbugt (at approximately 50 km) and also near the river Zackenberg (at approximately 70 km). The

distribution of phytoplankton is estimated by the fluorescence, which to some degree is influenced by the turbidity. Hence low fluorescence levels were found near the surface at the inner part of Tyrolerfjord and maximum values were found in the Greenland Sea. Apparent oxygen demand (AOP) measures the degree of over- or undersaturation compared to the atmosphere

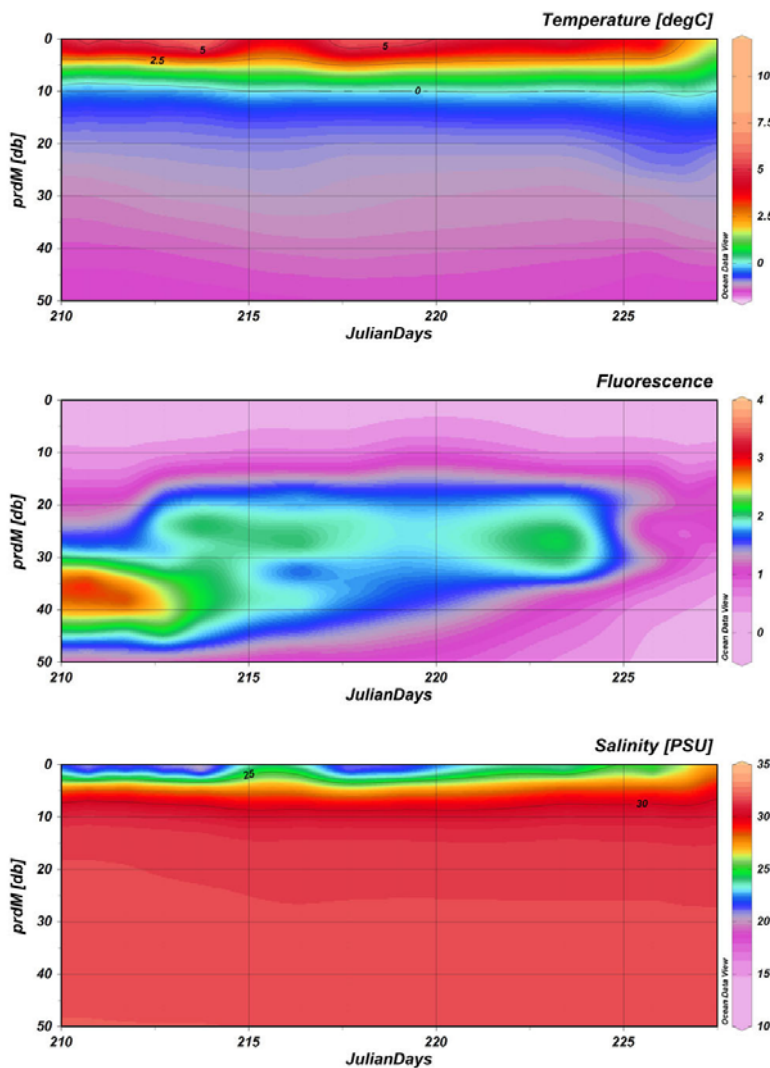


Figure 5.8 Temporal variation in oceanographic conditions at the Main Station. Measurements of temperature, fluorescence and salinity were conducted to the bottom at 160 m but only the top 50 m are shown.

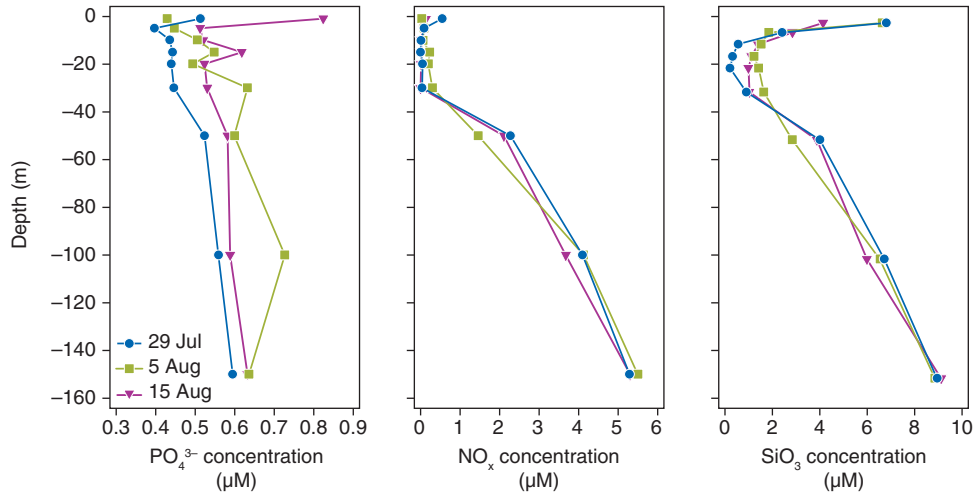
with negative values meaning oversaturation. Oversaturation of around 40 $\mu\text{mol O}_2$ was found just below the pycnocline at 10 m depth indicating that most part of Tyrolerfjord has a net production of oxygen by phytoplankton. In the Greenland Sea where fluorescence shows maximum values the oversaturation of oxygen is less than in the inner fjord. This is most likely because increased surface mixing since the freshwater wedge disappears at the sill at the entrance of Young Sund.

Another transect was conducted traversing the fjord near Basaltø (figure 5.7). Data on temperature, salinity, turbidity and fluorescence shows that freshwater predominantly flows out of the fjord along the southern coast whereas oceanic water with higher concentration of phytoplankton enters along the opposite coast.

In addition to the spatial variation in the fjord, the short-term variation during three weeks in August is quantified by vi-

siting the same station in the central part of Young Sund eight to twelve times (figure 5.8). Variation in the upper 50 m is primarily driven by weather conditions where windy days can cause mixing of the surface layer with high temperature and low salinity but also influence the phytoplankton concentration at greater depth. Two episodes with windy conditions occurred 3 and 13 September (day 215 and 225) resulting in partial mixing of the warm surface water in the top five metres. The fluorescence, which indicated a distinct subsurface peak at the beginning, was diluted and subsequently moved up to about 25 m before disappearing during the second windy period. Nutrient conditions were quantified three times at the Main Station (figure 5.9). NO_x showed little variation during the sampling period with low values near the detection limit at the upper 30 m most likely in response to phytoplankton uptake with increasing concentrations from 50 to

Figure 5.9 Vertical nutrient profiles at the Main Station in outer Young Sund 2011.



150 m. Phosphate concentration showed less vertical variation with most values ranging from 0.4 to 0.6 μM. Silicate concentration was also low at the depth of phytoplankton production and increase toward the surface and the bottom.

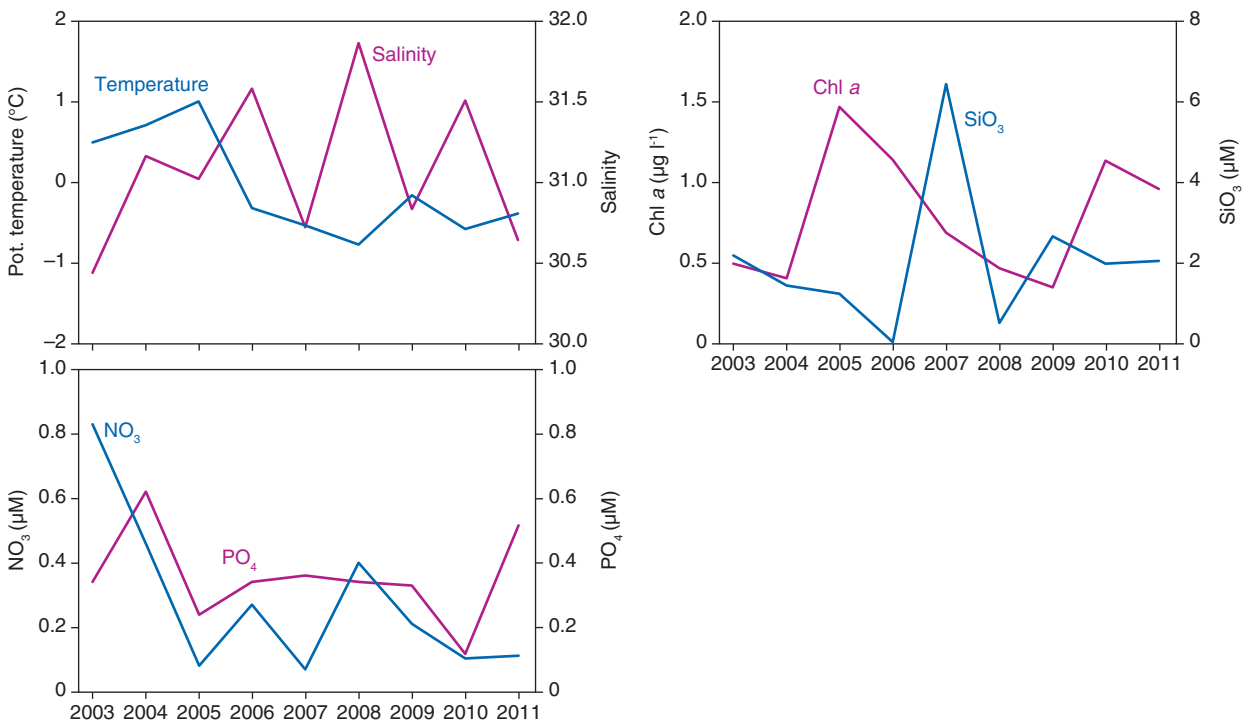
When averaging conditions for the upper 45 m at the Main Station, the summer of 2011 was characterized by low salinity and around average temperature compared to previous years (figure 5.10). Nutrient conditions were generally close to the average except for phosphate, which was high.

fjord acts as a source or a sink for atmospheric CO₂. Measurements so far have revealed that the fjord takes up CO₂ during summer. Measurements of pCO₂ are conducted along fjord transect 1 but also as often as possible at the Main Station to estimate the temporal variation. At the Main Station, the surface water was undersaturated with CO₂ compared to the atmosphere resulting in negative ΔpCO₂ values with an average of -88 ppm (figure 5.11a) which is close the average for the previous years. ΔpCO₂ values along the fjord transect showed less variation compared to previous years where lowest values generally were observed in the inner part of Tyrolerfjord (figure 5.11b). The surface wa-

Figure 5.10 Summary of hydrographic conditions averaged over the 0-45 m in August at the Main Station in Young Sund.

Surface pCO₂

The partial pressure of CO₂ (pCO₂) of the surface water determines whether the



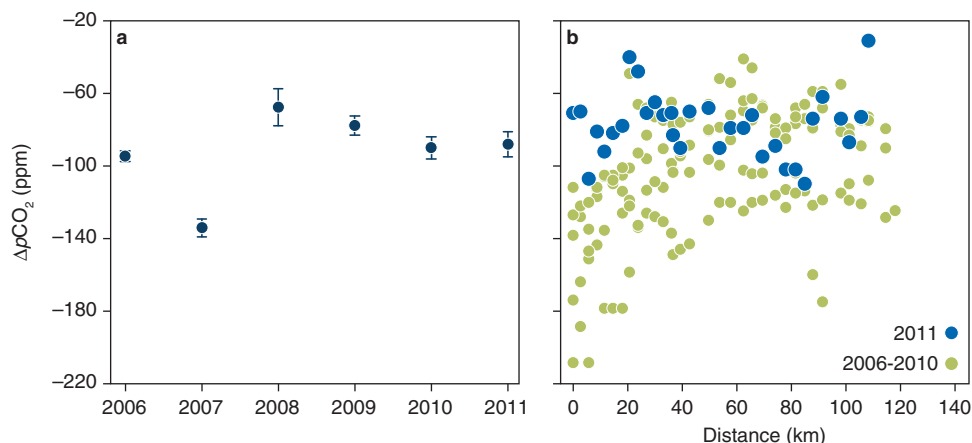


Figure 5.11 Difference in partial pressure of CO₂ (ΔpCO_2) in the atmosphere and surface water (1 m) in Young Sund. a) show average summer values (\pm se) for the Main Station and b) shows values along a transect starting in Tyrolerfjord and ending in the Greenland Sea. Negative ΔpCO_2 values indicate uptake of atmospheric CO₂ by the fjord.

ter was also generally less undersaturated than previous years.

Attenuation of PAR

The penetration of light into the water column is an important parameter for the distribution of phytoplankton in the fjord and is highly influenced by the high turbidity of the terrestrial run-off into the fjord. Attenuation of photosynthetically available radiation (PAR) is measured along all transects and multiple times at the Main Station. The average attenuation coefficient at the Main Station was 0.145 in 2011 (figure 5.12) which represents average conditions for 2003-2011.

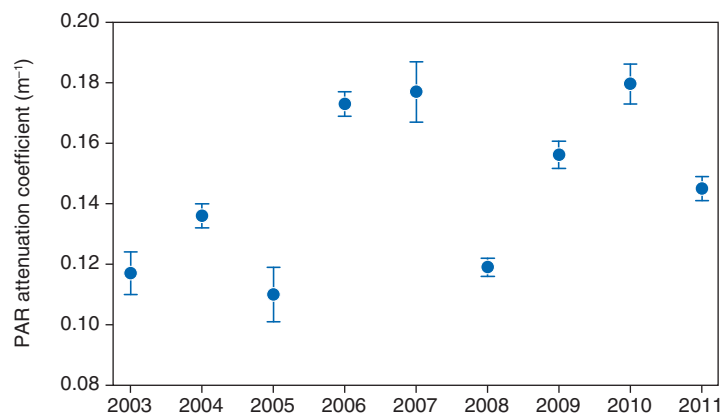


Figure 5.12 Attenuation coefficients (average \pm se) in the water column of photosynthetically available radiation (PAR) during summers (2003-2011).

Phytoplankton and zooplankton

Phytoplankton identification of the 2011 samples was carried out by Diana Krawczyk, Institute of Geosciences at University of Szczecin, Poland. Very high dominance of *Chaetoceros* species was found at the Main Station, which constituted at least 70% of all cells in the water column (table 5.2). The dominance of a few species resulted in low evenness and high Shannon Wiener diversity index values compared to previous years. However, the total number of species found was similar to previous years and the list of the ten most abundant taxa also resembles previous years except for the very strong dominance of *Chaetoceros* species in 2011. Zooplankton data (table 5.3) revealed very high abundance of *Oithona* species that constituted the high proportion of the total copepod fauna recorded so far (58%). The average proportion of *Oithona* for 2003-2010 was 35%. The Arctic copepod *Calanus hyperboreus* constituted about 6% of the total copepod fauna compared to 11% on average for the entire sampling period.

Table 5.2 Phytoplankton diversity in Young Sund at 0-50 m depth during 2011. The ten most abundant species are listed together with the relative proportion (%) of total cell count.

	29 Jul	5 Aug	14 Aug
No. species	23	23	22
Shannon Wiener index	1.7	1.6	1.4
Pilous evenness	0.6	0.5	0.5
Species			
<i>Chaetoceros</i> sp.	55.2	61.5	47.4
<i>Chaetoceros costatus</i>	72.9	70.7	58.8
<i>Chaetoceros socialis</i>	81.0	70.7	70.9
Pennate diatoms not determined	83.3	73.6	85.9
<i>Fragilariopsis oceanica</i>	87.2	80.2	87.3
<i>Thalassiosira antarctica</i> var. <i>borealis</i>	88.5	83.3	89.3
<i>Chaetoceros decipiens</i>	93.2	83.3	89.4
<i>Eucampia groenlandica</i>	93.6	84.9	93.1
<i>Thalassiosira</i> sp.	93.8	88.9	93.9
<i>Thalassiosira hyalina</i>	95.7	89.1	93.9

Table 5.3 Summary of the copepod species composition at the Main Station in 2011.

Species	staduim/sex	29 July		5 Aug		14 Aug	
		average	SE	average	SE	average	SE
<i>Calanus</i> spp.	C I	0.0	0.0	0.0	0.0	0.0	0.0
	C II	768.0	176.2	917.3	238.3	469.3	64.9
	C III	117.3	28.2	330.7	87.3	304.0	106.5
<i>Calanus finmarchicus</i>	C I	0.0	0.0	0.0	0.0	0.0	0.0
	C II	0.0	0.0	0.0	0.0	0.0	0.0
	C III	0.0	0.0	0.0	0.0	0.0	0.0
	C IV	53.3	10.7	10.7	10.7	10.7	10.7
	C V	405.3	153.8	736.0	115.4	368.0	40.3
	female	117.3	10.7	181.3	10.7	53.3	5.3
<i>Calanus glacialis</i>	male	0.0	0.0	0.0	0.0	0.0	0.0
	C I	0.0	0.0	0.0	0.0	0.0	0.0
	C II	0.0	0.0	0.0	0.0	0.0	0.0
	C III	0.0	0.0	0.0	0.0	0.0	0.0
	C IV	74.7	74.7	0.0	0.0	0.0	0.0
	C V	320.0	115.4	533.3	46.5	400.0	24.4
<i>Calanus hyperboreus</i>	female	42.7	10.7	64.0	48.9	32.0	9.2
	male	0.0	0.0	0.0	0.0	0.0	0.0
	C II	245.3	28.2	245.3	38.5	96.0	48.9
	C III	42.7	28.2	32.0	32.0	5.3	5.3
	C IV	298.7	94.8	448.0	55.4	133.3	23.2
	C V	234.7	123.0	149.3	46.5	96.0	24.4
<i>Microcalanus pygmaeus</i>	female	21.3	21.3	64.0	18.5	26.7	10.7
	male	0.0	0.0	0.0	0.0	0.0	0.0
	female	106.7	10.7	160.0	48.9	101.3	29.7
<i>Microcalanus pusillus</i>	male	128.0	48.9	138.7	38.5	58.7	23.2
	female	309.3	101.8	426.7	38.5	128.0	16.0
<i>Metridia longa</i>	male	74.7	59.4	32.0	18.5	58.7	14.1
	C I	74.7	46.5	85.3	28.2	16.0	9.2
	C II	85.3	28.2	32.0	0.0	16.0	9.2
	C III	74.7	38.5	53.3	10.7	69.3	32.4
	C IV	0.0	0.0	0.0	0.0	37.3	14.1
	C V	117.3	10.7	202.7	64.9	112.0	48.9
<i>Oncaea borealis</i>	female	128.0	84.7	117.3	21.3	106.7	26.7
	male	58.7	32.4	32.0	18.5	26.7	5.3
	female	394.7	46.5	661.3	21.3	800.0	199.8
<i>Oithona similis</i>	male	309.3	38.5	480.0	84.7	501.3	83.3
	male	0.0	0.0	0.0	0.0	0.0	0.0
	C I	21.3	21.3	0.0	0.0	37.3	14.1
<i>Oithona atlantica</i>	C II	213.3	83.3	384.0	97.8	245.3	120.2
	C III	309.3	28.2	544.0	48.9	309.3	83.3
	C IV	597.3	123.0	768.0	97.8	400.0	115.7
	C V	1120.0	254.0	1450.7	139.9	1226.7	318.0
	female	3797.3	710.1	5162.7	1259.2	2453.3	420.2
	male	437.3	93.0	618.7	21.3	186.7	41.7
<i>Oithona spp.</i>	female	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pseudocalanus</i> spp.	female	0.0	0.0	0.0	0.0	0.0	0.0
	C I	74.7	46.5	106.7	46.5	64.0	24.4
	C II	74.7	38.5	298.7	56.4	464.0	145.2
	C III	42.7	28.2	138.7	21.3	288.0	99.9
	C IV	117.3	28.2	106.7	21.3	112.0	24.4
	C V	106.7	42.7	85.3	28.2	165.3	35.0
<i>Pseudocalanus minutus</i>	female	74.7	10.7	170.7	76.9	170.7	74.7
	male	10.7	10.7	10.7	10.7	0.0	0.0
<i>Pseudocalanus acuspes</i>	female	0.0	0.0	64.0	18.5	10.7	10.7
	male	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pareuchaeta</i> spp.	C I	0.0	0.0	0.0	0.0	0.0	0.0
	C II	0.0	0.0	0.0	0.0	0.0	0.0
	C III	0.0	0.0	0.0	0.0	0.0	0.0
	C IV	0.0	0.0	0.0	0.0	10.7	10.7
	C V	0.0	0.0	0.0	0.0	10.7	10.7
<i>Pareuchaeta glacialis</i>	female	0.0	0.0	0.0	0.0	0.0	0.0
	male	0.0	0.0	0.0	0.0	5.3	5.3

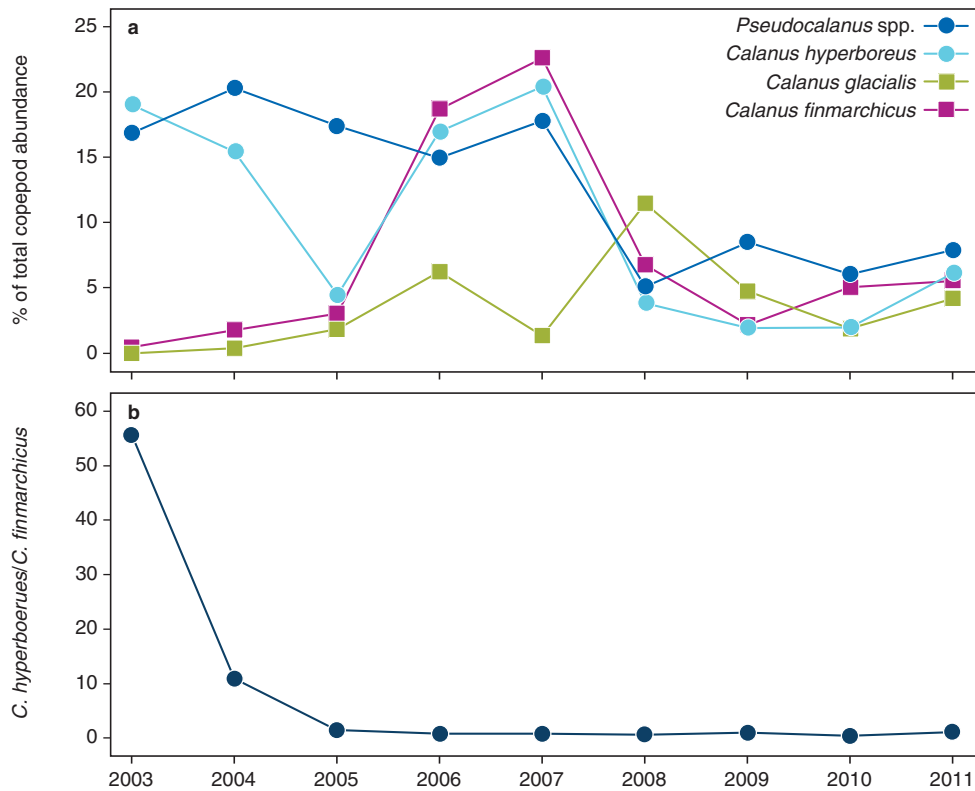


Figure 5.13 a) The relative abundance (%) of total copepods found in vertical net hauls at the Main Station in 2011. b) The ratio between the abundance of the Arctic copepod *Calanus hyperboreus* (adults and copepodites) and the temperate *Calanus finmarchicus* in Young Sund.

The relative proportions of the four large copepod species are shown in figure 5.13a. In 2009-2011 none of these species has constituted more than 10% and the dominance of the small *Oithona* species in 2011 corroborates this trend. Each year the ratio between the Arctic copepod *C. hyperboreus* and the more temperate *C. finmarchicus* is calculated. In 2011 the *C. hyperboreus*/*C. finmarchicus* ratio was 1.1 (figure 5.13b) which continues the trend of shift in the relative importance of the Atlantic species *C. finmarchicus* compared to the Arctic species *C. hyperboreus*. In 2003 and 2004 this ratio was significantly higher than for the rest of the period.

5.3 Sediment

Sediment-water exchange rates of oxygen and nutrients, oxygen conditions and sulphate reduction

Organic material is supplied to the benthos from the water column where it is mineralized or buried in the sediment. Different processes contribute to the mineralization of the organic material. The material is oxidized in the upper oxic zone of the sediment, while sulphate reduction is the dominant process in the

anoxic zone below. Intact sediment cores are collected at the permanent sampling station (water depth approximately 60 m) and incubated at *in situ* temperature in the laboratory where the exchange rates across the sediment-water interface are measured. The oxygen uptake (TOU) rate was in the high end of the rates previously observed, while the ratio between TOU

Table 5.4 Sediment-water exchange rates of O_2 (TOU), $NO_3^- + NO_2^-$, SiO_4 and PO_4^{3-} measured in intact sediment cores, diffusive oxygen uptake by the sediment (DOU) and the ratios of DOU to TOU and SRR (sulphate reduction rate) to DIC flux. SRR/DIC flux is calculated in carbon-equivalents. *n* denotes the number of sediment cores. Positive values indicate a release from the sediment to the water column. All rates are in $mmol\ m^{-2}\ d^{-1}$. SE denotes the standard error of the mean.

Parameter	$mmol\ m^{-2}\ d^{-1}$
TOU	6.611
DIC	-
$NO_3^- + NO_2^-$	-
NH_4^+	-0.04
PO_4^{3-}	0.011
SiO_4	0.198
SRR	-
DOU	4.009
TOU/DOU	1.649
SRR/DIC	-

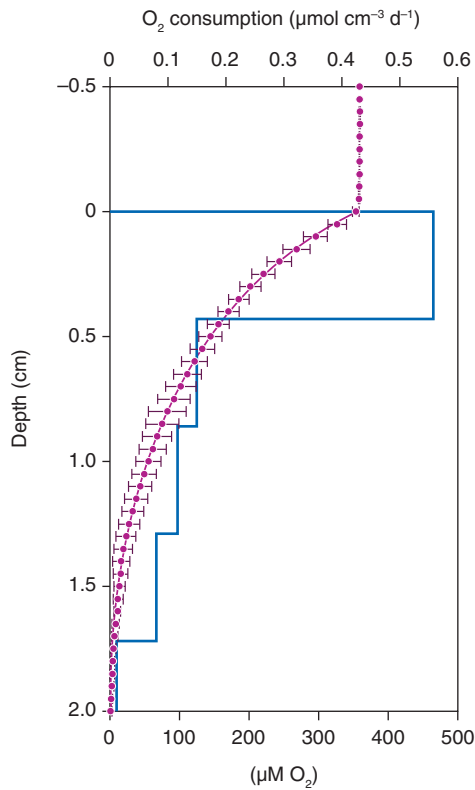


Figure 5.14 Vertical concentration profiles of oxygen (dots) and modelled consumption rates (line) in the sediment at 60 m depth in Young Sund, August 2011.

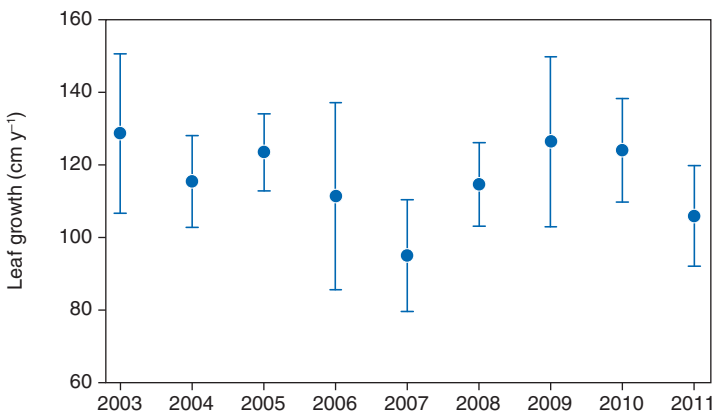


Figure 5.15 Average leaf growth (\pm SE) of the macroalgae *Saccharina latissima* at 10 m depth in Young Sund.

and diffusive oxygen uptake (DOU) was comparable to previous years (table 5.4). The TOU/DOU rate is an indicator of the bioturbation activity in the sediment. Similar to previous years the oxic zone extended down to approximately 1.5 cm (figure 5.14). Due to technical difficulties dissolved inorganic carbon (DIC) was not analyzed in time for this report, and due to bad weather sediment cores were not collected for sulphate reduction experiments in 2011.

Underwater plants

Large specimens of the brown algae *Saccharina latissima* are sampled in early August every year. In this species, annual production of new blades can be identified and the length, biomass and production in terms of carbon can be estimated (figure 5.15). In 2011, the length of the new leave was short compared to previous years. The average was 106 cm – only in 2007 has lower growth been recorded. Light availability is most likely the primary driver of annual growth in this species. Ice conditions are also an important factor determining growth. Because the species is perennial, the length of the leaf blade most likely integrates light condition during the year of collection and the previous years. The time series from Young Sund are currently being used in a study of how sea ice influence the spatial and temporal variation in macroalgae growth and depth distribution in Greenlandic waters (Krause-Jensen et al. 2012).

6 Research projects

6.1 Climate change and glacier reaction in the Zackenberg region

Bernhard Hynek, Daniel Binder, Gernot Weyss, Gernot Resch and Wolfgang Schöner

The 2011 field season was subject to two main activities: i) continuation of mass balance measurements at Freya Glacier on Clavering Ø and ii) field measurements for the project Refreeze (Quantifying the influence of refreezing melt water on the mass balance and runoff of Freya Glacier, NE-Greenland), which has been carried out in the frame of diploma thesis by Gernot Resch. Refreezing of melt water is known to play an important role in both the mass and energy budgets of Arctic glaciers, ice caps and the Greenland Ice Sheet. Refreezing may take place throughout a range of englacial and supraglacial locations. Project Refreeze aims to estimate refreezing melt water for Freya Glacier from both field measurements and a modelling approach (surface energy and mass balance model). Refreeze field work in summer 2011 included installation of an automatic weather station (measuring incoming and outgoing shortwave as well as longwave radiation, wind speed and wind direction, air temperature, humidity, air pressure, snow height, ice ablation and ice temperatures (figure 6.1) as well as mapping of refreezing melt water areas by GPR (ground penetrating radar) measurements, ice coring and GPS-surveying of the snow line.

Field work for the mass balance of Freya Glacier was carried out around the end of the melt season in late August 2011. In order to determine the surface mass balance 2010/2011, ablation was measured at approximately 15 stakes and accumulation was measured with GPR and in snow pits. Ablation during summer 2011 was higher than in the previous three years as shown in figure 6.2, which lead to a mean glacier-wide surface mass balance of approximately -1000 mm w.e. in 2010/2011 (compared to -750 mm w.e. in 2009/2010, -466 mm w.e. in 2008/2009 and -510 mm w.e.

in 2007/2008). The mass balance data of Freya glacier have been reported to World Glacier Monitoring Service WGMS and have been published in the annual mass balance bulletins (<http://www.wgms.ch/gmbb.html>).

Glacier mass balance observations are planned to be continued in summer 2012. Further glaciological investigations are planned at A.P. Olsen Ice Cap for spring 2012 for establishing a monitoring of sub- and englacial water by geophysical, hydrological and glaciological methods (project Glacioburst).

Figure 6.1 Automatic weather station at Freya glacier established during summer 2011.

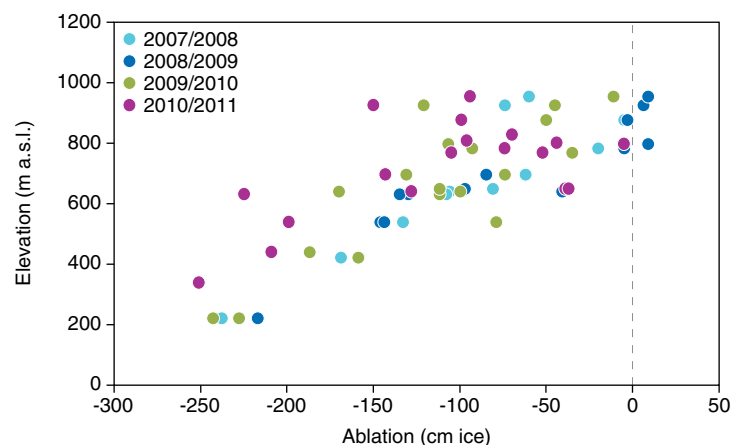


Figure 6.2 Measured annual surface mass balance at the ablation stakes during the last four years.

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

Frank Rigét, Mikkel P. Tamstorf, Martin M. Larsen, Gert Asmund, Julie Maria Falk, Kirstine Skov and Charlotte Sigsgaard

Inputs of mercury (Hg) to the environment comprise both natural and anthropogenic sources. Hg is present in the Earth's crust, mainly in the mineral cinnabar (HgS), and Hg is released in natural processes such as weathering of rocks and volcanic/geothermal activity (AMAP 2011). Anthropogenic Hg-emissions come mainly from fossil-fuel fired power plants, small-scale gold mining, cement production and metal manufacturing (AMAP 2011). Global Hg emissions are likely to increase in the future (Streets et al. 2009) and predicted climate variations in the Arctic are likely to influence Hg pathways.

It is uncertain how the influence of a warming climate will affect the Hg pathways although it is expected that changes will happen. Increasing or changing precipitation pattern may influence the Hg deposition from the atmosphere. Similarly, increasing temperatures will likely influ-

ence the process of methylation of inorganic Hg to methyl-Hg (Macdonald et al. 2003), which is much more bioavailable and will enter into the food web. Thawing glaciers and permafrost is another process, which may release Hg to the environment (Macdonald et al. 2003).

In 2009 and 2010, a project was carried out with the aim of estimating the amount of total mercury (Hg) that is transported to the coastal areas from the Zackenberg drainage basin and trying to identify the most important input sources of this transport. In 2009 and 2010, a total 92 and 70 water samples were collected, respectively. The samples were filtered and both the filtered water and the retained sediment were analysed for total Hg. A detailed description of sampling and analytical procedures is found in Rigét et al. 2011; Jensen and Rasch 2009.

The total amount of Hg transported by the sediment was 2.6 and 1.4 kg in 2009 and 2010, respectively (figure 6.3). In 2009, on 11 August an approximately 24 hours flood occurred in the Zackenberg river. The flood was caused by an emptying of a glacier lake (Jensen and Rasch 2009) and approximately 60% of the annual Hg transport by sediment occurred during

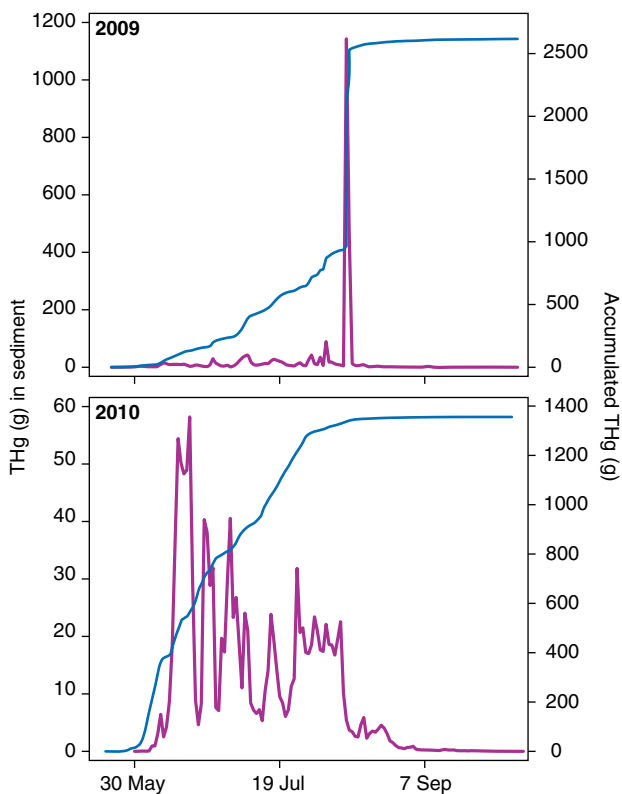


Figure 6.3 Hg amount (red-daily, blue-accumulated) transported by the sediment during the summer period 2009 and 2010.

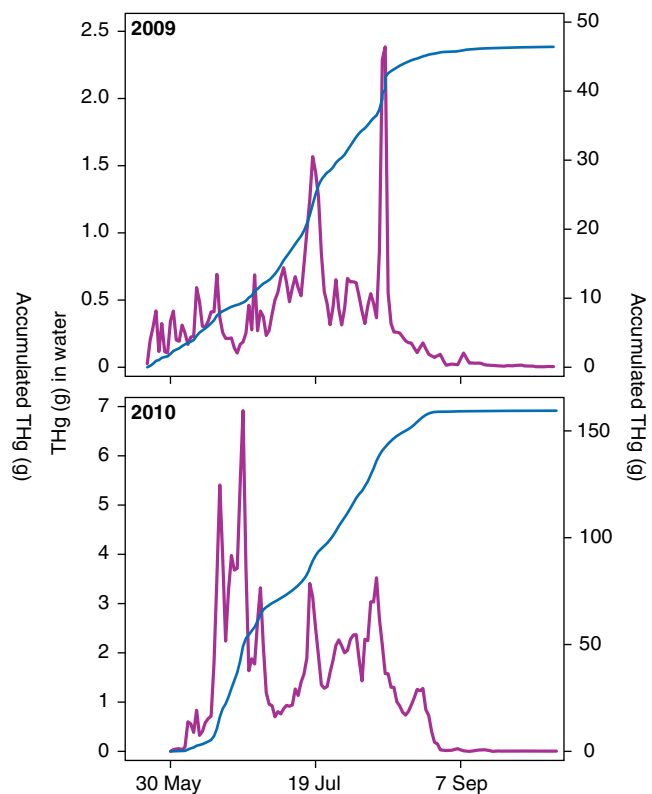


Figure 6.4 Hg amount (red-daily, blue-accumulated) transported by the water during the summer period in 2009 and 2010.

this flood. In 2010 no such flood occurred, which explains the lower total amount that year. The daily amount of Hg in 2010 was highest in the beginning of the season, from mid-August until the end of the discharge season it was very low.

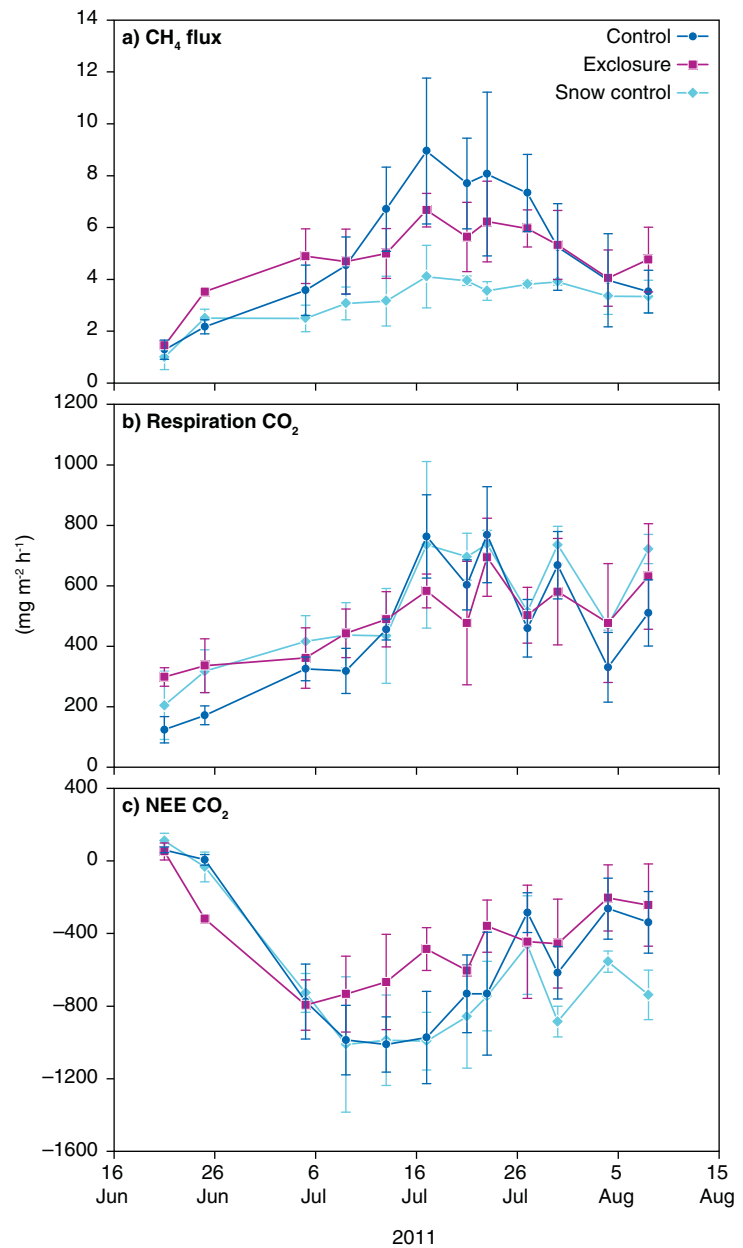
The total amount of Hg transported by the water (filtered samples) was 47 g and 159 g in 2009 and 2010, respectively, which is considerably lower than what was transported by the sediment (figure 6.4). The higher amount of Hg in 2010, even though there was a higher total discharge in 2009, is due to the higher Hg concentration in the water in 2010.

6.3 Plant-soil-herbivore interactions in the Arctic – feedback to the carbon cycle

Julie Maria Falk and Lena Ström

Climate change is proceeding faster in the Arctic than elsewhere on the Earth. These changes will most likely alter the carbon balance and the vegetation species composition, productivity and density (IPCC 2007b, ACIA 2005). The Arctic plant communities and their carbon balance are not only driven by the climate but can be affected by grazing (Post and Pedersen 2008, Rinnan et al. 2009, Van der Wal 2006). Grazing has previous been shown to influence the carbon allocation and root exudation (Holland et al. 1996, Van der Wal and Sjögersten 2007), greenhouse gas production and emission (Holst et al. 2008, Sjögersten et al. 2008) and plant species diversity (Post et al. 2008, Olofsson et al. 2009). The current understanding of these processes is however limited and knowledge about this can be of importance when discussing carbon balance in a changing climate.

In the summer 2010, five blocks were established by BioBasis (Department of Bioscience, Aarhus University, Denmark) in the wetter part of the grassland in the Zackenberg valley. Each block consisting of three 100 m² squares, i.e. a control, a snow fence and an enclosure preventing muskoxen from grazing. The first measurements were carried out in 2011 just after snow melt and continued throughout the growing season. Each block was measured once or twice per week and with several measuring plots (40×40 cm) in each treatment. The CO₂ and CH₄ fluxes were measured with a closed chamber technique using a



small portable Fourier Transform Infrared spectrometer (Gasetm Dx 40-30). Soil water samples were taken to determine the concentration of the labile carbon compounds (e.g. organic acids a readily available substrate for CH₄ production). The physical soil parameters; temperature, active layer depth, pH and water level were established within each square at every measurement and once during the season a vegetation analyze were made in all the measuring plots.

Figure 6.5 shows the CH₄ and CO₂ fluxes from one of the blocks. There is relatively large variation in the CH₄ fluxes from the different treatments and a big standard deviation within the treatments. A large part of the variation can be explained by the changes in water level, active layer, organic

Figure 6.5 Gas flux measurements from block three in the wet grassland in the Zackenberg valley summer 2011. The blocks consist of three treatments: A control, an enclosure and a snow control (only fence in the wind dominated direction). a) is the CH₄ flux in mg m⁻² h⁻¹. b) is the plant/soil CO₂ respiration, which is measured with a dark chamber. c) is the CO₂ flux net ecosystem exchange.

acid concentration and vegetation composition. The soil/plant respiration is more stable and is not leveling off as quickly as the other fluxes. This is due to the temperature still being relative high in mid-August. The graph of the CO₂ flux NEE (net ecosystem exchange) shows that the environment is taking up more CO₂ than is respired during the growing season.

We did not see any clear change in the greenhouse gas fluxes, as a consequence of excluding muskoxen grazing, after one year. It is very likely that a trend may be seen after several seasons of excluding grazing. Both the treatment described here and another grazing experiment will continue in the Zackenberg valley over the next couple of years. Together with a detailed laboratory study, which links grazing, pore-water chemistry and greenhouse gas fluxes, by using novel isotope techniques we hope to be able to determine both short and long-term effect of grazing on the ecosystem.

6.4 Effects of climate manipulations on soil organic matter under *Cassiope tetragona* dominated heath in Zackenberg, Greenland

Ji Young Jung, Yoo Kyung Lee, Anders Michelsen and Niels Martin Schmidt

It is projected that climate change will be more pronounced in the Arctic than further south. Climate change will affect soil organic carbon (SOC) pools, which are directly related to carbon dioxide fluxes. Thus, it is

crucial to understand how soil processes will respond to climate change in the Arctic where large amount of SOC is accumulated in many ecosystem types due to the low rates of decomposition. In this study, we aimed to understand the characteristics of SOC and the effects of climate manipulation on SOC in two high Arctic heaths. We hypothesized that change in temperature and in the growing season length would affect microbial activities and thus the amount and chemical composition of SOC.

This study was conducted in the long-term climate manipulation plots established in zone 1A in 2004 by Anders Michelsen and coworkers. There are one control (C) and four treatments plots, each replicated five times: Warming (T), shading (S), short growing season (SG) and long growing season (LG) (figure 6.6). A detailed description of the manipulation can be found in Klitgaard et al. 2006. Soil sampling was conducted in the *Cassiope tetragona* sites in 2011. Soil temperature, litter layer thickness and thawing depth were measured in the field. Three 15 cm depth soil cores (5 cm diameter) were taken in one plot, and each soil core was divided into litter layer of 0-5, 5-10 and 10-15 cm depths, and then three cores in the same depth interval were pooled together. For microbial community structure analysis, 0.3-0.5 g of fresh soil was allotted to 1.5 ml of RNAlater solution on the sampling date. Air-dried soil samples were passed through a 2-mm sieve for further physical and chemical analyses. Total carbon and inorganic carbon were measured, and the difference was regarded as soil organic carbon (SOC). Density fractionation (sodium polytungstate, 1.55 g cm⁻³) separated

Figure 6.6 Climate manipulation plots under *Cassiope tetragona* heath in Zackenberg. Photo: Ji Young Jung.



SOC as free light fraction (FLF), occluded light fraction (OLF), and heavy fraction (HF). For statistical analyses, one-way ANOVA was used and the significance level was set as 0.1.

Preliminary analyses show that thawing depth and litter layer thickness were not significantly different among treatments. Soil temperature in the T treatment was 1.2-1.5 °C higher than in the other treatments. Bulk density, moisture content, and soil pH did not vary among treatments. There were no statistical differences in SOC, and SOC in the 0-5 cm depth was in a range of 3.5 to 5.2%. Total inorganic carbon was rarely or never detected across all treatments. Density fractionation showed that there were differences in FLF, with lower amount of FLF in the T and SG treatments than that in control. Further analysis for SOC fractions is currently taking place.

6.5 The role of plant interactions on plant recruitment along a snow depth gradient

Oriol Grau and Josep M. Ninot

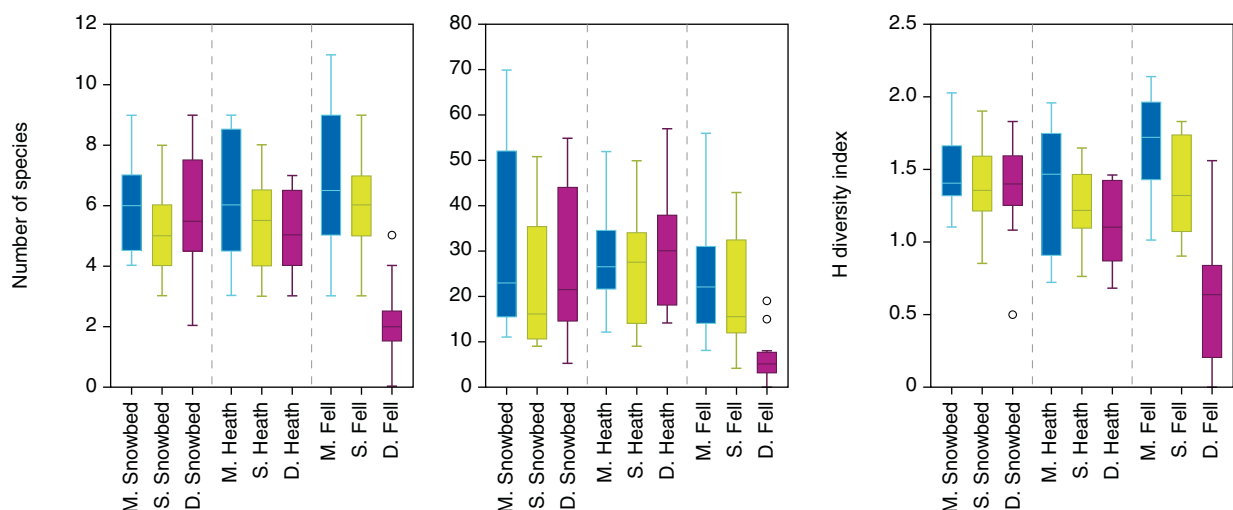
According to recent climatic models, Arctic regions are expected to undergo severe changes in precipitation and temperature regimes in the coming decades (IPCC 2007a). The occurrence of distinct vegetation types found in the high Arctic is strongly determined by the amount of snow cover and the length of the growing season (Elberling et al. 2008); therefore, variations in these parameters may lead to important alterations in the structure and

functioning of plant communities. For instance, changes in the strength of biotic and abiotic stressors may lead to changes in the nature of plant-plant interactions (i.e facilitative or competitive) along stress gradients (Lortie et al. 2004 and Maestre et al. 2009). Some studies suggest that plant-plant interactions play a key role in plant species recruitment in the high Arctic (Sohlberg and Bliss 1984, Jones and Henry 2003).

In this study we investigate whether plant-plant interactions affect plant recruitment in three distinct plant communities found along a mountain slope (*Salix* snow bed, *Dryas* heath and fell field) associated to a decreasing snow depth gradient from the snow beds at the Zackenberg valley bottom to the fell fields at higher altitude. The fieldwork was conducted in July 2011 on Aucellabjerg, near the Zackenberg Research Station. In each plant community we selected a number of patches with dense cover of i) *Salix arctica*, ii) *Dryas octopetala* x *intermedia* and iii) mosses; then, we identified the species and counted the individuals occurring in each sample (in replicates) in each of these communities.

We found no differences in species number and total number of individuals growing in the distinct patch types in snow bed and heath communities (figure 6.7), but these numbers decreased significantly in *Dryas* patches in the fell field. Besides, the Shannon diversity index in *Dryas* patches clearly decreased from the snow bed at the valley bottom to the fell field (figure 6.7). Species diversity in the fell field was significantly higher in moss and *Salix* patches compared to *Dryas* patches. These results suggest that moss carpets and *Salix* scrubs

Figure 6.7 Number of species (left), number of individuals (middle) and Shannon diversity index (right) in each patch type (M: mosses; S: *Salix*; D: *Dryas*) in each plant community (*Salix* snow bed, *Dryas* heath and fell field).



played a similar role in plant recruitment in all the communities studied despite their marked structural differences, whereas *Dryas* did not show a constant pattern. These differences could be ascribed to a differing performance of *Dryas* in the distinct plant communities. According to Kohls et al. 1994, *Dryas* species at higher elevations lack N-fixing nodulation, whereas at lower elevations becomes nodulated; under harsh growing conditions, these plants will accumulate soil N rather than fixing atmospheric N₂, which is an energy demanding process. Therefore, *Dryas* growing under the severe conditions found in the fell fields (i.e. with little protecting snow layer and harsher climate), may act as a strong competitor for soil N and may thus impair plant recruitment.

In conclusion, these preliminary results showed that species richness and diversity in fell fields may be strongly determined by the proportion of each patch type, whereas in *Salix* snow beds and in *Dryas* heaths the distinct patch types did not promote any significant differences. Mosses and *Salix* in fell fields may act as refugia for a high number of species, as diversity was not lower compared to the other two communities, in spite of the poorly vegetated aspect of this harsh, upper zone. Contrarily, *Dryas* patches in fell fields impaired plant recruitment and species diversity. Such results suggest that any future climatic changes altering the proportion of *Salix*, mosses or *Dryas* cover may have a noticeable influence on plant diversity, especially in the fell fields.

6.6 Arctic bell-heather – annual growth in the *Cassiope* heath

Claudia Baittinger and Noémie Boulanger-Lapointe

Although it has been shown that dendrochronological analysis can be carried out on dwarf shrubs, methodological difficulties have restricted their use in the past (Woodcock and Bradley 1994, Rayback and Henry 2006).

During summer 2010 we collected 12 individuals of the Arctic bell-heather (*Cassiope tetragona* (L.) D. Don.), an evergreen, strongly branched dwarf shrub, in a *Cassiope* heath in the lowland of the Zackenberg valley (figure 6.8). Even though the species has numerous fragile branches, it was usually possible to collect the whole plant.

The material is currently being processed in the laboratory and preliminary results show that some of the individuals are up to 100 years old. Part of the process is the measuring of the stem length increment as derived from the distances between “wintermarksepts”, which are formed at the end of the summer growth period when the pith is narrowing (Weijers et al 2010, Rozema et al. 2009). From these samples, we hope to be able to build chronologies. This will make it possible to produce time series and proxy data that can be used to describe past climate in the Zackenberg valley over the last 100 years.

Figure 6.8 *Cassiope tetragona* D. Don.
Photo: Noémie Boulanger-Lapointe.



To support our data obtained from the samples collected in 2010 and to study the growth patterns of *C. tetragona* more closely, we collected 12 more individuals in 2011. These plants were collected close to the area sampled in 2010 (Boulanger-Lapointe and Baittinger 2011). The annual growth of the samples from the two sites will be compared and we hope to be able to confirm tree-ring data by cross-dating. Earlier tree-ring studies, conducted in four community types in the Zackenberg valley have demonstrated a negative correlation between Arctic willow's (*Salix arctica* Pall.) annual growth and spring snow cover (Schmidt et al. 2010, Schmidt et al. 2006). Since *S. arctica* and *C. tetragona* are growing side by side in the *Cassiope* heath, we will compare the growth pattern of the two species.

This ongoing work is part of 'The Northern Worlds' project of the National Museum of Denmark. 'The Northern Worlds' project is mainly funded by the private foundation, Augustinus Fonden, and is a scientific focus of the National Museum of Denmark. This initiative hopes to generate new insights and knowledge in culture and climatic change.

6.7 Pollination networks and climate change

Claus Rasmussen, Jesper Bruun Mosbacher and Jens Mogens Olesen

Climate changes are affecting all continents and habitats, from the deserts to the oceans, and across taxonomic groups with about 41% of all investigated species being affected to some degree, particularly in their phenology (Parmesan and Yohe 2003, Parmesan 2006). One of the greatest challenges in the study of climate change is the prediction of the effects global environmental changes has on higher organizational levels in nature, e.g., how will a community assemblage of several hundred species and their interactions respond to the change. Our study focuses on the pollinator communities in the high Arctic, and attempt to determine how phenological shifts and other disturbances may cascade through the network, and affect other interacting species. The pollinator community in Zackenberg, NE Greenland has been followed in details during 1996, 1997, 2010 and 2011. In total 39 plant

species were followed on a daily basis during each season and the visit of more than 101 species of insects were recorded. With four field seasons completed a more precise pattern of pollinators interacting with plants at Zackenberg now appears.

A generalist core group of plants and insects are available through a large part of the season. The flies *Spilogona sanctipauli* (27 plant species visited during the four seasons), *Rhamphomyia nigrita* (24 species), and *Spilogona dorsata* (24 species) are all part of the core group of insects. Likewise, among the plants some of the most attractive core species are *Dryas octopetala* (47 visiting insect species during four seasons), *Papaver radicum* (41 species), and *Cerastium arcticum* (39 species). The interactions recorded follow a distinctive pattern known from mutualistic communities, namely the presence of both a generalist core (generalists species interacting with generalists species) and an asymmetrical specialization (specialists interacting with generalists). Specialized plants with only one insect species reported visiting includes *Pyrola grandiflora*, *Ranunculus hyperboreus*, *Saxifraga rivularis*, and *Stellaria humifusa*. A number of insects (11 species in total) have only been recorded from a single plant species during four years, including *Paradelia arctica*, *Zaphne occidentalis*, and a presumably new record for Greenland, *Spilogona tendipes*. The resulting network from the 2010 season is provided in figure 6.9.

Phenological shifts from 1996-1997 to 2010-2011 were on average five days earlier for plants and zero days earlier for insects. Although the shift for insects is less than a day, this spans over a large spread in shifts, with some insects arriving weeks earlier, and others, much later. A study of certain focal species at a larger area around Zackenberg (Høye et al. 2007) found the shift to be two weeks from 1996-2005 following a temperature rise of 2.5°C during the period (Hansen et al. 2008).

A detailed analysis of interaction patterns is underway and provides further insight into how the pollinator community reacts to climate change now and in the future. It is possible that the nested structure of the network, the robust community of core species, will maintain a functional ecological network, where minor changes will be the replacement in time and space of certain species.

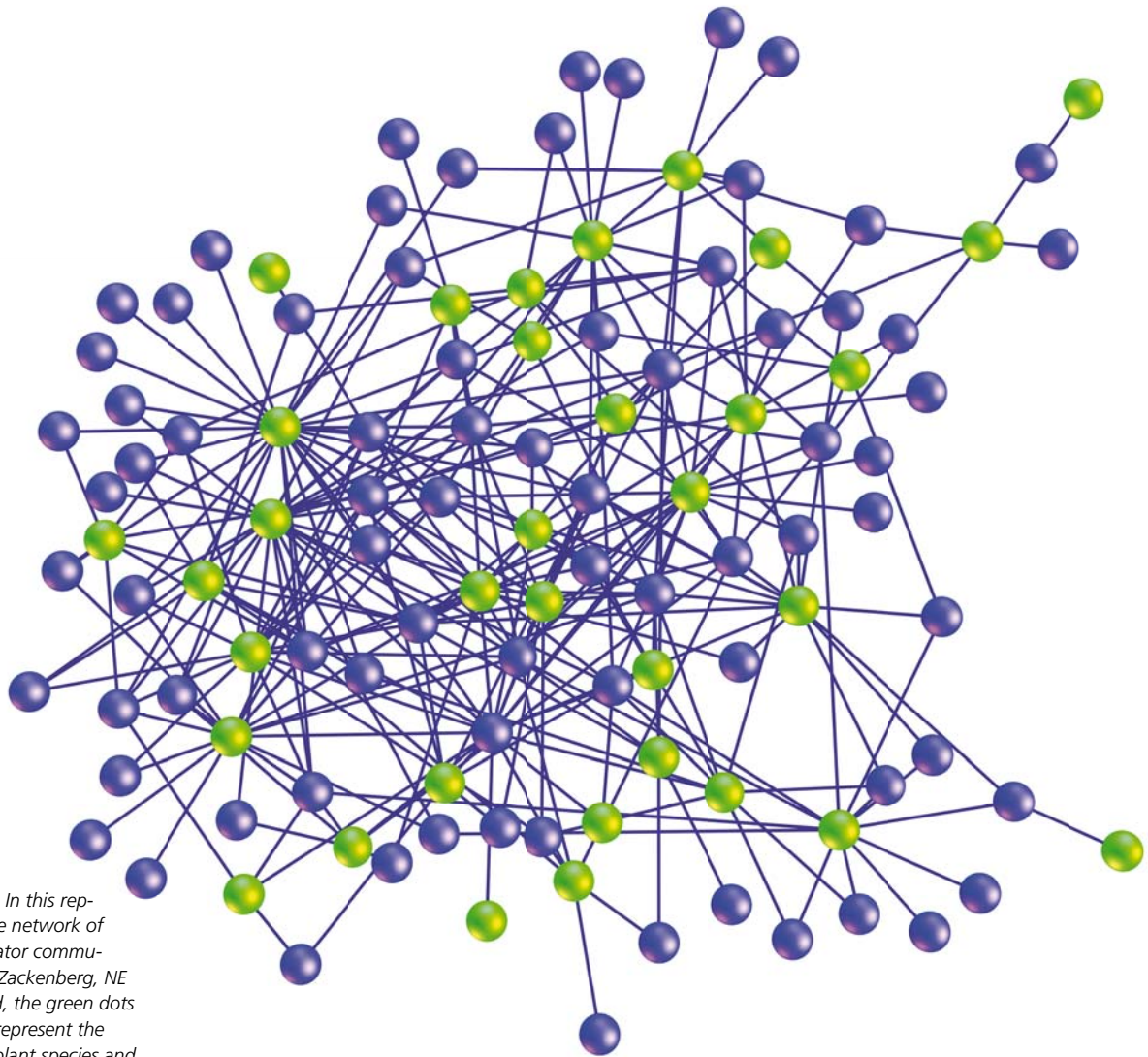


Figure 6.9 In this representative network of the pollinator community from Zackenberg, NE Greenland, the green dots or nodes represent the different plant species and the blue dots or nodes represent the different insect species. A line or link between an insect (blue) and a plant (green) indicates a visit or interaction. The most connected plant in 2010 was *Dryas octopetala*.

6.8 A high Arctic food web – phase II: The core web expanded

Tomas Roslin, Tapani Hopkins, Malin Ek, Bess Hardwick and Gergely Várkonyi

To understand the dynamics of natural communities, we need to consider not only their species composition, but also the functional links among these species. Quantitative food webs (*sensu* Morris et al. 2005, van Veen et al. 2006) describe both aspects of community organization. In this project, we aim to construct a quantitative food web for the Zackenberg valley. When monitored over time, the baseline web constructed now will help us discriminate the effects of environmental change in the high Arctic.

Work at Zackenberg was initiated in 2009. During the first two years, sampling was focused on dissecting the specific food web module consisting of Lepidoptera

and their parasitoids. This work was continued in 2011, with now-standard protocols (see Roslin and Várkonyi 2010, Roslin et al. 2011 for details) implemented for the third year in a row.

As a novel initiative for 2011, we extended the core web constructed during previous years by quantifying trophic links to key modules of the larger, surrounding food web. To achieve this aim, we measured two novel links of the web: the impact of lepidopteran larvae on the reproduction of their host plant, and the predation by birds on lepidopteran larvae (figure 6.10). To quantify the former link, we measured the rate and extent of herbivory on flowers of *Dryas*, and the resultant change in seed set and size. To measure the latter, we used two types of baits: live larvae tethered to fixed locations, and plasticine dummies mimicking live larvae (figure 6.11; see also Howe et al. 2009).

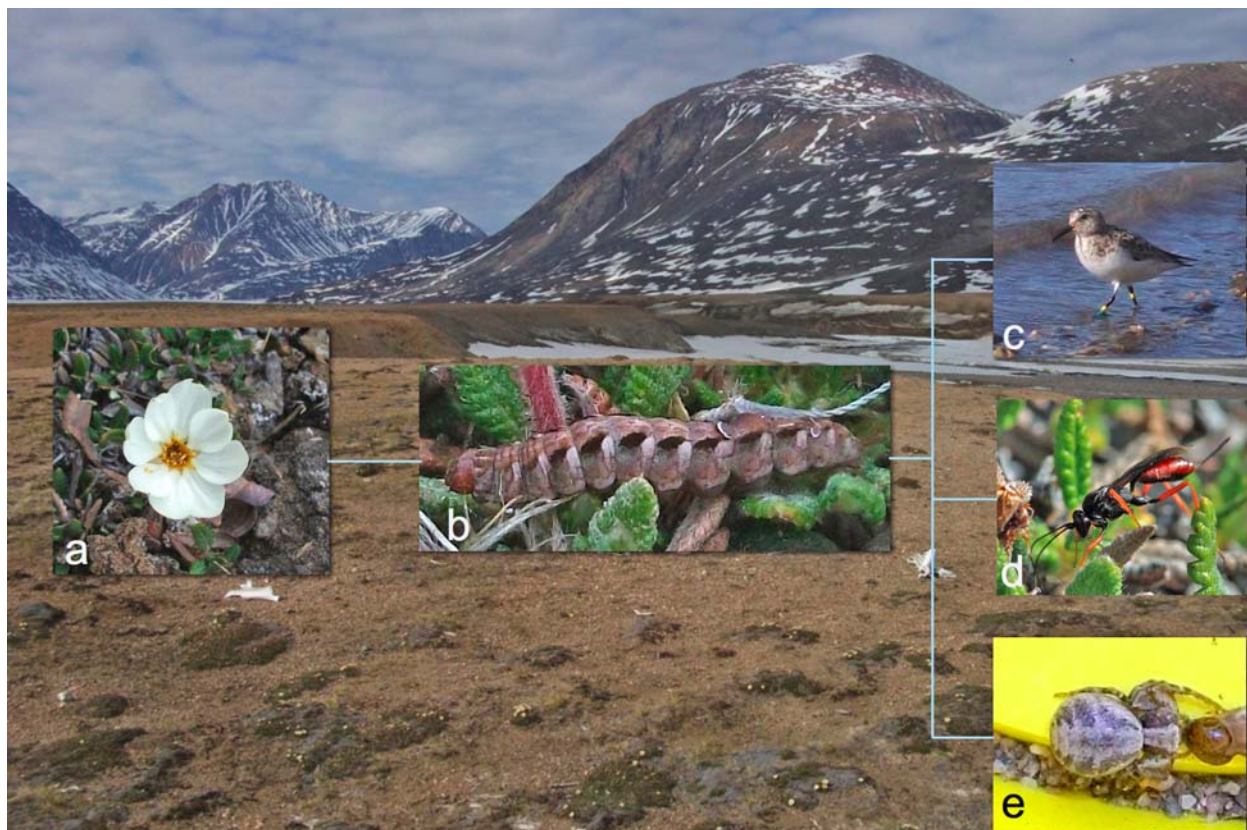


Figure 6.10 Tritrophic interactions quantified during 2011. To quantify interactions between herbivores and plants; we measured the impact of an abundant moth (b), *Sympistis nigrita*, on the reproduction of its host plant (a), *Dryas octopetala x integrifolia*. To quantify interactions between herbivores and predators, we examined attack rates by birds (c) and spiders (e) on larvae of *S. nigrita*. Finally, to quantify mortality incurred by parasitoids (d), we drew on extensive rearings of host larvae.

The impact of herbivory on plants proved both widespread and drastic. Of the *Dryas* flowers in two major samples (n=743 and n=672), 14.4% and 8.3%, respectively, were affected by herbivory. Herbivory was reflected in a significant reduction in the probability of seed set, and in a pronounced decrease in resultant seed size (figure 6.12). Our predation experiments revealed attacks by birds to be relatively infrequent among both tethered and dummy larvae, whereas, as a surprise outcome, pre-

dition by spiders turned out to be a key source of mortality among tethered larvae of *Sympistis nigrita* (figure 6.13).

Overall, the experiments conducted in 2011 offered some first extensions of our lepidopteran-parasitoid food web to the larger web of the Zackenberg valley. This approach revealed a strong impact of herbivores on their host plants, and allowed us to compare the relative mortality incurred by birds, spiders and parasitoids on these herbivores. Hence, it will help us



Figure 6.11 Baits used to quantify predation by birds and spiders. a) Larva of *S. nigrita* tethered to fixed spot by thin thread (exposed for 587 bait-days). b) Plasticine bait mimicking live larva (exposed for 9028 bait-days). For comparison, c) shows a wild larva feeding on a *Dryas* flower.

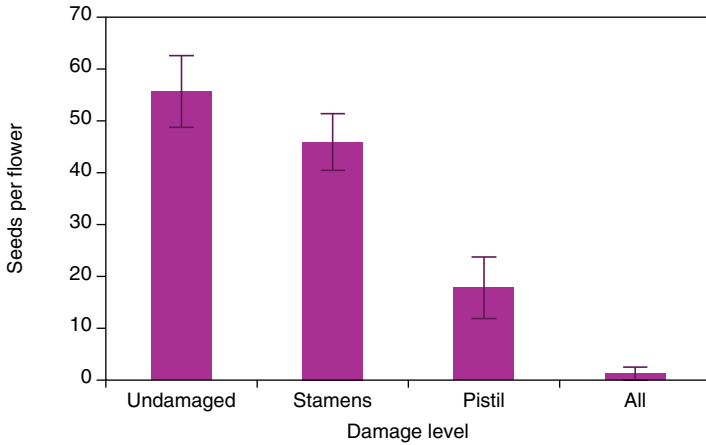


Figure 6.12 The effect of herbivory on the seed size of *Dryas*. Shown are means with SEs. For this analysis, flowers were classified into four categories: undamaged flowers; “stamens”, i.e. flowers in which the stamens had been (partly or wholly) consumed, but the pistil left intact; “pistil”, i.e. flowers in which the pistil had been at least partly consumed, sometimes along with some stamens; “all”, i.e. flowers in which both the pistil and the stamens had been consumed.

understand the dynamics of not only individual populations, but of compound communities. This offers an intriguing development, as most food webs constructed to date have been focused on single modules of the web (see van Veen et al. 2006). Thus, the strength of interactions observed within certain modules of a food web have rarely been related to those among multiple modules of the web (but see Pocock et al. 2012). To pursue and extend this approach, we are currently developing molecular techniques to reconstruct trophic relationships among multiple parts of the Zackenberg food web. Once established, they will offer unique opportunities for studying trophic relationships in high Arctic food webs.

6.9 Pelagic carbon cycling under influence of a melting ice cap

Mikael K. Sejr, Thomas Juul-Pedersen, Anette Bruhn, Colin Stedmon, Martin E. Blicher, Tage Dalsgaard, Nikolaj From Petersen, Daniel F. McGinnis and Diana Krawczyk

The Greenland fjords are strongly influenced by freshwater from land and the Greenland Ice Cap. The interaction between the fjords and the Ice Cap is two-way, as fjords can be an important heat source for sub-surface melting of glaciers. The input of freshwater has implications for the physical conditions in fjords such as circulation patterns, light regime and stratification, which in turn have implications for ecosystem structure, biological production and exchange of CO₂ with the atmosphere. The aim of this project was to quantify how the input of freshwater in Young Sund influences the physical and biological conditions in the fjord.

The availability and quality of light are key parameters controlling the productivity of Greenlandic coastal water. Although solar elevation and sea ice cover play an important role during summer, the underwater light environment is regulated by water constituents such as dissolved and particulate organic matter, phytoplankton and suspended sediments. The relative importance of each of these constituents varies depending on the influence of shelf water entering the fjords, extent of glacial ice melt and the size and vertical distribution of the phytoplankton biomass. Profiles of spectral irradiance were made at

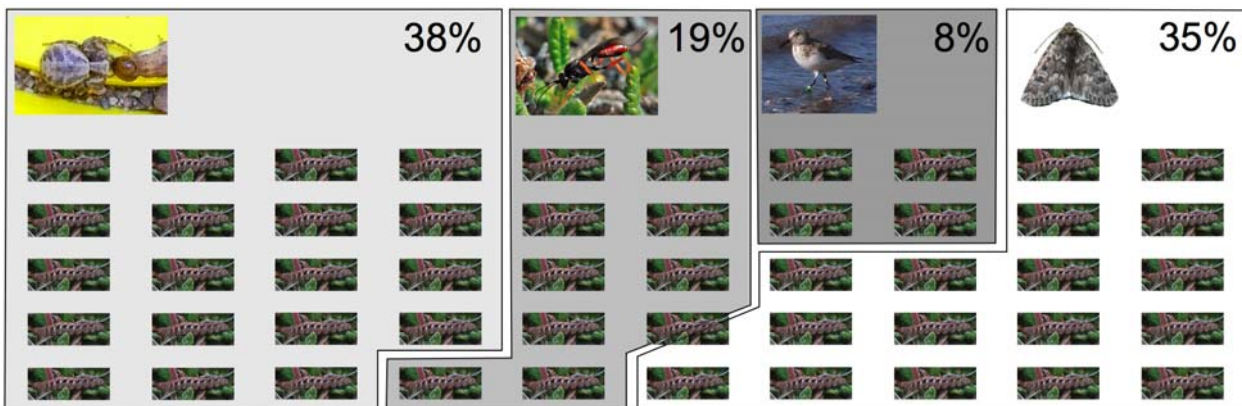


Figure 6.13 Tentative partitioning of mortality among an imaginary cohort of 50 larvae of the moth *Sympistis nigrita*. During the 25-day larval period, an estimated 38% of individuals are killed by spiders, 19% by parasitoids and 8% by birds. Only 35% survive predation or parasitism. Photos: Tapani Hopkins and Gergely Várkonyi.

the MarineBasis stations in Young Sund and water samples were collected to measure the light absorbing properties of the constituents (figure 6.14). The aim is to develop a spectral model of light penetration in these waters, which can be applied to evaluate the importance of different constituents for light attenuation and herein how we can expect the light environment in Greenlandic coastal waters to alter in response to climate driven changes in physical conditions.

Phytoplankton composition and production in Young Sund are influenced by the very different light conditions but also the degree of stratification and nutrient availability. To determine the degree of vertical mixing, which regulates the input of nutrients into the photic zone during summer, very high resolution vertical profiles of temperature and conductivity were measured along the fjord transect. Focus was also on determining the importance of deep chlorophyll maxima (DCM) for the total summer pelagic primary production in Young Sund. We identified the prevalence, species distribution, community structure and photosynthetic efficiency (F_V/F_M) of DCM and surface chlorophyll maxima, with emphasis on determining the factors affecting and limiting primary production. Phytoplankton dynamics were analyzed in a grid with a minimum of six sampling depths at each of the nine stations along the transect. From every water sample, species composition and size fractionated chlorophyll *a* concentrations were determined, and F_V/F_M was measured directly and after incubation in darkness or weak light. F_V/F_M gives a qualitative measure of the productivity and physiological status of the phytoplankton present (figure 6.15).

Primary produced material is either exported towards the benthos or diverted through the pelagic food web where the material may be more or less degraded and recycled within the water column. Understanding the vertical sinking flux of material and its composition therefore provide important information on the pelagic carbon cycle (figure 6.16). Other processes such as input of allochthonous material, e.g. riverine discharge, and advection of autochthonous material from the area also affect the pelagic carbon cycling, especially in coastal regions. The project carried out measurements of pelagic primary production (particulate and dissolved), and sinking flux of particulate

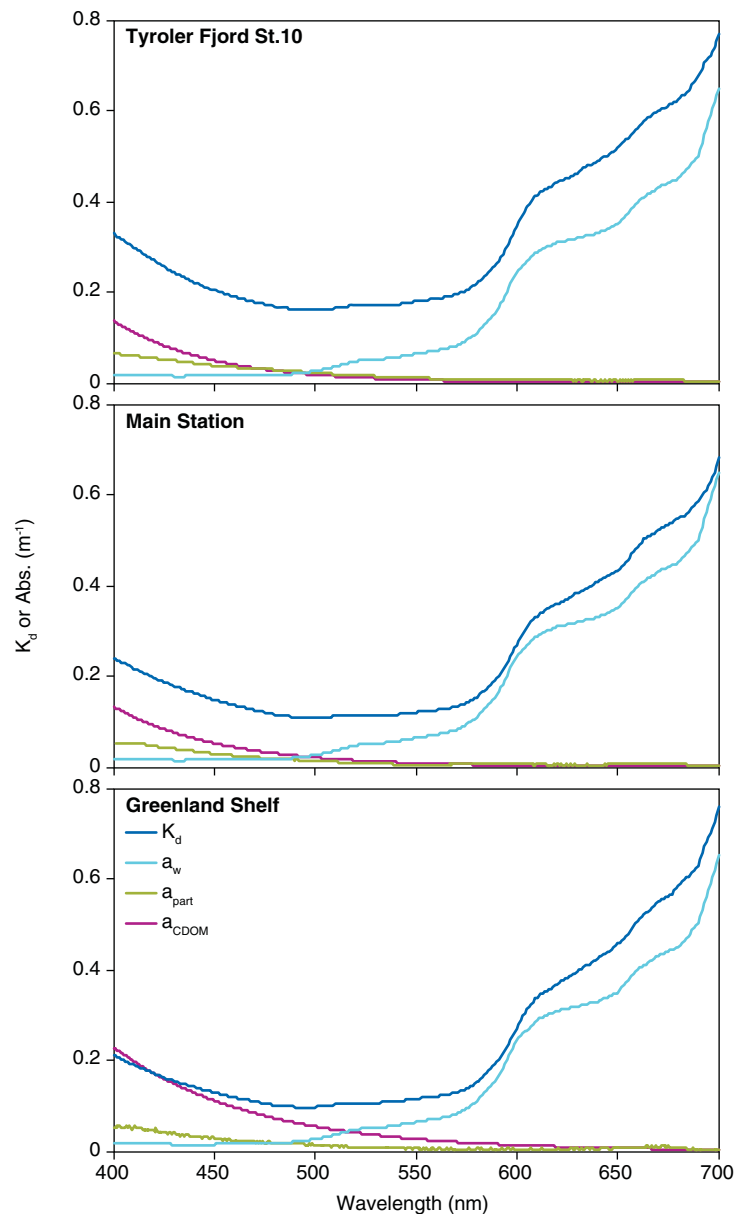


Figure 6.14 Diffuse attenuation coefficients (K_d) in surface 5 m calculated from the light profiles measured at three of the stations sampled: inner fjord (Tyrolerfjord St. 10), Young Sund (Main Station), and outside Young Sund (Greenland Shelf). Also plotted are the absorption spectra of particulate (a_{part}) and dissolved organic matter (a_{CDOM}), and water (a_w). K_d at wavelengths above 550 nm is largely due to absorption by water and effects of scattering by inorganics. At lower wavelengths particulate and dissolved organic matter dominate to a greater extent. The absorption by coloured dissolved organic matter (a_{CDOM}) is higher outside the fjord as the system imports Arctic terrestrial organic matter from shelf waters rather than from the surrounding landscape.

material, as well as bacterial O_2 -uptake and pCO_2 content of the surface water. Together these data provide information on the pelagic carbon cycling at different levels of terrestrial input within the fjord and in the adjacent coastal waters.

The project was funded by the Greenland Climate Research Centre, the Danish Environmental Protection Agency and the Ministry of Education and Research in Greenland (IIN).

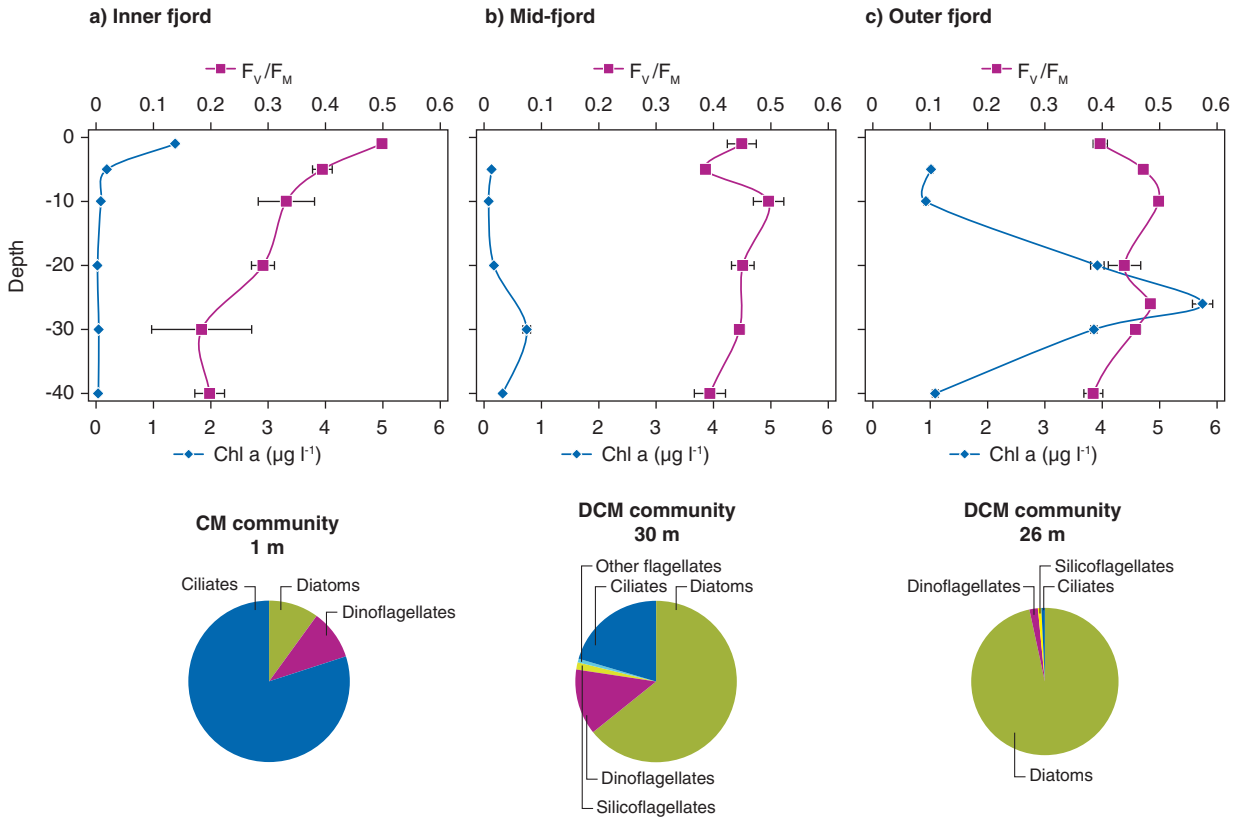


Figure 6.15 Overview of the different phytoplankton communities along the transect from the glacier to the open sea. The community composition shifts from a ciliate/flagellate dominated community in the inner fjord to a total domination of large chain-forming diatoms in the outer fjord. The chlorophyll maxima (CM) gradually move from the surface to become a deep CM (DCM), with moderate values in the inner fjord and high values in the mouth of the fjord. The maximal photosynthetic efficiencies (FV/FM) often not coincide with the depth of the CM.

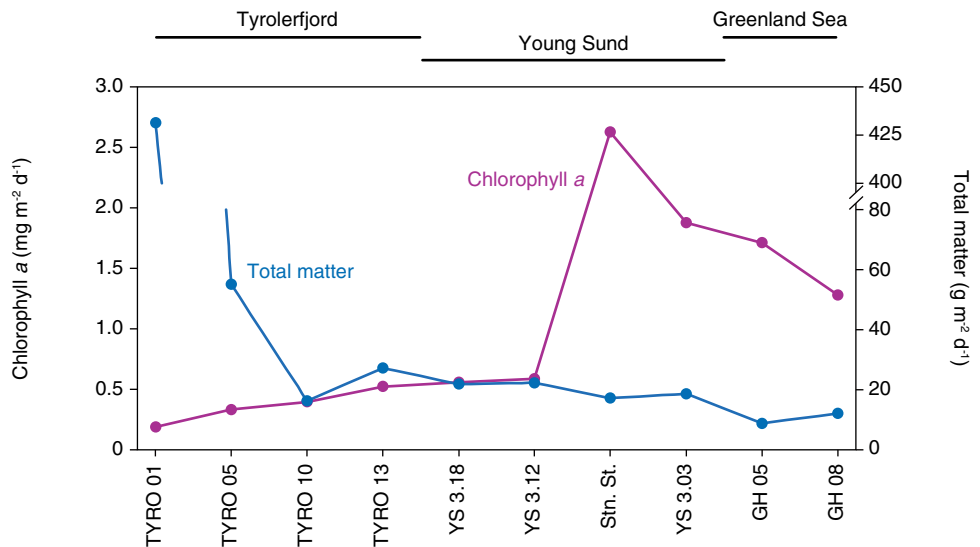


Figure 6.16 Vertical sinking fluxes of chlorophyll a ($\text{mg m}^{-2} \text{d}^{-1}$) and total matter ($\text{g m}^{-2} \text{d}^{-1}$) along the sampling transect. Stations ID (x-axis) are not spaced according to actual distances.

6.10 Ecological function of aquatic mosses in Arctic lakes

Tenna Riis, Birgitte K. Tagesen and Kirsten S. Christoffersen

Aquatic mosses are often the only macrophytes in high Arctic lakes. Despite the low nutrient availability and a short ice free period mosses can create massive stands on the lake bed even in deeper lakes if light penetrates to the bottom. Mosses most likely constitute an important component in the overall ecology of lakes as primary producers and food resource for secondary producers, and thereby as important organisms in carbon and nutrient cycling. However, macrophytes have seldom been included in food web studies (Christoffersen et al. 2008).

The aim of the project is to describe the ecological function of aquatic mosses in high Arctic lakes with low nutrient availability and a short food chain. Moreover, we will determine growth and photosynthetic rates of mosses in different water depths in lakes, and test the hypothesis that mosses constitute a significant food resource for benthic animals in high Arctic lakes. Furthermore, we will test a reconstruction method previously used for estimating growth rates of high Arctic aquatic mosses back in time in order to describe the influence of climate variations.

The project is running for two years with field work in Zackenberg August 2011 and August 2012. We are working in two of the lakes in Morænebakkerne (Sommerfuglesø og Langemandssø). In 2011, we

initiated *in situ* growth experiments for the two dominant moss species (*Scorpidium scopioides* and *Drepanocladus trifarius*; figure 6.17). Shoots of mosses were mounted on plastic frames and placed in two depths in Sommerfuglesø (0.9 m and 2.0 m; figure 6.18). Shoot length and shoot weight was measured before incubation. The plants are situated in the lake until August 2012 where shoots are re-measured, and annual growth rate on basis of weight and length calculated. We will also measure the area cover and biomass at different depth of the two moss species in order to estimate annual moss production in the lakes.

In 2011, we also analyzed growth rate for *D. trifarius* using a reconstruction method based on change in annual shoots morphology (Riis and Sand-Jensen 1997, Sand-Jensen et al. 1999). On weight basis, we measured a mean annual growth rate of 1.5 ± 0.6 mg shoot⁻¹ year⁻¹. Preliminary analyses suggest that the annual growth rate is limited by the snow cover in June. We will also analyze the internal carbon, nitrogen and phosphorus in shoots of different age to assess the allocation and usage of nutrient in the moss species. The nutrient analyses are currently being processed.



Figure 6.17 The two dominant moss species in Sommerfuglesø and Langemandssø in Morænebakkerne, *Scorpidium scopioides* (left) and *Drepanocladus trifarius* (right). Photo: Tenna Riis.

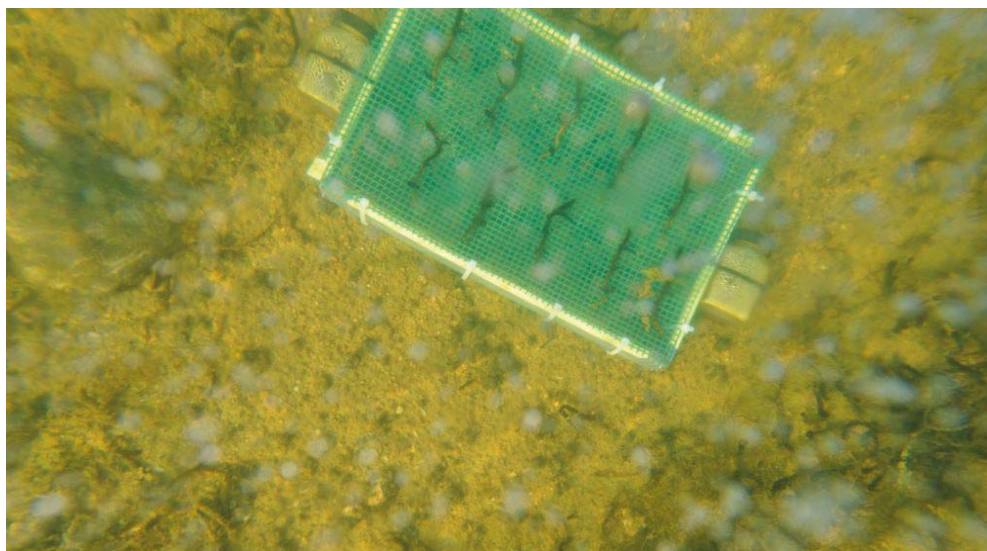


Figure 6.18 Moss mounted on plastic frames and left in the lake at 0.9 and 2 m depth for 12 months. Here seen through the ice in Sommerfuglesø in October 2011. Photo: Lars Holst Hansen.

Table 6.1 Photosynthetic rates of *Scorpidium scorpioides* and *Drepanocladus trifarius* measured in situ in Sommerfuglesø at 0.9 m and 2 m depths. Plants were incubated in lake water. Netto photosynthetic rate (NPR; n=5) and respiration (n=2) was measured.

Species	Depth (m)	NPR ($\mu\text{mol O}_2 \text{ g DW}^{-1} \text{ day}^{-1}$)	Respiration ($\mu\text{mol O}_2 \text{ g DW}^{-1} \text{ day}^{-1}$)
<i>Scorpidium scorpioides</i>	0.9	82.6 ± 31.6	1.9
	2.0	43.0 ± 11.7	2.5
<i>Drepanocladus trifarius</i>	0.9	81.2 ± 18.9	2.3
	2.0	63.6 ± 23.4	3.3

We measured *in situ* ambient photosynthetic rates by incubating moss shoots in small bottles over 24 hours in Sommerfuglesø in two different depths (table 6.1). The preliminary results show higher photosynthetic rate at 0.9 m compared to 2.0 m depth, but no differences between the two species (two-way ANOVA, $F=11.33$, $p < 0.05$) indicating light limitation at higher depths. In 2012, we will measure CO_2 limitation and effect of temperature on photosynthetic rates in the two moss species in order to predict changes in moss production with future climate changes.

We also collected samples for natural abundance of ^{15}N and ^{13}C in all biotic compartments in the lakes, in order to analyze food web relations and especially the role of mosses as food for other trophic levels. We will supplement these samples in 2012 to obtain a more complete data set. We will also conduct a laboratory experiment including selected grazers (*Lepidurus arcticus*, *Daphnia* sp. and chironomids) where the invertebrates are offered radioactive labeled (^{14}C) food sources in order to analyze the role of moss as food resource for benthic animals.

The project will be completed in 2012 and a thorough summary of the results will be presented in the 2012 annual report.

6.11 Winter ecology of lakes

Kirsten S. Christoffersen

Very little is known about the biological activity of planktonic and benthic organisms in ice covered high Arctic lakes. The ice cover typically lasts for 9-10 months and the winter season in Arctic lakes is considered a challenging period for any organism living in lakes due to low temperatures and poor light conditions and thus no or little food. The ice and snow cover has been shown to affect the abundance and composition of the plankton communities during

summer (Christoffersen et al. 2008). Recent studies from subarctic lakes have shown that the biota (plankton and fish) is active during most of the winter period and that some organisms (copepods) are capable of reproducing (Rautio et al. 2011). However, it is logistically difficult to run continuous and frequent sampling programmes during the winter period. Consequently, few studies have so far been conducted of winter ecology of high latitude lakes.

Our knowledge of winter ecology of plankton and benthic communities at high latitudes lakes is thus limited and potential interactions between species have rarely been investigated, even though the transition from summer to winter is expected to induce changes in the behavior of co-existing species due to their different survival strategies. Low temperatures and poor light conditions render primary production impossible and zooplankton must therefore rely on other food source. It appears that copepods are active under ice and are capable of doing so because of storage reserves (lipids) in their bodies. Furthermore, low water temperatures and a stagnant water body are known to favour small or mobile phytoplankton species while larger ones such as diatoms will sink out of the water column. Combining these factors with the assumed lower productivity and reduced prey availability during wintertime, leads to the expectation that both diet composition and feeding rates and energetic status as well as growth rates should differ highly between winter and summer seasons.

The aim of the project is to investigate how geochemistry and geophysics influence the biology of invertebrate organisms in ice covered lakes. Results from two previous years showed good growth conditions for plankton and therefore fish populations will be used to determine growth and reproduction rates of zooplankton, and to test the hypothesis that the long winter period constitutes an equally important growth period as the summer period for some species.

The main focus of the project that has been carried out for past three years (after the ISICaB-project in 2008), is to provide information about winter conditions by measuring ice thickness, water temperature, light, oxygen, inorganic nutrients, plankton abundances and to evaluate their winter survival strategies. The measurements have been carried out in several



Figure 6.19 Drilling holes in the 1.8 m thick ice and sampling through the ice in May 2011. Photo: Kirsten S. Christoffersen and Jørgen Skafte.



lakes with water depth of >2 m including the two monitoring lakes in Morænebakkerne, as well as Boresø. Most of the sampling is carried manually through holes in the ice (figure 6.19).

Light intensity and temperature have been recorded continuously in e.g., Sommerfuglesø and the results showed clearly that light was severely reduced due to the ice and snow cover from the beginning of November 2010 to mid-June 2011 (figure 6.20). The water temperature stayed low during the winter in this shallow lake (max. depth of around 2.5 m) but rose with the increased light climate from June and onwards (figure 6.21). Thus, the water temperatures change from close to zero up to 16 °C within few weeks.

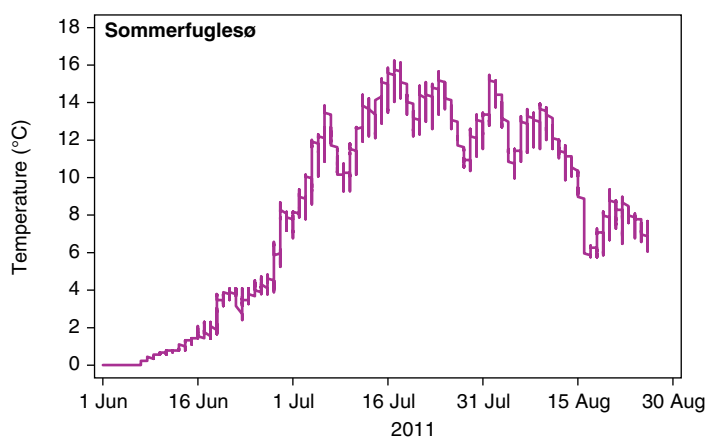


Figure 6.20 The light intensity (lux) in Sommerfuglesø through the season. From mid-June the light increases dramatically even though the lake had an ice cap until the beginning of July.

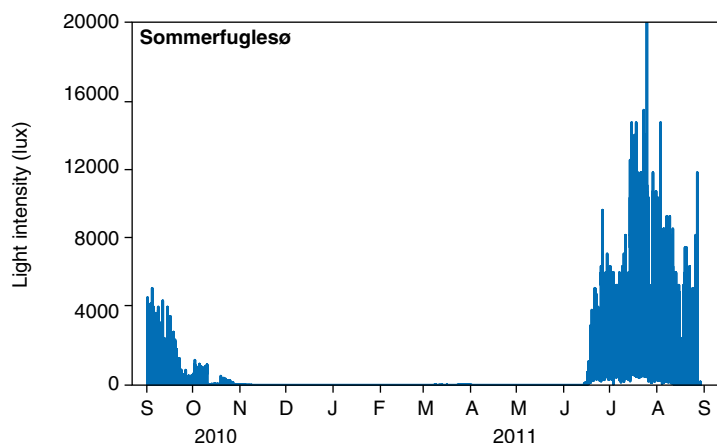


Figure 6.21 There is an exponential increase in temperature concomitant with increases in the light climate from June and onwards. The water temperatures change from close to zero up to 16°C within few weeks.

The project will continue in the following years depending on funding and the overall aim is to contribute with valuable data to the on-going monitoring programme (BioBasis) and to provide better understand of how freshwater ecosystems respond to climate changes.

6.12 Three-spined stickleback *Gasterosteus aculeatus* L. recorded for the first time at Zackenberg – short description and comparative analysis with Arctic char food biology

Anders Birk Nielsen, Ladislav Hamerlik and Kirsten S. Christoffersen

Nine dead specimens of three-spined stickleback (*Gasterosteus aculeatus* L.) was found on the shore near the old river delta in June 2010 (pos. 74° 27' 42.765" N; 20° 34' 55.881" W by Jannik Hansen, Department of Bioscience, Aarhus University). According to Nielsen and Bertelsen 1992 and the checklist for fish fauna of Greenland held by the Zoological Mu-

seum, University of Copenhagen (pers. comm. P.R. Møller) it is presumably the northernmost record of the species in East Greenland. The sticklebacks were therefore examined in details to obtain information of their biology.

The species has a circumpolar distribution and occur in Arctic as well as in temperate regions of the northern hemisphere. According to Froese and Pauly 2012 (<http://www.fishbase.org>) the species distribution extend south to the Black Sea, Southern Italy, the Iberian Peninsula and Northern Africa. In Eastern Asia the species is found north of Japan (35°N), and in North America above 32°N as well as in Greenland. Nielsen and Bertelsen 1992 state that the northernmost locations are Upernavik in West Greenland and Ittoqqortoormiit in East Greenland, while Møller et. al 2010 notes Ella Ø as the northern limit recorded for the species in East Greenland.

The three-spined stickleback is common in West and East Greenland and is known from many locations below 72°N (pers. comm. P. R. Møller). However, recent records of the species as far north as Svalbard (Pethon 1998) suggest that this species is expanding its natural distribution pattern most likely as a consequence of the actual warming that the Arctic is experiencing.

The three-spined stickleback occurs in the marine coastal zone, in brackish waters (e.g. large deltas), in rivers and streams with slow currents and in the littoral zone of lakes. However, sticklebacks spawn only in freshwater and can form migrating coastal populations or stationary populations in streams and lakes.

Their food may consist of almost anything they can manage to catch and swallow. The typical diet consists of invertebrates such as crustaceans, chironomids, oligochaetes and snails as well as their

Table 6.2 General characteristics of the collected three-spined sticklebacks.

Fish ID	Fork length (mm)	Body wet weight (g)	Sex	Colour	Stomach wet weight (g)
S1	46	0.85	Male	Dark/Silver	0.03
S2	55	1.41	Maturing female	Dark/Silver	0.045
S3	60	2.7	Mature female with eggs	Dark/Silver	0.04
S4	51	1.79	Mature female with eggs	Dark/Silver	0.04
S5	64	1.69	Maturing female	Dark/Silver	0.028
S6	85	7.58	Mature female with eggs	Dark/Silver	0.114
S7	49	2.98	Maturing female	Dark/Silver	0.034
S8	57	2.98	Maturing female	Dark/Silver	0.061
S9	53	1.58	Male	Dark/Silver	0.064

own eggs. Bergesen 1996 notes that since sticklebacks seem to occur almost everywhere in the aquatic habitat the species may represent an early stage of endemization. With no prior samplings of the three-spined stickleback at Zackenberg, an effort was made in order to determine whether the sticklebacks was of marine or freshwater origin. This evaluation was supported by analyzing chironomid stomach contents from the sticklebacks and Arctic char sampled at Zackenberg in 2010.

Methods

The fishes collected from Zackenberg were verified as three-spined sticklebacks, and weighted and measured fork length. The top layer of decomposed tissue was gently removed using a scalpel in order to determine the original skin colour. The development and extend of the stickleback’s lateral armor plating was visually inspected. The abdomen was opened from vent to esophagus using a scalpel and scissors. Internal decomposition of tissue was minor. Sex and gonadal maturation was determined. The stomach sac and esophagus was removed in one piece and weighed to the nearest gram. A tissue sample consisting of muscu-

lar tissue was taken above the lateral line between the caudal fin and the brain and subsequently conserved in 70% ethanol.

The stomach and esophagus contents were sorted using a dissection microscope and mounted on glass cover slides. Recovered chironomid larvae, pupae and head capsules were used to identify the stomach content to the lowest taxonomic level possible by means of light microscopy. Principal component analysis (PCA) and non-metric multidimensional scaling (NMDS) was run on binary data determining the presence or absence of specific chironomid taxa. This approach was also used on landlocked and anadromous Arctic char (*Salvelinus alpinus* L.) sampled at Zackenberg in 2010 (Nielsen 2011).

Results

The sampled sticklebacks showed similar morphological traits, with seven female fish within the nine collected fish (table 6.2). In order to evaluate the food consumption of the sticklebacks and compare them to other analyses conducted on anadromous and landlocked Arctic char from Zackenberg, a complete species list was developed (table 6.3). When evaluating the

Table 6.3 Species distribution of the chironomids recovered from anadromous Arctic char (RA1-RF1), landlocked Arctic char (LA1 and LB2) and the stickleback’s (S1-S9) stomach contents.

	RA 1	RA 2	RA 3	RA 4	RB 1	RB 2	RB 3	RC 1	RD 1	RE 1	RF 1	LA 1	LB 2	S1	S2	S3	S4	S5	S6	S7	S8	S9
<i>Procladius</i> (H.) sp.	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	1	-	-
<i>Diamesa</i> sp. 1 (cf. <i>aberrata</i>)	-	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Diamesa</i> sp. 2	-	1	-	1	1	1	1	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-
<i>Diamesa</i> sp. 3	-	-	1	1	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
<i>Diamesa</i> sp. 4	-	-	-	-	1	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-
<i>Diamesa</i> spp. - pupae	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-
<i>Corynoneura arctica</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1
<i>Cricotopus fuscus</i> gr. <i>tibialis</i> gr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-
<i>Cricotopus</i> (l.) <i>laricomalis</i> gr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-
<i>Cricotopus tremulus</i> gr.	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
<i>Cricotopus</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-
<i>Diplocladius cultiger</i>	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Limnophyes</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	1
<i>Metricnemus hygropetricus</i> gr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	1	1	1
<i>Orthocladius</i> (Eu.) sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Orthocladius</i> sp.	-	-	-	1	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<i>Psectrocladius limbatellus</i> gr.	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
<i>Psectrocladius sordidellus</i> gr.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
<i>Pseudosmittia</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-
<i>Tokunagaia</i> sp.	-	-	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<i>Chironomus anthracinus</i> -type	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	-	1	-
<i>Tanytarsus gracilentus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-

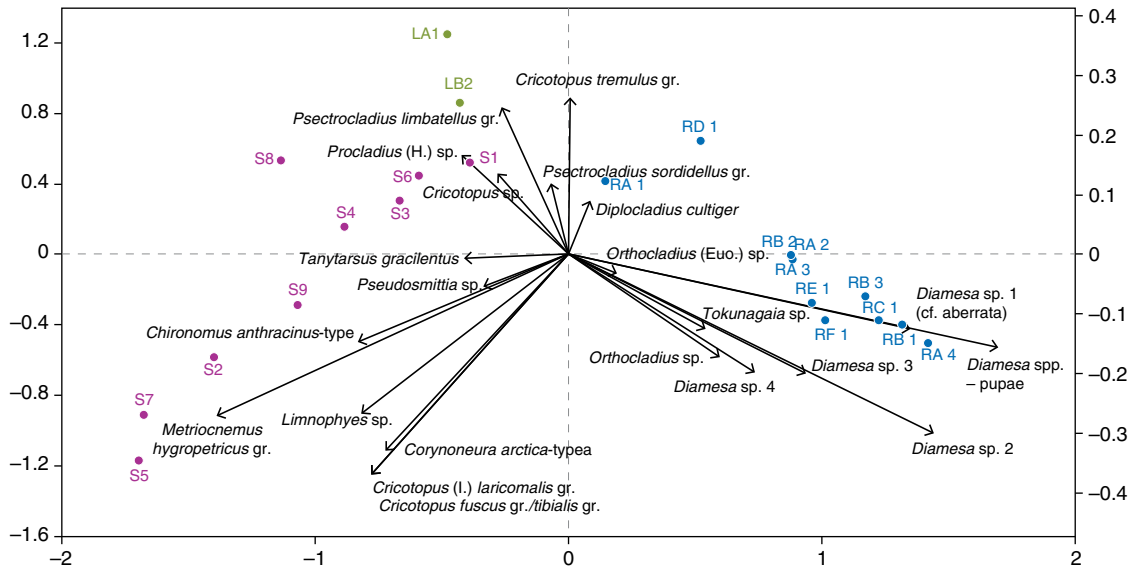


Figure 6.22 Principal Component Analysis of the stomach contents of stickleback (purple, n=9), anadromous Arctic char sampled from the river Zackenberg (blue, n=11), and landlocked Arctic char sampled from Langemandsø (green, n=2). All fish were sampled/caught in 2010.

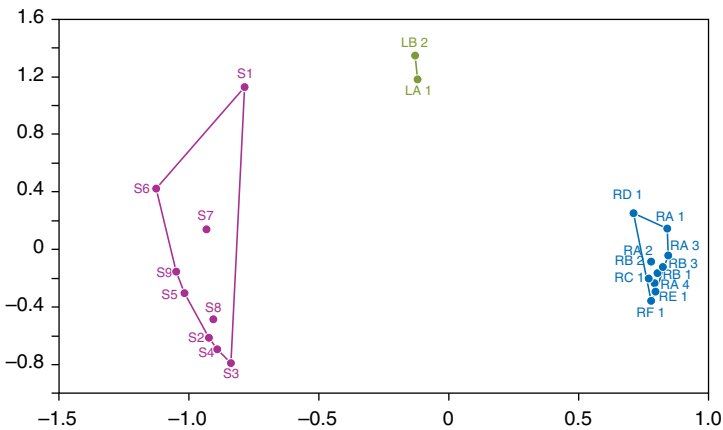


Figure 6.23 Non-metric multidimensional scaling (NMDS, Sørensen similarity, stress 0.32) analysis of the stomach contents of stickleback (purple), anadromous Arctic char (blue) and landlocked Arctic char (green).



Figure 6.24 Stickleback (S5) prior to analysis. External decomposition of the collected sticklebacks was evident, while internal decomposition was less profound. The sticklebacks from Zackenberg showed extensive lateral armour-plating, linking them to the distinct oceanic form. Photo: Anders Birk Nielsen.

species list with respect to the presence of chironomids with specific ecological traits, the sampled fish could be affiliated with three different compositions of ingested chironomids (figures 6.22 and 6.23).

Discussion

The measured bodyweight of the collected sticklebacks are probably minimum estimates as it was influenced by the varying degree of decomposition observed among the nine sampled fish. Furthermore, a number of the sampled sticklebacks had emptied their intestinal contents to the vial in which they were stored.

All investigated sticklebacks were silver colored with a dark nuance. The sticklebacks were equipped with lateral armor-plating covering two thirds of the back and sideline. Two characteristic dorsal spines were present in all sampled specimens as shown in figure 6.24. The dark nuance of the skin and the presence of dorsal spikes and lateral armor-plating are circumstantial evidence of the marine origin of the sampled sticklebacks (figure 6.24). The collected fish consisted of seven females and two males. All females contained ripening or mature eggs.

Sampled chironomids from the stomachs showed only minor signs of decomposition. This was seen as delicate features of the headcapsules, larvae and pupae remained visible in the samples. The presence of such details indicated recent feeding behaviour up until hours of being washed up on the shore.

Principal component analysis (PCA) and non-metric multidimensional scaling (NMDS) was applied to the stomach derived chironomid taxon distribution. Such analyses showed well defined groups among sticklebacks and anadromous/landlocked Arctic char samples. Based on the chironomid composition found in the guts we can conclude that the collected sticklebacks, with some certainty, had not been feeding within the river Zackenberg prior to sampling. It should be mentioned though that the collection of the sticklebacks was done two months prior to the sampling of the Arctic char. This could possibly explain some of the observed differences among stomach contents. As a consequence of the semi-terrestrial nature of some of the chironomid taxa found in the sticklebacks and landlocked Arctic char, these two groups appears to be closer to each other than the sampled anadromous Arctic char.

When evaluating the ecological properties of the investigated chironomids, two general characteristics became evident. Chironomids derived from the river dwelling fish was dominated by *Diamesa* sp. – a coldwater stenothermal, rheophilous genus affiliated with running waters with low fluctuations in water temperatures. While chironomids originating from the fish in the delta and Langemands Sø was dominated by the semi terrestrial *Metriocnemus hygropetricus* gr., and the predator *Procladius* sp. that lives in lakes and ponds.

Conclusion

The occurrence of three-spined stickleback as far north as Zackenberg could be a consequence of the species profound ability to utilize new habitats made available through climate change in central NE Greenland. Throughout our study it became evident that the sampled sticklebacks had been feeding recently and that several of them were ready to spawn. Because of the healthy state of the sampled specimens, we must consider the three-spined stickleback as a potential future inhabitant in the Zackenberg area. This should not give any reason to concern as sticklebacks are present at several high Arctic marine and freshwater localities outside Greenland, with no apparent effect on the aquatic ecology of the systems.

6.13 Brood mixing in Sanderling *Calidris alba*

Jeroen Reneerkens, Laura Kooistra, Jacques de Raad and Pieter van Veelen

Current knowledge of the breeding system of sanderling *Calidris alba* is, mainly based on observational data of a limited number of nests (e.g. Parmelee and Payne 1973). In Zackenberg, for several consecutive years sanderlings have been colour-marked (Reneerkens et al. 2010) and blood samples have been collected for parentage analysis and molecular sexing (Luttikhuizen et al. 2011). We now have a better understanding of mate and site fidelity as well as territory size (Reneerkens and Grond 2009). In addition, transponders and thermologgers in the nest cups clearly indicated that clutches within the same breeding area are being incubated by either one or two adults (Reneerkens 2011, Reneerkens et al. 2011). Such information is not only interesting for evolutionary biologists interested in the evolution of parental care systems (e.g. Andersson 2005), but also important to interpret results of bird censuses and to adequately measure and understand inter-annual variation in nest predation.

Recent research in Zackenberg of the breeding system of sanderling has mainly reported on the incubation stage of sanderling (Reneerkens 2011, Reneerkens et al. 2011). Within 24 hours after hatch, precocial chicks of waders start moving under guidance of one or both parents. For the interpretation of monitoring, it is essential to know whether each observed brood is the product of a single clutch, to what extent parents stay with their offspring and which of the sexes does so.

Here we report a case of brood mixing that we observed during summer 2011. On 4 July we found a sanderling clutch with four eggs and were able to catch both the incubating male and female the same day. The adults were colour-ringed and thus individually recognisable in the field. On 9 July, two days before the predicted hatch date based on egg flotation (Liebezeit et al. 2007), we found the male guiding two chicks 80 metres away from the nest cup. The chicks were metal ringed by us. There was no sign of the female or the other two chicks. Three days later we found the male with the same two chicks in the vicinity of where we first sighted the family. To our surprise, 13 July we resighted the female with two other chicks and another male. Based on their

body weight the chicks were three days older than the chicks that hatched from the clutch she incubated. Both the male and the female were observed to brood these chicks and both were alarming because of our presence. Two and four days later both the female and the other male were still guiding these two chicks. We caught the chicks and the male and collected a blood sample. Parentage analysis based on eight micro-satellite loci (Luttikhuisen et al. 2011) clearly showed that both males were the biological father of the chicks they were guiding. The female, on the other hand, had apparently left her own offspring that hatched from the clutch that she laid herself to guide chicks from a male she had not mated. Besides being an intriguing case that makes us wonder about the benefits of this behaviour for the female, it also shows that care should be taken when interpreting the number of breeding pairs in an area, based on the number of broods.

6.14 MANA Project

Philippe Bonnet, Kirsten Christoffersen, Javier Gonzalez, Joel Granados, Mohammed Aljarrah and Jesper Aagard Christensen

The MANA project is a collaboration between IT University of Copenhagen, the Department of Biology at University of Copenhagen, the school of computing at Reykjavik University, Arch Rock Corporation, a company based in San Francisco that provides wireless sensor networks systems, and Dan-System, a small Danish Enterprise, specializing in technical solutions for niche markets.

The overall goal of the MANA project is to improve scientific data acquisition in remote, harsh environments, e.g., polar regions, deep-sea locations, or other planets. Such environments are hard to access by humans, and provide limited communication bandwidth. As a result, manual measurements are costly, manually tapped data loggers are unreliable, and remote supervised control is impractical. We aim at enhancing sensors and data loggers with computation and communication capabilities so that we can programme them to be reliable and autonomous. We plan to develop sensor network-based data loggers that check the data they collect and correlate measurements in time and space, and autonomously adapt their sampling strat-

egy in order to optimize data quality as well as resource utilization.

We focus on the monitoring of limnic parameters in the Zackenberg region, North-east Greenland. The goal is to document the effects of climate change on lake environment, in particular during the winter season that has been neglected so far because of logistical constraints. The newly developed data loggers should introduce a remarkable progress in terms of temporal resolution with respect to the manual measurements that have been carried out a couple of times a year since 1996.

The MANA project started 1 February 2008. We installed the Capoh system composed of a buoy and a base station in August and October 2008, maintained it in August 2009, 2010 and 2011. The status as of August 2011 is the following:

- The Water Quality Monitor (WQM) sensor failed. We took it back to our lab in Copenhagen for maintenance. The WQM had a single point of failure in our online installation. We anticipated such a failure and attached external data loggers under the buoy. The acquired data is still being processed.
- We calibrated and tested a wireless link between the base station at the lake and House 6 at Zackenberg Research Station. The base station at the lake is now accessible from a laptop connecting to the "MANA" wireless network at Zackenberg.
- Javier Gonzalez designed and implemented a testbed replicating the MANA installation in the lab at IT University (MSc thesis), and Mohammed Aljarrah built a tool to test the MANA installation *in situ* at Zackenberg.

6.15 Virtual Instrumentation

Philippe Bonnet, Javier Gonzalez and Joel Granados

INTERACT is an FP7 infrastructure project under the auspices of SCANNET, a circumarctic network of 45 terrestrial field stations in northern Europe, Russia, USA, Canada, Greenland, Iceland, the Faroe Islands and Scotland. INTERACT specifically seeks to build capacity for research and monitoring in the European Arctic and beyond, and is offering access to numerous research stations through the Transnational Access programme.

The INTERACT consortium has identified gaps relating to methods for automatic data collection and methods for coordinated storage of data from many sites. The specialists will operate Joint Research Activities in close cooperation with the Station Managers to develop and test techniques for data collection and storage in relevant fields of research that particularly need improved methodology and observation.

Joint Research Activity Work package 5, "Virtual Instrumentation" has a main objective to leverage low-power wireless communication capabilities to make *in situ* sensing easier to manage and more effec-

tive. Another goal is to develop a new imager-based phenology workflow.

In August 2011, we proceeded to experiment with wireless links at Zackenberg. Our goal was to validate the radio link model worked out by Javier Gonzalez and Joel Granados. The result of their work was incorporated in an INTERACT deliverable (D5.1 - Survey Report of Sensor Networking in the Arctic).

In addition, Joel Granados experimented with the BioBasis team on different tools for our new imager-based phenology workflow.

7 Disturbances in the study area

Jannik Hansen

This account covers the period from 30 April to 7 November 2011. For details about the opening of the station and the operations, see chapter 8.

Surface activities in the study area

April – November: The number of ‘person-days’ (one person in the field one day) spent within the main research area, zone 1 was 1252 (table 7.1), which is approximately the same number as in previous five years. This area is open to research, and more activity in this area is expected. The “low impact area” 1b was visited 77 times, which is a little above the usual level. The “goose protection area”, zone 1c, was visited seven times during the closed period (20 June–10 August).

This season, the use of the all terrain vehicle (ATV) was mainly along the designated roads to the climate station and the beach at the delta of the river Zackenberg. There were three trips in June off the designated road system. In addition, during October, the ATV was in use three times. However, the use of the ATV at and near the station has become higher since 2007, remaining at this higher level.

During the early and late part of the season, snowmobiles were used for longer transportation and transportation of equipment.

Erratum: In previous years, the activities in area 1 have been miscalculated. The correct data will be published in the 2012 annual report.

Aircraft activities in the study area

In 2011, the station had 16 fixed-wing aircraft visits and no helicopter visits. See chapter 8 for details. During the 2011 season, the arrival of aircraft did not make the waterfowl fly up from the lakes, ponds and fens nearby.

Discharges

Water closets were in use from late May onwards, facilitated by frost preventing equipment in the house of residence. From here, all toilet waste was grinded in an electrical mill and led into the river.

Likewise, solid, biodegradable kitchen waste was run through a grinder mill, and into the river. The mill was in use until the end of the season.

Fly maggot killing agents are no longer used for the waste.

The total amount of untreated wastewater (from kitchen, showers, sinks and laundry machine) equalled approximately 1411 “person-days”, which is less than last year. The gradual phase-out of perfumed and non-biodegradable detergent, soap, dishwashing liquid etc. is continuing. More environmentally friendly products are being substituted for the former.

Combustible waste (paper, cardboard, wood etc.) was burned at the station. For management of other waste see chapter 8.

Manipulative research projects

For the eighth consecutive season, shade, snow melt and temperature was manipulated at two sites, each with 25 plots (see Jensen and Rasch 2011).

Avian predation on arthropod larvae was studied by putting out 162 tethered artificial arthropod larvae (play dough) at 16 sites, and 120 (in varying group sizes) untethered artificial arthropod larvae in 15 sites (section 6.8).

Table 7.1 ‘Person-days’ and trips in the terrain with an All-Terrain Vehicle (ATV) allocated to the research zones in the Zackenberg study area May–November 2011. The ‘Goose Protection Area’ (1C) is closed for human traffic from 20 June to 10 August (DOY 171–222). Trips on roads to the climate station and the delta of the river Zackenberg are not included.

Research zone	May	Jun	Jul	Aug	Sept	Oct	Total
All of 1 (incl. 1a)	161	280	319	321	78	93	1252
1b	N/A	10	40	16	7	4	77
1c (20 Jun–10 Aug)		1	6	0			7
1 w.o./Aucellaelv	N/A	10	69	49	8	9	145
2	N/A	5	12	9	0	2	28
ATV-trips	N/A	3	0	0	0	3	6

Take of organisms and other samples

The coordinates and the extent of all collection sites mentioned below are registered with BioBasis Zackenberg.

For the “Arctic bell-healer – annual growth in the *Cassiope* heath” project, twelve individuals of *Cassiope tetragona* were sampled (section 6.6).

A herbivore-plant-soil interactions study collected four monolith samples of soil including the vegetation within the monolith, at each of the two sites (section 6.3).

A stress gradient study collected 24 samples of soil and *Salix* and *Dryas* leaves (section 6.5).

31258 land arthropods were collected during the season, as part of the BioBasis programme (see section 4.2).

Fourty-two blood samples of approximately 80 µl were collected from adult and 88 of 10 µl from chicks of sanderlings *Calidris alba* for a parentage and breeding strategy study (section 6.13).

Tissue samples were collected from six adult and four calves of muskoxen *Ovibos moschatus* (from carcasses), two Arctic fox *Vulpes lagopus* (juvenile carcasses), eleven Arctic hares *Lepus arcticus* (carcass remnants), two pink-footed goose *Anser brachyrhynchus* (carcasses), one ruddy turnstone *Arenaria interpres* (full carcass, chick), one long-tailed skua *Stercorarius longicaudus* (full carcass), one common raven *Corvus corax* (carcass) and five four-horned sculpins *Myoxocephalus quadricornis* (three found freshly dead, two collected) for the BioBasis DNA bank.

In addition, for the BioBasis DNA bank, one long-tailed skua *Stercorarius longicaudus* egg (accidentally damaged during

work at the nest) and one ruddy turnstone *Arenaria interpres* egg were collected in addition to a blood sample from a common ringed plover *Charadrius hiaticula* chick.

Approximately 140 faecal samples from Arctic fox *Vulpes lagopus*, one from a polar bear *Ursus marinus*, five from long-tailed skua *Stercorarius longicaudus*, one from red knot *Calidris canutus*, nine from sanderling *Calidris alba*, two from dunlin *Calidris alpina* and one from a female Lapland bunting *Calcarius lapponicus*, along with 26 Eppendorf tubes filled with faecal samples from northern collared lemmings *Dicrostonyx groenlandicus*, which were collected for the ‘Interactions 2011-2014’ project. This project also took the following: Fourteen blood samples of approximately 20 µl were collected from adult and thirteen of 10 µl from chicks of dunlin, and seven 2×20 µl blood samples from adult and a single 10 µl samples from a young long-tailed skua (section 4.3).

For “a high Arctic food web”, approximately 16000 arthropods insects were caught in six malaise traps. The project also caught >200 lepidopteran larvae in five live-trapping pitfall traps at four locations. All other caught arthropods were released unharmed.

The “pollination network” project collected 608 specimens representing up to 95 different species of insects in a 500 m × 500 m area south of the research station (section 6.7). In addition, 50 *Polygonum viviparum* leaves were collected.

For the “Greenlandic seed bug: is sex necessary” project, approximately 600 *Nysius groenlandicus* were collected (Jensen and Rasch 2011).

8 Logistics

Henrik Spanggård Munch and Lillian Magelund Jensen

8.1 Use of the station

In 2011, the field season at Zackenberg Research Station was from 30 April to 7 November, in total 191 days. During this period, 53 scientists visited the station. Of the 53 visiting scientists, 12 stayed at Daneborg. They were serviced by 8 logisticians employed by the Department of Bioscience at Aarhus University and stationed at Zackenberg and Daneborg during different parts of the field season.

The total number of bed nights during 2011 was 1857. 1631 of the bed nights were spent at Zackenberg (1246 related to scientists and 385 to logisticians). 226 of the bed nights were spent at Daneborg (170 related to scientists and 56 to logisticians).

During the season, the station was visited by persons from 16 different countries: Finland, Austria, Greenland, Sweden, Canada, Chile, Italy, Switzerland, Russia, USA, Netherland, France, Spain, Korea, Cameroun and Denmark.

8.2 Transportation

During the field season, fixed winged aircrafts (DeHaviland DHC-6 Twin Otter) landed 35 times at Zackenberg. Of the 35 landings, 16 landings were related to transport of cargo.

8.3 Maintenance

During 2011, the following construction and maintenance was carried out at the station:

- At house no. 10, a new base for the building was completed. New stairs, platform and sewage pipe were put up
- At houses no. 2-5 and 8, new platforms for equipment and boxes were put up
- At the runway, a new platform for handling cargo was put up

The maintenance condition of the station is very good. Besides the normal painting of the houses, we do not expect larger maintenance costs during the next years to come.

8.4 Handling of garbage

The non-burnable waste was removed from Zackenberg Research Station by aircraft to Daneborg on the empty return flights during the fuel lifts from Daneborg to Zackenberg and from there by ship to Denmark. Approximately 33 m³ of waste were removed from the station.

Approximately 100 m³ non-burnable waste accumulated from the construction during 2010 was removed from Daneborg by ship to Denmark.

8.5 Zackenberg at Daneborg

The research house at Daneborg can accommodate 10 scientists (in five double rooms) and has modern laboratory and storage facilities. The house contains a fully equipped kitchen, a living room with TV and stereo, toilet, shower and laundry facilities.

For information concerning booking and/or renting the research house for a specific period please contact the Zackenberg Secretariat (zackenberg@dmu.dk) at the Department of Bioscience, Aarhus University.

9 Personnel and visitors

Compiled by Lillian Magelund Jensen

Research Zackenberg

- Noémie Boulanger-Lapointe, Research assistant, Département de Chimie-Biologie, Université du Québec à Trois-Rivières, Canada (BioBasis, 26 July-24 August)
- Kirsten Christoffersen, Researcher, Freshwater Biological Laboratory and Polar Science Center, University of Copenhagen, Denmark (Limnology and MANA, 17 May-31 May and 25 August-1 September)
- Michele Citterio, Researcher, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark (GlacioBasis, 30 April-17 May)
- Rasmus Egede, Technician, Asiaq – Greenland Survey, Greenland (ClimateBasis, 25 August-1 September)
- Malin Ek, Research assistant, Department of Biosciences, University of Helsinki, Finland (Insect community ecology, 16 June-14 July)
- Julie Maria Falk, Researcher, Department of Earth and Ecosystem Sciences, Lund University, Sweden (Plant-Soil-Herbivore, 16 June-11 August)
- Henrik Geisler, Technician, Asiaq – Greenland Survey, Greenland (ClimateBasis, 25 August-1 September)
- Javier Gonzales, Research assistant, IT University, Copenhagen, Denmark (MANA and INTERACT, 18 August-1 September)
- Joel Granados, Research assistant, IT University, Copenhagen, Denmark (MANA and INTERACT, 18 August-1 September)
- Oriol Grau, Researcher, Department of Plant Biology, University of Barcelona, Spain (Plant interactions, 7-21 July)
- Eric Steen Hansen, Researcher, Natural History Museum of Denmark, University of Copenhagen, Denmark (BioBasis, 7 July-21 July)
- Jannik Hansen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 31 May-4 August)
- Lars Holst Hansen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 17 May-16 June and 21 July-7 November)
- Tapani Hopkins, Research assistant, Department of Biosciences, University of Helsinki, Finland (Insect community ecology, 16 June-25 August)
- Ji Young Jung, Researcher, Division of Life Sciences, Korea Polar Research Institute, Korea (Soil microbial ecology and biogeochemistry, 11-18 August)
- Laura Kooistra, Research, assistant, Centre for Ecological and Evolutionary Studies, Animal Ecology Group, The Netherlands (Ornithology, 28 June-19 July)
- Line Anker Kyhn, Researcher, Department of Bioscience, Aarhus University, Denmark (BioBasis, 16 June-14 July)
- Signe Hillerup Larsen, Research assistant, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark (GlacioBasis, 30 April-17 May)
- Yoo Kyung Lee, Researcher, Division of Life Sciences, Korea Polar Research Institute, Korea (Soil microbial ecology and biogeochemistry, 11-18 August)
- Anders Lindroth, Researcher, Department of Earth and Ecosystem Sciences, Lund University, Sweden (GeoBasis, 4 August-11 August)
- Mikhail Mastepanov, Researcher, Department of Earth and Ecosystem Sciences, Lund University, Sweden (GeoBasis, 4 August-11 August)
- Lars O. Mortensen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 31 May-14 July)
- Jesper Mosbacher, Research assistant, Department of Biology, University of Copenhagen, Denmark (Ecological networks, 14 July-25 August)
- Josep M. Ninot, Researcher, Department of Plant Biology, University of Barcelona, Spain (Plant interactions, 7-14 July)
- Herbert Mbufong Njuabe, Research assistant, Department of Bioscience, Aarhus University, Denmark (GeoBasis, 30 April-16 June)
- Lau Gede Petersen, Research assistant, Department of Geography and Geology, University of Copenhagen, Denmark (GeoBasis, 30 June-1 September)

Maria Rask Pedersen, Research assistant, Department of Geography and Geology, University of Copenhagen, Denmark, (GeoBasis, 30 April-7 July)

Jacques de Raad, Research assistant, Centre for Ecological and Evolutionary Studies, Animal Ecology Group, The Netherlands (Ornithology, 28 June-19 July)

Claus Rasmussen, Researcher, Department of Bioscience, Aarhus University, Denmark (Ecological networks, 14 July-25 August)

Laura Helene Rasmussen, Research assistant, Department of Geography and Geology, University of Copenhagen, Denmark (GeoBasis, 28 July-1 September)

Jeroen Reneerkens, Researcher, Centre for Ecological and Evolutionary Studies, Animal Ecology Group, The Netherlands (Ornithology, 14 June-19 July)

Gernot Resch, Researcher, Climate Research Department, Central Institute for Meteorology and Geodynamics, Austria (Glaciology, 28 June-25 August)

Tenna Riis, Researcher, Department of Bioscience, Aarhus University, Denmark (Limnology, 25 August-1 September)

Tomas Roslin, Researcher, Department of Agricultural Sciences, University of Helsinki, Finland (Insect community ecology, 16 June-7 July)

Niels Martin Schmidt, BioBasis Manager, Department of Bioscience, Aarhus University, Denmark (BioBasis, 30 June-14 July)

Kirstine Skov, Research assistant, Department of Geography and Geology, University of Copenhagen, Denmark (GeoBasis, 7 July-4 August)

Lena Ström, Researcher, Department of Earth and Ecosystem Sciences, Lund University, Sweden (Plant-Soil-Herbivore, 30 June-7 July)

Birgitte K. Tagesen, Technician, Department of Bioscience, Aarhus University, Denmark (Limnology, 25 August-1 September)

Mikkel P. Tamstorf, GeoBasis manager, Department of Bioscience, Aarhus University, Denmark (GeoBasis, 30 April-17 May, 4 August-18 August and 19 October-7 November)

Gergely Várkonyi, Researcher, Finnish Environment Institute, Friendship Park Research Centre, Finland (Insect community ecology, 30 June-21 July)

Gernot Weyss, Technician, Climate Research Department, Central Institute for Meteorology and Geodynamics, Austria (Glaciology, 28 June-25 August)

Research Daneborg

Martin E. Blicher, Researcher, Greenland Climate Research Centre, c/o Greenland Institute of Natural Resources, Greenland, (MarineBasis, 27 July-19 August)

Anette Bruhn, Researcher, Department of Bioscience, Aarhus University, Denmark (MarineBasis, 27 July-12 August)

Tage Dalsgaard, Researcher, Department of Bioscience, Aarhus University, Denmark (MarineBasis, 27 July-12 August)

Egon R. Frandsen, Technician, Department of Bioscience, Aarhus University, Denmark (MarineBasis, 27 July-19 August)

Thomas Juul-Pedersen, Researcher, Greenland Climate Research Centre, c/o Greenland Institute of Natural Resources, Greenland, (MarineBasis, 27 July-19 August)

Steen Savstrup Kristensen, Researcher, DTU Space, National Space Institute, Denmark (PROMICE, 18-21 August)

Ivali Lennart, Technician, Greenland Climate Research Centre, c/o Greenland Institute of Natural Resources, Greenland, (MarineBasis, 27 July-19 August)

Nikolaj From Pedersen, Researcher, Department of Biology, University of Copenhagen, Denmark (MarineBasis, 27 July-12 August)

Mikael K. Sejr, Researcher, Department of Bioscience, Aarhus University, Denmark (MarineBasis, 27 July-19 August)

Henriette Skourup, Researcher, DTU Space, National Space Institute, Denmark (PROMICE, 18-21 August)

Colin Stedmon, Researcher, National Institute for Aquatic Resources, Technical University of Denmark, Denmark (MarineBasis, 27 July-12 August)

Sofie Louise Sandberg Sørensen, Researcher, DTU Space, National Space Institute, Denmark (PROMICE, 18-21 August)

Logistics Zackenberg and Daneborg

Søren Kyed, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (14 July-25 August)

Dina Laursen, Cook, Department of Bioscience, Aarhus University, Denmark (31 May-14 July)

Henrik Spanggård Munch, Logistics manager, Department of Bioscience, Aarhus University, Denmark (31 May-30 June and 14 July-1 September)

Henrik Philipsen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (30 June-11 August)

Morten Rasch, Scientific leader, Department of Bioscience, Aarhus University, Denmark (11 August-18 August)
 Klaus Winther Rasmussen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (14 July-11 August)
 Lone Riis, Cook, Department of Bioscience, Aarhus University, Denmark (14 July-1 September)
 Kim Simonsen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (31 May-14 July)
 Jørgen Skafte, Logistics coordinator, Department of Bioscience, Aarhus University, Denmark (30 April-31 May and 11 August-3 November)

Others

Peter Hansen, Carpenter, Department of Bioscience, Aarhus University, Denmark (GeoBasis, 4 August-11 August)

Further contributors to the annual report

Andreas Ahlstrøm, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark
 Mohammed Aljarrah, IT University, Copenhagen, Denmark
 Kristian R. Albert, Institute for Chemical Engineering, Technical University of Denmark, Denmark
 Claudia Baittinger, National Museum of Denmark, Denmark
 Daniel Binder, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria
 Philippe Bonnet, IT University, Copenhagen, Denmark
 Jesper Aagard Christensen, IT University, Copenhagen, Denmark
 Torben R. Christensen, Department of Earth and Ecosystem Sciences, Lund University, Sweden
 Daniel F. Ginnis, Institute of Biology, University of Southern Denmark, Denmark

Ladislav Hamarlik, Department of Biology and Ecology, Matthias Belius University, and Institute of Zoology, Slovak Academy of Sciences, Slovakia
 Per Hangaard, Asiaq – Greenland Survey, Greenland
 Birger Ulf Hansen, Department of Geography and Geology, University of Copenhagen, Denmark
 Bess Hardwick, Department of Agricultural Sciences, University of Helsinki, Finland
 Bernhard Hynek, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria
 Diana Krawczyk, Institute of Geosciences, University of Szczecin, Poland
 Aart Kroon, Department of Geography and Geology, University of Copenhagen, Denmark
 Morten Larsen, Asiaq – Greenland Survey, Greenland
 Magnus Lund, Department of Bioscience, Aarhus University, Denmark
 Anders Michelsen, Department of Biology, University of Copenhagen, Denmark
 Anders Birk Nielsen, Freshwater Biological Laboratory and Polar Science Centre, University of Copenhagen, Denmark
 Jens Mogens Olesen, Department of Bioscience, Aarhus University, Denmark
 Dorthe Petersen, Asiaq – Greenland Survey, Greenland
 Wolfgang Schöner, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria
 Charlotte Sigsgaard, Department of Geography and Geology, University of Copenhagen, Denmark
 Kisser Thorsøe, Asiaq – Greenland Survey, Greenland
 Pieter van Veelen, Centre for Ecological and Evolutionary Studies, Animal Ecology Group, The Netherlands

10 Publications

Compiled by Lillian Magelund Jensen

Scientific papers

- Abramson, G., Soto, C.A.T. and Oña, L. 2011. The role of asymmetric interactions on the effect of habitat destruction in mutualistic networks. *PLoS ONE* 6(6): e21028.
- Albert, K., Mikkelsen, T.N., Ro-Poulsen, H., Arndal, M.F. and Michelsen, A. 2011. Ambient UV-B radiation reduces PSII performance and net photosynthesis in high Arctic *Salix arctica*. *Environmental and Experimental Botany* 73:10-18.
- Berg, T.B. and Pedersen, H. 2011. Gylp fra Lille Kjove og Sneugle i relation til lemmingbestanden ved Zackenberg i Nordøstgrønland. (With English summary: Pellets from Long-tailed Skuas and Snowy Owls in relation to the lemming population at Zackenberg in NE Greenland). *Dansk Ornitologisk Forenings Tidsskrift* 105:206-210.
- Blicher, M.E. and Sejv, M.K. 2011. Abundance, oxygen consumption and carbon demand of brittle stars in Young Sound and the NE Greenland shelf. *Marine Ecology Progress Series* 422:139-144.
- Böcher, J. and Nachman, G. 2011. Coexistence of bisexual and unisexual populations of *Nysius groenlandicus* in the Zackenberg Valley, Northeast Greenland. *Entomologia Experimentalis et Applicata* 140:196-206.
- Hansen, J. 2011. Zackenberg, Greenland, Denmark (74°20' N, 20°34' W). *Arctic Birds* 12:43-44.
- Hansen, J., Schmidt, N.M. and Reneerkens, J. 2011. Egg hatchability in high Arctic breeding wader species *Charadriiformes* is not affected by determining incubation stage using the egg flotation technique. *Bird Study* 58:522-525.
- Hollesen, J., Elberling, B. and Jansson, P.E. 2011. Future active layer dynamics and carbon dioxide production from thawing permafrost layers in Northeast Greenland. *Global Change Biology* 17:911-926.
- Ilmonen, J. and Várkonyi, G. 2011. First record of *Prosimulium ursinum* (Diptera: Simuliidae) in Northeast Greenland. *Entomologiske Meddelelser* 79:27-30.
- Jørgensen, A., Møbjerg, N. and Kristensen, R.M. 2011. Phylogeny and evolution of the Echiniscidae (Echiniscoidea, Tardigrada) – an investigation of the congruence between molecules and morphology. *Journal of Zoological Systematics and Evolutionary Research* 49:6-16.
- Kristensen, D.K., Kristensen, E., Forchhammer, M.C., Michelsen, A. and Schmidt, N.M. 2011. Arctic herbivore diet can be inferred from stable carbon and nitrogen isotopes in C3 plants, faeces, and wool. *Canadian Journal of Zoology* 89:892-899.
- Luttikhuisen, P.C., Bol, A., Witte, H., van Bleijswijk, J., Haddrath, O., Baker, A.J., Piersma, T. and Reneerkens, J. 2011. Novel and cross-species microsatellite markers for parentage analysis in Sanderling *Calidris alba*. *Journal of Ornithology* 152:807-810.
- Moles, A.T., Wallis, I.R., Foley, W.J., Warton, D.I., Stegen, J.C., Bisigato, A.J., Cella-Pizarro, L., Clark, C.J., Cohen, P.S., Cornwall, W.K., Edwards, W., Ejrnæs, R., Gonzales-Ojeda, T., Graae, B.J., Hay, G., Lumbwe, F.C., Magaña-Rodríguez, B.N., Moore, B.D., Peri, P.L., Poulsen, J.R., Veldtman, R., von Zeipel, H., Andrew N.R., Boulter, S.L., Borer, E.T., Campón, F.F., Coll, M., Farji-Brener, A.G., De Gabriel, J., Jurado, E., Kyhn, L.A., Low, B., Mulder, C.P.H., Reardon-Smith, K., Rodríguez-Velázquez, J., Seabloom, E.W., Vesk, P.A., van Cauter, A., Waldram, M.S., Zheng, Z., Blendinger, P.G., Enquist, B.J., Facelli, J.M., Knight, T., Majer, J.D., Martínez-Ramos, M., McQuillan, P. and Prior, L.D. 2011. Putting plant resistance traits on the map: a test of the idea that plants are better defended at lower latitudes. *New Phytologist* 191:777-788.
- Olesen, J.M., Bascompte, J., Dupont, Y.L., Elberling, H., Rasmussen, C. and Jordano, P. 2011. Missing and forbidden links in mutualistic networks. *Proceedings of the Royal Society B* 278:725-732.
- Pedersen, J.B.T., Kroon, A. and Jakobsen, B.H. 2011. Holocene sea-level reconstruction in the Young Sound region, Northeast Greenland. *Journal of Quaternary Science* 26:219-226.

- Piepenburg, D., Archambault, P., Ambrose, W.G., Blanchard, A., Bluhm, B., Carroll, M.L., Conlan, K.A., Cusson, M., Feder, H.M., Grebmeier, J.M., Jewett, S.C., Levesue, M., Petryashev, V.V., Sejr, M.K., Sirenko, B.I. and Wlodarska-Kowalczyk, M. 2011. Towards a pan-Arctic inventory of the species diversity of the macro and megabenthic fauna of the Arctic shelf seas. *Marine Biodiversity* 41:51-70.
- Reneerkens, J., Grond, K., Schekkerman, H., Tulp, I. and Piersma T. 2011. Do uniparental sanderlings *Calidris alba* increase egg heat input to compensate for low nest attentiveness? *PLoS ONE* 6(2): e16834. doi:10.1371/journal.pone.0016834.
- Rigét, F., Tamstorf, M.P., Larsen, M.M., Søndergaard, J., Asmund, G., Falk, J.M. and Sigsgaard, C. 2011. Mercury (Hg) transport in a high arctic river in north-east Greenland. *Water, Air and Soil Pollution* 222:233-242.
- Schroeder, W., Holy, M., Pesch, R., Zechmeister, H., Harmens, H. and Ilyin, I. 2011. Mapping atmospheric depositions of cadmium and lead in Germany based on EMEP deposition data and the European Moss Survey 2005. *Environmental Sciences Europe* 23:19, doi:10.1186/2190-4715-23-19.
- Sejr, M.K., Krause-Jensen, D., Rysgaard, S., Sørensen, L.L., Christensen, P.B. and Glud, R.N. 2011. Air-sea flux of CO₂ in arctic coastal waters influenced by glacial melt water and sea ice. *Tellus B* 63:815-822. DOI: 10.1111/j.1600-0889.2011.00540.x
- Thulin, C.-G., Englund, L., Ericsson, G. and Spong, G. 2011. The impact of founder events and introductions on genetic variation in the muskox *Ovibos moschatus* in Sweden. *Acta Theriologica* 56:305-314.
- Tsyganova, A.N., Nijs, I. and Beyens, L. 2011. Does Climate Warming Stimulate or Inhibit Soil Protist Communities? A Test on Testate Amoebae in High-Arctic Tundra with Free-Air Temperature Increase. *Protist* 162: 237-248.
- Wassmann, P., Duarte, C.M., Agusti, S. and Sejr, M.K. 2011. Footprint of climate change in the Arctic marine Ecosystems. *Global Change Biology* 17:1235-1249.
- Weslawski, J.M., Kendall, M.A., Wlodarska-Kowalczyk, M., Iken, K., Kedra, M., Legezynska, J. and Sejr, M.K. 2011. Arctic Fjord and coastal macrobenthos biodiversity. *Marine Biodiversity* 41:71-85.
- Wu, Z., Dijkstra, P., Koch, G.W., Penuelas, J. and Hungate, B.A. 2011. Responses of terrestrial ecosystems to temperature and precipitation change: a meta-analysis of experimental manipulation. *Global Change Biology* 17:927-942.
- Zechmeister, H.G., Dullinger, S., Koellensperger, G., Ertl, S., Lettner, C. and Reiter, K. 2011. Do metal concentrations in moss from the Zackenberg area, Northeast Greenland, provide a baseline for monitoring? *Environmental Science and Pollution Research* 18:91-98.

Reports

- Boulanger-Lapointe, N. 2011. Étude de populations de Saules Arctiques dans le Haut-Arctique Canadien et Groenlandais. Master thesis, University of Quebec à Trois-Rivières. 67 pp.
- Faarup, S. 2011. Evapotranspiration i arktiske egne. Estimeret ved 6 forskellige metoder. Master thesis. Department of Geography and Geology, University of Copenhagen. 70 pp.
- Jensen, L.M. and Rasch, M. (eds.) 2011. Zackenberg Ecological Research Operations, 16th Annual Report, 2010. Aarhus University, DCE – Danish Centre for Environment and Energy. 114 pp.
- Jensen, S. 2011. Surface air temperature gradients in Greenland – Identification, quantification, and temperature modeling. Master thesis. Department of Geography and Geology, University of Copenhagen. 70 pp.
- Larsen, M., Petersen, D. and Thorsøe, K. 2011. Discharges in ice affected periods in Zackenbergelven. Asiaq Report 2011-16, Asiaq - Greenland Survey. 24 pp.
- Rasch, M., Schmidt, N.M. and Juul-Pedersen, T. (eds.) 2012. Greenland Ecosystem Monitoring Strategy and Working Programme 2011-15. DCE – Danish Centre for Environment and Energy, Aarhus University, 115 pp.
- Westergaard-Nielsen, A. 2010. Pixelating plants. Spatial temporal monitoring of phenology and snow cover dynamics in Arctic using unmodified digital cameras. Master thesis. Department of Geography and Geology, University of Copenhagen. 90 pp.

11 References

Compiled by Lillian Magelund Jensen

- ACIA 2005. Arctic Climate Impact Assessment 2005. New York, Cambridge University Press. 1024 pp.
- Ahlstrøm, A.P., van As, D., Citterio, M., Andersen, S.B., Maghami Nick, F., Gravesen, P., Edelvang, K., Fausto, R.S., Kristensen, S.S., Christensen, E.L., Meryman Boncori, J.P., Dall, J., Forsberg, R., Steenseng, L., Hanson, S. and Petersen, D. 2009. PROMICE 2007-2008: Status report for the first two years of the Programme for Monitoring of the Greenland Ice Sheet. GEUS Report 2009/77. 74 pp.
- AMAP 2011. AMAP Assessment: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 210 pp. (available online at <http://www.amap.no>).
- Andersson, M. 2005. Evolution of classical polyandry: Three steps to female emancipation. *Ethology* 111:1-23.
- Bergesen, R. 1996. Sticklebacks from Greenland. *Journal of Fish Biology* 48:799-801.
- Boertmann, D. 2008. Grønlands Rødliste – 2007. Danmarks Miljøundersøgelser, Aarhus Universitet, og Grønlands Hjemmestyre. 156 s. (In Danish).
- Boertmann, D. 1994. An annotated checklist to the birds of Greenland. *Meddelelser om Grønland. Bioscience* 38. 63 pp.
- Boulanger-Lapointe, N. and Baittinger, C. 2011. Arctic willow and Arctic bell-heather growth and populations' dynamic in four community types. In Jensen, L.M. and Rasch, M. (eds.) 2011. Zackenberg Ecological Research Operations, 16th Annual Report, 2010. DCE – Danish Centre for Environment and Energy, Aarhus University, Denmark. 114 pp.
- Böcher, J. and Nachman, G. 2010. Are environmental factors responsible for geographic variation in the sex ratio of the Greenlandic seed-bug *Nysius groenlandicus*? *Entomologia Experimentalis et Applicata* 134:122-130.
- Caning, K. and Rasch, M. (eds.) 2003. Zackenberg Ecological Research Operations, 7th Annual Report, 2001. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 75 pp.
- Caning, K. and Rasch, M. (eds.) 2001. Zackenberg Ecological Research Operations, 6th Annual Report, 2000. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation, Denmark. 80 pp.
- Caning, K. and Rasch, M. (eds.) 2000. Zackenberg Ecological Research Operations, 5th Annual Report, 1999. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 86 pp.
- Christoffersen, K.S., Amsinck, S.L., Landkildehus, F., Lauridsen, T.L. and Jeppesen, E. 2008. Lake flora and fauna in relation to Ice-melt, water temperature and chemistry at Zackenberg. In Meltofte, H., Christensen, T.R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-arctic ecosystem dynamics in a changing climate. Ten years of monitoring and research at Zackenberg. *Advances in Ecological Research* 40:371-390.
- Elberling, Christiansen, H.H. and Hansen, B.U. 2010. High nitrous oxide production from thawing permafrost. *Nature Geoscience* 3:332-335.
- Elberling, B., Tamstorf, M.P., Michelsen, A., Arndal, M.F., Sigsgaard, C., Illeris, L., Bay, C., Hansen, B.U., Christensen, T.R., Steen, Hansen, E.S., Jakobsen, B.H. and Beyens, L. 2008. Soil and Plant Community-Characteristics and Dynamics at Zackenberg. In Meltofte, H., Christensen, T.R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-arctic ecosystem dynamics in a changing climate. Ten years of monitoring and research at Zackenberg. *Advances in Ecological Research* 40:223-246.
- Froese, R. and D. Pauly (eds.) 2012. FishBase. World Wide Web electronic publication. www.fishbase.org.
- Hansen, B.U., Sigsgaard, C., Rasmussen, L., Cappelen, J., Hinkler, J., Mernild, S.H., Petersen, D., Tamstorf, M.P., Rasch, M. and Hasholt, B. 2008. Present-day climate at Zackenberg. In Meltofte, H., Christensen, T.R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-arctic ecosystem dynamics in a changing climate. Ten years of monitoring and research at Zackenberg. *Advances in Ecological Research* 40:111-149.

- Hansen, J., Hansen, L.H., Schmidt, N.M. and Reneerkens, J. 2012. Bird monitoring at Zackenberg, Northeast Greenland, 2010, with comparison with 1996-2009. *Bird Populations* 11:42-51.
- Hansen, J., Hansen, L.H., Schmidt, N.M. and Reneerkens, J. 2010. Bird monitoring at Zackenberg, Northeast Greenland, 2007. *Bird Populations* 10: 56-67.
- Hansen, J., Schmidt, N.M., Hansen, L.H. and Reneerkens, J. 2009. Bird monitoring at Zackenberg, Northeast Greenland, 2008 – with comparison to 1995-2007. *Bird Populations* 9:1-12.
- Holland, J.N., Cheng, W. and Crossley, D.A.J. 1996. Herbivore-induced changes in plant carbon allocation: Assessment of below-ground C fluxes using carbon-14. *Oecologia* 107(1):87-94.
- Holst, J., Liu, C., Yao, Z., Brueggemann, N., Zheng, X., Giese, M. and Butterbach-Bahl, K. 2008. Fluxes of nitrous oxide, methane and carbon dioxide during freezing-thawing cycles in an Inner Mongolian steppe. *Plant and Soil* 308 (1-2):105-117.
- Howe, A., Lövei, G.L. and Nachmann G. 2009. Dummy caterpillars as a simple method to assess predation rates on invertebrates in a tropical ecosystem. *Entomologia Experimentalis et Applicata* 131:325-329.
- Høye, T.T., Post, E., Meltofte, H., Schmidt, N.M. and Forchhammer, M. C. 2007. Rapid advancement of spring in the High Arctic. *Current Biology* 17:R449-51.
- IPCC 2007a. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, USA. 996 pp.
- IPCC 2007b. *Synthesis Report 2007*. Cambridge, United Kingdom and New York, USA. 104 pp.
- Jensen, L.M. and Rasch, M. (eds.) 2011. *Zackenberg Ecological Research Operations, 16th Annual Report, 2010*. Aarhus University, DCE – Danish Centre for Environment and Energy. 114 pp.
- Jensen, L.M. and Rasch, M. (eds.) 2010. *Zackenberg Ecological Research Operations, 15th Annual Report, 2009*. National Environmental Research Operations, Aarhus University, Denmark. 134 pp.
- Jensen, L.M. and Rasch, M. (eds.) 2009. *Zackenberg Ecological Research Operations, 14th Annual Report, 2008*. National Environmental Research Operations, Aarhus University, Denmark. 116 pp.
- Johnson, D.H. 1979. Estimating nest success: The Mayfield method and an alternative. *Auk* 96:651-661.
- Jones, G.A and Henry, G.H.R. 2003. Primary plant succession on recently deglaciated terrain in the Canadian High Arctic. *Journal of Biogeography* 30:277-296.
- Klitgaard, A.B. and Rasch, M. (eds.) 2008. *Zackenberg Ecological Research Operations, 13th Annual Report, 2007*. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 98 pp.
- Klitgaard, A.B., Rasch, M. and Caring, K. (eds.) 2007. *Zackenberg Ecological Research Operations, 12th Annual Report, 2006*. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 104 pp.
- Klitgaard, A.B., Rasch, M. and Caring, K. (eds.) 2006. *Zackenberg Ecological Research Operations, 11th Annual Report, 2005*. Danish Polar Center, Ministry of Science, Technology and Innovation, Copenhagen, Denmark. 111 pp.
- Kohls, S., Van Kessel, C., Baker, D.D., Grigal, D.F and Lawrence, D.B. 1994. Assessment of N₂ fixation and N cycling by *Dryas* along a chronosequence within the forelands of the Athabasca glacier, Canada. *Soil Biology and Biochemistry* 26(5):623-632.
- Krause-Jensen, D., Marbà, N., Olesen, B., Sejr, M.K., Christensen, P.B., Rodrigues, J., Renaud, P.E., Balsby, T.J. and Rysgaard, S. 2012. Seasonal sea ice cover as principal driver of spatial and temporal variation in depth extension and annual production of kelp in Greenland. *Global Change Biology* 18(10):2981-2994.
- Larsen, M., Petersen, D. and Thorsøe, K. 2011. Discharges in ice affected periods in Zackenbergelven. *Asiaq Report 2011-16, Asiaq – Greenland Survey*. 24 pp.
- Liebezeit, J.R., Smith, P.A., Lanctot, R.B., Schekkerman, H., Tulp, I., Kendall, S.J., Tracy, D.M., Rodrigues, R.J., Meltofte, H., Robinson, J.A., Gratto-Trevor, C., McCaffery, B.J., Morse, J. and Zack, S.W. 2007. Assessing the development of shorebird eggs using the flotation method: species-specific and generalized regression models. *Condor* 109:32-47.
- Lortie, C. 2004. Rethinking plant community theory. *Oikos* 107:433-438.

- Lund, M., Falk, J.M., Friberg, T., Mbufong, H.M., Soegaard, H. and Tamstorf, M.P. 2012. Trends in CO₂ exchange in a high Arctic tundra heath, 2000–2010. *Journal of Geophysical Research* 117 (in press).
- Luttikhuisen, P., Bol, A., Witte, H., van Bleijswijk, J., Haddrath, O., Baker, A.J., Piersma, T. and Reneerkens, J. 2011. Novel and cross-species microsatellite markers for parentage analysis in Sanderling *Calidris alba*. *Journal of Ornithology* 152:807-810.
- Macdonald, R.W., Harner, T., Fyfe, J., Loeng, H. and Weingartner, T. 2003. AMAP Assessment 2002. The Influence of Global Change on Contaminant Pathways to, within, and from the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 65 pp.
- Maestre, F., Callaway, R., Valladares, F. and Lortie, C. 2009. Refining the stress-gradient hypothesis for competition and facilitation in plant communities. *Journal of Ecology* 97:199-205.
- Mastepanov, M., Sigsgaard, C., Dlugokencky, E. J., Houwelling, S., Ström, L., Tamstorf, M. and Christensen, T.R. 2008. Large tundra methane burst during onset of freezing. *Nature* 456:628-630.
- Meier, M.F., Dyurgerov, M., Rick, U.K., O'Neel, S., Pfeffer, W.T., Anderson, R.S., Anderson, S.P. and Glazovsky, A.F. 2007. Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century. *Science* 317:1064-1067. DOI: 10.1126/science.1143906.
- Meltofte, H. 2006. Wader populations at Zackenberg, high-arctic Northeast Greenland, 1996-2005. *Dansk Ornitologisk Forenings Tidsskrift* 100:16-28.
- Meltofte, H. 1978. A breeding association between Eiders and tethered huskies in North-east Greenland. *Wildfowl* 29:45-54.
- Meltofte, H. and Rasch, M. (eds.) 1998. Zackenberg Ecological Research Operations, 3rd Annual Report, 1997. Danish Polar Center, Ministry of Research and Technology, Denmark. 68 pp.
- Meltofte, H. and Thing, H. (eds.) 1997. Zackenberg Ecological Research Operations, 2nd Annual Report, 1996. Danish Polar Center, Ministry of Research and Information Technology, Denmark. 80 pp.
- Meltofte, H. and Thing, H. (eds.) 1996. Zackenberg Ecological Research Operations, 1st Annual Report, 1995. Danish Polar Center, Ministry of Research & Technology. 64 pp.
- Morris, R.J., Lewis, O.T. and Godfray, H.C.J. 2005. Apparent competition and insect community structure: towards a spatial perspective. *Annales Zoologici Fennici* 42:449-462.
- Møller, P.R., Nielsen, J.G., Knudsen, S.W., Poulsen, J.Y., Sünksen, K. and Jørgensen, O.A. 2010. A checklist of the fish fauna of Greenland waters. *Zootaxa* 2378:1-84.
- Nielsen, A.B. 2011. Aquatic Ecosystem Climate Response Revealed from Retrospective Otolith Analysis of Arctic Char from NE Greenland (*Salvelinus alpinus*, L.). Master thesis. University of Copenhagen. Denmark. 56 pp.
- Nielsen, J.G. and Bertelsen, E. 1992. Fisk i grønlandske farvande. *Atuakkiortfik*. 65 pp.
- Olofsson, J., Oksanen, L., Callaghan, T., Hulme, P.E., Oksanen, T. and Suominen, O. 2009. Herbivores inhibit climate-driven shrub expansion on the tundra. *Global Change Biology* 15(11):2681-2693.
- Parmelee, D.F. and Payne, R.B. 1973. On multiple broods and the breeding strategy of arctic sanderlings. *Ibis* 115:218-226.
- Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution and Systematics* 37:637-669.
- Parmesan, C. and Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37-42.
- Pethon, P. and Nyström, B.O. 1998. Aschehougs store fiskebok. *Norges fisker i farger*. 4th revised edition. Aschehoug 468 pp.
- Pocock, M.J.O., Evans, D.M. and Memmott, J. 2012. The robustness and restoration of a network of ecological networks. *Science* 335:973-977.
- Post, E. and Pedersen, C. 2008. Opposing plant community responses to warming with and without herbivores. *Proceedings of the National Academy of Sciences of the United States of America* 105(34):12353-12358.
- Post, E., Pedersen, C., Wilmers, C.C. and Forchhammer, M.C. 2008. Warming, plant phenology and the spatial dimension of trophic mismatch for large herbivores. *Proceedings of the Royal Society Biological Sciences Series B*. 275(1646):2005-2013.
- Rasch, M. (ed.) 1999. Zackenberg Ecological Research Operations, 4th Annual Report, 1998. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation, Denmark. 62 pp.

- Rasch, M. and Caning, K. (eds.) 2005. Zackenberg Ecological Research Operations, 10th Annual Report, 2004. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 92 pp.
- Rasch, M. and Caning, K. (eds.) 2004. Zackenberg Ecological Research Operations, 9th Annual Report, 2003. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 92 pp.
- Rasch, M. and Caning, K. (eds.) 2003. Zackenberg Ecological Research Operations, 8th Annual Report, 2002. Copenhagen, Danish Polar Center, Ministry of Science, Technology and Innovation. 75 pp.
- Rasch, M., Elberling, B., Jakobsen, B.H. and Hasholt, B. 2000. High resolution Measurements of Water Discharge, Sediment and Solute transport in the river Zackenbergelven, Northeast Greenland. *Arctic, Antarctic and Alpine research* 32(3):336-345.
- Rautio, M., Dufresne, F., Laurion, I., Bonilla, S., Warwick S.V. and Christoffersen, K.S. 2011. Shallow freshwater ecosystems of the circumpolar Arctic. *EcoScience* 18:204-222.
- Rayback, S.A. and Henry, G.H.R. 2006. Reconstruction of summer temperature for a Canadian High Arctic site from retrospective analysis of the dwarf shrub, *Cassiope tetragona*. *Arctic Antarctic and Alpine Research* 38:228-238.
- Reneerkens J. 2011. The occurrence of uni- and biparental incubation by sanderlings *Calidris alba*. In Jensen, L.M. and Rasch, M. (eds.) 2011. Zackenberg Ecological Research Operations, 16th Annual Report, 2010. DCE – Danish Centre for Environment and Energy, Aarhus University, Denmark. 114 pp.
- Reneerkens, J., Grond, K., Schekkerman, H., Tulp, I. and Piersma T. 2011. Do uniparental sanderlings *Calidris alba* increase egg heat input to compensate for low nest attentiveness? *PLoS ONE* 6(2): e16834. doi:10.1371/journal.pone.0016834.
- Reneerkens, J., Dijksterhuis, K., Van den Eertwegh, S., Grond, K., Hallgrimsson, G.T., Hofstee, L. and Voets, T. 2010. Non-breeding distribution of sanderlings *Calidris alba* from Zackenberg. In Jensen, L.M. and Rasch, M. (eds.) 2010. Zackenberg Ecological Research Operations, 15th Annual Report, 2009. National Environmental Research Institute, Aarhus University, Denmark. 134 pp.
- Reneerkens, J. and Grond, K. 2009. Return rates, mate fidelity and territory size of sanderlings *Calidris alba* in Zackenberg. In Jensen, L.M. & Rasch, M. (eds.) 2009: Zackenberg Ecological Research Operations, 14th Annual Report, 2008. National Environmental Research Institute, Aarhus University, Denmark. 116 pp.
- Rigét, F., Tamstorf, M.P., Larsen, M.M., Søndergaard, J., Asmund, G., Falk, J.M. and Sigsgaard, C. 2011. Mercury (Hg) transport in a high Arctic river in Northeast Greenland. *Water Air Soil Pollution* 222:1-4.
- Riis, T. and Sand-Jensen, K. 1997. Growth reconstruction and photosynthesis of aquatic mosses: influence of light, temperature and carbon dioxide at depth. *Journal of Ecology* 85:359-37.
- Rinnan, R., Stark, S. and Tolvanen, A. 2009. Responses of vegetation and soil microbial communities to warming and simulated herbivore in a subarctic heath. *Journal of Ecology* 97(4):788-800.
- Roslin, T., Várkonyi, G. and Hardwick, B. 2011. A high Arctic food web. In Jensen, L.M. and Rasch, M. (eds.) 2011. Zackenberg Ecological Research Operations, 16th Annual Report, 2010. Aarhus University, DCE – Danish Centre for Environment and Energy. 114 pp.
- Roslin, T. and Várkonyi, G. 2010. A high Arctic food web. In Jensen, L.M. and Rasch, M. (eds.) 2010. Zackenberg Ecological Research Operations, 15th Annual Report 2009. National Environmental Research Institute, Aarhus University, Denmark. 134 pp.
- Rozema, J., Weijers, S., Broekman, R., Blokker, P., Buizer, Werleman, C., El Yaqine, H., Hoogedoorn, H., Fuertes, M.M. and Cooper, E. 2009. Annual growth of *Cassiope tetragona* as a proxy for Arctic climate: developing correlative and experimental transfer functions to reconstruct past summer temperature on a millennial time scale. *Global Change Biology* 15:1703-1715.
- Sand-Jensen, K., Riis, T., Markager, S., Vincent, W.F. 1999. Slow growth and decomposition of mosses in Arctic lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 56:388-93.

- Schmidt, N.M., Berg, T.B. and Meltofte, H. 2011. BioBasis, Conceptual design and sampling procedures of the biological programme at Zackenberg Basic. 14th edition. National Environmental Research Institute, Department of Arctic Environment, Aarhus University, Roskilde.
- Schmidt, N.M., Baittinger, C., Kollmann, J. and Forchhammer, M.C. 2010. Consistent Dendrochronological Response of the Dioecious *Salix arctica* to Variation in Local Snow Precipitation across Gender and Vegetation Types. *Arctic, Antarctic, and Alpine Research* 42:471-475.
- Schmidt, N.M., Baittinger, C. and Forchhammer, M.C. 2006. Reconstructing Century-long Snow Regimes Using Estimates of High Arctic *Salix arctica* Radial Growth. *Arctic, Antarctic, and Alpine Research* 38: 257-262.
- Sjogersten, S., van der Wal, R. and Woodin, S.J. 2008. Habitat type determines herbivore controls over CO₂ fluxes in a warmer arctic. *Ecology* 89(8):2103-2116.
- Sohlberg, E. and Bliss, L.C. 1984. Microscale patterns of vascular plant distribution in two high-arctic communities. *Canadian Journal of Botany* 62:2033-2042.
- Streets, D., Zhang, Q. and Wu, Y., 2009. Projections of Global Mercury Emissions in 2050. *Environmental Science and Technology* 43:2983-2988.
- van Veen, F.J.F., Morris, R.J. and Godfray, H.C.J. 2006. Apparent competition, quantitative food webs and the structure of phytophagous insect communities. *Annual Review of Entomology* 51:187-208.
- van der Wal, R. 2006. Do herbivores cause habitat degradation or vegetation state transition? Evidence from the tundra. *Oikos* 114(1):177-186.
- van der Wal, R. and Sjogersten, S. 2007. Spring feeding by pink-footed geese reduces carbon stocks and sinks strength in tundra ecosystems. *Global Change Biology* 13(2):539-545.
- Weijers, S., Broekman, R. and Rozema, J. 2010. Dendrochronology in the High Arctic: July air temperatures reconstructed from annual shoot length growth of the circumarctic dwarf shrub *Cassiope tetragona*. *Quaternary Science Reviews* 29:3831-3842.
- Woodcock, H. and Bradley, R.S. 1994. *Salix arctica* (Pall.): Its potential for dendroclimatological studies in the high Arctic. *Dendrochronologia* 12:11-22.

Appendix A

Lichens

Lichens: Degree of covering (A), number of lichen thalli (B), maximum thallus diameter in cm (C), presence of lichens (D) in plots in 1994, 2000, 2005 and 2011, respectively.
 Epilithic lichen communities: L 1-L8, L 10, L15, L16 and L 20-L 22.
 Epigaeic communities: L 11-L14 and L 17-L 19.

The degree of covering was estimated using the following, modified scale of Hult-Sernander:

- 5 = ½
- 4 = ½-1/4
- 3 = ¼-1/8
- 2 = 1/8-1/16
- + = just present
- ++ = dominating

L1	1994	2000	2005	2011
<i>Xanthoria elegans</i>	+	+	+	+
<i>Xanthoria sorediata</i>	+	+	+	+
<i>Umbilicaria virginis</i>	+	+	+	+
<i>Umbilicaria lyngei</i>	+	+	+	+
<i>Usnea sphacelata</i>	+	+	+	-
<i>Physconia muscigena</i>	+	+	+	+
<i>Pseudephebe minuscula</i>	+	+	+	-
<i>Sporastatia testudinea</i>	+	+	+	+
<i>Rhizocarpon geographicum</i>	+	+	+	+
<i>Lecanora polytropa</i>	+	+	+	+
<i>Lecidea atrobrunnea</i>	+	+	+	+
<i>Rhizoplaca melanophthalma</i>	+	+	+	+
<i>Aspicilia</i>	+	+	+	+
<i>Placynthium</i>				+
<i>Stereocaulon</i>				+
Rock	+	+	+	+

L2	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Umbilicaria lyngei</i>	2	100	2	2	100	2	2	100	2.7	2	100	2.7
<i>Pseudephebe minuscula</i>	+	1		1	2		1	2	4.2	1	2	4.2
<i>Sporastatia testudinea</i>	+	1		1	2	4.5	1	2	5.5	1	2	5.5
<i>Rhizoplaca melanophthalma</i>	+	1		+	2		+	2	1.5	+	2	1.5
Rock	5			5			5			5		

L3	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Rhizocarpon geographicum</i>	4			4		7	4			4		7
<i>Sporastatia testudinea</i>	3			3			3			3		
<i>Umbilicaria lyngei</i>	+	10		1	13	1.5	1	16	1.5	1	20	1.5
<i>Pseudephebe minuscula</i>	+			+	6	1.5	+	9	2.2	+	16	2.4
Rock	2			2			2			2		

L4	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Physcia caesia</i>	D			D			D			D		
<i>Umbilicaria decussata</i>		13			40			48			50	
<i>Xanthoria candelaria</i>		12			22	0.5		32	1		38	1
<i>Miriquidica garovaglii</i>		4			6	1		6	2.2		6	2.8
<i>Candelariella vitellina</i>		2			7	0.5		7	0.5		7	0.5
<i>Sporastatia testudinea</i>		–			2	2		2	2.5		2	2.5
<i>Acarospora</i>		–			1	1.5		1			1	2.3
<i>Rhizoplaca melanophthalma</i>								1			1	
Rock	5			5			5			5		

L5	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Dimelaena oreina</i>	3			3			3			3		
<i>Umbilicaria lyngei</i>	1	15		1	15	1.5	1	20	2	1	23	2
<i>Sporastatia testudinea</i>	1	6		1	6		1	6		1	8	
<i>Rhizoplaca melanophthalma</i>	1	7		1	7	3	1	7	4	1	7	5
<i>Rhizocarpon geographicum</i>	1	5		1	6	1	1	6	2	1	6	2
<i>Rhizocarpon</i> (gray thallus)	1	2		1	2		1	2	9.5	1	2	10
<i>Pseudephebe minuscula</i>	+	1		1	7	2	1	7	2	1	7	2.8
<i>Umbilicaria decussata</i>				+	2	2	+	2	2.7	+	2	2.7
<i>Lecidea atrobrunnea</i>				+	2	1	+	2	2	+	2	2
<i>Caloplaca epithallina</i>										+	1	
Rock	5			5			5			5		

L6	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Umbilicaria virginis</i>		29			31	1.5		41	1.5		50	1.5
<i>Lecidea atrobrunnea</i>						3.2			3.7			4.2

L7	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Miriquidica garovaglii</i>	4			5		7	5		7	5		7
<i>Umbilicaria decussata</i>	2	12		2	20	2	2	20		2		16
<i>Rhizocarpon geographicum</i>	1			1	32		1	40		1	1.2	40
<i>Candelariella vitellina</i>	+			1			1			1		
Rock	4			4			4			4		

L8	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Parmelia saxatilis</i>	4			5			4			4		
<i>Umbilicaria decussata</i>	+			–			+	2	1.5	–		
<i>Pseudephebe minuscula</i>	–			+			–			–		
Rock	4			4			5			5		

L10	1994			2000			2005			2011		
	A	B	C	A	B	C	A	B	C	A	B	C
<i>Umbilicaria lyngei</i>	3		1.2	3		1.5	3		1.7	3		1.8
<i>Sporastatia testudinea</i>	2			2						2		
<i>Rhizocarpon cf. superficiale</i>	1			1			1	20	2.2	1	20	2.2
<i>Pseudephebe minuscula</i>	+			1			–			+		
Rock	4			4			4			4		

L11	1994		2000		2005		2011	
	A	B	A	B	A	B	A	B
<i>Cassiope</i>	5		5		5		5	
<i>Salix arctica</i>	1		1		1		1	
<i>Cetrariella delisei</i>	1	7	1	5	1	5	1	7
<i>Cetraria islandica</i>	1	5	1	5	1	3	1	3
<i>Stereocaulon alpinum</i>	1	4	1	4	1	6	1	7
<i>Peltigera malacea</i>	+	2	+	2	+	2	+	1
<i>Flavocetraria nivalis</i>	+	1	+	2	+	1	+	3
<i>Solorina crocea</i>	+	1	-		-		-	
<i>Cladonia pyxidata</i>	+		+		+		+	
<i>Cladonia borealis</i>	+		+		+		+	
<i>Ochrolechia frigida</i>	+		-		+	1	+	1
<i>Psoroma tenue</i>	+		+		+		+	
<i>Peltigera rufescens</i>	-		1	4	1	4	+	8
<i>Peltigera leucophlebia</i>	-		+	1	+	2	+	50
<i>Flavocetraria cucullata</i>	-		+	1	+	1	+	1
<i>Candelariella canadensis</i>							+	
<i>Psoroma hypnorum</i>							+	
Moss	1		1		1		1	

L12	1994		2000		2005		2011	
	A	B	A	B	A	B	A	B
<i>Dryas</i>	4		4		4		4	
<i>Carex rupestris</i>	3		3		3		3	
<i>Hierochloë alpina</i>	+		+		+		1	
<i>Salix arctica</i>	+		+		+		+	
<i>Potentilla</i>	+		+		+		+	
<i>Silene acaulis</i>					+		+	
<i>Stellaria longipes</i>	+		+		+		+	
<i>Cerastium</i>	-		-		-		+	
<i>Flavocetraria nivalis</i>	1	25	1	30	1	30	1	30
<i>Cetraria islandica</i>	1	20	1	20	1	20	1	20
<i>Stereocaulon alpinum</i>	1	10	1	10	1	30	1	30
<i>Peltigera rufescens</i>	1	10	1	<5	1	6	1	12
<i>Candelariella canadensis</i>	1	10	+	5	+	5	+	5
<i>Ochrolechia frigida</i>	1		1		1		1	
<i>Cetraria muricata</i>	+	10	+	4	+	5	+	5
<i>Cladonia borealis</i>	+	5	+	<5	+	5	+	5
<i>Cladonia pyxidata</i>	+		+	5	+	5	+	5
<i>Baeomyces placophyllus</i>	+		+		+		+	3
<i>Arthrorhaphis alpina</i>	-		+	5	+	7	+	7
<i>Candelariella terrigena</i>	-		+	2	+	2	-	
<i>Peltigera didactyla</i>	-		+		+		+	
<i>Psoroma tenue</i>	-		+		+		+	

L13	1994		2000		2005		2011	
	A	B	A	B	A	B	A	B
<i>Kobresia myosuroides</i>	5		5		5		5	
<i>Carex bigelowii</i>	+		+		+		+	
<i>Luzula confusa</i>	+		+		1		1	
<i>Hierochloa alpina</i>					+		+	
<i>Polygonum viviparum</i>	+		+		+		+	
<i>Dryas</i>	+		+		+		+	
<i>Cladonia pocillum</i>	+	25	+	25	+	25	+	>25
<i>Physconia muscigena</i>	+		+		+		+	7
<i>Cladonia borealis</i>	+		+		-		+	
<i>Rinodina turfacea</i>	+		+		-		-	
<i>Peltigera rufescens</i>					+	3	+	3
<i>Cladonia pyxidata</i>					+		+	
<i>Caloplaca cerina</i>							+	
<i>Cetraria muricata</i>							+	
<i>Peltigera didactyla</i>							+	

L14	1994		2000		2005		2011	
	A	B	A	B	A	B	A	B
<i>Dryas</i>	4		5		5		5	
<i>Carex rupestris</i>	3		3		3		3	
<i>Cladonia pocillum</i>	1		1		1		1	
<i>Thamnotia vermicularis</i>	+		1	36	1	>100	1	c. 100
<i>Flavocetraria nivalis</i>	+	10	+	10	+	10	+	15
<i>Hypogymnia subobscura</i>	+	4	+	3	+	9	+	10
<i>Alectoria nigricans</i>	+	2	+		+	3	+	3
<i>Bryoria chalybeiformis</i>	+	2	+	3	+	1	+	1
<i>Ochrolechia upsaliensis</i>	+	2	+		+	2	+	2
<i>Peltigera rufescens</i>	+	1	-		-		-	
<i>Peltigera venosa</i>	-		+	2	+	2	+	1
<i>Rinodina turfacea</i>	+	1	+		+		+	
<i>Baeomyces</i>	+	1	+		+		+	
<i>Catapyrenium cinereum</i>	+		+		+		+	
<i>Cladonia pyxidata</i>	+		+		+		+	
<i>Lecanora epibryon</i>	+		+		+		+	
<i>Phaeorrhiza nimbosa</i>	+		-		+		-	
<i>Ochrolechia frigida</i>	+				+		+	
<i>Physconia muscigena</i>	+		-		+	1	+	1
<i>Solorina bispora</i>	+		-		+		-	
<i>Flavocetraria cucullata</i>	-		+	3	+	3	+	3
<i>Cetraria muricata</i>	-	10	+		+	1	+	1
<i>Caloplaca cerina</i>			+		+		+	
<i>Caloplaca tirolensis</i>			+		+		+	
<i>Lecanora behringii</i>					+		+	
<i>Saxifraga oppositifolia</i>							+	4
<i>Buellia papillata</i>							+	
Moss	+	5	+					

L15	2000			2005			2011		
	A	B	C	A	B	C	A	B	C
<i>Dimelaena oreina</i>	3			3			3		
<i>Lecidea atrobrunnea</i>	2			2			2		
<i>Rhizoplaca melanophthalma</i>	1			1			1		
<i>Sporastatia testudinea</i>	1			1			1		
<i>Umbilicaria decussata</i>	1	45	1.3	1	50	1.7	1	60	1.8
<i>Phycia caesia</i>	+	6		+	6		+	6	
<i>Melanelia infumata</i>	+	3		+	3		+	3	
<i>Rhizocarpon geographicum</i>	+			+			+	1.7	
Rock	4			4			4		

L16	2000			2005			2011		
	A	B	C	A	B	C	A	B	C
<i>Umbilicaria lyngei</i>	3	>100	2.5	3	>100	3.7	3	>100	4
<i>Pseudephebe minuscula</i>	1			1			1		1.8
<i>Rhizocarpon</i> (yellow thallus)	1			1			1		2.2
<i>Sporastatia testudinea</i> ¹	1			1		3.4	1		3.5
<i>Umbilicaria hyperborea</i>	+	3		+	3		+	3	
<i>Melanelia disjuncta</i>	+	1		+	1		+	1	
Rock	4			4			4		

L17	2000	2005	2011
	A	A	A
<i>Cassiope tetragona</i>	5	5	5
<i>Carex bigelowii</i>	2	2	2
<i>Salix arctica</i>	2	2	2
<i>Polygonum viviparum</i>	1	1	+
<i>Stellaria longipes</i>	1	+	-
<i>Cladonia amaurocraea</i>	2	2	2
<i>Stereocaulon alpinum</i>	2	2	2
<i>Cetrariella delisei</i>	1	1	1
<i>Cladonia mitis</i>	1	+	+
<i>Cladonia borealis</i>	+	+	+
<i>Cladonia pyxidata</i>	+	+	+
<i>Cetraria islandica</i>	+	+	+
<i>Ochrolechia frigida</i>	+	+	+
<i>Peltigera leucophlebia</i>	+	+	+
<i>Peltigera malacea</i>	+	+	+
<i>Psoroma tenue</i>	+	+	+
<i>Sphaerophorus globosus</i>	+	+	+
<i>Cladonia trassii</i>	-	+	+
<i>Nephroma expallidum</i>	-	-	+
<i>Psoroma hypnorum</i>	-	-	+

L18	2000		2005		2011	
	A	B	A	B	A	B
<i>Cassiope tetragona</i>	4		4		4	
<i>Dryas</i>	2		2		2	
<i>Salix arctica</i>	2		2		2	
<i>Carex rupestris</i>	1		1		1	
<i>Saxifraga oppositifolia</i>	+		+		+	
<i>Cladonia mitis</i>	1		1		2	
<i>Stereocaulon alpinum</i>	1		1		1	
<i>Cetrariella delisei</i>	+	15	+		+	15
<i>Flavocetraria cucullata</i>	+	<10	+		+	<10
<i>Arthrorhaphis alpina</i>	+	5	+		+	10
<i>Candelariella placodizans</i>	+	3	+	4	+	7
<i>Cladonia trassii</i>	+	2	+		+	2
<i>Baeomyces</i>	+		+		+	
<i>Cladonia phyllophora</i>	+		+		+	
<i>Cladonia pocillum</i>	+		+		+	
<i>Cladonia pyxidata</i>	+		+		+	
<i>Peltigera didactyla</i>	+		+		+	3
<i>Psoroma tenue</i>	+		+		+	
<i>Solorina bispora</i>	+		+		+	
<i>Caloplaca</i>	-		+		+	
<i>Buellia papillata</i>					+	
<i>Cladonia borealis</i>					+	2
Moss	2		2		2	
Bare soil	3		3		3	

L19	2000		2005		2011	
	A	B	A	B	A	B
<i>Cassiope tetragona</i>	5		5		5	
<i>Carex bigelowii</i>	2		2		2	
<i>Salix arctica</i>	2		2		2	
<i>Polygonum viviparum</i>	-		+		+	
<i>Stellaria longipes</i>	+		+		+	
<i>Cladonia mitis</i>	2		2		3	
<i>Cladonia phyllophora</i>	1		1		1	
<i>Stereocaulon alpinum</i>	1		1		1	
<i>Thamnolia vermicularis</i>	+	20	+		+	
<i>Cetrariella delisei</i>	+		+		+	
<i>Cladonia amaurocraea</i>	+		+		+	
<i>Cladonia borealis</i>	+		+		+	
<i>Cladonia pyxidata</i>	+		+		+	
<i>Peltigera scabrosa</i>	+		+		+	
<i>Psoroma tenue</i>	+		+		+	
<i>Pertusaria geminipara</i>					+	
<i>Cladonia borealis</i>					+	
<i>Cladonia macroceras</i>					+	
Moss	2		2		2	

L20	2011		
	A	B	C
<i>Phycia dubia</i>	3		
<i>Xanthoria candelaria</i>	3		
<i>Rhizoplaca melanophthalma</i>	1	12	1.4
<i>Rhizocarpon geographicum</i>	+	1	0.5
<i>Umbilicaria decussata</i>	+		
<i>Xanthoria elegans</i>	+	2	1.3
Rock	4		

L21	2011		
	A	B	C
<i>Xanthoria elegans</i>	3	9	6.5
<i>Physconia muscigena</i>	1	1	5.6
<i>Caloplaca alcarum</i>	+		
<i>Lecanora contractula</i>	+		
<i>Lecidea</i>	+		
Rock	5		

L22	2011		
	A	B	C
<i>Xanthoria elegans</i>	5		
<i>Lecidea tessellata</i>	3		1.3
<i>Phycia dubia</i>	1	12	
<i>Lecanora contractula</i>	+	1	
Rock	4		

Appendix B

Julian days

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

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

