Zackenberg Ecological Research Operations

5th Annual Report, 1999

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Cover photo: The Swedish botanist Anna Joabsson at her research site on wet tundra making chamber measurements of CH_4 and CO_2 fluxes. Photo Henning Thing / PolarPhotos.

Table of contents

1 Introduction 7
International cooperation 7
Zackenberg scholarships 7
Marketing 7
Plans for the year 2000 field season 7
Zackenberg Station and the study area 8

2 Logistics 9
Transportation 9
Accommodation 9
Electrical power production 9
Telecommunication 9

3 Zackenberg Basic: The GeoBasis and ClimateBasis programmes 10
3.1 The meteorological station 10
Meteorological data from 1998 10
Meteorological data from 1999 13
3.2 TinyTalk / TinyTag datalogger 14
3.3 The hydrometric station 15
The Q / h-relation 16
River water discharge 16
Suspended sediment 17
Water chemistry, pH, temperature and conductivity 18
3.4 Landscape monitoring 18
Monitoring photos 18
Active layer depth 19
Soil water chemistry 20
Coastal geomorphology 22
3.5 General observations on ice conditions 22
Lake and streams 22
The fiord 23

4 Zackenberg Basic: The BioBasis programme 24
4.1 Vegetation 25
ITEX reproductive phenology 25
ITEX quantitative flowering 26
Relative Vegetation Indexes (RVI) 26
Normalized Difference Vegetation Indexes (NDVI) 27
Berry production 27
4.2 Arthropods 28
Pittfall traps 28
Window traps 31
Predation on *Dryas* flowers by larvae of *Sympistis* zetterstedtii 31
Predation on *Salix arctica* 31
Bumble bees 32
4.3 Birds 32
Breeding populations 32

Reproductive phenology in waders (shorebirds) 33
Breeding success in waders 33
Reproductive phenology and success in long-tailed skuas 34
Breeding barnacle geese 35
Line transect 35
Sandøen 36
Other observations 36
4.4 Mammals 39
Collared lemming population 39
Muskox population biology 40
Arctic fox dens 42
Line transects 42
Other observations 43
4.5 Lake monitoring 43

5 Research projects 46
5.1 Carbon cycling and trace gas exchange in the Zackenbergdalen 46
The fen experiments 46
The heath experiments 47
Dry *Kobresia-Dryas-Salix arctica* heath experiment 47
5.2 Uptake and emission of CH_4 in Zackenbergdalen 47
5.3 The Zackenberg contribution to the panarctic flora 48
5.4 Thermophilous plants in Svalbard: conservation, immigration, and implication for global warming 48
5.5 Higher *Basidiomycetes* in Zackenbergdalen 49
5.6 Global change effects on unicellulars and plants 49
Communities and ecology of unicellulars 49
Heating experiment 50
Fieldwork in 1999 52
5.7 Freshwater studies 52
Macrophyte productivity in the shallow lakes in Morænebakkerne ... 53
Benthic and pelagic primary production of microalgae in shallow lakes around Zackenberg 53
Lake investigations in Lille Sødal 54
Distribution and density of *Lepidurus arcticus* in ponds and shallow lakes around Zackenberg 55
5.8 Raising a family on capital or income. Breeding strategies among birds 55
5.9 Collared Lemming Project – Zackenberg 56
5.10 The non-marine enchytraeid fauna of north-eastern Greenland 58
5.11 Turbulent exchange of carbon dioxide, water vapour and energy, and the physical atmosphere-landsurface environment 58
5.12 Snow cover distribution in Zackenbergdalen 59
5.13 Dynamics of high arctic soils. Physical and chemical processes in the active layer – permafrost system 60
5.14 Plant cover effects on soil development 63
5.15 Changes in Arctic Marine Production 64
Bathymetri and hydrographic descriptions 65
Physical and chemical properties of sea ice 65
Sea ice algal production and grazing 66

Pelagic primary production and grazing 67
Mineralization in the water column and sea ice 67
Sedimentaiton and mineralization in the sediment 68
Primary production of coralline algae 69
Macroalgal primary production 70
Filtration and respiration of benthic infauna 71
Studies of walrus energetics and behaviour 72
Public relations 73
Future studies 73
5.16 Foraging strategies by muskoxen cows 73

6 Disturbances in the study area 76
Surface activities 76
Aircraft activities 76
Discharges 76
Manipulative research projects 76
Take of organisms 76

7 Publications from ZERO 99 78
Scientific papers 78
Reports 78
General information 78

8 Personnel and visitors 80
Research 80
Logistics 82
Others 82
Further contributors to the annual report 82

9 Acknowledgements 84

10 References 85

1 Introduction

Morten Rasch

Also this year, Zackenberg Station experienced an increase in the number of people using the station. In total, 38 scientists worked from the main station at Zackenberg, and 26 scientists worked from the Daneborg facility for marine research. The number of overnights added up to 2077, an increase of 42% compared to 1998. In the busiest period in the beginning of August, the station at Zackenberg was a bit crowded, and with the existing facility an increase of the activity can not be recommended. An extension of the main station at Zackenberg with a house for accommodation is being considered in the Zackenberg Secretariat.

International cooperation

In 1999, Zackenberg Station has become involved in two larger international initiatives, ENVINET and SCANNET.

ENVINET is a European station manager network consiting of seventeen arctic and alpine research facilities. This programme is funded by EU. The purpose of the programme is to increase cooperation and networking between operators and users at the infrastructures of environmental science and to enhance the use of the participating stations. The first ENVINET meeting will be held in Ny Ålesund from 22 to 25 June 2000.

In cooperation with Abisko Scientific Research Station (Sweden) and Ny Ålesund Large Scale Facility (Svalbard), Zackenberg Secretariat has taken initiative to establish the research and monitoring network, SCANNET. SCANNET is a Scandinavian / Scottish programme constituted by ten research stations around the North Atlantic Ocean. The purpose of the programme is to coordinate monitoring and processing of existing environmental data from this climate sensitive region. EU has been applied for funding for the programme. SCANNET is already considered as one of the IGBP transects in the Arctic.

Zackenberg scholarships

In 1997 two Zackenberg scholarships were funded for the period 1998-2000 by the Danish Ministry of Research and Information Technology in cooperation with the Greenlandic Ministry of Health, Environment and Research. In 1999, the scholarships were awarded to the two Greenlandic university students, Nanna Høegh and Nicolai Herman Jørgensen. Nanna Høegh worked on CO_2 and CH_4 fluxes from lakes and delta areas at Zackenberg as a part of her PhD study (see section 5.2) while Nicolai Herman Jørgensen studied the behaviour of muskoxen as a part of his graduate study (see section 5.16). The stay at Zackenberg turned out as a great succes for both scholarship holders.

Marketing

Attempts were made to further improve the visibility of Zackenberg Station in the international research community. A new Zackenberg homepage has been produced (www.zackenberg.dk), a Zackenberg folder has been published and a Zackenberg poster is in preparation. It is our hope that the scientists already working at Zackenberg and other 'Zackenbergers' will help us distribute folders and posters by bringing the material with them to conferences around the world. The material can be ordered at the Zackenberg Secretariat (see address below).

Plans for the year 2000 field season

The activity at Zackenberg in year 2000 is expected to be less than in the previous three years, both at the main station at Zackenberg and at the Daneborg facility for marine research. This will allow the logisticians to take out time to maintain the station. The houses will be painted, a new radio mast will be established, the passage over the river will be improved, a new water containing system will be introduced, and the waste containers will be secured to withstand polar bears.

Zackenberg Station and the study area

Details about Zackenberg Station, the study area at Zackenberg and the administrative structure for the Zackenberg work have been given in previous annual reports (Meltofte and Thing 1996 and 1997; Meltofte and Rasch 1998; Rasch 1999), and information is also available on the website (www.zackenberg.dk).

The ZERO Site Manual has all the necessary information about journeys to the Zackenberg Station. The site manual can be obtained together with the Zackenberg Application Form from the Zackenberg homepage (www.zackenberg.dk) or by writing or phoning directly to the Zackenberg Secretariat, Danish Polar Center, Strandgade 100H, DK-1401 Copenhagen K, Denmark, phone: +45 3288 0100, fax: +45 32880101, e-mail: mr@geogr.ku.dk.

2 Logistics

Aka Lynge

In 1999, Zackenberg Station was open 103 days, from 29 May to 9 September. In this period, 38 scientists, 5 logisticians and 6 pilots or air mechanics worked at the station, and 15 guests paid Zackenberg Station a visit. The neighbouring station, Daneborg, was used in the periods 7 June-5 July and 4-26 August by 29 scientists, and visited by 6 guests. The total number of person days at Zackenberg and Daneborg was 2077, a considerable increase compared to person days the previous years: *105* (1991), *250* (1992), *0* (1993), *210* (1994), *321* (1995), *1422* (1996), *1462* (1997), *1474* (1998).

Transportation

The team to open Zackenberg was delayed by bad weather and snow, and used 4 days to get from Copenhagen to NE Greenland. They had to leave the Twin-Otter in Daneborg as there was too much snow on the air strip in Zackenberg. Two persons traversed the last 25 km on ski to Zackenberg Station to collect the ATV (All Terrain Vehicle), in order to pick up the rest of the team.

The number of landings was 16 in 1999, 11 in connection with arrival and departure of scientists and 10 in connection with freight from Daneborg. Further, two helicopter flights were used to fly to and from Store Sødal (scientists and equipment.)

As in previous years, transportation of heavy material took place with an ATV. Transportation was kept to a minimum in order to spare the environment. The ATV was only used outside the transportation corridor while there was still a snow cover.

Accommodation

Again in 1999, the Canadian Weatherhaven shelters were used to accommodate guests at Zackenberg. Although the shelters are still sound and strong, they are undeniably growing old. However, the scientists at Zackenberg may expect new accommodation facilities in 2001. By then we hope to be able to build new accommodation facilities with electricity, water and heating, as well as a larger livingroom.

Electrical power production

Due to experiences from earlier years a powerful generator was purchased in 1999. Until then electricity production was based on two small and noisy generators with insufficient capacity.

The new generator arrived in late June and it felt like sheer luxury (Fig. 2.1). At 21.15 hours on 6 July the generator was well installed and provided the whole station with more than sufficient electricity. For about a week the new era was celebrated by leaving all lights and power supplied tools on, to ensure the best performance of the generator.

Telecommunication

As in previous years, communication between Zackenberg and the world outside NE Greenland took place through satellite, telephone, fax, and e-mail. Telecommunication is still expensive, but considering the distant location, it worked satisfactory most of the time. The internet server at the Geographical Institute of the University of Copenhagen was used for e-mail transmission, and this was the most reliable solution tried out so far.

Fig. 2.1. A new 14.4 kW generator was purchased in 1999. The generator weighs 600 kg, and a crane was necessary to unload the generator from the Twin Otter. Photo: Aka Lynge, PolarPhotos.

3 Zackenberg Basic: The GeoBasis and ClimateBasis programmes

The GeoBasis and ClimateBasis programmes collect data describing the dynamics of the physical and geomorphological environment at Zackenberg. GeoBasis is operated by the Institute of Geography, University of Copenhagen, while ClimateBasis is operated by ASIAQ, Greenland Field Investigations. GeoBasis takes care of geomorphological monitoring, monitoring of water quality in rivers and soils and active layer monitoring. ClimateBasis operates the climate station and the hydrometric station.

Locations and specifications of GeoBasis and ClimateBasis installations are described in previous annual reports (Meltofte and Thing 1996 and 1997; Meltofte and Rasch 1998; Rasch 1999). Data collected by the two programmes may be ordered from Institute of Geography, University of Copenhagen (e-mail: mr@geogr.ku.dk).

3.1 The meteorological station

Lars Thomsen and Morten Rasch

The meteorological station at Zackenberg was constructed in the summer of 1995. The technical specification of the station is described in Meltofte and Thing (1996). Two major changes have been made since the station was established. In the 1997 field season, the radiation sensors were moved to a separate mast, and a mast for snow depth measurements was erected (see Meltofte and Rasch 1998).

The reason for moving the radiation sensors was that the vegetation in the nearest surroundings of the meteorological station had suffered from the intense traffic in the area. The resulting change of the terrain surface is expected to have changed the albedo of the surface.

In the 1999 field season no major changes to the station were conducted. As a minor change, the installation of soil temperature sensors in the ground was improved. In previous years there has been a problem with water percolating down through the soil along the sensor cables during the first intense snow melt. All sensors were calibrated and checked by ASIAQ – Greenland Field Investigations. Lars Thomsen (ASIAQ) performed all data processing on climate data from 1998 / 1999.

Most precipitation at Zackenberg falls as snow. The meteorological station is equipped with both a tipping bucket and a Belfort precipitation gauge. Neither of these sensors will measure snow precipitation very accurate. Therefore, they are suplemented by a snow depth sensor (Sonic Range). Besides, a digital camera on the mountain Zackenbergfjeldet is used to register the spatial distribution of snow in the southern part of Zackenbergdalen.

Table 3.1. Wind statistics 1998, 7.5 meters above terrain. Calm is defined as wind speed ≤ 0.5 m/s. Max Speed is the max wind gust in the given direction. Wind speeds are given in m/s.

Direction	Observations	Frequency	Mean Speed	Max. Speed
N	3938	7.9	4.2	41.3
NNE	1237	2.5	2.3	33.2
NE	1019	2.0	2.9	35.2
ENE	1199	2.4	1.9	19.7
E	2167	4.3	1.9	14.6
ESE	2931	7.9	2.1	11.4
SE	4093	8.2	2.1	14.4
SSE	2254	4.5	2.1	11.5
S	2079	4.2	2.2	13.8
SSW	1632	3.3	2.1	12.5
SW	1536	3.1	2.1	12.9
WSW	1638	3.3	2.4	12.8
W	1537	3.1	2.1	19.3
WNW	1879	3.8	2.5	26.4
NW	3865	7.7	3.8	31.9
NNW	13374	26.8	5.1	34.0

Meteorological data from 1998

Lars Thomsen

In Table 3.1 statistics of the measured wind speeds and directions are given, while Table 3.2 shows a summary of all the measured climatic parameters. Tables 3.3 and 3.4 show monthly mean values of climate and ground temperatures.

In 1998, the mean air temperature measured 2 m above terrain was -10.0°C, the maximum temperature was 13.8°C (mid

Parameter	Mean	Max.	Min.
Air temperature, 2 m above terrain (°C)	-10.0	13.8	-38.9
Air temperature, 7.5 m above terrain (°C)	-9.4	13.6	-37.1
Relative air humidity 2 m above terrain (%)	72.7	99.3	30.6
Relative air humidity 7.5 m above terrain (%)	71.1	99.7	26.6
Air Pressure (hPa)	1,010	1,035.6	974.7
Incoming shortwave radiation (W/m²)	171.1	833.0	0
Outgoing shortwave radiation (W/m²)	70.1	631.6	0
Net Radiation (W/m²)	11.7	556.7	-118.4
Wind Velocity, 2 m above terrain (m/s)	2.6	34.0	0
Wind Velocity, 7.5 m above terrain (m/s)	3.2	41.3	0
Ground temperature, 0 cm below surface (°C)	-7.3	16.5	-18.1
Ground temperature, 2.5 cm below surface (°C)	-7.7	19.9	-18.1
Ground temperature, 5 cm below surface (°C)	-6.7	17.0	-17.3
Ground temperature, 10 cm below surface (°C)	-6.2	13.0	-16.4
Ground temperature, 20 cm below surface (°C)	-7.4	8.0	-17.3
Ground temperature, 40 cm below surface (°C)	-8.2	3.5	-16.6
Ground temperature, 60 cm below surface (°C)	-6.3	2.8	-13.2
Ground temperature, 80 cm below surface (°C)	-6.1	1.2	-11.9
Ground temperature, 100 cm below surface (°C)	-7.3	-0.6	-12.9
Ground temperature, 130 cm below surface (°C)	-7.7	-2.2	-12.0
Precipitation (mm w.e.), total	181 mm		

Table 3.2. Summary of selected climate parameters 1998.

Year	Month	Air Temperature °C 2.0 m	°C 7.5 m	Relative humidity % 2.0 m	% 7.5 m	Air Press hPa	Net Rad. W/m²	Shortwave Rad. W/m² In	W/m² Out	Wind Velocity m/s 2.0 m	m/s 7.5 m	Dominant Wind Dir. 7.5 m
1998	Jan	-21.3	-20	62,2	59,4	1012,9	-23	0.3	0.3	3.4	3.9	NNW
1998	Feb	-19.7	-19	66,7	64	1005,4	-29	15.9	8.6	5.3	6.7	NNW
1998	Mar	-17.5	-16.6	69,4	66,5	1004,2	-10	96.9	63.1	5.6	4.5	NNW
1998	Apr	-13.1	-12.1	69,7	68,2	1016,2	-18	220.3	162.1	1.9	2.1	NNW
1998	May	-6.5	-6.2	76,1	75,7	1012,5	-8	282.5	229.0	1.9	2.2	NNW
1998	Jun	0.9	0.8	87,5	87,3	1016,9	51	269.2	172.3	1.4	1.6	ESE/SE
1998	Jul	4.7	4.4	81,5	80,9	1008,2	126	204.4	20.1	2.1	2.4	SE
1998	Aug	4.6	4.5	83,8	83,8	1004,4	64	123	12.3	2.1	2.4	ESE/SE
1998	Sept	-2.4	-2.3	76,8	76,1	1017,7	16,2	124,3	9.9	1.8	2.1	NNW
1998	Oct	-9.6	-8.8	70,3	67,5	1005,5	-26	35.9	6.3	3.6	4.3	NNW
1998	Nov	-13.9	-13.0	69,5	67,1	1012	-23	1.7	0.7	3.5	4.1	NNW
1998	Dec	-22.7	-21.5	61,4	59,1	1003,7	-33	0.3	0.2	2.8	3.3	NNW
1999	Jan	-22.0	-20.9	67,4	65,7	1003	-27	0.5	0.3	3.6	4.7	NNW
1999	Feb	-19.7	-18.8	70,7	67,9	1001,8	-18	13.2	7.5	4.2	5.7	NNW
1999	Mar	-18.0	-16.8	66	63,5	1014,7	-26	109.6	69.3	3.5	3.8	-
1999	Apr	-15.2	-13.9	61,6	58,1	1015,8	-27	201.1	157.1	2.4	2.9	-
1999	May	-4.1	-3.8	76,8	74,1	1010,3	-9,8	229.7	193.2	4.0	4.8	-
1999	Jun	1.5	1.6	78,1	77,1	1002,8	33,1	293.6	207.1	1.9	2.3	-
1999	Jul	6.2	6.1	76,8	76,1	1005,5	124	212.2	31.8	2.2	2.6	-
1999	Aug	2.9	2.7	80,8	81,4	1008	74,7	151.5	16.2	2.1	2.4	SE

Table 3.3. Monthly mean values of selected climate parameters, January 1998-August 1999.

July) and the minimum temperature was -38.9°C (end of February). The temperature varies much more in winter than in summer. The period with frequent temperatures above 0°C started in late May and ended in mid September.

The total amount of measured precipitation in 1998 was 181 mm w.e. This value is

Table 3.4. Monthly mean values of ground temperatures, January 1998-August 1999.

Year	Month	0 cm	-2.5 cm	-5 cm	-10 cm	-20 cm	-40 cm	-60 cm	-80 cm	-100 cm	-130 cm
1998	Jan	-15.2	-15.2	-14.4	-13.6	-14.6	-14.2	-1.2	-10.2	-11.2	-10.3
1998	Feb	-15.0	-15.1	-14.4	-13.6	-14.7	-14.7	-12.2	-11.3	-12.4	-11.6
1998	Mar	-14.3	-14.5	-13.7	-13.0	-14.1	-14.2	-11.9	-11.2	-12.3	-11.8
1998	Apr	-12.6	-12.8	-12.0	-11.3	-12.5	-12.9	-11.0	-10.5	-11.7	-11.6
1998	May	-10.5	-10.6	-9.9	-9.2	-10.6	-11.3	-9.8	-9.6	-10.9	-11.1
1998	Jun	-1.1	-1.4	-0.9	-0.7	-2.7	-4.5	-4.4	-5.2	-7.0	-8.5
1998	Jul	7.6	7.8	7.7	7.4	4.3	0.7	0.9	-0.1	-1.9	-4.4
1998	Aug	5.8	5.8	6.3	6.5	4.4	2.1	2.4	1.0	-0.9	-2.9
1998	Sept	-1.4	-1.5	-0.2	0.8	-0.2	-0.6	1.0	1.0	-0.7	-2.4
1998	Oct	-9.0	-9.6	-8.0	-6.9	-7.6	-6.6	-3.6	-2.3	-3.5	-3.4
1998	Nov	-8.5	-8.9	-7.7	-6.9	-8.0	-8.2	6.0	-5.2	-6.3	-6.0
1998	Dec	-12.9	-13.5	-12.2	-11.3	-12.2	-12.0	-9.5	-8.2	-9.2	-8.2
1999	Jan	-14.6	-15.0	-13.9	-13.1	-14.2	-14.2	-11.8	-10.6	-11.7	-10.6
1999	Feb	-13.4	-13.7	-12.7	-12.0	-13.1	-13.3	-11.2	-10.4	-11.5	-10.9
1999	Mar	-11.6	-11.7	-10.9	-10.2	-11.5	-12.0	-10.1	-9.7	-10.9	-10.7
1999	Apr	-12.0	-12.2	-11.3	-10.6	-11.8	-12.2	-10.3	-9.7	-10.9	-10.7
1999	May	-10.4	-10.5	-9.7	-9.1	-10.5	-11.1	-9.4	-9.2	-10.5	-10.6
1999	Jun	-2.3	-2.3	-1.8	-1.4	-3.2	-4.7	-4.1	-5.0	-6.6	-8.0
1999	Jul	7.6	7.9	8.0	7.4	3.7	0.2	0.5	-0.3	-2.2	-4.3
1999	Aug	5.1	4.3	4.9	5.4	3.4	1.2	1.8	0.8	-0.9	-2.9

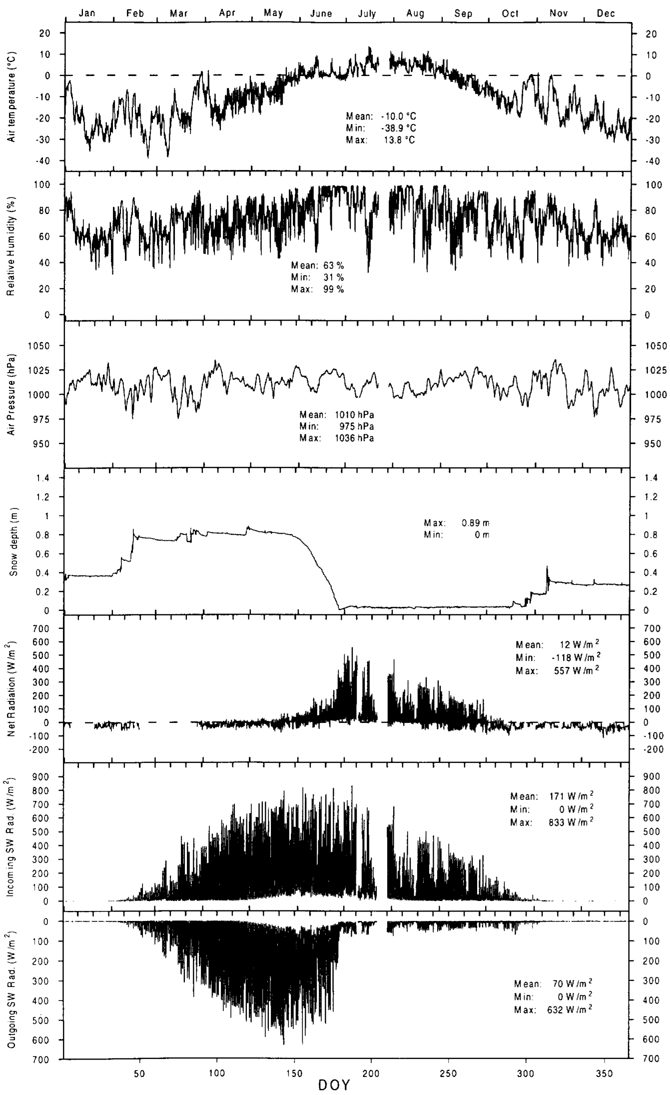


Fig. 3. 1. Variation in 1998 of selected climate parameters. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming shortwave radiation and outgoing shortwave radiation. All parameters are measured two meters above terrain.

probably too low, due to frozen gauge during winter. The registrations indicate that no precipitation occurred from January to March 1998, whereas the snow depth sensor registered approximately 0.5 meter of snow accumulation during the same period.

The mean air pressure was 1010 hPa. During the summer the air pressure was generally higher and more stable than in winter.

The relative humidity during summer was higher than during the rest of the year. Mean relative humidity was 72.7%. As for other climate parameters the relative humidity varies more during winter than summer due to more unstable weather conditions.

The mean net radiation in 1998 was 11.7 W / m^2. During winter the net radiation was consistently negative. Fig. 3.1 shows that the net radiation increased instantly when the last snow melted away at the climate station in the end of June.

Mean wind speed velocity 2 and 7.5 m above ground was 2.0 and 3.2 m / s, respectively. The highest wind velocity measured was 34.0 m / s at 2 m above ground and 41.3 m / s at 7.5 m above ground. The wind velocity was generally higher and fluctuated more in winter than in summer.

The dominant wind direction during winter was NNW, in summer between ESE and SE (Fig. 3.2).

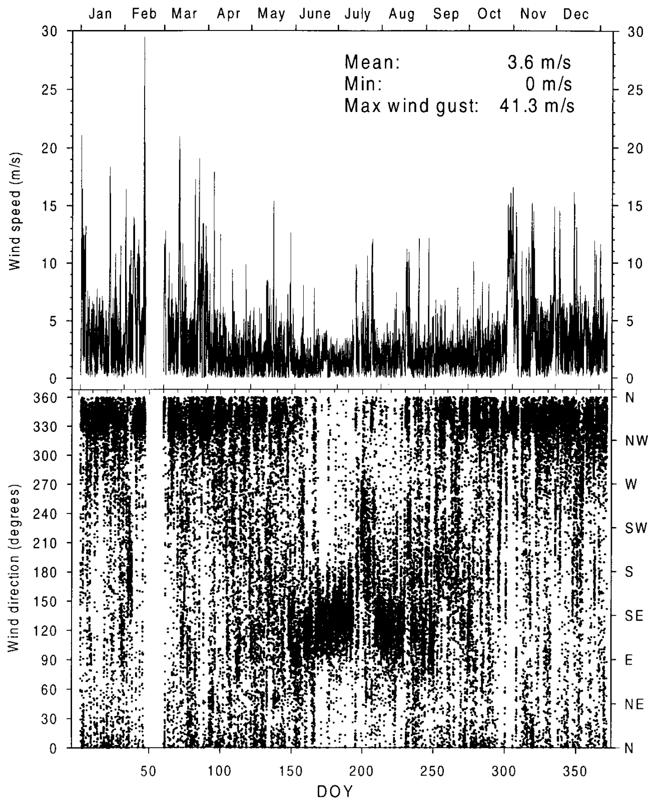


Fig. 3. 2. Variation in wind speed (m/s) and wind direction 1998. Parameters are measured 7.5 meters above terrain.

Table 3.4 shows the monthly mean ground temperatures in different depth. At -100 cm the ground is permanently frozen throughout the year. The temperatures in the uppermost layers exceed the air temperature during summer due to heat absorption (Table 3.2).

Meteorological data from 1999

Lars Thomsen and Morten Rasch

The variations of selected climatic parameters until 7 September are shown in Figs 3.3 and 3.4. The maximum snow depth in 1999 was much larger than in previous years. This resulted in much later disappearance of the snow. On 11 March the snow depth reached its maximum of 1.30 m at the climate station. Extensive snowmelt started at 21 May, and the snow did not disappear from the climate station before 15 July. This is 18 days later than in 1998. Also data from the digital camera on Zackenbergfjeldet (see section 5.12) indicate late snowmelt in 1999. The camera covers the southern part of Zackenbergdalen, and snow depletion curves for the area below 100 m a.s.l have been calculated for 1998 and 1999 (Fig. 5.18). These curves indicate that snowmelt in 1999 was approximately one week delayed compared to 1998.

A special weather situation occurred at the end of March 1999. In less than three and a half days the air temperature rose from -36°C to 5°C and stayed above zero for approximately 12 hours. The temperature increase from -36°C to 5°C is the most extreme temperature increase ever measured at Zackenberg.

Unfortunately, the wind direction sensor was damaged during a storm on 27 February and was not replaced until late August.

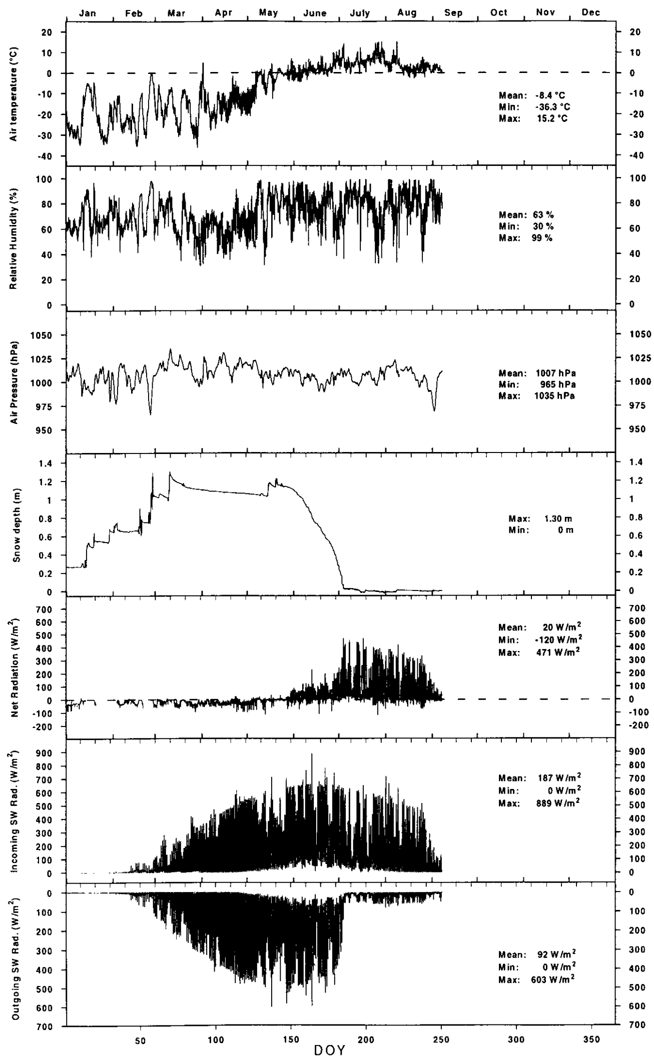


Fig. 3.3. Variation in 1999 of selected climate parameters. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming shortwave radiation and outgoing shortwave radiation. All parameters are measured two meters above terrain.

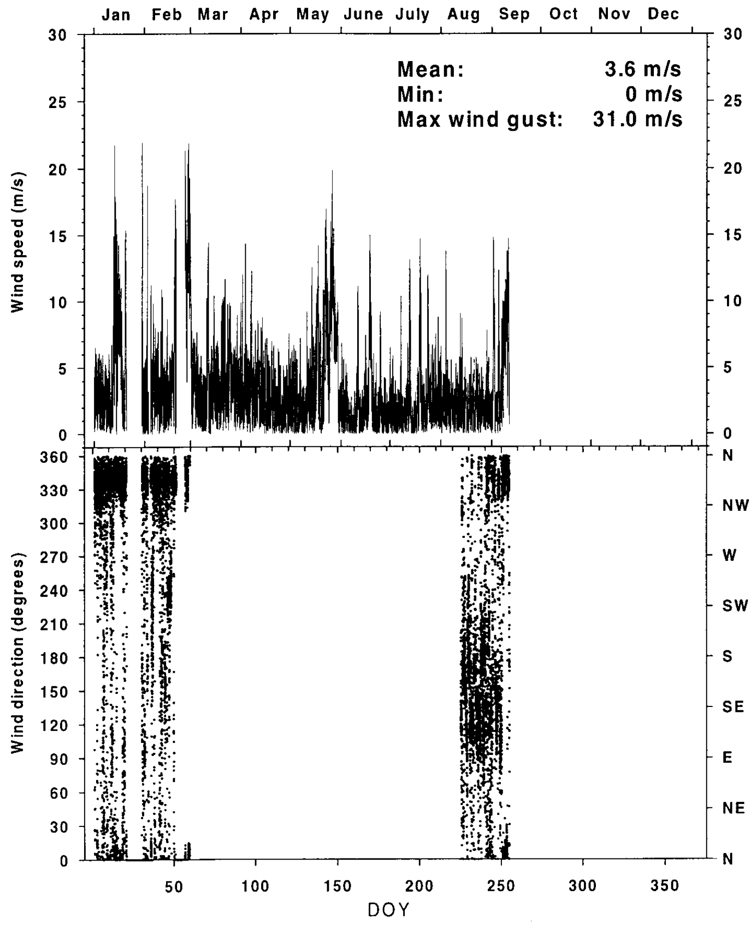


Fig. 3.4. Monthly mean values of ground temperatures, January 1998-August 1999.

3.2 TinyTalk/TinyTag datalogger

Morten Rasch

In 1999, GeoBasis operated 30 TinyTag/-TinyTalk temperature dataloggers. Position, purpose, interval between measurements and period of operation for all dataloggers are given in Table 3.2.1 in Meltofte and Rasch (1998). Statistics on time series from the period 1996-98 are given in Table 3.5. Most of the dataloggers (21) are used to measure soil temperature profiles at six different sites in different geomorphological settings at different altitudes. Three dataloggers measure air temperature in respectively Morænebakkerne, Store Sødal and on the top of Aucellabjerg, and two dataloggers measure water temperature in Zackenbergelven and Gadekæret. Finally, four dataloggers are used to describe the air temperature around and inside a large snowpatch. The advantage in using Tiny-Tag/TinyTalk dataloggers is mainly the low price of the dataloggers.

Data from three dataloggers at the P5 site were not downloaded in 1999. The quality control of data from the remaining dataloggers identified failures in the time series from 13 out of the 27 dataloggers, probably due to failures in the dataloggers. One datalogger was destroyed during the spring flood in 1999. The remaining 12 defect dataloggers were, however, damaged without any physical influence. Most of these dataloggers have temperature probes installed at different depths in relatively wet soils (P2, P3, P6). It is worth noting that on the three wet sites, only the dataloggers with probes on the ground (at 0 cm) did not fail. This indicates probably that the failures are due to corrosion of the

	Datalogger	Type
Active layer temperature profile	P1, 0 cm	Tin
	P1, 10 cm	Tin
	P1, 50 cm	Tin
	P1, 118 cm	Tin
Active layer temperature profile	P2, 0 cm	Tin
	P2, 10 cm	Tin
	P2, 70 cm	Tin
	P2, 155 cm	Tin
Active layer temperature profile	P3, 0 cm	Tin
	P3, 10 cm	Tin
	P3, 66 cm	Tin
Active layer temperature profile	P4, 0 cm	Tin
	P4, 10 cm	Tin
	P4, 85 cm	Tin
Active layer temperature profile	P5, 0 cm	Tin
	P5, 75 cm	Tin
	P5, 135 cm	Tin
Active layer temperature profile	P6, 0 cm	Tin
	P6, 10 cm	Tin
	P6, 30 cm	Tin
	P6, 60 cm	Tin
Air temperature in Morænebakkerne	T1	Tin
Air temperature in Store Sødal	T2	Tin
Air temperature on Aucellabjerg	T3	Tin
Water temperature in Zackenbergelven	V1	Tin
Water temperature in Gadekæret	V2	Tin
Air/snow temperature in snow patch	S1, Plateau	Tiny
	S1, Slope	Tiny
	S1, Snow	Tiny
	S1, Below	Tiny

sensor cables allowing water to penetrate into the dataloggers through the plug. Based on these experiences, the factory will introduce waterproof plugs in all new dataloggers for Zackenberg.

Since the failures probably are due to leaky cables, reinsertion of new and more resistant temperature sensors are necessary to avoid similar problems in the future. Therefore, it has been decided to install more resistant sensors at site P6 (the fen area south of the ZeroCalm-2 site). At the remaining wet sites, only air temperature will be measured in the future.

3.3 The hydrometric station

Mogens Brems Knudsen and Morten Rasch

The hydrological measurements started at Zackenbergelven in 1995. The hydrometric station is described in detail in Meltofte and Thing (1996). The station records the water discharge from the drainage basin of Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km^2. Out of this, 106 km^2 are covered by glaciers.

At the station, the water level is logged automatically with a sonic range sensor.

e	Position Easting (m)	Northing (m)	Elevation (m a.s.l.)	1996 Mean	Min. °C	Max. °C	1997 Mean °C	Min. °C	Max. °C	1998 Mean °C	Min. °C	Max. °C
yTag	512,388	8,263,490	20	-7.7	-37.6	29.9	-9.8	-40.7	30.7	-9.1	-40.7	28.1
yTag				-10.5	-32.6	15.0	-9.6	-39.1	19.1	-8.8	-37.6	17.0
yTag				-6.7	-25.2	7.3	-9.0	-29.4	8.8	-8.3	-28.4	7.3
yTag				-5.9	-15.6	-0.1	-8.1	-18.3	-0.1	-7.8	-17.6	0.6
yTag	512,713	8,264,257	23	-5.6	-30.5	34.1	-7.8	-29.4	25.9	-7.5	-24.1	22.0
yTag				-6.1	-24.6	12.4	-8.4	-25.7	12.8	X	X	X
yTag				-6.0	-19.1	2.3	-8.1	-19.6	2.3	X	X	X
yTag				-6.5	-14.6	-1.4	-8.6	-16.4	-1.8	X	X	X
yTag	515,917	8,268,224	ca. 400	-6.2	-31.5	25.2	-9.6	-36.3	23.4	-7.8	-34.8	23.4
yTag				-5.9	-27.5	18.1	X	X	X	X	X	X
yTag				-5.5	-20.3	6.9	-8.7	-23.3	6.5	X	X	X
yTag	516,936	8,269,597	ca. 820	-8.5	-33.7	27.0	-10.6	-39.1	27.4	-8.2	-27.5	30.7
yTag				-8	-28.4	16.3	-10.5	-33.7	14.9	-8.0	-24.9	19.1
yTag				-7.6	-18.9	1.9	-10.4	-22.5	1.1	-8.6	-20.3	2.7
yTag	509,964	8,267,457	ca. 259	X	X	X	-9.2	-36.0	20.4	X	X	X
yTag				X	X	X	-8.9	-22.4	11.0	X	X	X
yTag				X	X	X	-8.6	-21.7	11.3	X	X	X
yTag	513,068	8,263,921	11	X	X	X	-10.1	-37.6	19.1	-9.5	-32.6	18.4
yTag				X	X	X	-9.9	-25.7	10.6	X	X	X
yTag				X	X	X	-6.0	-23.3	15.6	X	X	X
yTag				X	X	X	X	X	X	X	X	X
yTag	511,09	8,268,397	85	-7.3	-33.6	21.6	-9.8	-37.2	23.6	-9.2	-39.1	19.1
yTag	509,105	8,269,215	129	-7.8	-35.0	20.6	-10.3	-39.1	21.6	-9.8	-40.7	24.5
yTag	518,023	8,269,902	965	-8.9	-36.0	19.8	-10.4	-37.6	17.7	-10.2	-40.7	20.2
yTag	512,654	8,264,548	14	-2.5	-11.9	8.4	-5.1	-11.8	20.2	X	X	X
yTag	512,978	8,264,538	35	-10.8	-23.8	15.9	-8.0	-27.4	19.4	-7.1	-27.5	18.1
yTalk	512,209	8,264,467	29	X	X	X	-12.0	-37.3	26.5	-12.5	-39.1	18.1
yTalk			25	X	X	X	-5.2	-11.5	20.5	-5.9	-21.7	22.3
yTalk			23	X	X	X	-5.2	-9.5	26.6	-8.0	-32.6	22.3
yTalk			16	X	X	X	X	X	X	X	X	X

Table 3.5. Statistics on time series from the TinyTag/TinyTalk dataloggers operated by GeoBasis.

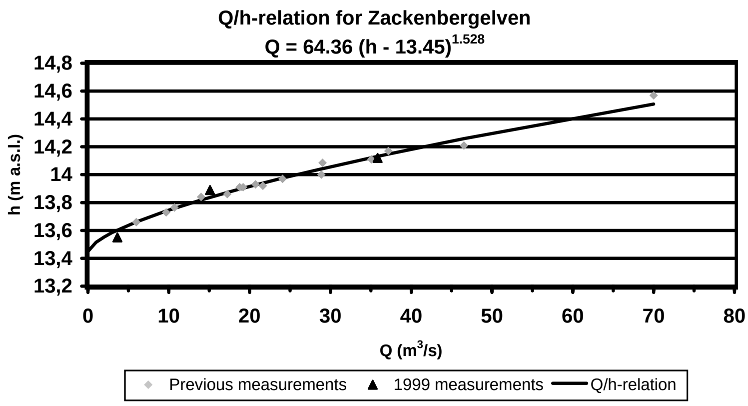


Fig. 3.5. Water level – discharge relation curve (Q/h relation) for Zackenbergelven at the hydrometric station, 1995-1998. The coefficient of correlation for the curve is 0,99.

This sensor determines by the use of sound the distance from a fixed point (the sensor) to the water surface. The signal is transformed to a water level, which again is transformed into discharge, using an established relation between water level and discharge (a Q/h-relation).

The hydrometric station was moved during the field season 1998 because the earlier location was inappropriate. Every year the station was buried in a large snow patch, which often damaged the equipment and hampered the data collection in late spring and early summer (Meltofte and Rasch 1998). During a very violent spring flood in 1999 the station was destroyed. After this event no automatic recording of the water level was obtained until 14 August 1999, when the station was reestablished at a position not far from its previous position. The spring flood will be described in details later.

The Q/h-relation

Mogens Brems Knudsen

The discharge and water level have been measured in the field seasons of 1995, 1996, 1997 and 1998. The function that describes the relation between water level and discharge is shown in Fig. 3.5. The good correlation of the data and the Q/H-relation indicates that the cross profile at the hydrometric station is stable. The Q/h-relation is based on discharge measurements ranging from 5.98 to 70 m^3/s.

In 1999, three manual discharge measurements were carried out under ice and snow free conditions. Only measurements carried out when the riverbed is ice- and snow free should be used in the Q/h-relation, because snow changes the cross profile of the river and ice layers at the bottom of the river gives a false water level.

The three measurements carried out in 1999 were all performed after the violent spring flood. However the discharge measurements fit well to the existing Q/h-relation, and indicate that no significant changes of the river cross profile at the hydrometric station had occurred (Fig. 3.5).

Late in the season, on 18 August, the discharge was measured to 3.65 m^3/s. This is well below the former lowest point on the Q/h-relation, and also lower than expected from the relation. At the time of the measurements the river was divided in two branches. This indicates that the lower part of the Q/h-relation should probably be described with another function than the one given in Fig. 3.5. To confirm this, further discharge measurements must be carried out during low flow (0 and 5 m^3/s). At this time the data is not sufficient to establish a Q/h-relation for discharges lower than 5 m^3/s.

River water discharge

Mogens Brems Knudsen

In 1999, the hydrometric station was buried in snow when the station was opened. The excavation of the station took place on 2 June 1999, and water was first observed on 9 June. At that time, the water was heavily coloured though the discharge was very low. On 17 and 18 June discharge was measured. At this time only a minor part of the river was carrying water and most of the cross profile was still covered with snow. On 20 June at 12.00 another discharge measurement was started but not completed because large amounts of snow and ice made the work impossible. The water had cut a channel in the snow, approximately 8 m wide and 0.85 m deep at the bank. The current was quite heavy, and it was not possible to cross the river. During the next hour the water level raised rapidly. The distance from the sonic range sensor to the water surface was 1.33 m at 11.45 and only 0.97 m at 13:00. Between 13:00 and 13:15 the hydrometric station was washed away.

Since no automatic data collection occurred at peak discharge, the peak can only be estimated, based on descriptions and observations from the people at the field station.

It is likely that this dramatic event was caused by a collapse of a snow dam. A large snowdrift had probably dammed Lindemansdalen, and large amounts of melt water were held back untill the pressure caused the collapse of the dam.

As mentioned earlier, the hydrometric station was reestablished on 14 August 1999. In the period from the spring flood to the reestablishment of the station, the water level was observed manually and the discharge is calculated from these observations.

The river water discharge from Zackenbergelven in the summer of 1999 is shown in Fig. 3.6. Peak discharge occurred on 20 June (spring flood) and again on 30 June and 4 July 1999. Both of these later peaks came shortly after periods with high air temperature. On 4 July, the air temperature reached 14°C, and on 15 July, the water level reached the highest point (apart from the spring flood). This last peak flow episode followed a day with high temperatures and high wind velocities.

From 19 August and thereafter, the discharge in Zackenbergelven was so low that the sonic range sensor only measured the distance to the bed of the river.

The total amount of water drained from the catchment in the 1999 field season was 180 mill. m^3. With a drainage area of 514 km^2 this corresponds to a total water loss of 350 mm from the area. In 1998, the loss was nearly 500 mm w.e. The precipitation from 1 October 1997 to 30 September 1998 was 284 mm, whereas in the hydrological year of 1999, 1 October 1998 to 1 September 1999, the total amount of precipitation was 250 mm.

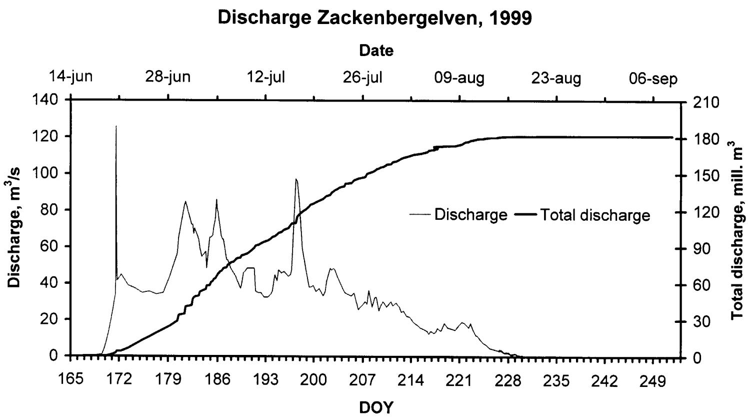


Fig. 3.6. Variation of river water discharge in Zackenbergelven, 1999.

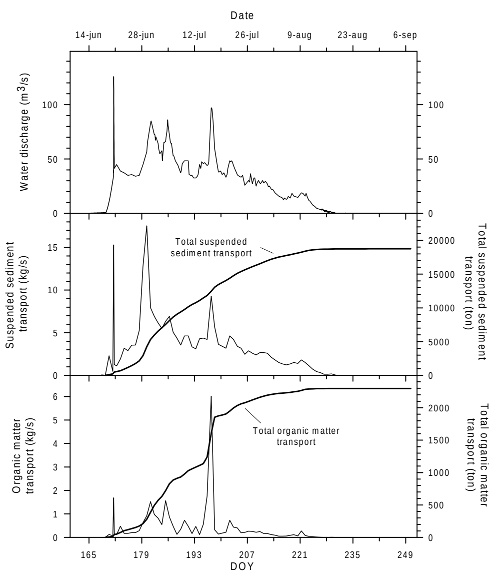


Fig. 3.7. Water discharge, suspended sediment transport, and organic matter transport in Zackenbergelven during the summer of 1999.

Suspended sediment

Morten Rasch

During the summer of 1999, suspended sediment discharge and organic matter discharge were measured once every day in Zackenbergelven. Fig. 3.7 shows the variation of the discharge in relation to water discharge. Maximum suspended sediment transport occurred during the second flood. At this time the riverbed was free of snow, and the flood probably washed it free of sediments deposited in the riverbed during the recession in the late summer of 1998. This second flood was not accompanied by a large organic matter discharge, probably because most of the soils in the drainage basin were still frozen. The maximum organic matter transport occurred during the last flood in mid July, when the active layer had started to develop.

Total suspended sediment and organic matter transport in the summers of 1997-99 are given in Table 3.6. The very large numbers for 1998 are the result of one flood event between 16 and 22 August. During this flood 105,013 ton of sediment was transported through Zackenbergelven. This is 3.6 and 5.6 times the amount of sediment transported during the entire seasons of 1997 and 1999.

Table 3.6. Total suspended sediment transport and total organic matter transport in Zackenbergelven during the summers of 1997-99.

	1997	1998	1999
Suspended sediment transport (ton)	29,444	130,133	18,761
Organic matter transport (ton)	1,643	11,551	2,297

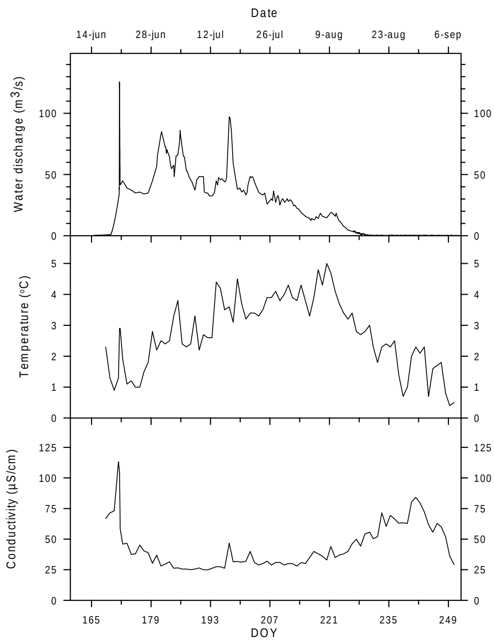


Fig. 3.8. Water discharge, water temperature and conductivity in Zackenbergelven during the summer of 1999.

Water chemistry, pH, temperature and conductivity

Morten Rasch

The river water sampled in 1999 for determination of solutes has not yet been analysed. Data from the two previous years have finally been processed and are now available for research projects. Time series of solute transport in Zackenbergelven in the field season 1997 have been reported by Rasch et al. (1999).

Unfortunately, both of the river water temperature sensors were destroyed during the spring flood in 1999. Therefore, only manual measurements of river water tempeperature from 1999 exist. Fig. 3.8 shows the variation of temperature and conductivity in Zackenbergelven in 1999. As in 1998 and 1997, the conductivity was at maximum during the first part of the season and decreased rapidly to a constant level around 30µS / cm. The high solute content in the water during the first snow melt is probably due to leaching of the snow leading to an ion pulse. The conductivity increase late in the season is probably controlled by the increasing importance of water that have been in contact with the soils, as the active layer develops.

3.4 Landscape monitoring

Morten Rasch, Bo Elberling and Bjarne Holm Jakobsen

Landscape monitoring at Zackenberg comprises

1. photos of different, dynamic landforms at 24 sites,
2. active layer depth measurements at two sites,
3. soil water chemistry measurements at two sites,
4. measurements of ice wedge growth rate at two sites,
5. measurements of cross shore landscape changes in the coastal zone at six sites, and
6. measurements of salt marsh accretion at two sites.

The monitoring of soil water chemistry has been carried out since 1996. In this report, results of monitoring from the entire period are summarised more thoroughly than in previous reports, and the applied procedure will be evaluated.

Monitoring photos

Morten Rasch

The 24 monitoring pictures included in the GeoBasis programme (see section 3.4.1 in Meltofte and Rasch 1998) were taken in August 1999. Although the photo monitor-

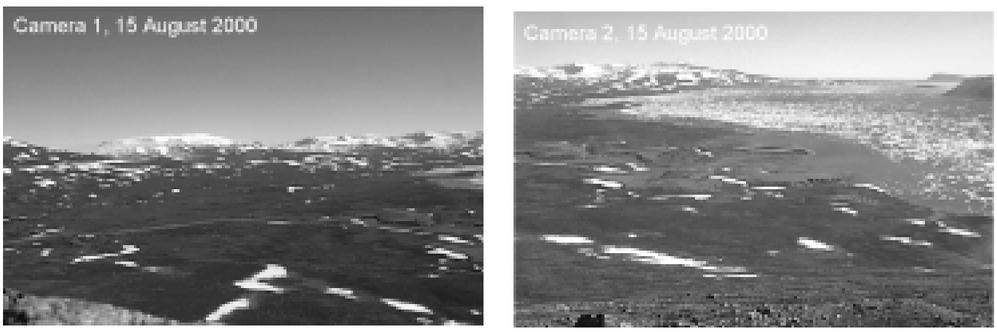


Fig. 3.9. Two digital cameras are installed at 500 m.a.s.l. at the mountain Zackenbergfjeldet. Together, the cameras cover the southern part of Zackenbergdalen.

ing programme was initiated already in 1995, the time series is still too short for observation of any geomorphological changes.

Photo monitoring of snow cover in the southern part of Zackenbergdalen is performed with a digital camera installed c. 500 m a.s.l. on the eastern slope of the mountain Zackenbergfjeldet (see section 3.4.2 in Meltofte and Rasch (1998) and section 3.4.1 in Rasch (1999)) and was continued without any operational problem in 1999. During the winter 1998-99, the camera ran out of electrical power, and therefore the first 1999 picture was taken at the first inspection visit to the camera on 5 June. During the rest of the season, the camera took pictures once every day at noon (Fig. 3.9). In 1999, the camera has been improved with a solar panel, allowing the operation to continue throughout the winter. A procedure for automatic mapping of snow cover based on pictures from the camera is being developed in cooperation between Institute of Geography at the University of Copenhagen, Department of Planning at the Technical University of Denmark and Danish Polar Center. The new technique is described in section 5.12. With this technique fully developed and operational for non-specialists, the automatic mapping of snow cover will be a part of the GeoBasis programme.

To extend the area covered by the automatic photo monitoring, one more camera was installed at the same site as the first camera on the mountain Zackenbergfjeldet on 15 August. This camera covers the southernmost part of Zackenbergdalen (Fig. 3.9) and is also programmed to take pictures once every day at noon.

Active layer depth

Morten Rasch

Two plots for measurements of active layer depth development have been operated by GeoBasis in cooperation with Dr. Hanne Hvidtfeldt Christiansen (Institute of Geography, University of Copenhagen) since 1996 (see section 5.1.12 in Metofte and Thing 1997).

One site (ZeroCalm-1) is situated on a horizontal and well-drained *Cassiope* heath near the climate station. At this site, active layer depth is measured in a 100 x 100 m grid with 121 measuring points.

The other site (ZeroCalm-2) is situated c. 500 m south of the runway on a southerly sloping *Eriophorum* fen with a snow patch. At this site, active layer depth is measured in a 120 x 150 m grid with 208 measuring points.

Time series of active layer development from 1997 to 1999 are shown in Figs 3.10 and 3.11. In both plots the active layer development was delayed in 1999 compared to the two previous years, probably due to the late snow melt. In ZeroCalm-1, the maximum active layer depth did, however, reach a level comparable to the 1997-98 level. This was not the case in Zero-Calm-2, probably because the snow patch at this site did not melt away before the active layer depth started to reduce in late August.

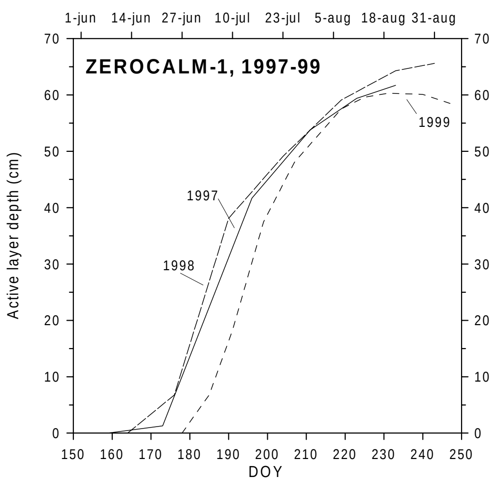


Fig. 3.10. Active layer development in the ZeroCalm-1 grid during the summers of 1997-99.

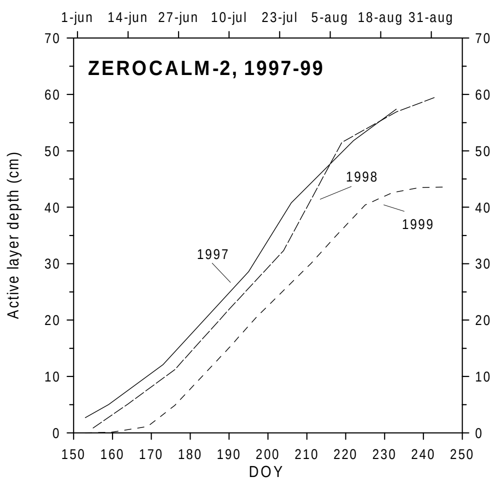


Fig. 3.11. Active layer development in the ZeroCalm-2 grid during the summers of 1997-99.

Table 3.7. Maximum active layer depth in ZeroCalm-1 and ZeroCalm-2 during the summers of 1996-99.

	1996 (cm)	1997 (cm)	1998 (cm)	1999 (cm)
ZEROCALM-1	60.1	61.7	65.6	60.3
ZEROCALM-2	60.7	57.4	59.5	43.6

Data on maximum active layer depth are reported to the Circumpolar Active Layer Monitoring Programme run by the International Permafrost Association. The numbers for 1996-99 for the two sites are given in Table 3.7.

Soil water chemistry

Bo Elberling, Bjarne Holm Jakobsen and Morten Rasch

Evaluation of soil-forming processes has traditionally been based on analysis of the solid phase. However, the interpretation of the soil water chemistry, in combination with analysis of the solid phase, is now considered important for evaluating the dynamics of soil systems. The composition of soil solutions, rather than the solid phase, reflects the present soil-forming processes, whereas the solid phase reflects the accumulated effects of the soil-forming processes over time. These processes include both weathering and transport processes and are important for the terrestrial response to changes in the environmental conditions.

As part of the GeoBasis Programme soil-forming processes in the area have therefore been assessed by combining analysis and interpretation of the chemical composition of the soil solid phase and the soil solution collected by suction-probes. Two characteristic soil types have been identified and soil solutions have been extracted on a regular basis throughout the summers since 1996 (Meltofte and Thing 1997). As a part of the probe installation in 1996, soil samples at 5 cm increments were collected (without sampling across boundaries). Data from 1996 are considered partly influenced by the installation procedure, but results on soil solution from the following summers are fairly consistent and provide an overview of the natural variation in soil solutions during the summer and between soil types. The conclusions also lead to an evaluation of the monitoring programme which in future will be reduced to four major campaigns each summer.

Two characteristic soil water regimes have been chosen. One location adjacent to the climate station is a relatively dry Cassiope heath (site K) and the other is a *Sphagnum-Eriophorum* dominated fen area 200 m south of the runway (site S). The latter site receives surface water from a nearby snow patch during most of the summer.

Fig. 3.12. Soil chemistry of profile S within the transect in the fen area and profile K in the nearby dry heath site.

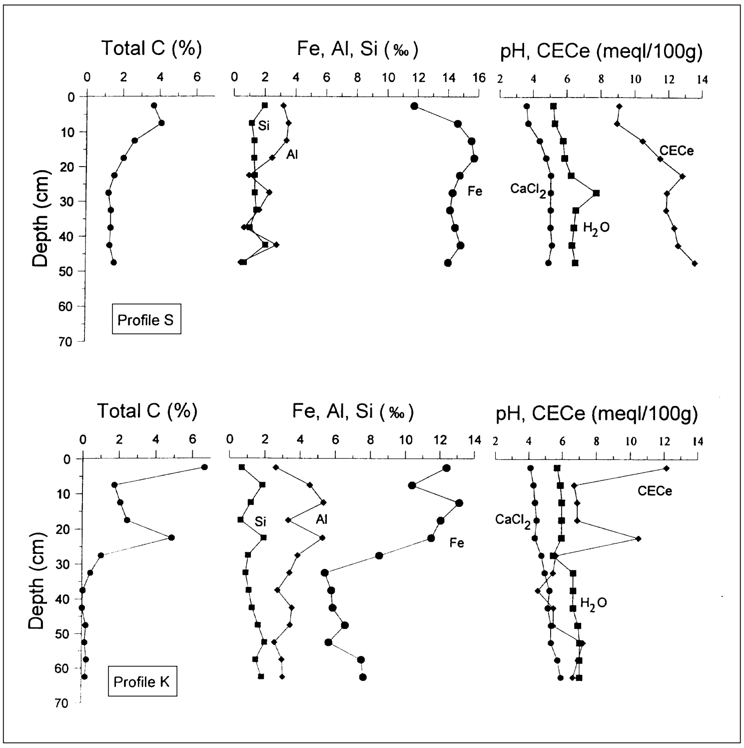


Fig. 3.12 shows the chemical composition of the solid soil, which has been developed on non-calcareous sandy sediments. X-ray analyses confirm that carbonate minerals are absent and that the sediment is dominated by silicate minerals including quartz, feldspar and hornblende, and that muscovite, illit and smectites are present. The sediments are dominated by fluvial deposits (with marine influence) covered by eolian deposits. The profiles show a distinct increase of the fine fraction (<0.01mm) from less than 5% at a depth of 60 cm to more than 30% towards the surface. Both soils are weakly acid with pH in the range of 5-6 and have a maximum in carbon, iron, and aluminium in the upper 30 cm. Below this depth, fairly constant amounts of C, Fe, and Al are observed with depth. In the fen area (site S), pH and effective cation exchange capacity (CECe) increase with depth in the top 25 cm of the soil profile from pH 5-5.5 and CECe equal to 9 meq/l to pH 6.5 and CECe equal to

12-13 meq/l. The cation exchange capacity is due to the presence of organic matter and Al- and Fe-hydroxides. The CECe maximum coincides with the maximum pH and mark a characteristic transition in the soil profile. Below 25 cm, values of pH and the CECe are fairly constant. At the heat site (site K), maximum concentrations of Al and Fe are found in the upper part of the soil profile, although a weak depletion zone of Al in the top 5 cm can be observed. A change in pH from 5.5-6 in the top 25 cm to 6.5-7 below is a similar to the change in pH in profile S. In contrast to profile S, the CECe is high (between 7-12 meq/l) in the top 25 cm, and relatively constant below (6 meq/l). Peaks in the CECe corresponds to maximums in Fe and total organic matter. The variation in CECe with depth is probably a combined effect of pH and organic matter (%C).

Both profiles show a weak soil development (brunification) on siliceous parent material dominated by a progressive acidification front 20-30 cm below soil surface. Generally, the soil can be classified as Typic Psammoturbels although grades for Spodic Psammoturbels have been observed (Soil Survey Staff, 1999).

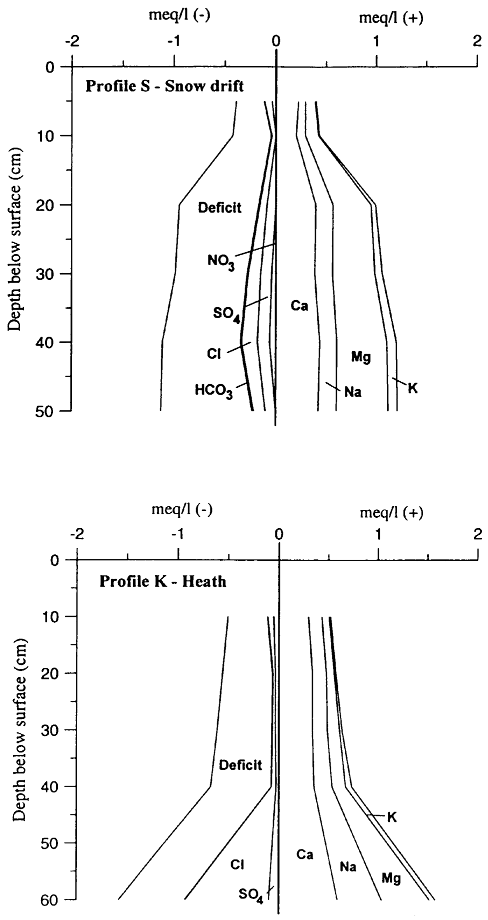


Fig. 3.13. Soil solution chemistry of profile S within the transect in the fen area and profile K in the nearby dry heath site.

Soil solution chemistry

The solution charge balance of the two profiles differs significantly from each other (Fig. 3.13). However, in both profiles the anions are dominated by organic acids (shown as deficit), chloride and sulphate, while bicarbonate is virtually absent. A change in total concentration of ions between 10-20 cm below the surface is observed in profile S, resulting from a contribution of calcium, sodium and magnesium. The increase corresponds to the increase in soil CECe and pH indicating that cation exchange processes are acting as a buffer mechanism. Above, silicate weathering is probably the main process responsible for the contribution of base ions. An equivalent increase in concentrations of cations is not observed in profile K in relation to the acidification front. Higher concentrations of sodium and chloride are found at site K at depths below 40 cm which possibly result from dissolution of salt (NaCl) from marine deposits.

Chemical temporal trends

Soil solutions at various depths were collected up to fifteen times during the summer 1997 (Fig. 3.14). Lowest pH-values are consistently observed nearest the soil surface and almost neutral pH-values are observed near the permafrost table. An overall acidification near the surface reflects the temperature-dependent respiration and corresponding production of organic acids. Over time, the pH fluctuate, in particular in the zone of high root intensity (0-10 cm) where CECe is low. However, the

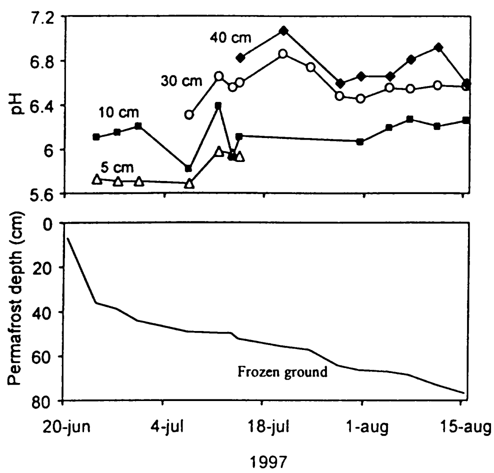


Fig. 3.14. Soil solution pH trend during soil thaw in 1997.

overall slight decrease in pH during the warm period from mid July to the beginning of August has been observed in both summers 1996 and 1997.

Soil acidification

Among the soil-forming processes the natural production of protons in the top soil is considered among the most important chemical processes, giving rise to acidification, chemical weathering and transport processes within the soil profile. In high arctic environments, carbonic acid and organic acids represent the most important contributors of protons as the atmospheric contribution of stronger acids as nitric acid and sulfuric acid is limited. Rain water in equilibrium with atmospheric carbon dioxide has a theoretical pH of 5.7. As a result of subsurface decomposition and plant respiration the concentrations of carbon dioxide (CO_2(g)) in the soil are typically in the range 0.5-1% at site K which is more than 15 times atmospheric CO_2 content. In the absence of carbonate dissolution, silicate weathering and cation exchange processes become important in the control of acidification. As chemical weathering of silicate minerals is slow, silicate buffering may not keep up with the near-surface acid production resulting in a progressive soil acidification. At pH-values between 5 and 6 cation exchange processes become important as acid consuming processes. Thus, the silicate weathering and the ion exchange may act simultaneously. However, chemical weathering of silicates is the only process by which acidity can be neutralized over long time periods in silicate bed rocks, as cation exchange in the soil zone can cause neutralization only if base cations are replenished by weathering. Besides a pH buffering effect, silicate weathering also results in an addition of cations and silica to the soil solution and contribute thereby to the chemical fluxes in the landscape which can be observed as the chemical river load (Rasch et. al., 1999) as well as representing a delay or possibly a sink for the cycling of carbon in Arctic regions.

Coastal geomorphology

Morten Rasch

The monitoring of coastal geomorhology comprises surveying of cross shore profiles at two sites, registrering coastal cliff retreat at four sites and photographic monitoring af 10 sites. A map indicating the GeoBasis coastal monitoring sites are given in Fig. 3.4.4.1 in Meltofte and Rasch (1998).

In 1999, the two cross shore profiles were surveyed again. As in previous years, no significant changes of the profiles were registered. The mean coastal cliff recession along the southern shoreline at Zackenberg for the period 1996-99 has been measured to 0.4 m.

3.5 General observations on ice conditions

Hans Meltofte

Due to the very large amounts of snow in the study area (see section 3.1), the snow and ice melt was the latest recorded during our 4-5 years of study.

Lakes and streams

On 5 June, the small pond just south of the station ("Teltdammen") was half free of ice, and on the next day open water started to form both in the ponds north ("Gadekæret") and south ("Sydkærene") of the station. On 16 June, the small western pond in Gadekæret was ice free, while the large one was still half covered with ice. This pond was 95% ice-free on 19 June, which means that these ponds thawed about one week later than in 1998. The large pond in Sydkærene was ice-free on 19 June, but the last ice on the ponds in Sydkærene did not disappear before 28 June, which is nine days later than in 1998 and three weeks later than in 1996 and 1997. A few ponds in Sydkærene dried up during the last days of August. New ice had formed on all ponds on 9 September.

A small area of open water had formed in the eastern end of Lomsø on 18 June. On 10 July, the ice had broken up, and on 19 July only a few square metres of ice remained. This is not much different from 1998, but 1-2 weeks later than in 1996 and 1997. Store Sø was still totally ice covered on 12 July, and ice-free on 17 August.

Melt water had started to run from Gadekæret on 9 June, and from 10-12 June a few of the rivulets on the slopes of Aucellabjerg began to run on top of the snow. From about 15 June, most of the rivulets in Research Zone 1A were running. This is only a few days later than in 1998, but about ten days later than in 1996 and 1997.

Slowly, small amounts of water started to flow in Zackenbergelven from 10 June, but proper amounts of water did not appear until 20 June, when a powerful wave of sludge, water and gravel washed down through the riverbed. This is 10 days later than in 1998 and a further 2, 2 and 1 week later than in 1995, 1996 and 1997, respectively.

The fjord

On 1 June, when we passed Daneborg by plane *en route* to Zackenberg, the polynya off Young Sund stretched 7-8 km into the sound, and only a narrow 'ice-bridge' connected Sandøen to the fast ice and thereby to the mainland.

By 1 July, only small open water areas had formed in the fjord ice outside Zackenbergelven and the smaller rivers to the east, but already between 10 and 16 July, the ice off Zackenbergdalen disappeared. However, the ice in the outer part of Young Sund did not break until 24 July, and the general timing of the break up of the fjord ice probably did not differ much from average.

During the first three weeks of August, large amounts of drift ice were present in Young Sund.

4 Zackenberg Basic: The BioBasis programme

The BioBasis programme at Zackenberg is carried out by the Danish National Environmental Research Institute (NERI). It is financed by Dancea, the Environmental Protection Agency, Ministry of Environment and Energy, Denmark. This does not include that evaluations presented in this report will mirror the opinions of the Environmental Protection Agency.

In the autumn of 1998, the entire programme was evaluated by an international panel, resulting in a number of suggestions for changes. Among those adopted, some were implemented in 1999, while others will be implemented in the years to come. The most important changes in 1999 were the inclusion of a limnic compartment in the programme and the initiation of weekly Relative Vegetation Index (RVI) measurements in all flower plots. Furthermore, the satellite image analyses of Normalised Difference Vegetation Indexes (NDVI) initiated in 1998 are presented here for the first time.

Table 4.1. Interpolated dates of 50% snow cover and 50% flowers (50/50 ratio of buds/open flowers) for white Arctic bell-heather (Cassiope tetragona), mountain avens (Dryas integrifolia/octopetala), Arctic poppy (Papaver radicatum), Arctic willow (Salix arctica), purple saxifrage (Saxifraga oppositifolia) and moss campion (Silene acaulis) for ITEX study plots in 1996, 1997, 1998 and 1999, respectively. Interpolations based on samples of less than 50 buds/flowers are given in brackets.

Plot no.	1996		1997		1998		1999	
	50% snow	50% flowers	50% snow	50% flowers	50% snow	50% flowers	50% snow	50% flowers
Cassiope 1	14.6	2.7	9.6	6.7	13.6	6.7	27.6	13.7
Cassiope 2	19.6	6.7	21.6	20.7	27.6	(21.7)	4.7	(26.7)
Cassiope 3	15.6	9.7	21.6	18.7	20.6	(19.7)	3.7	(26.7)
Cassiope 4	20.6	15.7	15.6	15.7	20.6	(21.7)	4.7	(26.7)
Cassiope 5					11.6	20.7	28.6	14.7
Cassiope 6			?	28.7	6.7	(31.7)	21.7	-
Dryas 1	<3.6	19.6	<27.5	22.6	23.5	26.6	6.6	3.7
Dryas 2	26.6	13.7	27.6	4.8	4.7	8.8	12.7	-
Dryas 3	6.6	2.7	<27.5	26.6	7.6	6.7	19.6	13.7
Dryas 4	1.6	27.6	3.6	6.7	13.6	(9.7)	21.6	14.7
Dryas 5	6.6	30.6	31.5	5.7	4.6	1.7	14.6	7.7
Dryas 6	21.6	19.7	4.7	9.8	5.7	(7.8)	11.7	19.8
Dryas 7					2.6	30.6	26.6	23.7
Dryas 8					30.5	25.6	30.6	23.7
Papaver 1	20.6	14.7	18.6	20.7	21.6	24.7	3.7	2.8
Papaver 2	20.6	14.7	20.6	23.7	21.6	26.7	4.7	30.7
Papaver 3	21.6	14.7	15.6	19.7	20.6	26.7	3.7	1.8
Papaver 4	21.6	15.7	4.7	7.8	5.7	11.8	11.7	15.8
Salix 1	<3.6	6.6	<27.5	6.6	<27.5	12.6	<1.6	14.6
Salix 2	14.6	21.6	20.6	29.6	23.6	10.7	1.7	17.7
Salix 3	7.6	20.6	8.6	25.6	12.6	(28.6)	24.6	5.7
Salix 4	20.6	29.6	5.6	23.6	21.6	2.7	22.6	3.7
Saxifraga 1			<27.5	31.5	<27.5	5.6	<1.6	7.6
Saxifraga 2			<27.5	2.6	<27.5	7.6	27.5	14.6
Saxifraga 3	?	5.6	<27.5	1.6	27.5	9.6	6.6	16.6
Silene 1	<3.6	20.6	<27.5	24.6	<27.5	21.6	<1.6	28.6
Silene 2	<3.6	23.6	<27.5	29.6	<27.5	1.7	27.5	30.6
Silene 3	?	30.6	<27.5	26.6	27.5	23.6	6.6	6.7
Silene 4	24.6	26.7	28.6	10.8	20.6	20.8	6.7	-

Besides the programme reported here, BioBasis personnel sampled *Betula nana* and *Vaccinium uliginosum* tissue for genetical analysis and oligochaeta from soil together with radio nuclides from soil and lichens as part of the Arctic Monitoring and Assessment Programme. Furthermore, down and feathers from young waders were collected for chemical ‘fingerprints’ on origin of nutrients used to produce eggs (see section 5.8).

Details on BioBasis methods and sampling procedures are presented in a manual (Meltofte and Berg 1999), which is available from NERI (mel@dmu.dk).

4.1 Vegetation

Hans Meltofte

The botanical work was supervised by Hans Meltofte and performed by Claus Nordstrøm from 1 June-5 July, by Sidsel Larsen from 5 July-18 August and by Thomas B. G. Berg from 18 August-3 September.

The programme was extended this year with weekly measurements of Relative Vegetation Indexes (RVI) in all flower plots. Also satellite image analyses of Normalised Difference Vegetation Indexes (NDVI), initiated by Greenland Field Investigations in 1998, are presented here for the first time. Furthermore, a berry production programme, initiated in 1998, was fully implemented this year.

ITEX reproductive phenology

The 1999 season was the latest flowering season recorded so far. Due to the extraordinary large amounts of snow, snow melt was about two weeks later than in the three previous years. Apart from a few exposed plots that were snow-free already in late May, snow disappeared 6-20 days later from the flower plots than during 1996-1998. However, as the weather during the growing season was generally fine, the time span between snow melt and flowering in several plots was as short as during the very fine season of 1996 (Table 4.1). The span was 16-23 days in five *Cassiope* plots (17-39 days in 1996-1998), 23-27 (39) days in six(seven) *Dryas* plots (17-36), 26-35 days in four *Papaver* plots (23-36), 11-16 days in three *Salix* plots (7-18), 10-18 days in two *Saxifraga* plots (13) and 30-34 days

Plot no.	Area (m²)	1995	1996	1997	1998	1999
Cassiope 1	2	1321	1386	1855	322	312
Cassiope 2	3		1759	550	19	16
Cassiope 3	2	256	844	789	35	18
Cassiope 4	3	456	1789	391	24	6
Cassiope 5	2.5			1224	455	474
Cassiope 6	2					3
Dryas 1	4	-936	-797	138	223	852
Dryas 2	60	534	1073	230	42	49
Dryas 3	2	603	522	123	255	437
Dryas 4	6	-325	-164	155	69	356
Dryas 5	6	-654	-504	123	191	655
Dryas 6	91	809	1406	691	10	25
Dryas 7	12			787	581	1355
Dryas 8	12			391	240	798
Papaver 1	105	302	337	265	190	220
Papaver 2	150	814	545	848	316	315
Papaver 3	90	334	238	289	266	183
Papaver 4	91	196	169	192	80	30
Salix 1 mm.	60		807	959	63	954
Salix 1 ff.		520	1096	1349	149	1207
Salix 2 mm.	300		790	1082	132	416
Salix 2 ff.		617	1376	1909	455	418
Salix 3 mm.	36	239	479	412	32	52
Salix 3 ff.		253	268	237	38	68
Salix 4 mm.	150		1314	831	509	718
Salix 4 ff.		1073	1145	642	709	880
Saxifraga 1	7		-1010	141	163	584
Saxifraga 2	6		513	387	432	158
Saxifraga 3	10		529	322	288	707
Silene 1	7		-251	403	437	993
Silene 2	6		493	524	440	400
Silene 3	10		348	211	127	313
Silene 4	1	466	270	493	312	275
E. scheuz. 1	10		395	423	257	309
E. scheuz. 2	6		537	344	172	184
E. scheuz. 3	10		392	545	482	587
E. scheuz. 4	8		260	755	179	515
E. triste 1	10		0	3	1	1
E. triste 2	6		98	59	21	16
E. triste 3	10		0	0	0	0
E. triste 4	8		0	0	0	0

Table 4.2. Area size and total number of flower buds, flowers and senescent flowers of white Arctic bell-heather (Cassiope tetragona), mountain avens (Dryas integrifolia/octopetala), Arctic poppy (Papaver radicatum), Arctic willow (Salix arctica), purple saxifrage (Saxifraga oppositifolia), moss campion (Silene acaulis), Arctic cotton-grass (Eriophorum scheuzerii) (corrected data for 1996) and ‘dark cotton-grass’ (Eriophorum triste) in ITEX plots in 1995, 1996, 1997, 1998 and 1999, respectively. Numbers in brackets have been extrapolated from 1995 and 1996 data to make up for enlarged plots (see Meltofte and Rasch 1998).

Table 4.3. Peak ratio (%) of female Salix pods infested by fungi in Salix plots in 1996-1999.

Plot no.	1996	1997	1998	1999
Salix 1	5	4	0	22
Salix 2	0	1	2	2
Salix 3	0	0	0	6
Salix 4	16	3	0	6

in two *Silene* plots (32-61). The result was that flowering in the early snow-free plots was only 6-12 days delayed in four *Dryas* plots, 3-9 days delayed in three *Salix* plots, 5-11 days delayed in the three *Saxifraga* plots and 5-7 days delayed in three *Silene* plots, as compared to 1996-1998. In the intermediate group, flowering was 6-15 days delayed in four *Cassiope* plots, 7-18 days delayed in three *Papaver* plots and 7-26 days delayed in one *Salix* plot. In the late snow-free plots, flowering was 10-31 days delayed in one *Dryas* plot, whereas the other late *Dryas* plot never reached 50% flowers, one *Papaver* plot flowered 4-31 days later than previous years and one *Silene* plot did not reach 50% flowers either.

Several plots did not succeed to produce seeds. Besides the late *Dryas* and *Silene* plots that did not even reach 50% open flowers, only 0-19% of the *Papaver* capsules in four plots showed seed dispersal on 26 August. In *Saxifraga*, it was 75-100%, and in *Salix* one late plot developed exposed seed hairs from only 61% of the catkins. In the three other plots, all catkins developed exposed seed hairs. In 1995 and 1996 virtually all flowers in the analysed plots produced seeds, while varying numbers failed in 1997 and 1998 as well.

ITEX quantitative flowering

For the second year in succession, white Arctic bell-heather had a poor flowering season, while mountain avens largely recovered from low numbers in the two previous years (Table 4.2). This only applies to the exposed, and hence early flowering plots, while flowering in the two late plots (Dryas 2 and 6) were as poor as last year. The amount of flowering in Arctic poppy, Arctic willow, purple saxifrage, moss compion and Arctic cotton-grass was more variable (Table 4.2).

In 1999, a relatively high fungi infection rate was found on female *Salix arctica* pods (Table 4.3). The effect of the fungi is that the leaves of the pods turn yellow and twisted.

In those plots that have not been analysed before (see Meltofte and Thing 1997), pH was measured in August this year. The results are presented in Table 4.4.

Table 4.4. pH in eight ITEX flowering plots not measured previously.

Plot no.	pH
Cassiope 5	6.7
Cassiope 6	6.7
Dryas 7	7.3
Dryas 8	6.7
Eriophorum 1	6.1
Eriophorum 2	5.7
Eriophorum 3	6.3
Eriophorum 4	6.1

Snow melt in 400 m^2 plant community study plots and Eriophorum plots

Snow melt in the three plant community study plots and in the four *Eriophorum* plots followed the general trend of late snow melt this year (Table 4.5). In particular, the almost one month delayed snow melt in vegetation plot 2, as compared to the three previous years, is indicative of the much larger amounts of snow that had accumulated in snow-beds during the 1998-1999 winter.

Table 4.5. Date of 50% snow cover in the three plant community study plots and in the four Eriophorum plots.

Plot no.	1996	1997	1998	1999
Vegetation 1	13.6	30.5	6.6	13.6
Vegetation 2	<3.6	22.6	24.6	20.7
Vegetation 3	20.6	20.6	20.6	28.6
Eriophorum 1		14.6	19.6	4.7
Eriophorum 2		14.6	20.6	2.7
Eriophorum 3		27.6	21.6	7.7
Eriophorum 4		25.6	22.6	28.6

Relative Vegetation Indexes (RVI)

In 1999, weekly measurements of RVI were initiated for all ITEX study plots. The values obtained reflect the extent of 'greening' in the different plant communities ranging from low figures in the relatively barren purple saxifrage / moss campion (*Saxifraga/Silene*) plots to high values especially in the cotton grass (*Eriophorum*) plots (Table 4.6).

Plot no.	RVI	Date
Cassiope 1	2.36	29.7
Cassiope 2	2.40	29.7
Cassiope 3	2.41	19.8
Cassiope 4	2.21	26.8
Dryas 1	2.49	22.7
Dryas 2	2.29	19.8
Dryas 3	2.62	29.7
Dryas 4	2.05	19.8
Dryas 5	2.02	29.7
Dryas 6	2.09	26.8
Papaver 1	2.37	19.8
Papaver 2	2.56	19.8
Papaver 3	2.17	26.8
Papaver 4	2.09	26.8
Salix 1	3.65	29.7
Salix 2	3.15	29.7
Salix 3	2.39	29.7
Salix 4	2.69	29.7
Saxifraga/Silene 1	1.79	29.7
Saxifraga/Silene 2	2.12	29.7
Saxifraga/Silene 3	1.61	29.7
Silene 4	1.93	26.8
Eriophorum 1	3.67	5.8
Eriophorum 2	3.81	29.7
Eriophorum 3	3.36	19.8
Eriophorum 4	6.51	5.8

Table 4.6. Peak Relative Vegetation Indexes (RVI) recorded in the ITEX study plots in 1999 together with date of maximum record. RVI values presented are averages of eight measurements in each plot (four in very small plots).

Normalised Difference Vegetation Indexes (NDVI)

Since 1998, Greenland Field Investigations (Asiaq) has analysed satellite images (Landsat TM) as part of the Zackenberg Basic monitoring programme. The analyses are funded by the Dancea programme, Ministry of Environment and Energy. Data for 1998 have been published by Bøcker (1998, 1999), and only the main results are presented here (Table 4.7).

Our study area in Zackenbergdalen has been divided into 12 sections covering the bird and muskox monitoring areas. Numbers 1-5 cover the bird monitoring area from SW to NE, while the remaining numbers cover the muskox monitoring areas west (nos. 6-8) and east (nos. 9-12) of the bird monitoring area, respectively (see Meltofte and Berg 2000). Sections 1, 2 and 9 are below 50 m a.s.l., sections 3, 6 and 10 are between 50 and 150 m a.s.l., sections 4, 7 and 11 are between 150 and 300 m a.s.l., and sections 5, 8 and 12 are between 300 and 600 m a.s.l. Besides these sections, the lemming monitoring area, situated within section 2, has been analysed separately. Data for 30 July 1998 are presented in Table 4.7.

When more data from our RVI measurements in all ITEX plots are generated, we expect to be able to extrapolate NDVI values from different dates to one standard date in early August.

Section	Min.	Max.	Mean
1	-0.33	0.76	0.43
2	-0.33	0.82	0.50
3	-0.29	0.80	0.52
4	0	0.84	0.43
5	0.01	0.77	0.37
6	-0.36	0.75	0.45
7	0	0.79	0.44
8	0.03	0.84	0.41
9	-0.27	0.81	0.50
10	0.01	0.81	0.52
11	0.01	0.82	0.42
12	-0.01	0.88	0.44
Lemmings	-0.33	0.82	0.49
Total	-0.36	0.88	0.46

Table 4.7. NDVI values for 12 sections of the bird and muskox monitoring areas in Zackenbergdalen together with the lemming monitoring area (part of section 2) based on a Landsat TM satellite image from 30 July 1998. The image has been georectified and corrected for atmospheric humidity, aerosols and solar angle. NDVI-values of 1 have been omitted, as they represent shaded areas.

Berry production

Three plots for monitoring of berries produced by alpine bearberry *Arctostaphylos alpina*, Arctic blueberry *Vaccinium uliginosum* and crowberry *Empetrum nigrum* were established in 1998. Both years, berries were counted on 31 August, except for *Vaccinium* which in 1998 was counted on 17 August. In 1999, the first two species produced more berries than in the previous year, while berry production by crowberry was negligible (Table 4.8).

	Area (m²)	1998	1999
Arctostaphylos alpina	6	365	455
Vaccinium uliginosum	4	240	532
Empetrum nigrum	4	27	1

Table 4.8. Area and numbers of berries recorded in three plots of alpine bearberry (Arctostaphylos alpina), Arctic blueberry (Vaccinium uliginosum) and crowberry (Empetrum nigrum) in 1998 and 1999, respectively.

Station no.	1996	1997	1998	1999
1	3.6	30.5	6.6	15.6
2	<3.6*	28.5	29.5	8.6
3	14.6	19.6	18.6	27.6
4	14.6	22.6	26.6	2.7
5	4.6	<29.5*	1.6	12.6
7	-	-	-	<3.6**

*0% snow

**7% snow

Table 4.9. Date of 50% snow-cover (ice cover on pond at Station 1) in the arthopod plots.

4.2 Arthropods

Sidsel Larsen

The yellow pitfall traps and the window traps were operated in essentially the same way as in 1998 and 1997 (see Meltofte and Rasch 1998), but one pitfall station (no. 7) was added to ensure catches in an early exposed dry habitat from the beginning of the season. Station no. 6, situated in a snow-bed, will not be operated in the coming years.

Sampling was performed by Claus Nordstrøm (3 June-1 July), Sidsel Larsen (8 July-12 August) and Thomas B. G. Berg (19-26 August). Sidsel Larsen sorted the material, and sorted samples are kept in 70% alcohol at the Zoological Museum, University of Copenhagen. The spiders were sorted to species, which is reported separately (see section 5.11).

Snow (and ice) melt in all arthropod plots was about 1-2 weeks later than in previous years (Table 4.9). In spite of this, c. 67,000 arthropods were collected this year.

Pitfall traps

All pitfall traps were put in place at the end of the 1998 season and could be activated as soon as the ground was snow-free. The first traps were opened on 3 June, and all traps were active on 15 July and remained open until 26 August. No traps were disturbed by Arctic foxes, and only on one occasion (14 June) a fox defecated in a trap. Unlike 1997, this did not lead to a significant increase in the number of *Cyclorrapha* larvae in the trap.

The total numbers of arthropods caught each week during the field season are presented in Table 4.10. Total catches from 1996, 1997 and 1998 are given for comparison. 1996 data have been doubled to allow for comparison, as only half the number of yellow pitfalls were operated that year. The total catches from 1996, 1997 and 1998 have then been extrapolated to fit the 1999 sampling design: The snow-bed Station 6 was excluded from the total catches, and the new Station 7 on an early snow-free, tufted *Dryas* heath was added. In 1996, 1997 and 1998, Sciaridae was not separated from Mycetophilidae, and Ceratopogonidae not from Chrironomidae. In 1996, Anthomyiidae was not separated from Muscidae.

In 1999, the taxa diversity was high compared to all other years and the total number of arthropods caught was the highest ever. Several additions to the fauna list were made:

1) A single specimen of butterfly in the family Lycaenidae was found in late July. Several were seen south of the station in late July and early August.

2) Among the Hymenoptera, two new super-families were represented: Ceraphronoidea and Platygastroidea (family Scelionidae).

3) Platygastroidea, minute wingless wasps parasitizing the eggs of spiders, were found.

4) Also a new family of Diptera, Heleomyzidae, was found.

5) 3 specimens of Siphonaptera in mid July, Tardigrada (3 specimens), Ostracoda (84 specimens) and Enchytraeidae (2 specimens) occurred in the traps for the first time.

Only one specimen of *Nysius groenlandicus* was found in the traps, but the species was seen in great numbers south of the station in early august.

Several observations of fungi-infected dead flies were made in the samples and on catkins of *Salix*, on marking poles and the like.

Even though the snow melt was very late, many groups occurred in greater numbers than in previous years, *e.g.* the abundance of Chironomidae was more than doubled. Also Muscidae, Collembola, Nematocera larvae and Linyphiidae showed great increases. The warm and sunny weather in 1999 is the most obvious reason for the increased arthropod activity

A serious decline in the number of Lepi-

Date	10.6	17.6	24.6	1.7	8.7	15.7	22.7	28.7	5.8	12.8	19.8	26.8	1999	1998	1997	1996
No. of active stations	1	3	3	3	5	5	5	5	5	5	5	5	5	5	5	5
No. of trap days	56	116	168	168	238	280	280	280	280	280	280	280	2706	2702	2797	-1512
COLLEMBOLA	27	25	617	936	1822	4619	2094	2022	2911	4916	2479	975	23443	8957	10830	4636
HETEROPTERA																
Nysius groenlandicus	0	0	0	0	0	0	0	0	0	0	1	0	1	0	5	40
Aphidoidea	0	0	0	0	0	4	0	1	0	0	1	5	11	185	10	6
Coccoidea	0	0	1	10	12	11	9	41	112	158	35	42	431	3	548	254
THYSANOPTERA	0	0	0	0	0	0	0	0	0	1	0	1	2	0	0	2
LEPIDOPTERA																
Lepidoptera larvae	0	0	1	4	4	2	0	3	0	3	2	2	21	106	168	354
Colias hecla	0	0	0	0	0	1	0	6	9	11	10	5	42	12	19	88
Clossiana sp.	0	0	0	0	0	1	1	8	17	28	25	2	82	56	180	1052
Lycaenidae	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Plebeius glandon	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Noctuidae	0	0	0	0	0	1	0	0	3	2	0	0	6	2	45	68
DIPTERA																
Nematocera larvae	0	17	7	60	2	3	5	2	4	2	2	1	105	58	39	52
Tipulidae larvae	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Tipulidae	0	0	0	0	0	1	1	0	1	1	0	0	4	1	4	14
Trichoceridae	0	0	0	1	0	0	1	1	0	0	0	0	3	0	1	0
Culicidae	0	0	0	0	1	4	16	24	25	11	1	1	83	22	16	2
Chironomidae	0	19	39	904	1112	1874	1841	1501	575	370	135	172	8542	2402	3337	3292
Ceratopogonidae	0	0	0	5	9	7	16	24	6	1	0	0	68	*	*	*
Cecidomyiidae														1	0	0
Mycetophiliidae	0	2	0	0	9	47	65	27	37	12	5	1	205	1764	1194	526
Sciaridae	0	0	1	16	26	70	139	241	113	65	86	39	796	*	*	*
Brachycera larvae	0	0	1	0	0	0	1	0	0	1	0	0	3	0	0	0
Empididae	0	0	0	0	0	1	1	1	5	6	3	4	21	10	6	8
Phoridae	0	0	0	1	0	11	150	117	62	31	35	28	435	344	214	118
Syrphidae	0	1	0	6	3	8	12	10	2	1	7	0	50	28	81	72
Cyclorrhapha larvae	0	0	3	1	0	0	2	0	1	0	0	0	7	19	75	16
Agromyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Anthomyiidae	0	1	12	3	7	5	6	2	2	7	30	13	88	416	573	*
Calliphoridae	0	0	1	0	1	1	1	2	1	3	12	4	26	49	48	48
Fannidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Heleomyzidae	0	0	0	0	0	1	0	0	3	0	3	0	7	0	0	0
Muscidae	6	15	59	186	514	943	953	1971	2007	1387	1558	406	10005	5463	6217	8114
Scatophagidae	0	0	10	3	9	12	1	1	0	2	3	0	41	0	385	26
Tachinidae	0	0	0	0	0	0	1	5	11	14	5	1	37	0	19	0
HYMENOPTERA																
Hymenoptera larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Ichneumonidae	0	0	1	10	11	16	88	85	64	42	34	35	386	297	567	954
Braconidae	0	0	0	0	0	1	2	1	2	3	1	0	10	105	59	44
Ceraphronoidea	0	0	0	0	1	0	1	1	0	1	0	1	5	0	0	0
Chalcidoidea	0	0	0	0	0	0	1	3	1	2	2	0	9	2	123	48
Cynipoidea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Scelionidae	0	0	0	0	0	1	7	61	16	4	8	4	101	0	0	0
Bombus sp.	0	0	0	0	1	1	0	0	0	0	0	0	2	6	12	2
ACARINA	131	174	357	196	418	600	414	1276	1639	1383	1011	664	8263	6304	19781	8182
ARANEA																
Dictynidae	2	9	5	3	2	4	9	23	2	2	8	10	79	0	53	0
Linyphiidae	19	83	313	391	361	229	178	131	80	86	150	222	2243	1108	1644	1436
Lycosidae	6	8	77	210	220	222	137	384	275	202	262	115	2118	2123	3806	4548
Lycosidae egg sac	0	0	0	1	3	10	4	53	31	31	21	6	160	160	138	82
Thomisidae	3	4	19	12	7	18	19	32	13	3	4	10	144	89	245	198
Unident.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120
OSTRACODA	0	0	0	74	0	0	5	5	0	0	0	0	84	0	0	0
SIPHONAPTERA	0	0	0	0	0	3	0	0	0	0	0	0	3	0	0	0
Total	194	358	1525	3034	4555	8732	6184	8067	8030	8792	5939	2769	58174	30095	50446	34404

Table 4.10. Weekly totals of arthropods caught at the five pitfall trap stations in 1999. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous week. Totals from 1996, 1997 and 1998 are given for comparison. Total catches from 1996 have been doubled to allow comparison. The data from 1996, 1997 and 1998 have been extrapolated to fit the 1999-sampling design (see text). Asterisks mark groups not separated from closely related groups.

Date	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	19.8	26.8	1999	1998	1997	1996
No. of trap days	13	14	14	14	14	14	14	14	14	14	14	153	174	184	182
COLLEMBOLA	1	11	5	5	24	9	0	1	1	0	4	61	5	15	65
COLEOPTERA															
Latridius minutus	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
HEMIPTERA															
Nysius groenlandi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Coccoidea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
THYSANOPTERA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
LEPIDOPTERA															
Colias hecla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Clossiana sp.	0	0	0	0	0	0	0	1	1	0	0	2	1	1	6
Noctuidae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Geometridae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
DIPTERA															
Nematocera larva	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Tipulidae	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Trichoceridae	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Culicidae	0	0	2	40	99	62	51	12	54	1	1	322	138	142	98
Ceratopogonidae	0	0	811	857	57	12	24	14	24	0	0	1799	*	*	*
Chironomidae	14	25	1698	1627	882	724	264	242	235	19	57	5787	3743	7725	6477
Cecidomyiidae	0	0	1	4	0	1	0	0	0	0	0	6	0	0	1
Mycetophiliidae	0	0	0	0	1	0	3	6	6	0	0	16	624	240	64
Sciaridae	0	0	53	99	5	4	6	3	1	0	0	171	*	*	*
Empididae	0	0	0	1	1	0	0	1	4	1	1	9	9	1	77
Phoridae	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0
Syrphidae	0	0	0	0	0	0	0	1	0	0	0	1	8	16	4
Agromyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
Anthomyiidae	0	0	0	0	1	0	0	0	0	1	1	3	26	11	*
Calliphoridae	0	0	0	0	2	0	0	1	1	1	0	5	7	6	2
Heleomyzidae	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Muscidae	1	1	2	110	147	123	172	68	51	47	32	754	745	809	1355
Scatophagidae	2	0	1	3	1	2	0	0	0	0	1	10	0	30	11
Tachinidae	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
HYMENOPTERA															
Braconidae	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Ichneumonidae	0	0	0	0	1	6	5	6	4	1	1	24	18	44	43
Chalcidoidea	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Bombus sp.	0	0	0	0	0	0	0	0	1	0	0	1	2	6	5
ACARINA	0	0	3	9	22	38	44	26	47	0	2	191	826	189	299
ARANEAE															
Linyphiidae	0	0	0	0	0	2	0	1	0	2	1	6	1	1	8
Lycosidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Grand total	18	37	2577	2755	1243	986	569	383	431	73	106	9178	6155	9248	8547

Table 4.11. Weekly totals of arthropods caught at the window trap station in 1999. The station holds two window traps situated perpendicular to each other. Each window measures 20 x 20 cm. Values from each date represents catches from the previous week. Totals from 1996, 1997 and 1998 are given for comparison. An asterisk marks a group not separated from a related group.

doptera larvae was seen. The number of adult *Clossiana sp.* and Noctuidae has fallen dramatically since 1996, and this is probably affecting the abundance of larvae.

Window traps

The season started late this year. On 3 June, the trap station was still surrounded by snow and ice. The traps were established the week after and remained active until 26 August. Only once, a window was broken by a muskox, and no arthropods were lost from the traps during the entire season. Catches from each week in the 1999 field season are presented in Table 4.11, together with total catches from 1996, 1997 and 1998. In 1996, 1997 and 1998, Sciarida was not separated from Mycetophilidae, and Ceratopogonidae not from Chironomidae. In 1996, Anthomyiidae was not separated from Muscidae.

The total number of arthropods caught and the taxon diversity was comparable to the catches of 1996 and 1997 (but note that the number of trap days was lower in 1999 due to the late snowmelt).

For the first time, a species of Coleoptera showed up in the traps: Two specimens of a very small reddish beetle (1.5-2.5 mm) from the family Latridiidae, *Latridius minutus* (Linnaeus, 1767), were caught on 26 August. The beetle is reported to have a scattered occurrence in the southern part of Greenland, northwards to Godhavn on the west coast and Hekla Havn, Danmark Ø, on the east coast, and this finding is the northernmost in Greenland. The species is almost cosmopolitic and is distributed in Europe up to northernmost Norway, the Faeroes and Iceland (Böcher 1988). *Latridius minutus* is considered highly synanthrophic and has probably been imported with freight to Zackenberg. In Iceland, overwintering can only take place under synantrophic conditions. The species is associated with rotting and mouldy vegetable matter and feeds exclusively on moulds, hyphae as well as spores (Böcher 1988). Other additions to the fauna list from the window traps were Tipulidae, Tachinidae, Phoridae, Nematocera larvae and Heleomyzidae. A single tardigrade was found in the window trap on 29 July.

Plot no.	Date 1996	Preyed on	Date 1997	Preyed on	Date 1998	Preyed on	Date 1999	Preyed on
Dryas 1	17.7	2	24.6	6	15.7	3		0
Dryas 2		0	05.8	5		0		0
Dryas 3	01.7	11	24.6	18	08.7	3		0
Dryas 4	24.6	17	15.7	1	15.7	7		0
Dryas 5	08.7	2	08.7	8	15.7	2		0
Dryas 6		0		0		0		0
Dryas 7		-		-		0	21.8	26
Dryas 8		-		-		0	21.8	27

Table 4.12. Peak ratio (per cent) of Dryas flowers eaten by larvae of Sympistis zetterstedtii in Dryas plots in 1996-1999.

Predation on Dryas flowers by larvae of Sympistis zetterstedtii

No larvae of *Sympistis zetterstedtii* were encountered during the weekly visits to the *Dryas* study plots, and predation was only recorded in the two plots on the lower slopes of Aucellabjerg (Table 4.12).

Predation on Salix arctica

Numbers of woolly-bear *Gynaephora groenlandica* caterpillars recorded during bird monitoring work in Zackenbergdalen have increased markedly from 1996-1999 (Table 4.13). One caterpillar was recorded on 8 July this year inside *Salix* plot 4 as the first one ever.

Predation on female *S. arctica* pods by an unknown Lepidoptera larvae seen in 1996 was found again this year. An unprecedented peak ratio of 43% was recorded in *Salix* plot 1 on 22 July (Table 4.14).

	1996	1997	1998	1999
June	1	2	7	7
July	0	1	4	17
Total	1	3	11	24

Table 4.13. Numbers of woolly-bear Gynaephora groenlandica caterpillars recorded by one observer (Hans Meltofte) in study area 1A (the bird monitoring area) in June and July 1996-1999.

Plot no.	1996	1997	1998	1999
Salix 1	+	0	0	43
Salix 2	3	0	0	6
Salix 3	9	0	0	3
Salix 4	0	0	0	1

Table 4.14. Peak ratio (per cent) of female Salix pods infested by an unknown Lipidoptera larvae in Salix plots in 1996-1999.

Table 4.15. Number of trips and hours (trips; hours) allocated to bird censusing and breeding phenology sampling west and east of Zackenbergelven during June and July, respectively.

	West of river	East of river	Total
June	6; 18	15; 57	21; 75
July	12; 50	13; 54	25; 104
Total	18; 68	28; 111	46; 179

	West of river (3.39 km²)	East of river < 100 m (9.15 km²)	East of river > 100 m (6.26 km²)
Red-throated diver	0	2-3	0
Pink-footed goose	1	1	0
King eider	1	1-2	0
Long-tailed duck	0	7-8	0
Rock ptarmigan	1	5-6	1
Great ringed plover	6-11	15-22	32-34
Red knot	1-3	13-15	11-15
Sanderling	12-13	22-26	26-28
Dunlin	24-27	47-56	4-5
Ruddy turnstone	4-5	34-38	5
Red-necked phalarope	0	1-2	0
Long-tailed skua	2-4	14-17	3
Snow bunting	20-24	24-31	8-10

Table 4.16. Estimated number of pairs/territories in three sectors of the 18.8 km² census area in Zackenbergdalen, 1999.

	1996	1997	1998	1999
Red-throated diver	1-2	2	3	2-3
Pink-footed goose	0	1	0-1	2
King eider	2-3	2	1	2-3
Long-tailed duck	5-8	4-6	6-8	7-8
Rock ptarmigan	3	11-15	4-6	7-8
Great ringed plover	54-56	40-48	38-45	53-67
Red knot	33-43	35-44	27-32	25-33
Sanderling	51-63	55-70	62-70	60-67
Dunlin	69-82	75-91	75-94	75-89
Ruddy turnstone	42-52	49-58	56-63	43-48
Red-necked phalarope	0-1	0-2	1-2	1-2
Red phalarope	0	0	0-1	0
Long-tailed skua	25-29	22-25	21-24	19-24
Northern wheatear	0	0	1	0
Snow bunting	45-55	45-56	41-46	52-65

Table 4.17. Census results from the 18.8 km² census area in Zackenbergdalen, 1996-1999.

Bumble bees

The first bumble bees *Bombus* sp. were recorded on 17 June (3-4 individuals). This is 11-17 days later than in previous years. On the line transects through Store Sødal (18-20 July) and from Daneborg to Zackenberg (25 July) 13 and 0 bumble bees were recorded. This is similar to earlier records. A total of 35 were recorded by the bird census worker, Hans Meltofte, in July. Unfortunately, they were not recorded systematically in this nor in previous year.

4.3 Birds

Hans Meltofte

Bird observations were recorded by Hans Meltofte from 1 June-8 August, by Thomas B. G. Berg from 8 August-1 September and by Claus Nordstrøm until the station was closed down on 9 September. Valuable observations were provided by several other researchers and staff during the entire season.

In June, the main effort was to census the breeding birds in the 19 km² census area in Zackenbergdalen, while in July emphasis was on breeding phenology, *i.e.* finding nests and young and rechecking these. During late July and all of August, waders and other waterbirds were counted every third day in the recent and the old delta of Zackenbergelven.

Breeding populations

The 18.8 km² census are in Zackenbergdalen was covered on almost daily trips between mid June and early August (Table 4.15). Due to the unprecedented large amounts of snow and the resulting late snow melt, the main census effort in the extensively covered area east of Zackenbergelven was as late as 18-23 June. Another effect of the late snow melt was that the river was very difficult to cross after the torrential break up on 20 June. The result was that the intensive study area west of the river was only covered on 17 and 26 June, until the passage became more safe from 4 July. In total, the hours used for the initial complete coverage of the entire area between 18 and 23 June amounted to 30 hours, as compared to 44 hours in 1998, 43 hours in 1997 and 43 hours in 1996. The reduced amount of time used was due to the extensive snow cover that made the area easier to cover, especially because skies could be used more extensively. In early and mid June regular reconnaissance trips were made in both areas.

The census results are presented in

Table 4.16, and in Table 4.17. They are compared with figures for 1996, 1997 and 1998. In spite of the large amounts of snow, most species were recorded in numbers very much similar to 1998. The most striking difference is the higher number of great ringed plovers, but this is an artefact, as many of them were "pairs" and individuals hanging around until late June in post-breeding feeding habitats, and hence not necessarily belonging to the local population. On the contrary, the somewhat lower number of ruddy turnstones reflects a real reduction in the local population. Furthermore, apparently only between one third and one half of the turnstone population actually bred. The remaining birds rambled in pairs or as singles over the tundra until they left the area in the last days of June or early July. They would often give some alarm calls at my presence or towards predators, whereupon they could lift and fly away. Except for the red knot, which may also have bred in reduced numbers, the other species apparently bred to a normal extent in the census area, but earlier post-breeding flocks of waders were seen from around 1 July, which could indicate that other waders failed as well.

	Median date	Range	N
Great ringed plover	27.5 June	13-28 June	4
Red knot	19.5 June	19-20 June	2
Sanderling	23.5 June	19 June - 9 July	18
Dunlin	22 June	17 June - 3 July	22
Ruddy turnstone	24 June	18 June - 3 July	13
Red-necked phalarope	26 June	-	1

Table 4.18. Median first egg dates for waders at Zackenberg 1999 as estimated from incomplete clutches, egg floating, hatching dates and weights of pulli.

	1995	1996	1997	1998	1999
Great ringed plover			(15 June)		
Sanderling		(16 June)	18 June	18 June	23.5 June
Dunlin	(18 June)	11.5 June	13 June	16.5 June	22 June
Ruddy turnstone	(12 June)	18.5 June	13 June	12.5 June	24 June

Table 4.19. Median first egg dates for waders at Zackenberg 1995-1999. Data based on less than 10 nests/broods are in brackets, data on less than five are omitted …

	1995	1996	1997	1998	1999
Great ringed plover	(4.00)	(4.00)	(3.50)	(4.00)	(3.50)
Red knot				(4.00)	(4.00)
Sanderling	(4.00)	4.00	3.86	4.00	3.67
Dunlin		(4.00)	(3.75)	3.90	3.70
Ruddy turnstone		3.71	3.79	3.81	3.58

Table 4.20. Mean clutch size in waders at Zackenberg 1995-1999. Samples of less than five clutches are given in brackets.

Reproductive phenology in waders (shorebirds)

First egg dates from 1999 are presented in Table 4.18, and in Table 4.19 median dates are compared to results from previous years. In accordance with the extensive and late disappearing snow cover it appears that egg-laying in 1999 was later than in any previous year. In sanderling, the delay in the median date was 6-8 days, in dunlin 5-10 days and in ruddy turnstone it amounted to 5-12 days. Also the delay in the earliest recorded first egg dates is pronounced. In sanderling, the earliest records for 1996-98 were 8-13 June, in dunlin 6-10 June and in ruddy turnstone 4-8 June. This is 6-14 days earlier than in 1999. The same applies to the very latest clutches, where especially the sanderling stand out with seven clutches that were later than any previously recorded in this species.

Breeding success in waders

In accordance with the delayed egg-laying, more wader pairs produced 3 egg or even 2 egg clutches. The resulting reduced average clutch sizes (Table 4.20) are significantly smaller than those recorded during previous years (Fisher's exact probability test: p(0.05 for both sanderling, dunlin and ruddy turnstone and p=0.005 for all species combined). The average reduction amounts to 7.3% in sanderling, 4.6% in dunlin and 9.4% in ruddy turnstone.

Also the hatching success was apparently the lowest at Zackenberg so far. Out of 43 wader nests found with eggs, 25-33 (58-77%) hatched at least one young, compared to 64-83% in 1998 (N=36), 78-92% in 1997 (N=26) and 73-87% in 1996 (N=15). Eight were preyed on (two apparently by birds), another eight were probably preyed on. In one dunlin nest the embryos died due to water in the nest cup, and one ruddy turnstone nest was deserted. The latter is noticeable, as it was the latest turnstone clutch recorded so far (1st egg

	1996	1997	1998	1999
Great ringed plover	(100)	(0-25)	0	(25)
Red knot			(0-100)	(50)
Sanderling	17	0-40	0-11	21-29
Dunlin	(0)	0	11-33	0-33
Ruddy turnstone	0-29	0-8	27-47	18-55
Red-necked phalarope				(100)
All species pooled	13-27	0-17	14-34	20-39
N	15	24	35	41
Foxes encountered	3	1	6	6

Table 4.21. Predation rate in wader nests at Zackenberg 1996-1999 expressed as minimum and maximum percentage of nests fallen prey, of those found with eggs throughout the nesting period. Partially nests fallen prey are given as successful, if at least one young hatched, and so are nests eventually controlled with starred or pipped eggs found empty and without indications of predation later on. Nest failures for other reasons are omitted. Samples of less than five nests are given in brackets. Also given are numbers of foxes encountered when bird monitoring (by one field worker) in June-July.

	1995	1996	1997	1998	1999
Great ringed plover	96	126	249	42	44
Sanderling	304	726	149	333	445
Dunlin	325	360	323	232	509
Ruddy turnstone	80	108	82	109	23
Total	810	1342	803	722	1021

Table 4.22. Cumulative numbers of juvenile waders recorded at low tide in the old and the present deltas of Zackenbergelven during counts every third day in the period 1-31 August, 1995-1999. In case of missing counts etc., data have been interpolated.

laid on 4 July). In a sanderling nest, one infertile egg was left behind, in each of two turnstone nests two eggs were infertile, and in another turnstone nest, three out of four eggs apparently fell prey. In one dunlin nest, a starred egg with a fully developed embryo was left behind. One pipped egg in a ringed plover nest was deserted, probably due to human disturbance, and two eggs in a sanderling nest were damaged, probably also due to human activities.

Predation accounted for losses of 20-39% of the clutches that did not perish for other reasons (Table 4.20). Predation rates during 1996-1999 show some correlation with number of foxes encountered in the valley, but no negative correlation with the number of lemmings, as often postulated. Like in 1998, ruddy turnstones suffered most from predation. Unfortunately, the data do not allow for calculation of daily nest survival, as we do not visit nests between finding and estimated hatching. This is to minimise the risk of guiding foxes and other predators to the nests by smell or tracks. However, the data presented in Table 4.20 may be used as an index of nest predation, as the ‘scatter’ of nest finding is very much the same from year to year.

The number of juvenile waders recorded in the deltas of Zackenbergelven is in reasonably good agreement with the findings mentioned earlier, supplemented with data presented in this chapter. In spite of the extensive and late disappearing snow cover, sanderlings and dunlins bred to a normal extent and with good success (Table 4.22), while turnstones suffered from significantly reduced breeding effort and reduced hatching success. Data for great ringed plovers also show low production, but the occurrence of this species in the deltas may be more variable, and we need more material, before the validity of data for this species can be evaluated.

Reproductive phenology and success in long-tailed skuas

The reduced number of lemmings together with the extensive snow cover and the late snow melt meant that long-tailed skuas bred late, in reduced numbers and apparently even laid small clutches. About the ‘normal’ number of skua pairs (19-24) established territories in the census area during June, but egg-laying was only recorded in seven pairs. First egg dates were between 14 June and 22 June, which is later than any of the previous years. Three clutches held two eggs, while four clutches held only one. Of these, two may have been incomplete. On 3 July, one pair produced a second clutch of one egg after predation of an initial two egg clutch.

Six or seven clutches were preyed on, including the re-laid clutch. A two egg clutch was apparently prey to a glaucous gull after having been deserted. One nest was preyed on just around hatching, and only one young hatched successfully. It was checked for the last time on 3 August at an age of 20 days, *i.e.* just before fledging, whereupon it was not recorded again. Its weight was 247 g and the wing measured 176 mm, which means that it had developed normally (de Korte 1986).

Breeding barnacle geese

A few days later than during the previous years, the first barnacle goose pair with one gosling appeared in the old delta of Zackenbergelven on 1 July. A further 11 pairs with goslings had arrived in the present delta on 6 July, and on the next day a pair with a several days old gosling was encountered at Zackenbergelven north of the station.

During most of July, the families at the coast alternated between the deltas and Lomsø, where a maximum of 16 families were recorded in late July. A further five pairs with a total of 12 goslings were encountered at the coast and at ponds near the peninsula in the southeastern part of the valley on 19 July, and a total of 11 pairs with 20 goslings were recorded east of the peninsula on 25 July. In the upper part of the valley, one further pair with three relatively small goslings were encountered in Morænebakkerne on 23 July.

Hence, 29 pairs of barnacle geese brought their young to Zackenbergdalen in 1999. Of these, 18 families stayed in the parts of the valley, where similar numbers were recorded during the two previous years. At least a further four pairs stayed at Lomsø during July. The average brood size among successful pairs was significantly lower than in previous years (Mann-Whitney U-test: $p<0.05$ for early, mid and late July, but not significant for early August) (Table 4.23), which together with the apparently slightly later breeding schedule may be attributed to the unprecedented large amounts of snow during June and possibly to fox predation due to late formation of open water along the coasts.

On the line transect through Store Sødal, two broods of 1 and 2 goslings, respectively, were recorded along the southeastern shore of Store Sø on 20 July.

Data on average brood size and per cent juveniles from the wintering grounds on the Isle of Islay in Scotland were kindly provided by Malcolm Ogilvie. From these it appears that the 1999 average brood size was the lowest recorded during our study years, but not much lower than in 1997, when the percentage of juveniles was even lower than in 1999. The lowest breeding success recorded on Islay was in 1992 (2.6% juveniles and an average brood size of 1.31), when extreme amounts of snow and a late snow melt was also recorded at Zackenberg – and in most of the Arctic (Tamstorf 1997, Barbara Gander *in litt.*).

Line transect

This year, the line transect through Store Sødal did not include the northeastern part of the valley. Therefore, average figures from 1997-1998 have been added to the totals in Table 4.24 for the relevant species.

For most species, the totals recorded resemble the results from 1996, 1997 and 1998. The number of pink-footed geese in Store Sødal was considerably lower (122 in 1996, 203 in 1997 and 123 in 1998), and so was the number of common eiders along

	1995	1996	1997	1998	1999
Primo July		(3.0)	3.07	(2.9)	1.92
Medio July		(2.3)	2.71	2.31	1.82
Ultimo July	(2.0)	(3.0)	2.63	2.22	1.72
Primo August	(2.3)	(2.3)	2.35		1.75
No. of broods	>7	6-7	19-21	>18	29
Britain	2.00	2.30	1.95	2.28	1.92
Per cent juv.	7.2	10.3	6.1	10.5	8.1

Table 4.23. Average brood sizes of barnacle geese in Zackenbergdalen in July and early August, 1995-1999, together with the total number of broods brought to the valley. Samples of less than 10 broods are given in brackets. Data from autumn on the Isle of Islay in Scotland are given for comparison, including per cent juveniles in the population (M. Ogilvie in litt.).

	Store Sødal 18-19 July	Daneborg 25 July	Total
Red-throated diver			0
Pink-footed goose	26	1	27
Barnacle goose	204/3	23/20	227/23
Common eider		55/6	55/6
Long-tailed duck		2	2
Rock ptarmigan			0
Great ringed plover	(70)	8	(78)
Sanderling	2	31	33
Dunlin	(45)	11	(56)
Ruddy turnstone	7	1	8
Long-tailed skua	1	13	14
Glaucous gull	7	1	8
Arctic tern	1		1
Common raven		2	2
Snow bunting	(51)	3	(54)

Table 4.24. Birds recorded (adults/young) during line transect surveys through Store Sødal and from Daneborg to Zackenberg (see map in Meltofte and Thing 1997). Figures in brackets include extrapolated numbers from the north side of outer Store Sødal.

the coast between Daneborg and Zackenberg (390 in 1997 and 119 with 5 ducklings in 1998). Also, many more snow buntings were recorded in 1997 (104), but not in 1998 (66).

The relatively high number of sanderlings recorded between Daneborg and Zackenberg was caused by a flock of 30 individuals. Also the 13 long-tailed skuas were in one group.

Sandøen

During the period 26 July-1 September, Erik W. Born, Mario Acquarone and David Griffiths stayed on Sandøen in connection with a walrus study (see section 5.15). It is estimated that about 2000 Arctic terns and 300 Sabine's gulls occupied the island. These are the highest numbers ever recorded at Sandøen (see below). Totals of 258 Arctic tern chicks and 13 Sabine's gull *pulli* were ringed on 14, 17 and 18 August. Based on the ratio marked / unmarked *pulli* found on 18 August, it was calculated that 657 Arctic tern chicks (95% confidence interval: 454-860) and 17 Sabine's gull *pulli* (95% confidence interval: 13-23) were present on the island.

Most birds left around 26 August, leaving only about 50 Arctic terns and no Sabine's gulls at the island on 27 August. Five ravens and three gyr falcons ate the remaining young. In gyr falcon casts at Kap Berghaus on the mainland coast rings from eight tern chicks and one Sabine's gull chick were found on 24 August (O. Gilg *in litt*.).

The terns were breeding all over the island, while the Sabine's gulls only inhabited the 'high' central part (about 4 m a.s.l.).

With an average clutch of 1.7-2.0 eggs in this and other Arctic colonies (Meltofte 1972, Cramp *et al.* 1985), it is most likely that a minimum of about 250-500 pairs of Arctic terns succeeded in hatching young on Sandøen in 1999. The corresponding figure for Sabine's gull is about 10-15 pairs based on a 'normal' clutch size of two eggs (Cramp *et al.* 1983). The only previous data on the number of terns on Sandøen, were 200-300 individuals in 1964, of which hardly more than 15 pairs were breeding (Rosenberg *et al.* 1970), 100-200 breeding pairs in 1972 (Meltofte 1972), 1000 individuals in 1973 (many breeding) and at least 400 pairs in 1976 (Meltofte *et al.* 1981). In 1976, at least 100 pairs were found with chicks. The actual number of tern nests has never been recorded in a 'normal' breeding year.

Previous records of Sabine's gulls were 26 shot and one nest found in 1930, three breeding pairs and 25 non-breeders in 1932, three pairs observed in 1947 and up to four birds together with one nest in 1964 (Rosenberg *et al.* 1970). One pair bred in 1972 (Meltofte 1972), and three pairs bred in 1976, while no Sabine's gulls were encountered at the island in 1973 (Meltofte *et al.* 1981).

Two nests of long-tailed ducks were found. A nest with six eggs was deserted on 7 August possibly due to disturbance. At another nest, three dead ducklings were found on 25 August. No breeding common eiders were found.

Other observations

When nothing else is stated, observations refer to the census area in Zackenbergdalen.

Red-throated diver *Gavia stellata*

The first birds were circling over the valley on 4 June, and on 8 June a pair was sitting on a pond for the first time. On 10 June, three pairs were present.

In Sydkærene, incubation was initiated on 18 June, and from 20 June, a pair occupied the east end of Lomsø, where one was incubating on 27 June. It is possible that the nest in Hestehale Sø saw an unsuccessful breeding attempt, but otherwise, no further breeding attempts were recorded in Zackenbergdalen. As late as 22 July, a pair appeared on Ryledammene, and pairs and individuals were recorded regularly in July and August on the lakes in Morænebakkerne. On Lindemanssø, only one individual was observed in mid July. A pair was recorded twice on Tørvedammen in the second half of August.

The nest in Sydkærene apparently fell prey on 11 July, and the nest at the east end of Lomsø fell prey by 15 July. Pairs and single individuals stayed in Sydkærene and on Lomsø throughout July and most of August.

The first birds were seen in the delta of Zackenbergelven on 17 June. In July, a maximum of eight were recorded here, while up to 11 were found in August.

Pink-footed goose *Anser brachyrhynchus*

Two pairs were seen regularly from 3 June. A pair and later an alert gander was observed until 17 June at the same place west of the river, where a pair nested in 1997, and one further pair was recorded a number of times in the western part of Rylekærene in early June. On 6 July, a pair with four goslings appeared in the delta of Zackenbergelven, but they were not seen later. On 5 June, no signs of nests nor geese were found on the point six kilometres west of the station, where two pairs were recorded in 1997.

On 13 June, eight pink-footed geese arrived together with a flock of barnacle geese, and from 17 June moult migrating immature were recorded almost daily. Up until 12 July, a total of 540 migrated north, and a cumulated total of 222 rambled over the valley or were staging. Most were seen in late June.

On 15 July, 29 flightless birds were encountered off the old trapping station, and on 19 July, when the entire coast east of the station was searched, a total of 127 moulting individuals were recorded. 36 were found off Grænseelv, 41 on the west side of the peninsula, and 50 east of it. A much lower number of moulting pink-feet was recorded in Store Sødal (26), than in previous years. 21 were encountered in the upper part of the valley and five along Zackenbergelven in the lower part.

In late August, up to 600-700 were feeding in Rylekærene and around Ulvehøj. Two flocks of 80 individuals flew south on 24 August.

Barnacle goose *Branta leucopsis*

Up to 30-50 mainly immature barnacle geese were recorded regularly in June with 73 at Lomsø on 29 June as the maximum. In July, 61-63 moulted at Lomsø, 27 along the river and in Morænebakkerne, 25-30 at Lindemanssø and 66 around the peninsula in the southeastern part of Zackenbergdalen. The first flightless birds were recorded on 8 July, and the last flying on 9 July. The moulting immatures were flying again by 3 August.

A total of 87 barnacle geese was recorded in upper Store Sødal during the line transect in mid July together with 117 in the lower part. This adds up to a grand total of about 385 moulting barnacle geese in the study area.

In August and early September, maximum records were 170 west of the peninsula together with 100 in Lindemanssø on 7 August, 200 in Tørvekæret on 29 August, and 500 southeast of Ulvehøj together with 60 south of the station on 2 September.

Common eider *Somateria mollissima*

As late as 29 June, the first common eider (a male) was recorded in the study area. From the next day, a male with up to four females were seen on the coast until 11 July. During the rest of July, the number of females increased to a maximum of 55 on 22 July and 70 on 8 August. The first eight *pulli* appeared on 23 July, and in late August a maximum of 200 adult females and juveniles were recorded along the coast.

King eider *Somateria spectabilis*

On 16 June, a pair of king eiders arrived to the ponds at the station, where they remained during the rest of the month, sometimes together with an additional female. On 30 June, three pairs plus one female were present, and two pairs remained until 7 July, when the males were seen for the last time. Single males were seen on the coast on 19 and 22 July together with a single female on the 19th.

A female was sitting on a nest in the middle of a *Cassiope* heath west of the river from 13 July until the eggs hatched between 5 and 7 August. She was not seen later.

Long-tailed duck *Clangula hyemalis*

A single male arrived on 6 June, and on 11 June, the first pair appeared on ponds at the station. Already from the next day, seven pairs were present, and varying numbers of pairs and singles were seen on ponds and in the deltas until early / mid July.

A nest with six eggs were found in Gadekæret on 9 July, and on 16 July one more nest with four eggs were found in Sydkærene. They were both preyed on, by 15 July and 24 July, respectively. On 30 July, a nest prey from this year was found at Kærelv. No ducklings were seen.

From mid July, small flocks of long-tailed ducks appeared on Lomsø and along the coast, with a maximum of 17 on Lomsø and Kystkærene on 23 July and 20 distributed along the coast on 19 July.

Gyr falcon *Falco rusticolus*

The remains from three snow buntings and one dunlin apparently eaten by a gyr falcon were found on 5 and 12 June, respectively. On 20 June, a falcon was seen, and one more on 30 July. Two juveniles appeared on 1 August, and they (?) were seen again on 6 September. Single individuals were seen seven times during 11-25 August.

The nest on the point three kilometres west of the delta of Zackenbergelven reported in 1998 (Rasch 1999), was searched on 5 June this year, but no nest nor any possibility for a nest could be ascertained.

Rock ptarmigan *Lagopus mutus*
In early June, males and pairs were displaying almost daily in different parts of the census area. During the rest of June, they were seen more sporadically, and the last 'territorial' male was seen on 5 July. A hen with three small *pulli* was encountered west of the river on 24 July, and another hen (?) was found with four *pulli* on the west bank of the river on 12 August. A few more adults were recorded in August.

Waders *Charadrii*
All the common waders, great ringed plover *Charadrius hiaticula*, red knot *Calidris canutus*, sanderling *Calidris alba*, dunlin *Calidris alpina* and ruddy turnstone *Arenaria interpres* were present at our arrival on 1 June. Song and other display was recorded from the very first days, but in accordance with the heavy and extensive snow cover, territory establishment and pair formation was 5-10 days delayed as compared to the three previous years. Even until mid-summer, many pairs and individuals had not yet settled.

The first post-breeding flock of 8-9 sanderlings and 3-4 turnstones was seen on 27 June, and on the next day, a flock of 13 knots, five dunlins and two turnstones was encountered besides a group of three sanderlings. Similar flocks were seen on the tundra during July, with 30 sanderlings in one flocks on 25 July as the largest observed.

During the waterbird counts in the deltas of Zackenbergelven, up to 14 adult ringed plovers (on 1 August), 81 adult sanderlings (on 17 August), 110 adult dunlins and 20 adult turnstones (on 20 July) were recorded. Peak numbers of juveniles were 28 ringed plovers on 25 August, six knots on 2 September, 122 sanderlings on 28 August (1 adult, 17 juveniles and 117 unspecified sanderlings on 25 August), 152 dunlins on 25 August and 10 turnstones on 8 August. First observation dates of independent juveniles were: ringed plover 11 August, sanderling 8 August, dunlin 1 August and turnstone 29 July. The latter is earlier than for birds from the study area, where the earliest juvenile could have fledged on 5 August and would have needed a few more days on the tundra before gaining independence.

European golden plover *Pluvialis apricaria*
One individual flew over the station on 4 June.

Eurasian curlew *Numenius arquata*
A curlew was feeding south of the station on 20 and 21 June. On 29 June, it was found dead. The curlew was an immature female with a bill of 137 mm. Its weight was only 543 g, and it had died from starvation in spite of the fact that its guts were full of year-old crowberries.

This is the sixths record in Greenland of which three were at Zackenberg (Meltofte and Rasch 1998).

Red-necked phalarope *Phalaropus lobatus*
Two pairs appeared on the ponds in Gadekæret on 10 June. From a few days later, only one pair or single individuals were seen until two males and one female were recorded as the last ones inland on 15 July. In the meantime, a nest with four eggs was found in Sydkærene on 1 July. It was preyed on by a fox three days later. A female was feeding on the shore of the old delta of Zackenbergelven on 26 July.

Long-tailed skua *Stercorarius longicaudus*
Pairs and singles were recorded from our arrival on 1 June, and on 2 June a flock of 10 were seen. From mid July, the pairs started to break up and the birds began to ramble over the tundra. An assemblage of 15 was sitting on the snow on 14 July. Most left during the last days of July, and only a few were seen until 5 August.

Glaucous gull *Larus hyperboreus*
Up to two or three were recorded almost daily during all of June and the first half of July. A maximum of five were hunting lemmings in June. In July, a maximum of 18 adults and four immatures were counted in the deltas of Zackenbergelven on 29 July. The first two immatures were seen on 16 July. On 5 August, 15 flew north at great height. A maximum of four adults, three immatures and one juvenile was recorded in the deltas in August – the first juvenile on 22 August.

Great black-backed gull *Larus marinus*
A great black-backed gull flew over the valley together with four glaucous gulls on 2 July.

Snowy owl *Nyctea scandiaca*
A grey (female?) was seen on 30 June.

Northern weathear Oenanthe oenanthe
A female was seen twice on 17 June. One was seen at the trapping station on 25 August, and on 27 August, two juveniles were recorded at Nansenblokken on the slopes of Zackenbergfjeldet.

Common raven *Corvus corax*
Single ravens were recorded regularly during the first half of June, and a nest apparently with one or two birds were seen on the south facing bluff of Zackenbergfjeldet on 5 June. In July, one or two birds were recorded regularly, and on 1 July one individual appeared to be a juvenile. 1-3 were seen occasionally during August.

Arctic redpoll *Carduelis hornemanni*
During early and mid June, a total of nine Arctic redpolls were recorded. The only other observation was of a flock of about 15 at Nansenblokken on 27 August. At least three of them were juveniles.

Lapland longspur *Calcarius lapponicus*
A male was seen on both 5, 7 and 21 June.

Snow bunting *Plectrophenax nivalis*
Newly fledged young were recorded for the first time on 21 July, which is 6-9 days later than in previous years. In late August, flocks of up to 70-100 birds were recorded.

4.4 Mammals

Thomas B. G. Berg

Observations on mammals were made by Hans Meltofte (1 June-8 August) and Thomas B. G. Berg (28 June-3 September). Most other personnel supplied additional observations during the entire field season. The 2.5 km^2 census area for collared lemming *Dicrostonyx groenlandicus* was censused for winter nests and summer burrows from 21 July-9 August. The total number of muskoxen *Ovibos moschatus* was censused once a week within the 39 km^2 census area from 3 July-28 August. During the entire season, additional counts were taken almost daily from a fixed elevated point at the station covering the area from Lindemansdalen along the shore line to Lille Sødal north of Daneborg. The two line transects Zackenberg – Store Sødal and Daneborg – Zackenberg were walked by Thomas B. G. Berg and Nicolai Jørgensen from 18-25 July. One new fox den and a single burrow were recorded, and all known dens were checked regularly for occupation.

Collared lemming population

A total of 305 winter nest and 403 active summer burrows were recorded within the 2.5 km^2 census area (Table 4.25). The numbers of winter nests declined by 57% from 1998 and reached a number comparable to the number found during 1997, whereas the numbers of summer burrows almost equalled the number recorded in 1998. The marked decrease is also indicated by the reduction in number of lemmings observed by the ornithologist (Hans Meltofte) mainly during snow melt in June (Table 4.25). The 1998-1999 decline of the lemming population found in Zackenbergdalen was also apparent along the two line transects (Table 4.26).

Lemming abundance fluctuates by season and year, most often in a cyclic pattern. The increase and decline phase may take one or two years. At Zackenberg, there has apparently been a two year increase followed by a two year decline (Table 4.25). In Karupelv valley on Traill Ø, Sittler (1999, pers. comm.) has covered almost three full cycles, with a maximum number of winter nests of up to 25 times the number found during the low phase (Table 4.25), whereas we still have to see a full scale low at Zackenberg.

The density of lemming winter nests preyed upon by ermines dropped from 28 in the lemming peak year of 1998 to 4 in 1999, which almost equals numbers found at Karupelv (Table 4.25). This pattern is in contrast to the more classical situation

Table 4.25. Annual numbers of recorded winter nests and summer burrows within the 2.5 km^2 census area in Zackenbergdalen. Category 1 denotes nests from the previous winter, category 2 are nests from earlier winters that were not recorded previously. Numbers of animals were recorded by one person from June-July.

	Winter nest category 1	Winter nest category 2	Summer burrows	Number of animals
1995	279*	830	-	-
1996	161	263	-	0
1997	342	109	710	1
1998	711	109	327	43
1999	305	57	403	9

*The 1995 numbers include nests from 1993/1994 and 1994/1995.

Table 4.26. Records of lemming winter nests and active summer burrows obtained along the transects Zackenberg – Store Sødal (80 km) and Daneborg – Zackenberg (25 km). Nests and burrows were recorded within 3 m on each side of the track by two observers walking the transect, giving total lengths of 160 km and 50 km, respectively.

		Winter nests		Summer burrows	
		No.	No./km	No.	No./km
Lower St. Sødal					
1996	90 km	1	0.011	0	0
1997	180 km	8	0.044	9	0.050
1998	90 km	8	0.089	0	0
1999	90 km	2	0.022	0	0
Upper St. Sødal					
1996	60 km	1	0.017	1	0.017
1997	120 km	3	0.025	0	0
1998	60 km	13	0.217	6	0.100
1999	70 km	1	0.014	0	0
DNB-Zackenberg					
1997	50 km	22	0.440	21	0.420
1998	50 km	17	0.340	1	0.020
1999	50 km	1	0.020	0	0

seen at Karupelv, where ermines peak a year after a lemming peak due to the delayed implementation of the foetus in the ermine.

Another major difference between Zackenberg and Karupelv is the presence of snowy owls. At Karupelv, the snowy owl population may peak with 21 breeding pairs within 50 km^2 (11 years of records; Sittler 1999, pers. comm.), while only one breeding pair has been observed in Zackenbergdalen (also 50 km^2) from 1995-1999. The long-tailed skua populations at Karupelv and Zackenberg have almost equal densities (1-2 pairs per km^2). It is obvious from these data that the predator-prey link differs between the two locations. The presence of snowy owls at Karupelv may have a negative effect on the size of the ermine population and their ability to benefit from an increasing lemming population, as it was experienced at Zackenberg in 1997-1998, and hence affect the fluctuation of the lemming population.

The 29 fixed sample sites for casts and scats from long-tailed skuas, snowy owls, Arctic foxes and ermines, respectively, were checked on 31 August (Table 4.27). Only the number of scats from ermines increased as compared to the previous years.

Table 4.27. Numbers of casts and scats collected from 29 sites within the 2.5 km^2 lemming census area in Zackenbergdalen. The samples represent the period from mid August the previous year to mid August in the year denoted.

	Skua casts	Owl casts	Fox scats	Ermine scats
1997	44	0	10	1
1998	69	9	46	3
1999	31	3	22	6

Muskox population biology

Censuses of the muskox population in Zackenbergdalen showed the same seasonal changes as in previous years starting with less than 20 animals in June and increasing to around 100 animals by the end of August. The maximum number of muskoxen recorded (28 August) within the 39 km^2 census area was 106, of which 11 were calves.

Daily censuses from a fixed elevated point at the station have been used to calculate the grazing pressure by muskoxen within the census area, expressed as 'muskox days' (sum of weekly average of animals per census). This shows a continuos 62% decrease in the grazing pressure from 1996 to 1999 (Table 4.29) in the 39 km^2 study area, despite the increasing number of animals seen in the 200 km^2 area (Table 4.30). The snow distribution, plant phenology and yearly changes in the spatial use of Wollaston Forland may be the most important reasons for these changes.

The weekly censuses are presented in

Table 4.28. Average number of 'muskox days' per month within the 39.1 km^2 census area in Zackenbergdalen based on the daily counts from a fixed elevated point at the station.

	1996	1997	1998	1999
June	455	290	534	371
July	496	1111	652	408
August	2241	1343	1047	1216
Total	3192	2744	2233	1995

Table 4.31. In evaluating these data, it must be taken into account that the musk-oxen recorded during the field season only represent a fraction of the total sub-population on Wollaston Forland. Migration in and out of the area occurs all the time. The amount of snow accumulated during the 1998-1999 winter was larger than the previous year and seems to have had a considerable effect on the number of calves, and the survival of calves from the year before (Table 4.31). The number of calves in 1998 and 1999 was only half the ratio in 1996, a year with little snow, and less than one third of the number in 1995, which apparently also was poor in snow (Meltofte and Thing 1996). Only one yearling, a female born in 1998, was seen during the entire field season, whereas the survival of calves born in 1997 seems to be normal. Otherwise, changes in the population demography are most explicit within the adult bulls, of which the ratio has increased considerably during the study years (Table 4.31).

From 18-25 July, a total area of 200 km^2 was censused along the line transect and a total of 171 animals was recorded. It is assumed that the risk of double counting muskoxen during this census is minimal. The age distribution based on this census shows a slightly different pattern than the figures obtained from the weekly censuses made in Zackenbergdalen. As seen from Table 4.30, the total number of muskoxen within the 200 km^2 area has increased over the years. Out of the 171 animals, calves made up 14% as compared to 8.6% in Zackenbergdalen (Table 4.31).

The number of cows in the reproductive age (3 years or more, without calves) accessible to bulls within the 39 km^2 census area during the rutting season, was between 46.9% and 82.6% of the total numbers of adult cows during 1996-1999. From 1996-1998, only 30-40% of the accessible cows gave birth the following year. Considering the fact that we only have useful data from these three years, it is noteworthy that the number of accessible cows recorded one year is positively correlated with the number of calves the next year ($R2= 0.9794$, $N=3$). This may indicate that pregnant cows remain within or return to the census area from year to year. On average, there are 17.4 cows (SD=3.1639, range 12.7-20.0) accessible to an average of 17.3 adult bulls (SD=6.2681, range 13.3-27.0). The ratio of accessible cows to bulls varied

	F-calf	M-calf	F1	M1	F2	M2	F3	M3	F4+	M4+	Total
1997	6.3	6.3	4.9	5.8	12.6	13.6	7.8	1.9	31.1	9.7	103
1998	4.5	4.5	4.9	5.7	6.6	6.6	6.6	5.7	36.1	18.9	122
1999	7.0	7.0	0.0	0.0	5.3	4.7	7.6	4.1	33.9	30.4	171

Table 4.29. Sex and age distribution (%) of musk-oxen in the entire study area based on the total counts of muskoxen along the two line transects and the related census in Zackenbergdalen. The counts were made from 16-25 July and covered an area of 200 km^2.

	F-calf	M-calf	F1	M1	F2	M2	F3	M3	F4+	M4+	N
1996	8.9	8.9	11.4	11.4	3.3	9.2	5.3	1.1	24.8	15.8	456
1997	6.8	6.8	5.1	6.1	10.2	8.8	6.3	3.7	29.0	16.6	411
1998	4.3	4.3	2.5	2.5	8.4	9.2	5.3	6.1	30.3	27	393
1999	4.3	4.3	0.9	0	2.5	2.8	5.7	6.6	30.8	42.1	318

Table 4.30. Sex and age distribution (%) of the muskox population in Zackenbergdalen as they appear from weekly censuses during the period 12 July-28 August, in the years 1996-1999. Sex of calves could not be assessed but the distribution is assumed to be 1:1. Numbers from 1997 of 3 years old and 4+ years old are interpolated from the averages of the years 1996 and 1998.

		Store Sødal	Daneborg-Zackenberg	Zackenberg
Muskox	M4+	18	9	21
	M3	3	1	2
	M2	4	2	1
	M1	0	0	0
	F4+	29	10	12
	F3	6	1	4
	F2	5	1	2
	F1	0	0	0
	Unsp. calves	17	2	5
	Unsp. adults	16	0	0
	Winter piles	1002	183	-
	Summer piles	260	123	-
Lemming	Winter nests	3	1	-
	Summer burrows	0	0	-

M=male, F=female, 4+= 4 years or more.

Table 4.31. Muskox and lemming data from the 80 km line transect through Store Sødal (18-20 July), the 25 km transect from Daneborg to Zackenberg (DNB-Zac) (25 July), and muskox data from Zackenbergdalen (Zac Val)(24 July). M=male, F=female, 4+= 4 years or more. Piles of faeces from muskoxen were recorded by two observers giving total transect lengths of 160 km and 50 km. Faeces piles are counted within one meter from the transect, while lemming winter nests and summer burrows are censused within three meters. One lemming nest in Store Sødal had fallen prey to an ermine.

	Store Sødal	Zackenberg-dalen	DNB-Zackenberg
Muskoxen / **km²**			
1996	0.37	0.35	-
1997	0.39	1.61	0.13
1998	0.62	1.18	0.86
1999	0.78	1.20	0.70
Faeces piles / km			
1997 winter/summer	1.59/0.49	-	4.90/0.82
1998 winter/summer	1.55/0.39	-	1.14/0.68
1999 winter/summer	6.26/1.63	-	3.66/2.46

Table 4.32. Muskox densities (animals/km²) in Store Sødal (92 km² in 1996-1998 and 125 km² in 1999, in Zackenbergdalen (39 km²), and in the coastal region between Daneborg and Zackenberg (37 km²) in mid July 1996-1999. Piles of faeces are recorded per kilometer observed.

between 0.74 and 1.22. Even though bulls younger than 7 years do not count much in reproduction, they do interfere with the cows in the area and may affect the reproductive strategy used by the prime bulls.

Only one fresh muskox bull carcass (ID no.: 99-1) was found at Østerport in 1999, estimated to be 10+ years. Cross cutting of the hind leg (femur) showed a dense white bone marrow, indicating that the animal did not die from starvation. The ribs and backbones showed clear signs of wolf chewing.

Arctic fox dens

One new den with two entrances was found on the western bank of the western tributary of Grænseelv (UTM Zone 27; 8,265,300 m N, 514,300 m E). A single entrance was also found on the slope facing east towards Sydkærene (UTM Zone 27; 8,264,039 m N, 512,649 m E). Both seemed to be several years old. None of the dens were occupied during the summer, but moulted white fur was found in the snow around an entrance of den no. 1 in early June.

Line transects

The line transect through Store Sødal was checked from 18-20 July. It was extended with 5 km in order to cover the valley behind the hill (Valhalla) in the inner part of Store Sødal. This extension has enlarged the muskox census area from 92 km² to 125 km². The valley behind Valhalla may be an important grazing area for muskoxen and probably also for geese. According to earlier observations made by the military sledge patrol Sirius, quite large numbers of muskoxen have been seen in this valley, both in winter and spring.

Recordings of muskoxen in 1999 (Table 4.32) from the inner part of Store Sødal (100 km²) show a density of calves 36% higher than in Zackenbergdalen at the same time. The ratio between F4+ and M4+ is remarkably low in Zackenbergdalen as compared to both line transects (1.6:1 in Store Sødal, 1.1:1 along DNB-Zac. and 0.6:1 in Zackenbergdalen), indicating that the bulls gather in Zackenbergdalen prior to the rutting season.

Even when the muskox records from the valley behind Valhalla are excluded, the number of muskoxen recorded on the Store Sødal transect exceeded the numbers counted in the previous years, giving total numbers of 72 in 1999, 57 in 1998, 36 in 1997, and 34 in 1996.

Observations along the Daneborg-Zackenberg transect were made on 25 July and showed the same density of muskoxen as in Store Sødal (Table 4.33). The major difference between these two transects is found in the number of calves, where 17 were recorded in the inner part of Store Sødal compared with only two along the coast.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date	23.7	03.8	06.8	16.8	23.7	03.8	14.8	16.8
Ice cover (%)	15	5	2	2	40	15	2	2
Temperature (°C)	4.2	6.8	8.5	6.4	2.4	4.6	4.8	4.8
Conductivity (µS/cm)	7.9	9.1	11.5	11.0	7.1	5.7	8.0	6.0
pH	6.4	7.1	6.6	6.8	6.3	6.4	6.1	6.4
Total nitrogen (µg/l)	190	230	ND	210	140	130	ND	90
Total phosphorous (µg/l)	10	19	ND	4	4	2	ND	15
Chlorophyll a (µg/l)	0.09	0.55	0.56	0.58	0.24	0.24	0.54	0.75

Table 4.33. Physico-chemical conditions and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July and August 1999. ND = no data.

Other observations

Collared lemming *Dicrostonyx groenlandicus*

During a visit to Orienteringshøjen (1,342 m) on 15 August, fresh lemming tracks were seen in snow at 1,200 m a.s.l.

Polar bear *Ursus maritimus*

On 10 July, a male bear came north from Lindemansdalen entering Rylekærene and Oksebakkerne, where it rested on a snow-bed 2.5 km from the station until the early morning of 11 July. From here it went towards Daneborg on the ice-covered fjord, where it appeared on the same day. On 13 July, probably the same bear was observed resting on a snow-bed close to the old Zackenberg trapping station. On 14 July, tracks showed that the bear had left the trapping station going south onto the fjord after a short glance toward the kitchen at the station. On 15 June, probably the same bear showed up again passing north along the west side of Zackenbergelven.

On 15 August, a mother bear with one cub was recorded 3 km east of Kap Breusing by the Sirius patrol.

Arctic wolf *Canis lupus*

Tracks and faeces of wolves were recorded in the area. On 23 July, two wolves were seen at Revet in Tyrolerfjord, and on 1 August, three were seen at the same place (Kathleen Cartwright, Arcturus Expeditions, *in litt.*). In mid August, 3 wolves were recorded at Revet in Tyrolerfjord, where they attacked a flock of muskoxen (Brigit Sabart and Olivier Gilg pers. comm.).

Arctic fox *Alopex lagopus*

18 independent records were made of foxes during the field season, 17 were in the white phase and 1 in the dark. Details in the records indicate that the number of animals within the area was 3 to 4 white phase adults and 1 dark adult. One carcass of an adult winter white phase fox was found close to the station. Additional fragments of at least one other winter white phased fox was found at the airstrip.

Arctic hare *Lepus arcticus*

Arctic hares were recorded 22 times between 23 June and 24 August. A minimum of 2 animals was seen on the west side of Zackenbergdalen, while a minimum of 8 animals was seen on Aucellabjerg. 1 animal was recorded on the transect in Store Sødal.

Ermine *Mustela erminea*

3 animals were seen. Two records were made in Morænebakkerne and one in the eastern part of Rylekærene. Tracks were found in Favoritdal, 500 m a.s.l. 1 animal was recorded on the transect in Store Sødal.

Walrus *Odobenus rosmarus*

9 walruses were observed on Sandøen during late July and August. In 1998, 28 walruses were counted there (see also section 5.15).

Seals *Pinnipidae*

During 22 of the daily muskox censuses from the station, from 1 June until the fjord ice broke up in the inner part of Young Sund in mid July, a total of 551 seals were counted, giving an average of 25 per count (range 2-61). This is almost four times the average recorded during 1996-1998. It should be noted, however, that there may be differences between the observers' experience in identifying seals on the fjord ice, and that the poor weather conditions in some years may influence the countings. However, it seems there were more seals in 1999 than in the previous seasons.

Arctic char *Salvelinus alpinus*

In mid August, the water level in Zackenbergelven dropped, at the critical time for Arctic char migration upstream, towards their winter quarters in the inland lakes. On 18 and 19 August, several hundreds of fish were trapped in front of an obstacle of boulders just downstream of Store Sø (Fig. 1). Several glaucous gulls and a few ravens were scavenging on the carcasses. No Arctic foxes were observed at the place.

4.5 Lake monitoring

Kirsten Christoffersen and Erik Jeppesen

A monitoring programme for two shallow lakes, one with and one without Arctic char, situated in Morænebakkerne, was initiated in 1999. Selected physical (ice cover and temperature), chemical (pH, conductivity, total nitrogen and phosphorous) and biological parameters (phytoplankton biomass and species composition) were measured at regular intervals during summer (*i.e.* late July to mid August). Pelagic invertebrates (zooplankton) were sampled

Fig. 4.1. Lemming winter nest (right axis) and ermine predation on lemming winter nests (left axis) shown as nest/km^2 and prey nests/km^2 at Karupelv, Traill Ø, and in the 2.5 km^2 census area in Zackenbergdalen. Data cover the numbers of nests built from October to May. Data from Karupelv were kindly provided by Benoît Sittler.

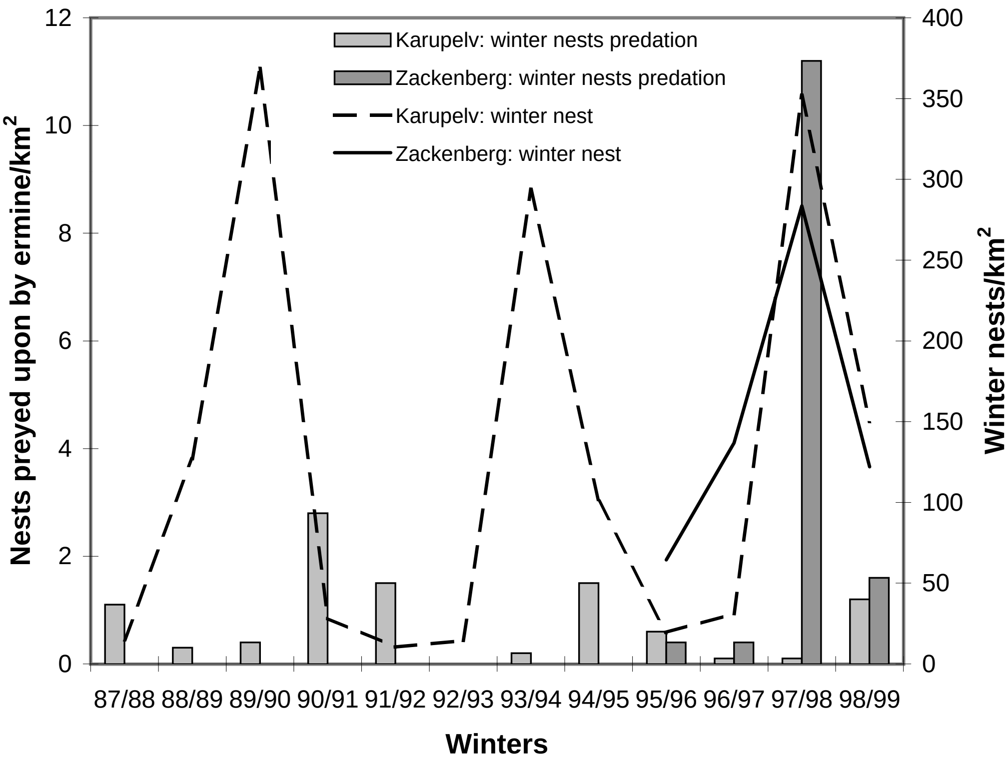


Fig. 4. 2. Obstacle of boulders some hundreds of meters downstream of Store Sø, where several hundreds of Arctic char were trapped around 18 August 1999. Photo: Ron Sletten.

in mid August for determination of species abundance and composition. The monitoring programme also includes investigations of the fish population every fifth year and finally analyses of the sedimented material (micro- and macrofossils) at about ten years intervals.

Both lakes, Sommerfuglesø and Langemandssø, were studied in 1997 and 1998 in connection with a research project on physico-chemical conditions of lakes at Zackenberg (see section 5.3 in Meltofte and Rasch 1998 and section 5.4 in Rasch 1999).

The average depth of Sommerfuglesø is 1.1 m and of Langemandssø 2.7 m, while the maximum depths are 1.8 and 6.1 m, respectively. The water temperature in Langemandssø is usually lowest owing to the occurrence of a large permanent snow patch along the northwest shore of the lake. The bottoms of both lakes are covered with mainly pebbles and boulders, though also sandy sediments are found. Only very small areas are covered with mud. Sparse moss vegetation is found in both lakes.

The lakes are nutrient poor and water transparency is high. A fish survey in 1997 revealed that Langemandssø hosts a population of dwarf Arctic char, *Salvelinus alpinus*, while no fish were recorded in Sommerfuglesø. The presence of fish implies that the zooplankton population in Langemandssø is usually dominated by copepods and rotifers, while cladocerans are more common in Sommerfuglesø.

Samples were taken from the lakes four times between 23 July and 16 August 1999. The water temperatures ranged from 2.4 to 8.5ºC, with a mean water temperatures of 6.5º in Sommerfuglesø and Langemandssø (Table 4.33). The conductivity of Sommerfuglesø (8-12 µS/cm) was slightly higher than in Langemandssø (6-8 µS/cm), while concentrations of total phosphorous and total nitrogen were highest in Sommerfuglesø. pH varied between 6.1 and 7.1. The chlorophyll-*a* concentration increased with decreasing ice coverage and reached approximately the same average level (0.36-0.45 µg/l) in both lakes. Generally, the basic physico-chemical conditions were found to be within the range observed in previous years, although the 1999 season was characterised by low water temperatures due to the occurrence of ice as late as mid August, especially in Langemandssø (Table 4.33).

The phytoplankton species composition for 1999 has not yet been analysed, but plankton investigations from 1997 and 1998 showed that chrysophytes and dinophytes are the main components of the phytoplankton communities.

The zooplankton species composition included *Daphnia pulex*, *Macrothrix hirsuticornis*, *Cyclops* spp., *Polyarthra* spp. and *Keratella* spp., the two latter genera (rotifers) being highly abundant (Table 4.34). Two additional zooplankton species were found in 1997-1998. The observed dominance of copepods in Sommerfuglesø does not follow the trend from previous years. The low water temperatures during the first part of the 1999 season are probably the main reason for a low abundance of zooplankton as compared to previous years.

A comparison of weighed average values for physico-chemical conditions in July-August 1999 with single measurements from mid August 1997 and 1998 give evidence of relatively stable levels (Table 4.35), except for the prolonged period of ice cover in 1999, especially in Langemandssø. There was no sampling in late August, but the lake was still 80% covered with ice when visited by Morten Rasch on 7 September. The two previous years the ice disappeared in July.

Another exception is chlorophyll *a* concentrations that show considerable annual variation (Table 4.35).

Table 4.34. Density (n/l) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) on 16 August 1999.

	SS	LS
Cladocera		
Daphnia pulex	+	0.3
Macrothrix hirsuticornis	0.2	
Chydorus sphaericus	+	
Copepoda		
Cyclops spp. (adults+copepodites)	4.1	0.5
Cyclops spp. (nauplii)	6.4	6.5
Rotifera		
Polyarthra spp.	274	184
Keratella quadrata	33.6	16.8
Conochilius spp.		+

Table 4.35. Weighed average values for physico-chemical conditions in Sommerfuglesø (SS) and Langemandssø (LS) in 1999 (July-August) as compared to single values from mid August 1997 and 1998. ND = no data.

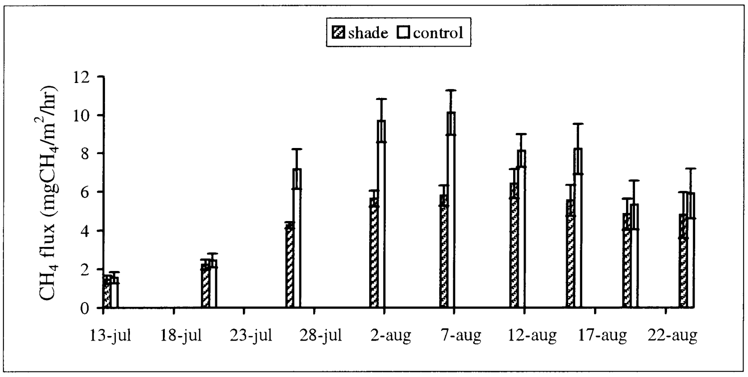
Lake	SS	SS	SS	LS	LS	LS
Year	1997	1998	1999	1997	1998	1999
Ice cover (%)	0	0	6	0	0	17
Temperature (ºC)	6.3	6.5	6.5	6.8	6.4	4.1
Conductivity (µS/cm)	15	13	9.9	8	6	6.6
pH	6.5	7.4	6.7	6.5	8	6.3
Total nitrogen (µg/l)	ND	130	210	ND	80	120
Total phosphorous (µg/l)	4	9	11	8	7	7
Chlorophyll a (µg/l)	0.84	0.24	0.45	1.04	0.63	0.36

5 Research projects

5.1 Carbon cycling and trace gas exchange in the Zackenbergdalen

Torben R. Christensen, Anna Joabsson, Lotte Illeris, Fredrik Joabsson, Anders Michelsen and Sven Jonasson

This joint project between the Copenhagen and Lund Universities was maintained in 1999 as briefly described below. The fen experiments manipulating the incoming light level in order to study the interactions between photosynthesis and CH_4 emission (Joabsson et al., 1999) form part of a larger EC funded project called CONGAS with comparable experiments at four other northern wetland and tundra sites. The experiments at the drier habitats concentrate on moisture effects on soil respiration and form part of a project funded by the Danish Research Councils Polar Programme coordinated by Professor Sven Jonasson.



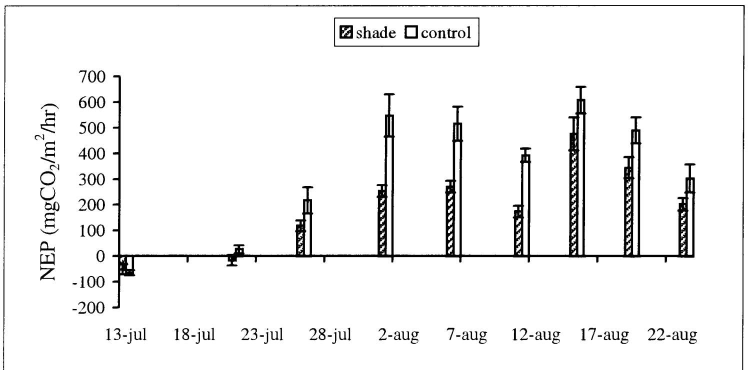


Fig. 5.1. Net ecosystem production (NEP) of CO_2 and CH_4 exchange as measured in control and treatment plots at the "dry" site through the 1999 field season.

The fen experiments

Anna Joabsson and Torben R. Christensen

The shading experiments in Rylekærene (UTM Zone 27; 8,266,000 m N; 513,300 m E), set up in 1998, continued throughout the 1999 field season with only minor changes. The overall subject of the experiment is to investigate the linkage between vascular plant production and methane (CH_4) formation and net emission in the wet fen ecosystem. Chamber measurements of net exchange of carbon dioxide (CO_2) and methane (CH_4) were carried out once or twice per week, and soil temperatures, air temperatures and PAR (photosynthetic active radiation) were continuously logged. The shading tents were placed, as last year, in two slightly different habitat types, one with no visible flowing surface water (denoted »dry«) and one where a small stream was running between the plots (denoted »wet«). The shading treatment resulted in c. 50% decrease in the net uptake of CO_2 in »dry« plots during peak season, and the net flux of CH_4 showed a similar pattern (Fig. 5.1). However, the shading also gave rise to decreased soil temperatures and the effects of lowered net ecosystem production (NEP) and decreased temperatures on net CH_4 emissions can not be easily separated. Both factors, nevertheless, had a significant impact on the CH_4 flux and together explained c. 30% of the variation during peak season. In the »wet« habitat, the patterns were not as clear as in the »dry«. No temperature effect from the shading treatment was found and both CO_2- and CH_4 fluxes were generally lower than in the »dry«. The shading treatment (lowered NEP), soil temperature and watertable depth together explained almost 40% of the variation in CH_4 flux during peak season. The most important factor was watertable depth. The running water seemed to bring more oxygen into the system, as compared to the »dry« habitat, possibly leading to both decreased CH_4 production and a greater sensitivity to CH_4 oxidation as the watertable moved up and down.

	Temperature (°C)	Surface flux (mg CH_4 / m^2 / d)	Sediment flux (mg CH_4 / m^2 / d)	CH4 oxidation (mmol / l / d)	CH4 concentration (mmol / l)
Vesterport Sø	10.3	150.1	0.07 (99%)	6.75	0.25
Træsko Sø	6.7	348.2	1.17 (90%)	60.37	0.53
Bore Sø	3.7	0.29	1.60 (34%)	0.22	0.02
Hjerte Sø	5.3	0.67	0.18 (99%)	0.24	0.08

Table 5.1. Temperature, surface and sediment fluxes of CH_4, CH_4 concentration and in situ oxidation of CH_4 in the water column of four different lakes in Moræ-nebakkerne. The percentage values shown in brackets are the amount of CH_4 oxidised in the sediments. The parameters were measured in the first week of August.

The heath experiment

Lotte Illeris, Torben R. Christensen, Anders Michelsen and Sven Jonasson

The experiment which aimed at manipulating soil moisture level by weekly watering with 3 different amounts of water, was initiated in 1998 (Rasch 1999), and continued in 1999 with an additional treatment, exclosure of precipitation. The exclosure was carried out by placing 6 additionel frames used for measuring CO_2-flux at the experimental site. The new frames were covered with 1 m^2 plastic in a hight of 35 cm above soil surface to prevent precipitation from reaching the soil in and around the frames. The experiment comprised 30 plots in 1999. As in 1998, weekly measurements of ecosystem CO_2 fluxes were performed along with measurements of soil moisture, soil and air temperature, and light level. Additionally, a number of soil properties were analysed including field capacity, bulk density, soil organic matter, soil inorganic nitrogen and phosphorus, soil microbial carbon, nitrogen and phosphorus content and soil pH.

Dry *Kobresia-Dryas-Salix* arctica heath experiment

Lotte Illeris, Anders Michelsen and Torben R. Christensen

The experiment started in 1996 (Meltofte and Thing 1997) and was maintained in 1999 by weekly watering throughout the growing season. As in 1998, no addition of nutrients to the plot was performed. Soil respiration was measured on a weekly basis, from dark chambers inserted to the soil in each plot in an area without any vegetation above ground. Within hours after the watering of the plots the respiration measurements were performed in order to assess how soil microbial activity reacted to the treatment. It turned out to be governed by a combination of the air and soil temperatures and soil moisture level. Data are still being processed.

A significant atmospheric uptake of CH_4 was observed in these experimental plots and the treatment responses of this uptake are being studied in collaboration with Nanna Høegh (see Fig. 5.2).

5.2 Uptake and emission of CH_4 in Zackenbergdalen

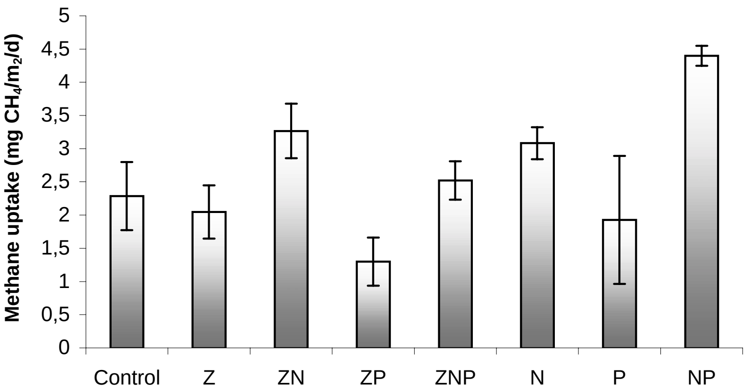
Nanna Høegh

Chamber measurements of fluxes of CH_4 were carried out from several different aquatic sites in Zackenbergdalen in August 1999. The study was initiated in 1998 with the objective to identify carbon loss through the aquatic system. The study sites include lakes in Morænebakkerne and the old Zackenbergelven delta. Further, the response in oxidation of atmospheric CH_4 in a factorial fertilisation and watering experiment was investigated.

Sven Jonasson, Torben R. Christensen and Anders Michelsen initiated this experiment in 1996. For more information about the experiment please refer to ZERO 2nd Annual Report.

The field season of 1999 was very different from that of 1998 due to the late thawing of the ice covered lakes. This resulted in lower fluxes of CH_4 compared to 1998. Different parameters were measured in four lakes (Table 5.1). The highest surface fluxes occurred in Træsko Sø and

Fig. 5.2. The uptake of atmospheric CH_4 from the different plots in the fertilisation experiment. K = control, N = nitrogen, P = phosphor and Z = water. Each bar is a mean of quadratic analyses; vertical bars represent the standard deviation.



Vesterport Sø, consistent with the higher concentrations and *in situ* oxidation of CH_4 in these lakes. Depth profiles of the *in situ* CH_4 oxidation in the water column indicated that 60-99% more CH_4 was oxidised near the sediment surface. The fluxes of CH_4 were also measured in four other lakes (Hjertesø, Langemandssø, Trip Sø and Trap Sø). The fluxes varied between 0.3 to 4.37 mg CH_4 m^2 / d. There was a pronounced variation in fluxes throughout the season with a peak in the beginning of August for the shallow lakes and in late August for the deeper (>4 m) lakes. This variation seemed to follow the water temperature and ice cover.

In the old Zackenbergelven delta atmospheric CH_4 was taken up by the water column during high tide. In the sediment CH_4 was produced and only a low per-centage was oxidised before leaving the sediment. A small amount CH_4 (0.27 nmol / l / d-1) was also oxidised in the water column but this oxidation could not account for the observed uptake from the atmosphere. CH_4 produced in the sediment must therefore be transported out to of the delta with the tide.

The uptake of atmospheric CH_4 from the experimental sites are shown in Fig. 5.2. Fertilisation with nitrogen (N) result in a small increase in the uptake rate compared to control plots, while phosphor (P) and water (Z) addition have no effect. A combination of nitrogen and phosphor (NP) addition greatly stimulate the oxidation of CH_4. This effect must be a long-term response since no fertilisers were added in 1999, and the stimulation in oxidation rates must be a result of a secondary effect. Nitrogen has been shown to have a direct inhibition of oxidation of CH_4, but the maximum activity of methanotrophic bacteria was located at a depth of 2-4 cm, which could make them less sensitive to fertilisation addition. Interestingly, the rate of atmospheric CH_4 oxidation in these dry tundra soils is similar to what has been measured in more temperate forest areas.

5.3 The Zackenberg contribution to the panarctic flora

Bengt Jonsell and Inger Nordal

As a contribution to a checklist of Arctic vascular plants, samples of different plant groups were taken at Zackenberg. The material will be part of the Panarctic Flora Project, which aims at producing a critical panarctic flora.

Leaf fragments were sampled for isoenzyme studies and RAPD molecular studies, and to obtain pressed material for biometric investigations. Furthermore, shoots were collected from 30 individuals and living plants for cultivation in the phytotrone at Olso University.

The following plant groups are represented in our samples from Zackenberg:

Papaver radicatum-complex
Arenia pseudofridiga
Draba arctica / groenlandica-complex
Festuca hyperborea complex
Potentilla hyparctica – pulchella – chamissonis
Campanula uniflora
Saxifraga hirculus
Campanula giesieckiana

Furthermore, for RAPD, 30 shoots were collected from the following species: *Armeria scabra, Betula nana, Cassiope tetragona, Dryas* and *Silene acaulis* (30 males and 30 hermaphrodites).

Preliminary sampling of species with variation of interest, as Saxifraga oppositifolia, was also made.

5.4 Thermophilous plants in Svalbard: conservation, immigration, and implications for global warming

Inger Greve Alsos, Christian Brochmann and Torstein Engelskjøn

Svalbard populations and reference populations from other areas of three selected model species (*Betula nana* s. lat., *Vaccinium uliginosum* s. lat., and *Campanula rotundifolia* s. lat.) are investigated for molecular genetic variation (AFLPs, PCR-RFLPs, RAPDs), morphology and taxonomic relationship. The data will be used to analyse the relationship between the Svalbard populations and populations from other source areas to estimate divergence times and immigration routes.

A probable immigration route would be from Greenland. Therefore, it was very important to gather plant material from all over Greenland, especially the Zackenberg area, which is the land area closest to Svalbard where all three species are found today.

With the combined effort of scientist from the Nordic countries, we have gathered sufficient material from East Greenland (Zackenberg, Scoresby Sund and Ammassalik), West Greenland (Disko and Upernavik) and Northwest Greenland (Inglefield Land) this year. We hope to obtain also some material of *Vaccinium uliginosum* from North Greenland next year. Analyses of the collected material are still in progress.

5.5 Higher *Basidiomycetes* in Zackenbergdalen

Torbjørn Borgen Lindhardt

In the 1999 field season (18 July to 27 August) an extensive study of higher basidiomycetes was carried out in Zackenbergdalen. Basidiomycete funga are almost unknown in high Arctic NE Greenland, mainly because they have not been studied previously in this area. In 1999 good collections were annotated and colour slides were made. The dried collections are placed in a fungarium in Paamiut, West Greenland, for further study. After examination, they will be transferred to Botanical Museum, University of Copenhagen.

Although the main objective of this study was on higher basidiomycetes, other macrofungi were collected as well. In total, 455 collections were made, representing c. 205 species of which 179 are higher basidiomyceres.

The collected material will be studied in detail during the coming years. The results will be part of a book on Greenland basidiomycetes (written in cooperation with Henning Knudsen, University of Copenhagen). An annotated checklist of basidiomycetes in the Zackenberg area is in preparation.

5.6 Global change effects on unicellulars and plants. Experimental, physical-ecological and paleo-ecological approach of tendencies in diversity and community structure

Louis Beyens, Ivan Nijs, Andy van Kerckvoorde, Koen Trappeniers, Mark Heuer, Fred Kockelbergh, Willem De Smet and Ivan Impens.

This project started in 1998 with fieldwork including:

1. A survey of the communities of testate amoebae and diatoms in different habitats,
2. An experimental study on soil carbon budget, and
3. The sampling of some peat sediments for paleo-ecological studies.

The objectives of the overall project are explained in the Zackenberg Ecological Research Operation 4th Annual Report (Rasch 1999). We present here some of the results on topics 1 and 2, followed by a short summary of the fieldwork realized during the summer of 1999.

Communities and ecology of unicellulars

Testate amoebae

Aquatic habitats. Twenty-five different waterbodies, incl. the pools in the old Zackenberg delta and the lakes in the moraines west of the river, were selected for the study of the recent testate amoebae fauna. The questions are: Which taxa do occur? What is their community structure? Which environmental parameters influence them? The waterbodies harbour a relatively rich testate amoebae fauna, altogether 67 taxa, among them seven taxa which are recorded for the first time in the Arctic. The genera *Centropyxis* and *Difflugia* have the highest number of taxa. The most common taxa belong to the genera *Trinema*, *Euglypha* and *Centropyxis*. Interesting from a biogeographical point of view is the occurrence of *Centropyxis gasparella* and *Cyphoderia perlucidus*. Both taxa are only known from arctic localities. This again raises the question of the validity of theories on the dispersal of unicellulars, and adds weight to the argument against a cosmopolitan distribution. Striking differences in testate amoebae assemblages were found between the ponds of the old Zackenberg delta, and the waterbodies situated in the moraines, and east of the river. Differences in habitat structure (*e.g.* presence / absence of waterplants and submerged mosses), habitat age and structure of the surrounding vegetation are possible parameters influencing the aquatic assemblage composition (Trappeniers et al. 1999).

Soil habitats. 38 testate amoebae taxa were observed in 39 soil samples. The genera *Euglypha* and *Nebela* have the highest number of taxa, but the most common

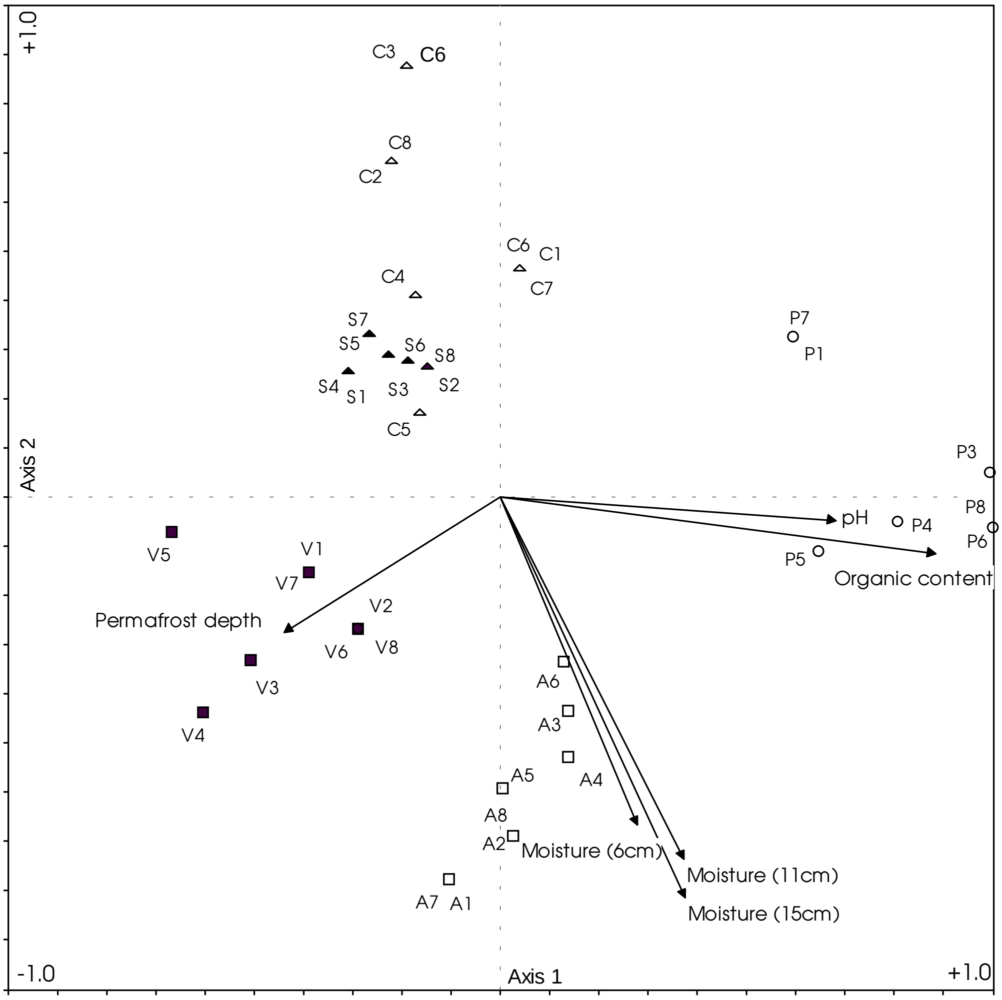


Fig. 5.3. Result of a RDA-analysis showing the position of the soil samples of different vegetation types (C: Cassiope; S: Salix; V: Vaccinium; A: Arctagrostis; P: Poa) in relation with some environmental variables.

species is *Trinema lineare*. The soil dwelling testate amoebae assemblages are mainly differentiated by the moisture content of the soil and the organic content. Other quantitativly important taxa are *Difflugia globulus*, *Centropyxis aerophila var. sphagnicola* and *Euglypha rotunda*. Since there is a strong interaction between the measured parameters and the vegetation type, it is not surprising to find a relation between the vegetation and the soil testate amoebae assemblages (Fig. 5.3).

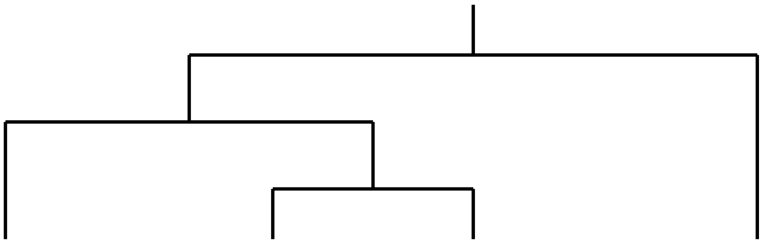
Diatoms

Soil habitats. Soils from different vegetation types have also been analysed for their diatom flora. 81 taxa were encountered in 30 soil samples. Most taxa are found in the genera *Navicula*, *Pinnularia* and *Eunotia*. Relatively high abundances are observed for the genera *Diadesmis, Pinnularia* and *Navicula*. Some common taxa are: *Caloneis aerophila, Diadesmis contenta f. biceps, Diadesmis perpusilla, Hantzschia amphioxys, Pinnularia borealis* and *P. lagerstedtii*. Differences in vegetation type are reflected in the soil diatom assemblages (Fig. 5.4). A correlation could be found between assemblages and soil moisture, organic content, pH and permafrost depth.

Moss habitats. The terrestrial mosses harbour more diatom taxa than the soils, no less than 122 have been found in the 34 moss samples. Most important genera were Eunotia, Nitzschia and Pinnularia, with a.o. *Eunotia fallax, Nitzschia perminuta, Pinnularia obscura, Fragillaria pinnata var pinnata, Cymbella paucistriata* and *Diadesmis contenta f. biceps* as quantitatively important taxa. Three different assemblages were recognized.

Heating experiment

The second objective of the project was to examine how climate-warming affects tundra ecosystems, with an emphasis on the response of micro-organism commun-



Arctagrostis	Cassiope + Vaccinium	Salix + Vaccinium	Poa
Pinnularia divergentissima var. *martinii* *Pinnularia obscura* *Pinnularia aequilateralis* *Pinnularia borealis* Ehrenberg var. *thuringiaca* *Diadesmis contenta*	*Diadesmis perpusilla* *Eunotia fallax* *Eunotia praerupta*	*Pinnularia lagerstedtii* *Caloneis aerophila* *Navicula krasskei* *Stauroneis borrichii*	*Navicula atomus* *Hantzschia amphioxys* *Fragilaria elliptica*

Fig. 5.4. Result of a Twinspan classification. The characteristic diatom taxa are given for each group.

ities and whole-ecosystem carbon metabolism. The first CO_2 flux data were collected on small plots of grassland south of the airstrip at the end of the growing season in 1998, using chamber techniques. This autumn period represents the transition from photosynthetically active to senescent vegetation and may potentially release large amounts of CO_2 to the atmosphere since the soil is not yet frozen. Based on the flux data, we modelled the relationships between carbon fluxes, PAR and air and soil temperatures.

Three of the six plots studied were exposed to infrared radiation to increase the surface temperature by 2.5°C. Main species in the plots are *Arctagrostis latifolia* and *Salix arctica*. From the response of soil CO_2 flux to temperature, we fitted an exponential curve to the data (Fig. 5.5), with a single temperature-sensitivity function describing readings from different heating treatments. This was based on an analysis of variance with soil temperature at -2.5 cm as a covariate, showing no residual difference in soil CO_2 flux between heating treatments over the two-week heating period, after direct temperature effects had been eliminated by the covariate. Gross photosynthesis was also not significantly different between treatments. The reconstructed carbon balance for 18-29 August (Fig. 5.5) shows that both sets of plots were a source of carbon. When separated by component (Fig. 5.5), soil respiration was the largest contributor to the carbon balance, followed by aboveground respiration and gross photosynthesis. The prediction equations are based on seven days of photosynthesis, dark respiration, and

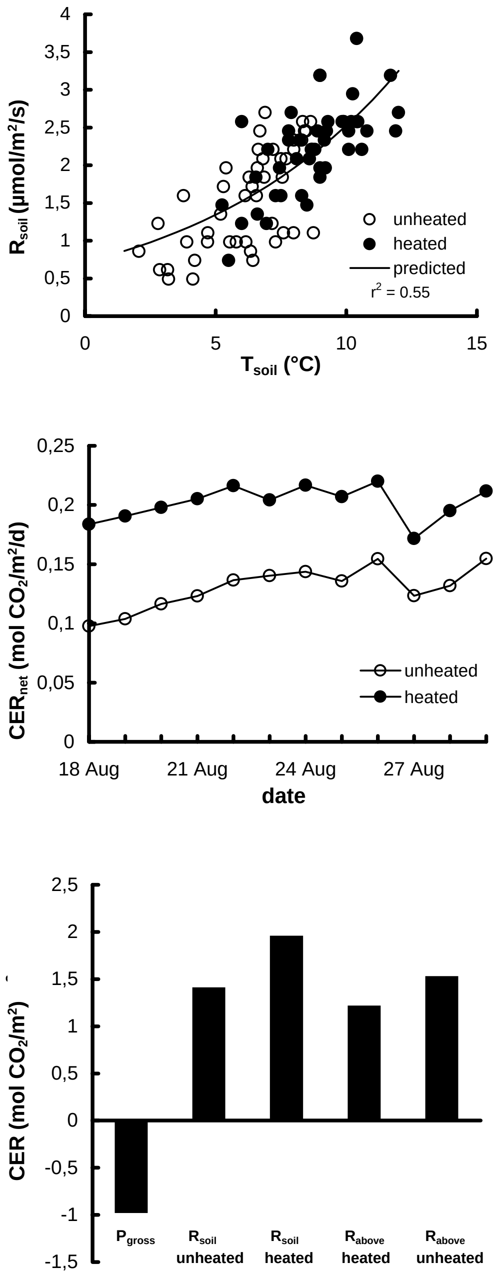


Fig. 5.5. Measured soil CO_2 flux and fitted line (top), modelled daily net ecosystem CO_2 exchange rate (middle), and total modelled CO_2 flux for gross photosynthesis, soil respiration and aboveground respiration (bottom) in unheated and heated plots, during 18-29 August 1998.

soil respiration measurements taken with a closed system CO_2 analyser. Continuous (30-minute sample) measurements of PAR and temperature were used in the equations to generate daily flux totals. Aboveground respiration was significantly different between treatments, but flux data measured before heating began showed that this difference already existed at that time. We eliminated this difference in the model reconstruction of the budget, but took into account the observed differences in temperature-sensitivity of aboveground respiration (which was higher for plots exposed to heating). Overall, these first carbon budgets demonstrate the importance to whole-season flux of transitional periods characterised by rapid changes in component fluxes (notably senescence). As could be expected, simulated climate-warming did not affect the rate of leaf mortality in any of the species, which varied widely in their stage of senescence at the onset of heating. This does not preclude, however, that end-of-season decline of photosynthesis could be affected by warming applied throughout the growing season.

Fieldwork in 1999

The fieldwork on diatom- and testate amoebae ecology was focused on monitoring the changes in the community structures

- during an eight week period in the soils of the experimental heated plots (sampling was done every two weeks),
- during a period encompassing nearly the whole vegetation period, in different aquatic, moss and soil sites selected on the results from 1998 (sampling was on a weekly basis).

The rotifers of Greenland, and especially NE Greenland, are virtually undocumented. We therefore started a study on rotifer diversity and rotifer associations during August. A total of 191 samples were taken at 80 sampling sites in the Zackenberg delta and in the area of the moraines west of the river. Basic physico-chemical parameters were measured in the field, and water samples were collected for further chemical analysis in the laboratory. Waterbodies as diverse as possible were included in order to allow for the distinction of several types of planktonic, periphytic and benthic communities.

From eight weeks of CO_2 flux data collected in 1999 (early July through late August), we will use the same methods reported above to model carbon flux over this longer period. Additionally, soil efflux has been examined in more detail on extracted cores to relate it to biotic and abiotic variables (temperature profiles, heat transfer to the soil, soil humidity, root and soil carbon and nitrogen content). To explain and model trends in the above ground fluxes we measured plant biomass, leaf extension rates, chlorophyll content, and NDVI, and recorded digital images of the plots to monitor changes in 'greening' and cover. Point quadrat methods were also used to detect shifts in species composition. Preliminary results for the whole season indicate significant enhancement of standing biomass by a 2.5 °C surface temperature increase.

5.7 Freshwater studies

Hans Henrik Schierup, Kirsten Christoffersen, Yvonne Vadeboncoeur, Frank Landkildehus, Torben L. Lauridsen, Jens Peder Jensen, Susanne L. Amsinck, Erik Jeppesen

The freshwater lakes and ponds around Zackenberg have been studied during the last three years in an inter-disciplinary, ecological project called *The influence of climate changes on past and present biological*

Table 5.2. Activities at plots used for heating experiment by UIA, University of Antwerp, 1999 (UTM Zone 27; 8,264,200-300m N; 512800-900m E).

- Laid down wooden walkway south of experimental plots; removed at end of season
- Heated 3 plots (40 x 50 cm each) with infrared radiation to increase surface temperature 2.5 °C.
- Removed 30 soil cores of 5 cm diameter, 40 cm deep
- Removed leaves and litter from a 2 m^2 area
- Wooden corner markers and three 5-cm diameter PVC rings left in soil for the winter

structure in Greenland lakes. Data from more than 40 lakes including those in Store Sødal and Lille Sødal now contribute to a better understanding of the wax and vane of limnic organisms in the extremely nutrient poor freshwater systems where the ice free period may be as short as a few weeks.

This year focus has been on

- evaluation of the density and activity of the primary producers (*i.e.* macrophytes, periphyton and phytoplankton),
- investigations of lakes in Isdal and Lille Sødal and (near Daneborg) and
- attempts to estimate the density of *Lepidurus arcticus* (tadpole shrimps) in some lakes and ponds.

A summary of each of these projects is outlined below.

Macrophyte productivity in the shallow lakes in Morænebakkerne

Hans Henrik Schierup

Eight shallow lakes or ponds (Hestehale Sø, Thors Hammer, Kathrine Sø, Gniht Sø, Trip Sø, Hob Nobs Sø, Boresø, Sommerfuglesø and Vesterport Sø) situated in Morænebakkerne were included in a study of the species composition, density and productivity of macrophytes. The lakes were investigated from 4 to 18 August.

In high arctic lakes a few moss species are far the most important macrophytes from a primary productivity point of view. Three species *(Calliergon trifarium, Scorpidium scorpioides, Aulacomnium turgidum),* as identified by E. Warncke and G. Mogensen, dominated in studied lakes. However, the angio-sperm species *Hippuris vulgaris, Ranunculus hyperboreus, Pleuropogon sabinei* and *Eriophorum arcticum* were also present in the littoral zone at a number of the lakes. In general most lake bottoms were covered with stones from the size of boulders to pebbles. Central parts of the deeper lakes had soft sediment (silty / clayish low in organic matter).

Since the quantitatively most important moss species were free-floating, *i.e.* non-rooted, they were distributed in a net-like pattern in the calm water between stones leaving most of the bottom free of macrophyte vegetation (Fig. 5.6).

Primary production was estimated from a number of 0.25 m^2 samples from transects across lakes to the depth of 1 m. Moss samples were dried and weighed. For two species of mosses it was possible to separate increases in biomass from year to year. Based on the dry weight of the fractions and degree of coverage, moss production per square meter lake bottom covered by less than 1 m of water was calculated. Estimates of macrophyte production for the eight lakes in Morænebakkerne were between 0.6 and 3.9 g dry weight / m^2 / y and averaged 1.7 g dry weight / m^2 / y. Taking deeper parts of the lake basins in consideration these figures will be even less.

Benthic and pelagic primary production of microalgae in shallow lakes around Zackenberg

Kirsten Christoffersen and Yvonne Vadeboncoeur

Phytoplankton primary production is often very low in arctic lakes because of extremely low water column nutrient concentrations. Most nutrients in such lakes accumulate in sediment pore water or in algal mats growing on bottom (benthic) surfaces. Although surface light is attenuated with water depth and can limit benthic algal production, this mechanism is unlikely to be important in very shallow, clear lakes such as those in the Morænebakkerne. Therefore, a majority of primary production may take place on benthic surfaces in these very oligotrophic (nutrient poor), clear, arctic lakes.

We quantified pelagic and benthic primary production in 12 lakes and evaluated the importance of nutrients and light as controlling factors for growth. Each lake was sampled once between 6 and 17 August 1999. We included four groups of primary producers: phytoplankton, epiphytes (algae on mosses), epilithon (algae

Fig. 5.6. Example of moss distribution from Thors Hammer in Morænebakkerne, Zackenberg. Photo: Hans-Henrik Schierup.

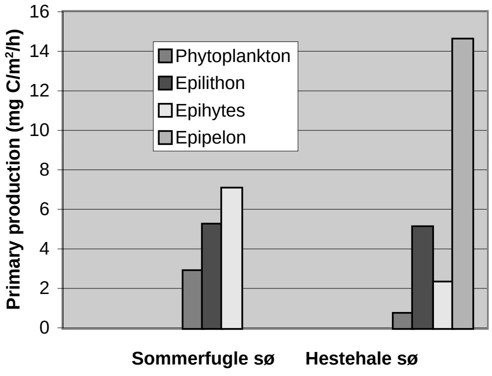


Fig. 5.7. Primary production rates of four different types of primary producers recorded the same day in August in two shallow lakes.

on stones) and epipelon (algae on unconsolidated sediments). Primary production was measured in situ as ^{14}C-labelled bicarbonate uptake during 2 hours incubations. We collected benthic algae on natural substrata from the average depth of each lake (up to 1.5 m). We incubated intact benthic communities in 55 ml plexiglas chambers. Composite water samples covering the entire water column were incubated in bottles at 2-4 m depths for phytoplankton production. We also measured biomass and species composition of benthic and pelagic algae and water column bacterial biomass and production. Water column temperature, pH, dissolved inorganic and organic carbon, and conductivity were also measured.

Light intensities at the average depth were generally higher than levels required for maximum photosynthesis. Thus, neither phytoplankton nor benthic algal production appeared to be light limited. Benthic primary production per square meter of substrata was much higher than the phytoplankton production per square meter of lake surface (Fig. 5.7). Phytoplankton species were mainly Chrysophytes while benthic algae and epiphytes were diatoms.

Production on organic sediments tended to be higher than on other benthic surfaces, probably due to high pore water nutrient concentrations. Organic sediments were most often found in lakes used by moulting geese, and geese faeces may be an important nutrient source in some lakes. Two of the studied lakes have Arctic char populations but this did not appear to influence primary production patterns. The calculated annual productivity varied among lakes (data not shown) and reflected differences in nutrient availability, catchment areas and the composition of the benthic substrata. This study clearly shows that the benthic microalgae are responsible for the majority of total primary production in these Arctic shallow lakes and ponds.

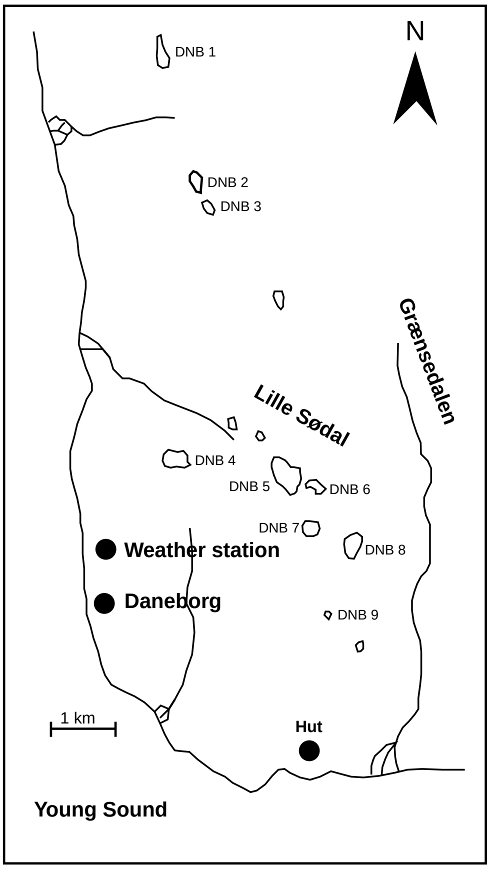


Fig. 5.8. Map of Lille Sødal and the area around Daneborg showing the sampling sites.

Lake investigations in Lille Sødal

Frank Landkildehus, Torben L. Lauridsen, Jens Peder Jensen and Susanne L. Amsinck

As a supplement to the 1998 investigations of the lakes in Store Sødal, three additional high altitude lakes (230 m a.s.l.) in the area between Isdal and Lille Sødal and 6 lakes in Lille Sødal (Fig. 5.8) were investigated in 1999. The lakes are situated in a stony landscape with no glacial influence.

The lakes are relatively small and shallow with a surface area ranging between 0.005-0.28 km^2 and a maximum depth between 0.6-6.3 m. The lakes are all oligotrophic and extremely nutrient-poor. The lake water concentrations of total phosphorus and total nitrogen were 2-15 and 40-230 µg/l, respectively. The corresponding averages were 5 and 131 µg/l, which are lower than in lakes around Zackenberg and in Store Sødal.

Arctic char (*Salvelinus alpinus*) were caught by gill nets in four of the Lille Sødal lakes. The catch per unit effort (CPUE) ranged between 0.25-3.67 fish per net (Fig. 5.9). The mean size and weight of the fish were 30 cm and 378 g, respectively.

Ten different zooplankton genera/-species were observed in the nine lakes: 2 copepods, 2 cladocerans and 6 rotifers. On average, only 3 zooplankton genera/-species were found. The occurrence of the cladocerans *Daphnia pulex* and *Chydorus* sp. was closely related to the presence/-absence of fish. Cladocerans were found only in lakes without fish, except in one lake with a very low catch per unit effort (CPUE) (Fig. 5.9). Contrarily, cladocerans were recorded in all but one lake without fish, a cold (4(C) pond where a few chironomid larvae in the sediment were the only invertebrates observed.

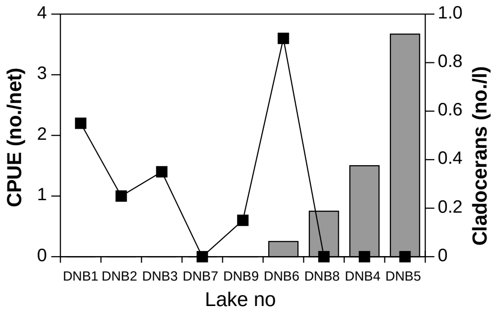


Fig. 5.9. Density of Arctic char as catch per unit effort per net (CPUE) (bars) and abundance of cladocerans in no per l (squares) in the investigated lakes.

It is concluded that *Lepidurus arcticus* is abundant in the studied Arctic shallow waters. Thus *Lepidurus arcticus* must be considered when studying the aquatic food webs.

Distribution and density of Lepidurus arcticus in ponds and shallow lakes around Zackenberg

Kirsten Christoffersen

Lepidurus arcticus (tadpole shrimp) is a conspicuous invertebrate that is often seen along the shore of shallow lakes and in almost all ponds around Zackenberg. It is a mainly benthic dwelling organism except for a short pelagic period after the hatching as larvae. The later stages of animals are actively searching for food in and on the sediment, on plants as well as on stone surfaces. The diet includes midges, benthic and pelagic microinvertebrates and epiphytes

Small PVC frames fitted with 1 m nets were put into a number of lakes/ponds in order to obtain an estimate of the density of *Lepidurus*. The frames were half buried in the sediment and covered with the prevailing sediment type(s). Three traps were left in each of the investigated lakes/ponds for c. 24 hours before the animals were collected. The procedure was repeated at least twice. All animals were counted and the length of animals from a subsample were measured.

The density of *Lepidurus* varied considerably (from 0 to 245 individuals per m^2) as did the average length of the animals (from 2.8 to 16.4 mm). The density depends on the presence of predators (fish and birds) and the availability of food while the length reflects local temperature conditions.

5.8 Raising a family on capital or income. Breeding strategies among birds

Marcel Klaassen

Arctic birds have a short summer period and probably need to lay eggs soon after their arrival at the breeding grounds. However, food availability is often low upon arrival and females may be forced to produce a clutch using body stores accumulated during their journey. Birds using such a strategy are called 'capital breeders', in contrast to 'income breeders', using resources obtained at the breeding grounds.

With the joint efforts of ornithologist from Canada, Sweden, Denmark and The Netherlands working in Arctic Canada and Greenland, we hope to find out how common the 'capital breeder' strategy is. The capital breeding strategy is expected to be more common

- in larger species because they may be more stressed,
- at northern sites, where breeding has to start immediately upon arrival,
- and in species arriving relatively early, when food is not yet available at the breeding sites.

One way to study capital and income breeding strategies is to collect tiny pieces of downy feathers from chicks and look at their chemical 'fingerprints'! The chemical fingerprints contain indicators of stable isotopes of carbon and nitrogen ($^{12}C/^{13}C$ and $^{14}N/^{15}N$) and will often reflect the na-

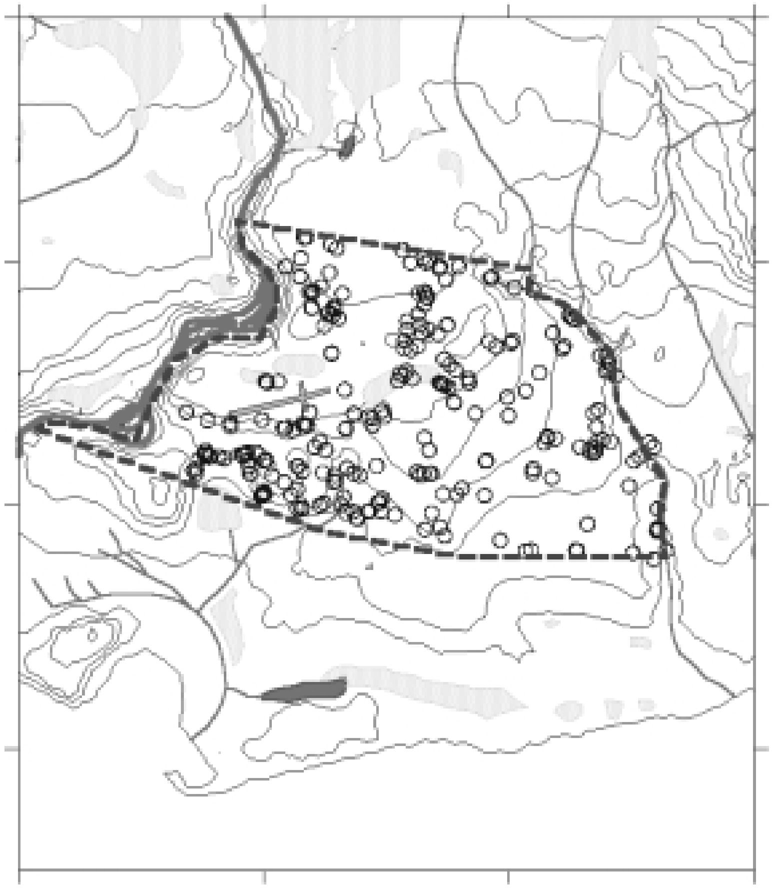


Fig. 5.10. Spatial distribution of the 305 winter nests build during the winter 1998/1999 and recorded during the summer of 1999 within the 2.5 km² lemming census area. Many nests are placed only few meters apart, and the scale of the map does not allow separation between such nests. The shaded area represents meadows and darker areas are lakes. The square shows the position of the station and the cross is the 450 m airstrip.

ture of the food sources and the location at which it was ingested, depending on the biotic and abiotic environment. As shorebird chicks hatch with a complete downy plumage, built from nutrients which the mother put into the egg, distinct differences may be expected in the down of newly hatched young from capital and non-capital breeders. Such differences may also appear within the clutch in case the female has used a mixed strategy. The isotopic signs of the nutrients picked up along the migration route or at the breeding site may find its expression in the chemical composition of the eggs and ultimately in the chick down.

At Zackenberg, Hans Meltofte collected down from the chicks of 21 shorebird clutches: Red knot (1 brood), Sanderling (7), Dunlin (9), Great ringed plover (1) and Ruddy turnstone (3). The samples are presently being analysed for ^{12}C / ^{13}C and ^{14}N / ^{15}N ratios using mass spectrometry at the Centre for Limnology at Netherlands Institute of Ecology.

5.9 Collared Lemming Project – Zackenberg

Thomas Bjørneboe Gomes Berg

Observations on the collared lemming *Dicrostonyx groenlandicus*, regarding habitat selection, feeding biology, population dynamics and morphology, has been carried out since 1995.

An estimate of the winter and summer

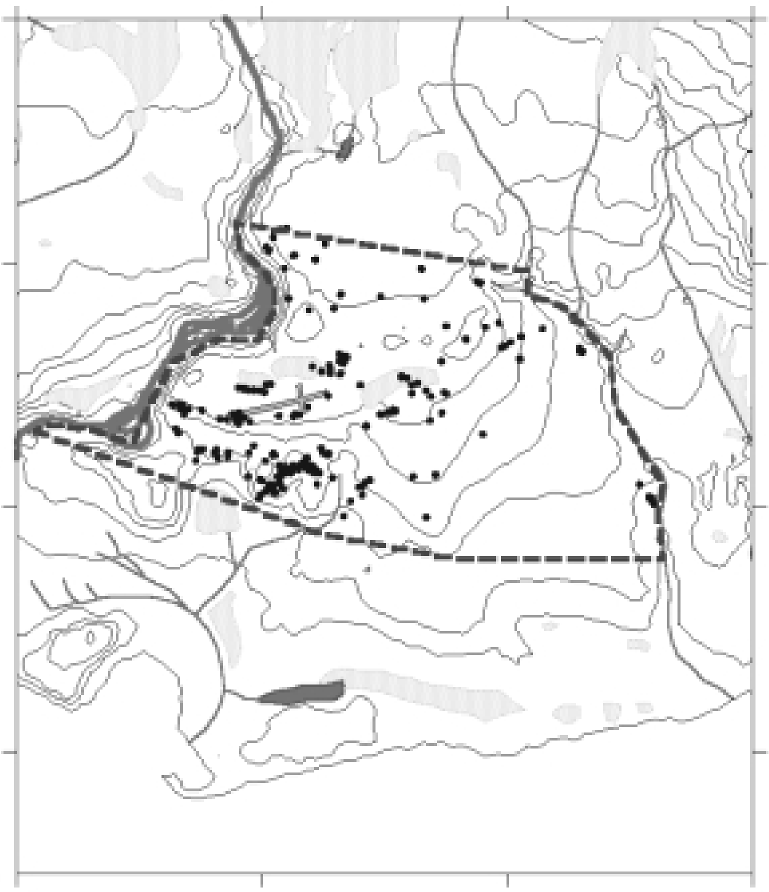


Fig. 5.11. Spatial distribution of the 403 active summer burrows recorded during the summer of 1999 within the 2.5 km² lemming census area. Many burrow entrances are placed only few meters apart, and the scale of the map does not allow separation between such entrances. The shaded area represents meadows and darker areas are lakes. The square shows the position of the station and the cross is the 450 m airstrip.

populations of the lemming is expressed as numbers of winter nests and active summer burrows within the 2.5 km^2 lemming census area. It appeared that the winter population was low after the population peak in 1998.

One lemming uses several winter nests and summer burrows. While the number of winter nests used by an animal is difficult to determine, radio telemetry may indicate the relation between the number of inhabited summer burrows and the number of animals in the summer population. 20 animals were caught and ten of them were radio collared and radio tracked within the same area as in 1998 (Rasch 1999). Initial analysis shows no difference between 1998 and 1999.

Out of 20 animals, 14 were males (five sexually mature adults) and six were females (four sexually mature adults). Two females gave birth, primo and medio July. One of the mature females died in a cage from a high content of abdominal tapeworms (*Taelia crassiceps*). The worms weighed14.5 g (fresh weight) or 20% of her body mass (72.5 g).

By the end of August subadult animals were dispersing within the radio telemetry area. They were easily recognised by their black dorsal midline.

Telemetry data from 1998 and 1999 and the number of active summer burrows within the 2.5 km^2 census area give a rough estimate of the number of animals present within area. According to this estimate the number may have been less than 50 in 1999 and less than 100 in 1998, but data still need a more careful analysis. From the distribution of active summer burrows it seems that the more flat and open the habitat, the more borrows are used per animal.

The spatial distribution of winter nests and active summer burrows were surveyed with an electronic teodolit as shown in Figs 5.10 and 5.11. Data from the past five years show that the geographical area used for winter habitats is larger than the area for summer habitats. During the increase and peak phase of the lemming population, as registrered from 1997 to 1998, the lemmings spread out to the marginal habitats. In this context, the extent of suitable dry summer habitat, protective vegetation and topographical features may be seen as limiting factors to the lemming density.

Lemmings may locally affect the vegetation and hence be affected by the response of the plants through their quantity and quality. The field data give a clear indication of increased forage by lemming during the peak phase shown as estimated number of pellet around winter nest (Fig. 5.12).

There seems to be no difference in nest material from year to year (Table 5.3). The number of nests containing lemming pellets equalled the number from 1996, a year with a relatively low population. During the increase and peak phase, 1997 to 1998, the frequency of nests with pellets was 55% higher, which may indicate a higher level of activity.

The ratio between the »in surface« and »on surface« position of the winter nests may be related to the fluctuation of the lemming population. A declining population (winter 1998 / 1999) will have more »in surface« nests than »on surface« nests while the opposite is the case for an increasing population (winter 1996 / 1997) (Table 5.3).

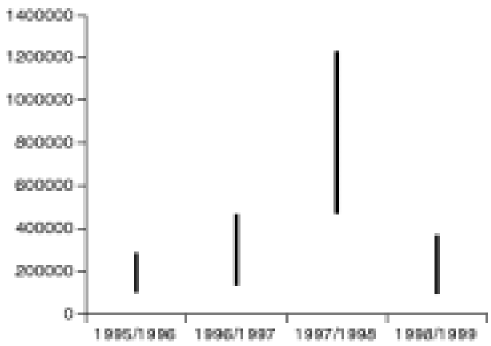


Fig. 5.12. Range of the yearly pellet production (min.-max.) as recorded during the winter nest examination. Numbers of pellets were estimated as categories (cat. 1: n<500; cat. 2: 500(n<2000; cat. 3: 2000(n<4000 and cat. 4 n(4000). The bottom of the bars denotes the sum of all minimum values of the respective categories and the top denotes the sum of all maximum values.

Table 5.3. Data from the winter nest examination. »In surface« indicates that the nest was dug into the surface/vegetation (often less than one cm.) before the soil froze. »On surface« indicates that the nest had been build after the soil was frozen. »Breeding« is indicated by small pellets (length <2 mm) within the nest or along the edge of the nest. »Pellet« indicates that the nest contained faeces and may have been left in favour of a new nest. »Grey fur« indicates that the nest was build before the winter moult (mid October/November). »White fur« indicates that the nest was in use during the spring moult in mid May/June.

N / %	1995/1996	1996/1997	1997/1998	1998/1999
In surface	-	151/45	349/50	179/61
On surface	-	181/55	348/50	114/39
Breeding	22/14	37/11	163/23	23/7.5
Pellet	36/23	158/37	257/36	74/24
Grey fur	23/14	58/17	105/15	18/6
White fur	1/0.6	1/0.3	30/4.2	3/1

Analyses on faeces collected from winter nests (1996-1999) will be initiated in 2000.

5.10 The non-marine enchytraeid fauna of north-eastern Greenland

Klara Dozsa-Farkas and Bent Christensen

The enchytraeid fauna of NE Greenland from Mestersvig in the south to Kronprins Christian Land in the north has been examined with particularly strong sampling efforts in the Zackenberg area. The species diversity is low (11 species) amounting to one fifth of that of the Palearctic tundra and less than one half of that of West Greenland, Iceland and Svalbard.

Half the species has a wide distribution on the northern Hemisphere including temperate regions, the other half has a more or less circumpolar distribution in arctic / subarctic regions. This indicates a broad ecological tolerance and / or excellent dispersal ability of the present fauna.

5.11 Turbulent exchange of carbon dioxide, water vapour and energy, and the physical atmosphere-landsurface environment

Claus Nordstrøm, Birger Ulf Hansen, Åsa Rennermalm and Henrik Søgaard

In continuation of two research projects, *The arctic landscape: Interactions and feedbacks among physical, geographical and biological processes* and *The LAPP project* (Land Arctic Physical Processes) carried out in 1996, 1997 and 1998, measurements of the turbulent exchange of CO_2, water vapour and energy, and measurements of spectral signatures, radiation and physical surface parameters were carried out in Zackenberg 1999. For instrumentation, site descriptions and general information see the ZERO Annual Reports of 1996, 1997 and 1998.

Continuous measurements of turbulent fluxes of CO_2, water vapour, heat and momentum by the eddy correlation technique were preformed in the large fen area, Rylekærene, situated c. 2 km north of the re-

Fig. 5.13. Eddy correlation system, the micro-meteorological set-up and solar panels during the snow melt. Photograph taken the 20 June 1999, with the mountain Zackenberg in the background to the left.

search station. With this fourth year of carbon dioxide exchange measurements at the same location, a picture of the year to year balance is developping.

The 1999 campaign began 12 June and ended 6 September. The electrical power supply for the eddy correlation equipment was derived entirely from solar panels (Fig. 5.13). 1-2 m of snow covered the landscape on 12 June, but c. one month later the fen area was almost snow-free. The onset dates of the sink periods in 1996, 1997, 1998 and 1999, regarding CO_2, were found to vary up to 22 days during the four years, while the end of the sink periods occurred at almost the same date each year, *i.e.* late in August. This preliminary status indicates that there are large annual variations in the CO_2 budget for the Rylekærene fen, primarily controlled by the duration of the snow cover.

Measurements of spectral signatures, radiation and physical surface parameters were made in order to continue the measuring campaign at the two dominating surfaces in Zackenbergdalen, *i.e.* the fen and the heath. The measurements include incoming and reflected PAR (Photosynthetic Active Radiation), incoming and reflected global radiation, net-radiation, incoming and outgoing long wave radiation, top soil moisture, NIR (Near Infra Red), VIS (Visible), MIR (Mid Infra Red) radiation to calculate the RVI (Ratio Vegetation Index) and the NDVI (Normalised Difference Vegetation Index). NDVI and RVI are both related to the green biomass which again can be related to the green LAI (Leaf Area Index).

Additional data material was obtained from photos with an NDVI camera, manually performed RVI and soil moisture measurements along the transect representing the Rylekærene fen area, and from some 30 selected plots representing different surfaces / vegetation types in the Zackenbergdalen. Linking these data with information from satellite images, landscape fluxes obtained from the eddy correlation mast may be upgraded to an estimate of regional fluxes.

The photosynthetic response of the plants to the incoming PAR is illustrated in Fig. 5.14. Up to a PAR level of about 400 $\mu mol/m^2/s$ there is a clear correlation between PAR and the carbon dioxide net ecosystem exchange. As the PAR increases the CO^2 uptake increases. Above PAR levels of 600 $\mu mol/m^2/s$ the plants seems

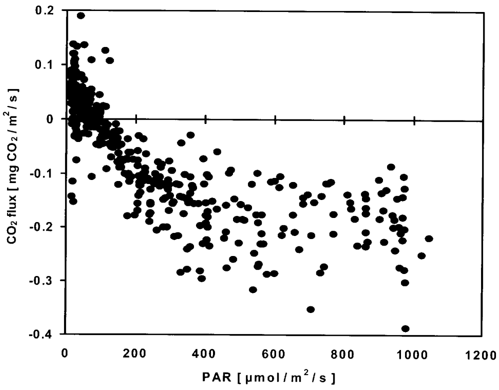


Fig. 5.14. Half-hourly average values of carbon dioxide net ecosystem fluxes as function of photosynthetic active radiation (PAR) for a seven days period in the peak of the growing season. Downward directed fluxes (uptake by the plants dominates) are negative.

to be saturated regarding light and no correlation is evident. The figure also indicates that solar radiation and especially PAR is one of the most important factors for modeling the photosynthesis.

5.12 Snow cover distribution in Zackenbergdalen

Jørgen Hinkler and Steen Birkelund Pedersen

This project investigates inter- and intra-annual snow distribution in Zackenbergdalen.

The investigation is based on three types of digital images: Satellite images, images obtained by a digital camera, and digitalized slides from a conventional camera. The different types of images all have advantages and drawbacks. The main advantage of the satellite images is that they come as multispectral data which can be transformed into physical values, and that they cover a larger part of the electromagnetic spectrum than the two other image types. In contrast to the satellite images, the camera images are taken once every day in the melt-off season. Despite the fact that snow can easily be detected from the visible part of the spectrum, investigations using satellite images have shown that classification results can be improved by also using the mid-infrared part of the spectrum.

The following relationship is commonly used as a Normalized Difference Snow Index (NDSI):

$$NDSI = \frac{\text{Green} - \text{Midinfrared}}{\text{Green} + \text{Midinfrared}}$$

Fig. 5.15 Camera-image from 9 July 1999.

It has been attempted to find the coherence between the visible and the midinfrared part of the spectrum through correlation analysis on satellite data. This has been done in order to treat the images obtained by the cameras by analogy with the above mentioned relationship. The coherence was then used to evaluate a substitute for the midinfrared part of the spectrum when using camera images.

Figs 5.15 and 5.16 show an example of snow detection from digital images. The orthophoto shown in Fig. 5.16 is created using the "ortho-software" developed by Kim Have, Technical University of Denmark. In Fig. 5.17, two regions that are limited by the altitudinal levels of 100 m.a.s.l. and 250 m.a.s.l., respectively, are also shown. The snow cover percentages through the melt-off season have been calculated for the (100 m region for 1998 and 1999, and the resulting depletion-curves are shown in Fig. 5.18. The decrease of the snow cover is delayed about one week in 1999 compared to 1998. This is due to a larger snow precipitation in winter 1999 than in winter 1998.

For 1999, snow cover percentages have been calculated for both regions (Fig. 5.18). As expected, the snow cover percentage is decreasing faster in the region below 100 m than in the region below 250 m.a.s.l.

Fig. 5.18 shows that the depletion curves for 1998 and 1999 has similar shapes but are displaced with respect to time. This relationship is used for modelling snow cover depletion for years before 1998 where only satellite data are available.

5.13 Dynamics of high arctic soils. Physical and chemical processes in the active layer – permafrost system

Bjarne Holm Jakobsen, Hanne Hvidtfeldt Christiansen, Bo Elberling, Charlotte Sigsgaard, Ron Sletten and Birgit Hagedorn

The focus of this project is on the the carbon cycle and on the role of physical and chemical feed-back mechanisms in the active terrestrial layer, focussing on the following topics:

- Thermodynamic conditions of the active layer and phase transformation of water and ice.
- Transport mechanisms of gas and water in snow and partly frozen soil.
- Chemical fluxes.
- The effect of climatic changes on active layer processes (snow fence experiment).

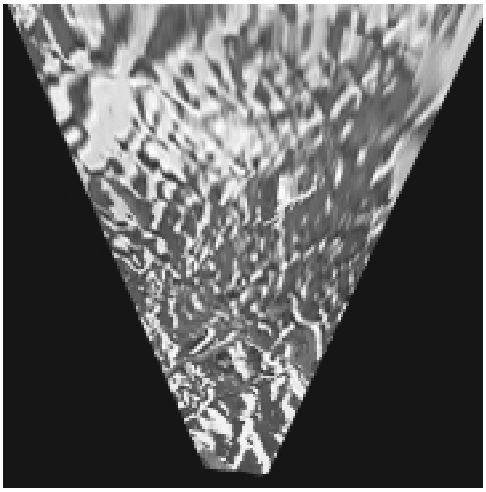


Fig. 5.16 Camera-image from 9 July 1999 transformed into an orthophoto.

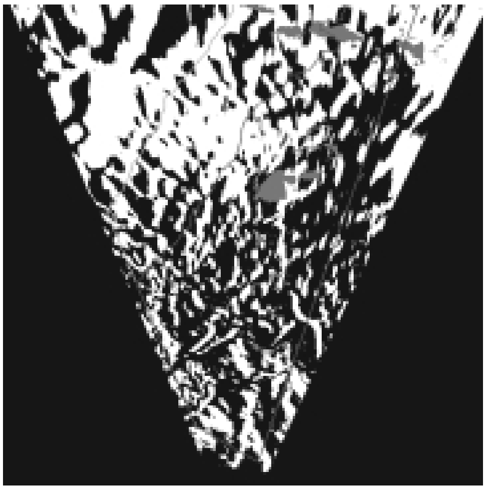


Fig. 5.17. The snow distribution mapped from the orthophoto in Fig. 5.16. (The 100 m and 250 m altitude regions are shown. Furthermore, the areas that are invisible from the camera position are also present).

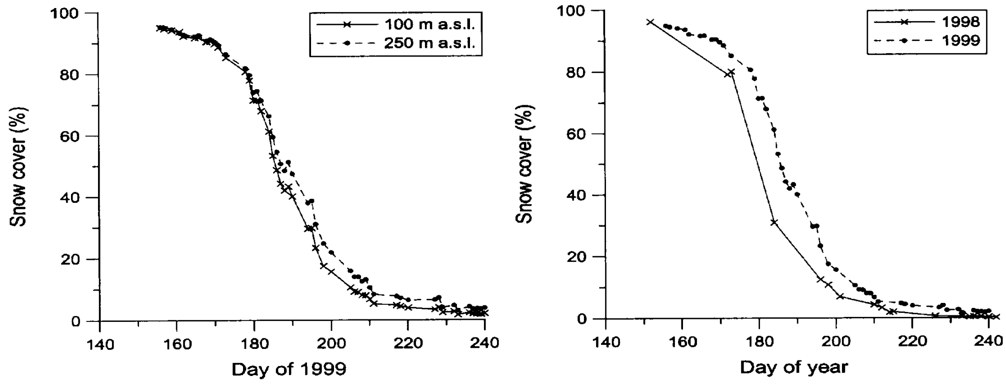


Fig. 5.18. Snow cover depletion-curves calculated from the digital images.
a) The area covered by the orthophoto below 100 m altitude (1998 and 1999).
b) The area covered by the orthophoto below 100 m and 250 m altitude, respectively (1999).

Snow manipulation, site installations, and monitoring program

A snow fence was established in late July 1998 east of the Zackenbergelven in the central part of Zackenbergdalen on slightly sloping fluvial deposits, in order to study the effect of a prolonged snow cover on active layer processes. Special emphasis has in 1999 been on the snow distribution, the active layer development, the soil water regime, soil gasses (particularly CO_2), soil temperature and soil water chemistry. In addition, the effect on the vegetation has been registered. In the following, preliminary data on snow distribution, active layer development and soil CO_2 concentrations are reported.

Snow distribution and active layer development

When snow depth measurements started in mid June 1999, the grid was almost completely snow covered (Fig. 5.19). The snowfence is oriented perpendicular to the dominating NNW winter wind direction (Rasch 1999). Obviously the last redistributing winds in the spring of 1999 were from NNE directions, giving rise to a c. 80 m long zone with maximum snow depths at 1.5 m, SW of the snowfence. Areas upwind the snowfence had 80-90 cm of snow. This distribution shows that much snow precipitation fell in the 1998-1999 winter, and that the winter wind activity had been large enough to almost completely fill the artificial lee site behind the snowfence. Weekly measurements of snow depth in the 195 grid points during the 1999 summer showed that the average depth was 100 cm in mid June, falling to 3 cm in mid July. All snow had melted before 17 July.

The average snow ablation rate in the grid was around 3-4 cm / day. Once the snow has melted away the active layer can start developing. Active layer progression was monitored in the snowfence grid also on a weekly basis. On 3 July the average thawing layer was 0.1 cm and on 21 August a maximum active layer of 52 cm had developed. This thickness was maintained on 28 August, and on 4 September refreezing had begun, as the average active layer was now only 51 cm. After this date snowfall prevented further measurements in all grid points. The active layer was 56 cm thick on 31 August, 1998.

The distribution of the maximum active layer thickness in the grid (Fig. 5.20) shows that there is some correlation be-

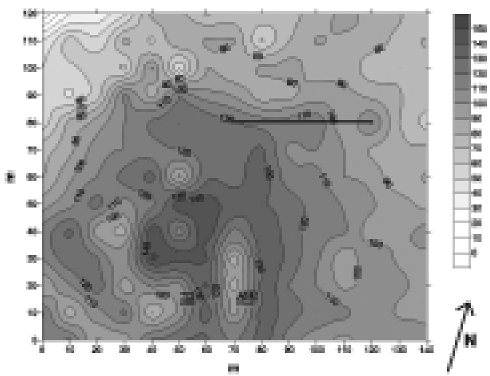


Fig. 5.19. Snow depth in cm in the snowfence grid on 11 June 1999. The 50 m long snowfence is marked as a thick solid line inside the grid.

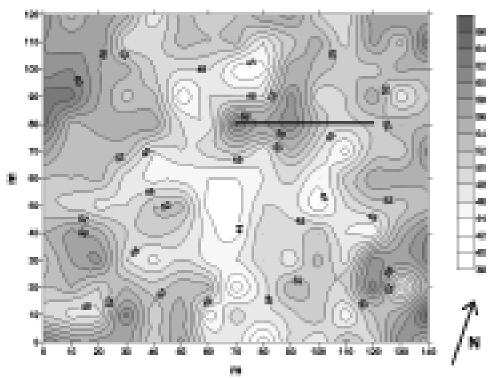


Fig. 5.20. Maximum active layer thickness in cm on 21 August 1999 in the snowfence grid. The 50 m long snowfence is marked by the thick solid line inside the grid.

Fig. 5.21. Examples of the automatic photographs obtained from the ZeroCalm-2 grid 23 August 1998 and 23 February 1999, respectively. In the background the mountain Zackenberg, 1365 m a.s.l. The photo direction is towards WNW. Measuring poles, 1.2 m long, stand in a transect through a snowpatch site.

tween the areas with maximum snow depth in June and the areas with the thinnest active layer in late August. However, there is also some correlation between the areas with the thinnest active layers in 1998 and 1999 in the grid, thus indicating that local factors, such as water content and drainage, also controls active layer development.

The timing of the active layer development in the snowfence grid is contemporary with the unmanipulated, active layer monitoring grid ZeroCalm-1. Here the active layer was 60 cm thick at 19 August, and had decreased to 58 cm on 8 September in 1999. In 1998 the same active layer was 66 cm thick on 31 August, synchronic with the active layer in the snowfence grid. The ZeroCalm-1 grid is topographically comparable with the snowfence grid (Meltofte, H. and Thing, H. 1997). Therefore, the equal timing in active layer development and almost identical reduction in thickness, in 1998 and 1999, indicate that the effect of the snowfence on active layer development in the snowfence grid is limited.

Continuous photographic snow cover registering

As reported previously (Rasch 1999) automatic and continuous daily photographing of the snow distribution was initiated in 1998 in the ZeroCalm-2 grid, at the snowpatch site. This new technique, using an automatic digital camera, has now proved successful, and a full year, August 1998-September 1999, of photos was obtained (Christiansen in prep), see Fig. 5.21 a and b. The photographs show that the winter snow cover was established on 18 October 1998, and that it lasted (180 days in the exposed parts of the landscape, but (365 days in the snowpatch site. Also data on snow depth and distribution are achieved from the photographs.

Several data series on surface temperature were also obtained, using mini temperature dataloggers, from selected places within the snowpatch area. Combining these data it is possible to calculate how thick a snow cover is needed for significantly isolating the ground against air temperature variations.

Soil CO_2 gas concentrations

Soil carbon dioxide (CO_2) gas concentrations have been studied intensively within several types of dry tundra soils. This part of the study aims to examine the production and transport of CO_2 within the soil profile and thereby to improve the understanding of the dynamics and the role of the soil gas carbon pool which play an important role for the soil weathering processes. From mid July to the end of August, soil CO_2 concentrations were measured within the active layer below *Cassiope*, *Dryas* and *Salix* vegetation which represent the dominant dry heath vegetation types in the area. Metal tubes were installed at most sites at depths of 5, 10, 15, 25 and 35 cm. Gas samples were withdrawn every 3-10 days and CO_2 concentrations were measured using an infrared gas detector (Gas Data Ltd). In addition, destructive profiles were made at the same locations where CO_2 concentrations were measured for every 5 cm from the soil surface to the permafrost table using a Dräger probe system. Soil moisture content and temperature were measured at the same depths.

CO_2 concentrations typically increase from atmospheric CO_2 concentrations (about 0.037%) at the surface to a maximum near the permafrost boundary or with a local maximum around 15-20 cm below the surface (Fig. 5.22). A local maximum may correspond to either a maximum in root development or older layers rich in organic matter which is often observed at this depth. Preliminary results indicate a distinct variation in CO_2 level between vegetation types, as CO_2 concentrations are consistently higher in soil covered by *Salix arctica* than found under *Cassiope* and *Dryas* vegetation (Fig. 5.22). CO_2 concentrations as high as 3.5% were measured below *Salix arctica*, whereas maximum values for the two other sites were around 1%. Measurements over time suggest an overall decline in soil CO_2 gas concentrations over the study period (Fig. 5.23). This trend is observed in most depths and can be partly explained by changes in CO_2 production and soil aeration (diffusion) over the season. Diffusion models are considered an important tool for evaluating these observation of soil gas and will be applied in the future.

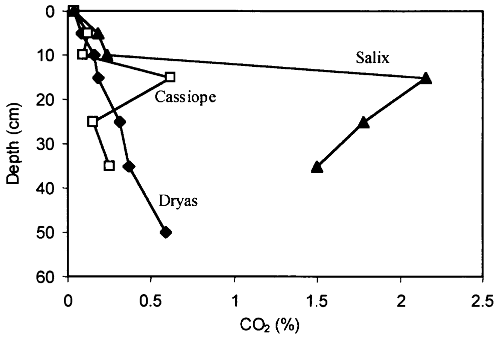


Fig. 5.22. Carbon dioxide concentrations measured within the active layer below different vegetation types on 28 July 1999.

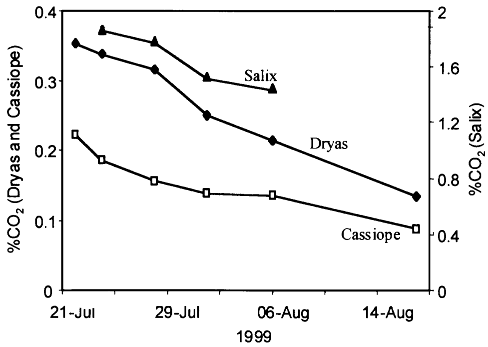


Fig. 5.23. Changes in carbon dioxide concentrations in the active layer at a depth of 25 cm. During the study period a decline in concentrations is observed at all sites (note the different axes).

5.14 Plant cover effects on soil development

Jakob Simonsen

The aim of this project was to estimate plant cover effects on soil properties, *i.e.* nutritional state, humus composition and susceptibility to frost action (cryoturbation). Plant cover is controlled by a number of parameters, some of which are likely to change with a changing climate. When the plant cover changes, soil development will change accordingly. In order to obtain comparable physical settings, samples were taken from soils beneath different adjacent plant communities growing on the same morphological unit. Two sites were chosen: A gentle hill slope in the ancient delta, and a lobe of gelifluctuated till west of the delta, where a so-called frost boil was investigated. Field work included standard profile description, soil sampling and temperature measurements in the active layer.

On the hillslope three plant communities were recognized: 1) Dryas, dominated by mountain avens (*Dryas integrifolia/octopetala*), 2) Cassiope, dominated by white Arctic bell heather (*Cassiope tetragona*), and 3) Salix, dominated by Arctic willow (*Salix arctica*). Although community borders are sharp, overall conditions for the extent of the dominant species is thought to be the extent of the annual snow cover, guiding both temperature, available light and drainage conditions. The sharp borders are thought to reflect some kind of buffer mechanism due to preferred properties of the specific humus composition to the plant species (or community).

The hill slope soils are arctic brown soils consisting of discontinuous layers of different grain sizes, reflecting different flow regimes during settlement. The layering is frequently disturbed by churning due to frost processes (cryoturbation), which creates involution patterns or simply mixes the original layers into a semihomogeneus matrix.

Soil development in the three chosen sites on the hill slope generally reflected drainage conditions, with a weakly developed brown soil on the upper, dryer part. Further down the slope, moister conditions allow a more mature brown soil to develop. Towards the bottom of the slope the soil is water saturated (or frozen) most of the year and soil development is reduced to a minimum. For more detailed information on soil chemistry and development in related soils in the area, see Jacobsen (1992) and Meltofte and Rasch (1998).

The frost boil in question is developed on a lobe of solifluction on the border of the old delta. Soil development was compared between the relatively bare frost boil and the Cassiope covered surroundings. Again, the border is quite sharp, this time because of the soil dynamics of the frost boil, which inhibits plant settlement. The origin of the frost boils in this area is uncertain. Several explanations are proposed in literature, but more detailed studies are needed. A relatively high content of easily leached ions suggests, that some convectional movements of soil act to renew the topsoil of the frost boil. These soil dynamics are probably connected to the formation and maintenance of the frost boil.

At both locations, the active layer is shallower beneath the Cassiope cover. This is mainly due to the insulative effect of the humus-rich horizon which evolves in association with Cassiope growth.

Involutions due to frost mediated churning showed more or less distinct patterns, and were mainly related to the frost susceptibility of the sediment (in most cases equivalent to hydraulic conductivity). The grain size distribution in the soil column is highly diverse, as well as the outline of the involutions. Layers with a high content of organic matter show high frost susceptibility, and thus the amount of humus and (to a lesser extent) the composition of the humus in the soil, has a pronounced effect on the type of involutions evolved.

Laboratory analyses suggest that humus decomposition is limited underneath a Cassiope cover, probably because of the high lignin contents of this species, in comparison to most other plants in the area. This results in a significantly higher organic matter content in the topsoil, and thus a higher frost susceptibility. Some characteristic hummocks seem to be highly correlated to the presence of a Cassiope cover, and are thought to originate mainly from these conditions.

There is noticeable difference in the humus composition between Cassiope and other plant communities. As humus composition influences the ability to retain exchangeable cations, water, and also the ability of the different layers to act dynamically in forming involutions, this difference is of major importance in local soil development. The water mediated translocation of the isolated humus ions also strongly depend on humus composition. Most mobile is fulvic acid, which is more abundant beneath Cassiope. Thus it seems that any previous podzolization in the area would most likely have occurred beneath a Cassiope cover. This might add yet another piece of information to the question of paleo soil formation (Jacobsen, 1992).

Humus composition is related to type of plant cover. Humus composition, as well as the total content of organic matter in the soil, has an influence soil development, both chemically and dynamically. Thus the type of plant cover will be reflected in the active layer. More detailed research might reveal whether specific types of involutions are connected to a specific plant cover, and may give useful information also about paleo soil formation.

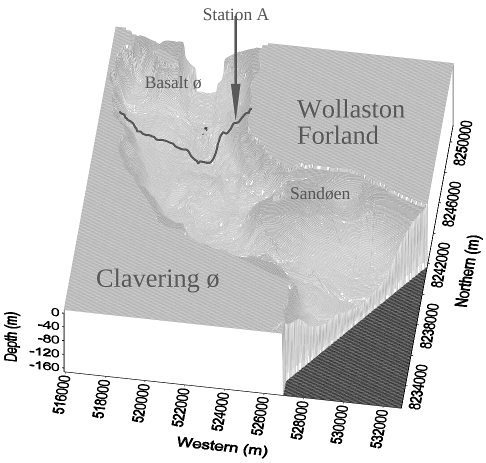


Fig. 5.24. The bottom topography of the outer part of Young Sund. Station A and the transect investigated are shown with an arrow and a line, respectively.

5.15 Changes in Arctic Marine Production (CAMP)

Søren Rysgaard, Torkel G. Nielsen, Benni W. Hansen, Mikael K. Sejr, Jens W. Hansen, Henrik Fossing, Bo Thamdrup, Michael Kühl, Ronnie N. Glud, Lars D. M. Ottesen, Rodney Roberts, Jens Borum, Dorte Krause-Jensen, Morten F. Pedersen, Peter B. Christensen, Kurt Nielsen, Jens K. Petersen, Erik W. Born, Mario Acquarone, David Griffiths, Doug Allan, Gordon Downie, Göran Ehlmé

The overall hypothesis of this project is that global warming will affect the thickness and distribution of sea ice and thereby the availability of light in polar regions. Investigations concerning the response of production, consumption, and degradation in Arctic coastal marine ecosystems to future changes in temperature and sea ice-cover were carried out in Young Sund in 1999.

The research was divided into two field campaigns, one during June-July when sea ice was present and one in August where open water conditions prevailed. The work focused on:

1. Bathymetry and hydrographic descriptions
2. Physical and chemical properties of sea ice
3. Sea ice algal production and grazing
4. Pelagic primary production and grazing
5. Mineralization in the water column and sea ice
6. Sedimentation and mineralization in the sediment
7. Primary production of coralline algae
8. Macroalgal primary production
9. Filtration and respiration of benthic infauna
10. Studies of walrus energetics and behaviour, and
11. Public relations.

The marine study area was located in the eastern part of Young Sund approximately 25 km SSE of Zackenberg (Fig. 5.24). A locality at 36 m water depth (Station A; 74°18.58'N, 20°15.04'W) was selected for intensive sampling of both sea ice, water column and sea bottom during this summer's field campaigns. Several other locations were investigated along a depth transect from Daneborg (74°18.51'N, 20°13.71'W) to Clavering Ø (74°18.38'N, 20°28.36'W). The team investigating walrus energetics and behaviour used Sandøen in the outer part of Young Sund as base.

The field work was a collaboration between several scientific institutions (see chapter 8) and is expected to supply new knowledge of the mechanisms regulating production and consumption in Arctic marine areas, and to provide an extensive data-set for use as reference in the future. A description of the main headlines of the research in Young Sund during the field campaigns will be presented in the following sections.

Bathymetry and hydrographic descriptions

Søren Rysgaard, Torkel G. Nielsen, Benni W. Hansen, Mikael K. Sejr.

Survey of the bottom topography of the outer region of Young Sund was carried out from a rubber boat using a combined echo sounder and GPS receiver. Data were recorded continuously by a computer while sailing along pre-defined transects (Fig. 5.24). We intend to combine our data with earlier data of bottom topography further inside Young Sund and to map the remaining part of Young Sund next year.

Detailed investigations of salinity, temperature, oxygen, DIC and nutrients were performed every second day throughout the field campaign in June-July to describe the structure of the water column during melting of the sea ice. Furthermore, regular measurements were obtained in August. We plan to combine the bathymetric data with measurements of salinity, temperature, tidal amplitude, and current velocity in order to construct an overall mass balance of carbon and nutrient cycling in Young Sund. In addition, this combined data-set will be a valuable basis for more sophisticated computer models of changes in Arctic marine production when integrated with all the other investigations presented in the following sections.

Physical and chemical properties of sea ice

Jens W. Hansen, Henrik Fossing, Bo Thamdrup, Michael Kühl

Sea ice covers Young Sund for about 10 months per year. It represents a physical barrier that reduces wind stress and wave action, structures the water column by the large freshwater input during the summer thaw, and reflects a major fraction of the incoming light. One of the aims of the CAMP project during the field campaigns in June-July 1999 was to study the sea ice in detail to understand its role as: (1) a barrier to light, and (2) a habitat for plant production, mineralization, and grazing.

Sea ice as a barrier for light

On arrival to Station A in early June, the sea ice thickness was 1.6 m with 30 cm snow cover. In one month the snow cover disappeared and the ice started to melt. This resulted in large melt ponds covering the sea ice at the end of June, where melt water started to drain through the ice and initiate the sea ice break up.

When sea ice breaks up, typically in the middle of July, the algal production in the water column of Young Sund responds exponentially due to the increased availability of light (Rasch 1999). Likewise, the photosynthesis of plants at the sea-floor is dependent on the increased availability of light during the short open-water period. Hence, as global warming in the future will affect the sea ice distribution and thickness, it will also dramatically alter the light penetration to the water column and the seafloor and thus greatly stimulate the primary production in these compartments.

To study the effect of sea ice and snow cover on light, we measured the light penetration (irradiance and spectral composition) at various snow and sea ice conditions through June-July. Snow cover impedes light penetration considerably. Even 10 cm of snow reduced the light penetration with about 80%, whereas light reduction in the ice was less dramatic (Fig. 5.25). The obtained relationships between sea ice conditions and light penetration will be a valuable tool for predicting alterations in primary production and, thus, alterations in all higher food chain levels.

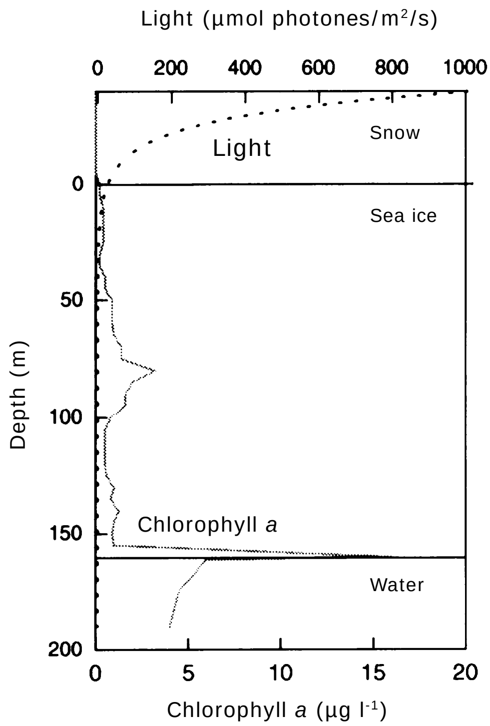


Fig. 5.25. Light penetration and concentration of chlorophyll a through snow and sea ice in the beginning of June. Note that chlorophyll a is found throughout the sea ice with maximum concentrations near the sea ice-water interface.

Sea ice conditions for primary production

An important question raised by the earlier investigations in Young Sund concerns the importance of plant production within sea ice compared to plant production in the water column and at the sediment. Such information will elucidate the role of the sea ice as a source for organic carbon production in coastal Arctic ecosystems. Therefore, we supplemented our field studies of light with measurements of other parameters regulating sea ice algal productivity. Ice profiles of temperature, salinity, and nutrients (NH_4^+, NO_3^-, urea, PO_4^{3-}, and Si) were measured at regular intervals throughout the study period. The salinity and nutrients were determined both in the brine drained from ice cores and in melted samples of the remaining ice structure to obtain information about the spatial conditions for sea ice algal production.

Sea ice algal production and grazing

Søren Rysgaard, Ronnie N. Glud, Michael Kühl, Torkel G. Nielsen, Benni W. Hansen, Jens W. Hansen

Detailed investigations of sea ice species composition, algal biomass and primary production, bacterial biomass and production, and of the oxygen conditions at the sea ice-water interface were conducted during the field campaign in June-July 1999. Every second day during the field period, primary production measurements were performed at Station A with three different techniques; radio (^{14}C) tracer, pulse amplitude modulated (PAM) fluorometry and oxygen microsensor techniques. In short, a newly developed microprofiler mounted with an oxygen microelectrode and an optical fibre was placed below the sea ice by a diver in order to obtain measurements at *in situ* conditions. Fine-scale measurements of chlorophyll *a*, primary production, oxygen concentration profiles, light and temperature regimes at the sea ice-water interface were performed 10 m from the sea ice hole to avoid interference from the increased light intensity near the hole. Preliminary results show that sea ice algal production was low in the beginning of June and increased through June to July where production ceased due to the huge amount of melt water draining through the sea ice.

To complement our measurements at the sea ice-water interface, intact sea ice cores were sampled several times throughout the field campaign to measure the vertical concentration of chlorophyll (Fig. 5.25), and primary production through the entire sea ice matrix. Finally, in order to investigate the heterogeneity of sea ice algal distribution and production at the sea ice-water interface, a large amount of measurements were performed at cm to dm scale, dm to m scale, and m to km scale. Kilometer scale measurements were performed at different sea ice holes. This was done in order to be able to extrapolate our data to a larger scale and thus form a valuable data-set for a more global understanding of the importance of the sea ice algal community.

Global warming will cause a reduction in sea ice thickness and distribution which, in turn, will affect light availability. In order to estimate the effect of future changes, *in situ* measurements of primary production at various light intensities were carried out with the dive-PAM, with which the light regime can be manipulated through its internal light source.

Pelagic primary production and grazing

Benni W. Hansen, Torkel G. Nielsen, Jens W. Hansen, Søren Rysgaard

Trophic interactions in the water column

To describe the entire pelagic system and to parametrisize trophic interactions in the water column, investigations of several parameters were performed at Station A (36 m water depth) every second day throughout the field campaign in June-July 1999. Pelagic primary production was monitored from several water depths (0, 1, 2, 5, 10, 15, 25, and 35 m) together with the biomass and species / group composition of phytoplankton, bacteria, and protozooplankton. Furthermore, the biomass of mesozooplankton was determined from integrated net-samples representing the upper 35 m of the water column. Finally, the growth rates of bacteria and protozooplankton were measured at the selected water depths.

To investigate secondary production and estimate grazing loss due to grazing upon phytoplankton, we conducted a large number of measurements of protozoan growth as well as copepod egg production in incubations of size fractionated seawater. The growth rates will form the basis for calculating grazing activities upon phytoplankton from both ciliates and heterotrophic dinoflagellates. Egg production reveals life cycle strategies and forms the basis for estimating grazing activities upon phytoplankton for the most common grazer species.

As the air temperature increased during our field campaign, it was observed that a low saline layer beneath the sea ice was established due to input of freshwater from the melting sea ice and from the surrounding terrestrial areas. At the same time, high food availability (chlorophyll concentration) was associated with the sea ice-water interface as compared to the water column below. In order to test whether mesozooplankton was physiologically capable of tolerating low salinity values while grazing on sea ice algae, we conducted a series of preliminary salinity tolerance experiments with the most abundant copepod species.

Future changes

If global warming causes further reduction in sea ice distribution and thickness it will increase light availability for phytoplankton and, hence, primary production. However, an increase in phytoplankton production could be limited by nutrients. To evaluate the interaction between phytoplankton, grazing, and nutrients under conditions of elevated food supply, several growth and egg production experiments were performed at the sea ice-water interface with incubations of size fractionated seawater at natural or elevated nutrient concentration and with or without addition of cultivated phytoplankton.

To investigate other future possible changes in the trophic pathways of the pelagic system in Young Sund, experiments of carnivorous behaviour on the part of the most abundant copepod species were carried out. These consisted of a series of grazing experiments where the predators were offered nauplii larvae of their own offspring.

Mineralization in the water column and sea ice

Lars D.M. Ottosen, Henrik Fossing, Søren Rysgaard

If future global warming causes increased light availability for primary producers it may be expected that further increase in primary production eventually will be limited by nutrients. However, bacteria in both sea ice, water column and sediment will mineralize organic matter and thus recycle nutrients to the primary producers. Until now, estimates of bacterial mineralization of organic matter have only been obtained from the sediment of Young Sund, and in order to understand nutrient re-mineralization on a system level, further investigations in the sea ice and water column were needed.

Thus, during the June-July campaign 1999, several investigations of mineralization activity in the water column and sea ice were undertaken. Although a tight coupling between primary production and benthic mineralization has been observed during earlier field campaigns, the nutrient demand during the short growth season probably exceeds the capacity of mineralization in the system. However, during the dark winter period where no primary production takes place, continuous bacterial mineralization of organic matter produced during the summer thaw, will return nutrients to pre-summer concentrations.

The importance of nitrogen mineralization in the water column in proportion to mineralization in the sediment is unknown. Likewise, current knowledge about the fate of dead sea ice algal material is limited. It ismnot known whether it is primarily mineralized within the sea ice, water column or in the sediment. To quantify the accumulation of inorganic nitrogen in the water column, we measured net and gross NH_4^+ production in different layers of the water column at Station A at regular time intervals during the field campaigns. Nitrogen mineralization in the water column was measured by means of a new ^{15}N technique based on stable isotopes that allowed accurate measurements of NH_4^+ at very low concentrations. Using this new method, we were able to quantify both net and gross NH_4^+ production in the water column and sea ice, and thus to estimate the importance of re-assimilation of mineralized NH_4^+. Finally, the bacterial mineralization activity in the sea ice was estimated by measurements of sulfate reduction, denitrification and production of dissolved inorganic carbon.

Sedimentation and mineralization in the sediment

Bo Thamdrup, Henrik Fossing, Jens W. Hansen, Lars D. M. Ottosen, Søren Rysgaard

Part of the CAMP project was to investigate the biogeochemical coupling between sediment and water column in Young Sund and how this coupling may be affected by increases in marine primary production. The investigations were conducted during ice cover in June 1999 at Station A. The investigation consisted of two parts:

- With sediment traps, we studied the vertical flux of particles from the ice to the sediment. A primary goal was to identify sources of organic carbon, particularly the contribution from ice algae.
- In sediment incubations we experimentally investigated the effect of increasing pulses of fresh organic matter on benthic metabolism.

Sediment trap studies

The sinking of particles from the sea ice communities and the particle flux to the seafloor was investigated from 12 June to 2 July using sediment traps. Two pairs of traps were placed 2 m below the sea ice 20 m away from holes to collect particles from the ice and uppermost water column, while two other pairs were placed 2 m above the seafloor.

With the help of divers, the contents of the traps were collected at intervals of 4 days. The captured material was collected for the determination of mass, organic carbon and nitrogen contents, the isotopic composition of the organic carbon, and for a microscopic examination of the sediment to determine the number, mass, and species composition of algae and the number and mass of faecal pellets. The analyses, which have yet to be completed, will complement the direct measurements of primary productivity (Rasch 1999) in the determination of the relative importance of ice algae and pelagic phytoplankton in new production. They will also document to what extent the particle flux is affected by grazing. Finally, information from the sediment trap studies on the composition of sinking particles will be important in the interpretation of how the seafloor responds to changes in primary productivity (see below).

Benthic metabolism

The temporal dynamics of benthic mineralization are important issues for understanding how the Arctic sediment responds to changes in primary production. This understanding, in turn, is a prerequisite for predicting the effects of such changes on the carbon and nutrient cycles of Arctic marine ecosystems.

In June 1999, we conducted controlled experiments on the dynamics of sediment metabolism after sedimentation of fresh algal detritus. In terms of organic carbon, the additions corresponded to approx. 11%, 33% and 100% of the annual benthic mineralization at the site. During three weeks of incubation, the sediment-water exchange rates of oxygen and products of the mineralization processes (dissolved inorganic and organic carbon (DIC and DOC), nitrate, ammonia, urea, and phosphate) were determined at regular intervals. The depth distributions of these species and of soluble reduced manganese and iron in the sediment porewater were analyzed at the beginning and end of the incubation. The microscale distribution of oxygen at the sediment surface was measured using oxygen microelectrodes. Initially and terminally we further measured rates of the anaerobic bacterial respiration types, denitrification and sulfate reduction, and sampled for determination of the depth distribution of bacterial numbers. The role of animals in the vertical transport of water and particles was quantified by means of tracer studies.

The most significant preliminary result of the experiment is that the Young Sund sediment responded much more slowly to the addition of algae than has been observed in temperate sediments. In Fig. 5.26 the stimulation of the flux of oxygen into the sediment in our experiment, conducted at -1.5°C, is compared to that observed in a very similar experiment with sediment from Aarhus Bay, Denmark, conducted at 15°C. Both experiments used the same diatom species as carbon source and added it in almost the same amounts. Although a stimulated oxygen flux was measured shortly after the addition of algae to the Young Sund sediment, the initial stimulation in the temperate sediment was almost 10 times larger. Our preliminary conclusion is that, although the Arctic benthic community in steady state may metabolize as rapidly as do communities from warmer waters, it appears that low temperature has a significant inhibitory effect on the dynamic response to rapid perturbations. Further data analysis will reveal if

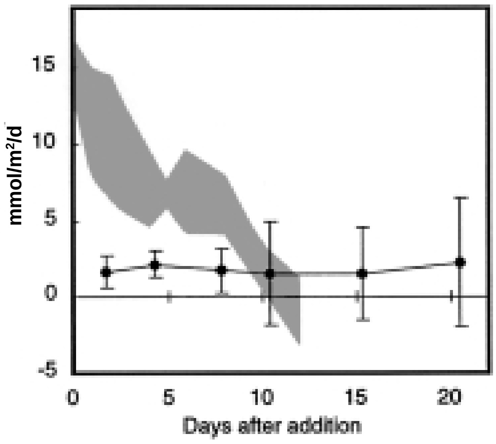


Fig. 5.26. The effect of fresh algal detritus on sediment oxygen uptake of the sediment in Young Sund at -1.5°C (black dots; ±SD, n=5) and Aarhus Bay, Denmark at 15°C (grey shading envelopes data from 3 replicates, Hansen and Blackburn 1992). The oxygen uptake of unamended control sediment has been subtracted.

the slow mineralization kinetics observed for organic carbon also apply for the macronutrients nitrogen and phosphorus.

Primary production of coralline algae

Rodney Roberts, Ronnie N. Glud, Michael Kühl, Søren Rysgaard

Coralline algae are abundant from tropical to polar seas, but there have been very few studies of their productivity. The corallines are conspicuous in Young Sund, where they grow on rocks dropped to the seafloor from floating ice. This project aimed to estimate the primary productivity of corallines at Daneborg in Young Sund by determining:

- The coralline species present and their relative abundance.
- Rates of net primary production for key species in relation to light intensity and season (June *vs* August).
- Light intensity at seafloor *vs* water depth with ice-cover (June) and open water (August).
- The abundance of corallines *vs* depth.

Species, primary production and light adaptation

Corallines were collected by divers, and identified based on material provided by a Danish expert, Susse Wegeberg, University of Copenhagen. Production measurements were made using oxygen microelectrodes in laboratory flow chambers. Light measurements were made under sea ice (June), through the water column (June and August) and on the seafloor (August) with submersible light sensor / logger. Coralline abundance was estimated from video recordings and sampling.

Corallines were common from 17-50 m depth, where they covered 1-2% of the seafloor surface. Four species of corallines were present, but only two were abundant – *Phymatolithon foecundum* (56% of corallines by area) and *Phymatolithon tenue* (35%). Production measurements were made on these two abundant species.

The corallines were attuned to low light, with compensation points of 1-2 µmol photons / m^2 / s, and Ek values (light at maximum production) of 20-40 µmol photons / m^2 / s. Pmax (maximum production) values ranged from 20-90 mmol oxygen / m^2 / d, with most plants having Pmax values of ~30-50 µmol / m^2 / d. There were no obvious differences in production rates between the two coralline species, or between the months sampled. In June when the sea ice was present, light intensity at 20 m depth averaged only 1 µmol photons / m^2 / s, with daily maxima of ~2-3 µmol photons / m^2 / s. In August, during the open water season, light intensity at 20 m depth averaged 7 µmol photons / m^2 / s with daily maxima of ~30 µmol photons / m^2 / s.

Thus, the corallines would have negligible primary production under sea ice cover, even during the longest days of the year. Their growing season appears to be limited to the brief period of open water. This implies that their productivity will be strongly influenced by global warming through its effect on the duration of the open water season.

Macroalgal primary production

Jens Borum, Dorte Krause-Jensen, Morten F. Pedersen, Peter B. Christensen, Kurt Nielsen

The photosynthetic performance, biomass, growth and production of benthic macroalgae, with special focus on the brown alga *Laminaria saccharina*, were analyzed to estimate how much the benthic macroalgal community contributes to total primary production and how the macroalgae cope with the Arctic conditions of extremely low temperature and a very short period with sufficient light for photosynthesis.

Depth distribution and light adaptation

Benthic macroalgae occurred from 2-30 m depth in Young Sund. More densely vegetated areas were confined to 2-15 m, where the perennial brown algae *Fucus evanescens*, *Laminaria saccharina* and *Desmerestia aculeata* were the dominant species. Filamentous algae were found in between the larger brown algae, while leaf-formed red algae dominated vegetation at depths exceeding 15 m. Maximum biomass was around 80 g C / m^2 at the study site, but much more dense vegetation occurred at the mouth facing open waters, where feeding activities of walruses, and hence disturbance of the sediment, were less violent than at the study site.

The macroalgae had low light requirements at the beginning of the growth season in June, when the locality was covered by 30 cm of snow and 1.6 m of ice. The light compensation point of *L. saccharina* was around 2 µmol photons / m^2 / s, corresponding to 1-2% of surface irradiance. The low light compensation point allowed *L. saccharina* to have a small net production even at 10 m depth under ice and snow cover. Light requirements increased during the open water period in August, but *L. saccharina* exhibited substantial net carbon incorporation almost 24 hours a day.

Growth

Although the seasonal changes in surface irradiance and ice cover provided a growth period of only 2-3 months, *L. saccharina* exhibited a surprisingly high annual growth rate of 0.5-1.5 m of leaf blade per fully grown individual. This is similar to growth of *L. saccharina* in temperate areas with less extreme temperatures and a much longer growth period. Accordingly, *L. saccharina*, is able, through physiological adaptation, to compensate for the extreme Arctic conditions. The Arctic individuals of *L. saccharina* maintain old, but photosynthetically active, thalli attached to the new leaf blades for 1-2 years, while the blades of temperate individuals are lost within one year. Since the different age groups of arctic *L. saccharina* leaf blades can be easily recognized, this provides the advantage that growth can be immediately assessed without using leaf marking techniques.

The vigorous growth of the benthic macroalgal community means that this component may add substantially to total primary production of coastal Arctic waters. We estimated a maximum annual production of *L. saccharina* to be only 2.5 g C / m^2, but localities less attractive to walruses as feeding areas harbor much higher algal densities and, hence, support much higher production. In addition, the other macroalgal species, which contribute with 5 to10-fold more biomass than *L. saccharina* in Young Sund, will further add to primary production and to the food webs of the delicate coastal Arctic ecosystem.

Filtration and respiration of benthic infauna

Mikael K. Sejr, Jens K. Petersen, Søren Rysgaard

Earlier work on the composition of benthic animals in Young Sund has revealed a high abundance of bivalves, especially the large species *Hiatella arctica* and *Mya truncata* which are a dominant food source for the walruses in the area. Little is known, however, of how the low temperature and variable food levels influence physiological processes such as filtration and respiration of these bivalves. The objective of this summer's work was to quantify biomass of dominant bivalves along a depth transect from Daneborg and to supplement earlier studies on benthic composition by the use of underwater photography. Furthermore, filtration and respiration in response to temperature and food level was studied for *H. arctica* in order to assess its level of adaptation and its role in benthic carbon cycling.

Biomass and abundance of dominant bivalves

Maximum biomass of bivalves was found at 35 m depth with a total of 238 g wet weight m-2 (Fig. 5.27), which is relatively high compared to total benthic biomass published from other high-arctic fjords. *H. arctica* showed highest biomass whereas several species of small (< 1cm length) *Astarte* were extremely abundant at 10 m.

Abundance and distribution of large seafloor organisms identified by UW photography

Underwater photography was tested as a technique for estimation of abundance and distribution of benthic fauna. The dominant benthic organisms in Young Sund are poorly sampled by standard equipment. Photos covering a known area of seafloor were taken at 5-60 m depth along a transect from Daneborg to supplement studies from 1996. The photos showed that at depths down to c. 10 m, only very few epifaunal organisms were present, most probably due to ice scour. Several individuals/-m^2 of large sea cucumbers (*Psolus sp.*) and sea lillies (*Heliometra glacialis*) where observed at 40-50 m together with very high numbers of brittle stars (predominantly *Ophiocten sericeum* and *Ophiura robusta*). Brittle stars reached maximum abundance at the deepest station sampled with an abundance of 250 individuals/m^2.

Filtration and respiration of the bivalve Hiatella arctica

A high level of adaptation was found as filtration rates at *in situ* temperature generally matched rates at *in situ* temperature from boreal temperate regions. Increasing filtration rates was found as a function of temperature up to about 7.5(C after which rates seemed to decrease again. For boreal temperate populations, increasing filtration rates are usually found from 5-20(C. This suggests that the adaptation to cold temperatures in bivalve filtration rates has been achieved at the expense of plasticity towards temperature changes. In parallel to filtration rates, investigation of respiration rates at different food concentrations

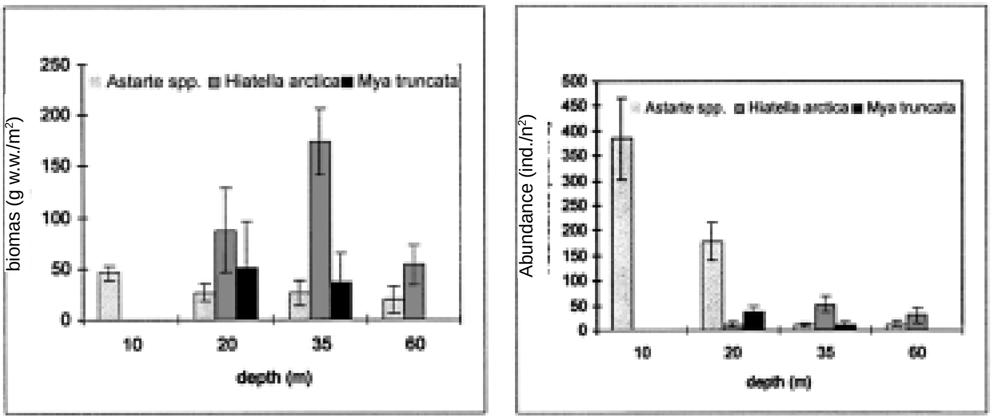


Fig. 5.27. Biomass left (g wet weight/m^{-2}) and abundance right of dominant bivalves as a function of depth along a transect off Daneborg.

were conducted, and our preliminary results suggest that *H. arctica* reaches maximum respiration rates at low food concentrations. In order to fully understand the level of adaptation of the Arctic population, similar measurements of the effect of temperature on filtration rates and respiration rates are currently taking place on individuals from southern Sweden where bottom water temperatures are much higher.

Studies of walrus energetics and behaviour

Erik W. Born, Mario Acquarone, David Griffiths

The field work in 1999 initiated a three-year-project to determine the areas used, the diving activity and the energy expenditure of walruses. This study is linked to the CAMP study and specifically aims at quantifying the role of walruses as predators in the benthic ecosystem.

Between 26 July and 1 September 1999 our research team was positioned on the western side of Sandøen about 250 m northwest of where the walruses traditionally haul out.

Observations

During the field period, walruses were registered continuously by use of a time-lapse camera at the haul-out and by “manual” observations conducted at 00, 06, 12 and 18 hours local. Generally, few walruses occurred at Sandøen during the field period and on several occasions walruses were absent from the beach. Similarly, only few walruses were observed in Young Sund and along Wollaston Forland and southern Clavering Ø. Visitors to the island reported that on 24 July, nine walruses hauled out. However, the highest number recorded on Sandøen during the study period was seven individuals that hauled out on 6 August.

The walruses used three different sites at the southeastern part of Sandøen for hauling out. These sites were placed about 50 m from each other. In each case where walruses were absent from the beach for several days, the animals had chosen to leave the haul-out unprovoked. After 11 August, only one or two animals occurred at the beach every now and then. Based on the occurrence of animals with different appearance it is estimated that c. 30 individuals hauled out on Sandøen during the observation period. Only in one instance were we able to identify an individual that occurred at the beach twice. On 26 July an adult female walrus hauled out on the beach. Otherwise only male walruses were observed at Sandøen.

Generally the field period was dominated by calm weather with no precipitation. After 27 August it became more windy and cold with snow showers. Until 21 August there was an unusually large amount of drift ice at the entrance to Young Sund and during several periods ice hummocks blocked the beach at the walrus haul-out.

Due to their general absence from Sandøen there were only very few occasions where walruses could be immobilized. On 23 August an adult male (estimated total body mass of 1080 kg) was immobilized. A satellite transmitter and a time-depth-recorder were attached to the tusks, and deuterium labeled water was injected into the animal. During the field period this animal did not appear again on the haul out on Sandøen for potential recapture and sampling. However, it reappeared once off the island together with other walruses. According to the telemetered relocations until the end of November the walrus has used the coastal areas between Lille Pendulum and southern Clavering Ø (*i.e.* between approximately 74° and 74° 45´ N). Apparently its has hauled out on Sandøen, Lille Pendulum and in Dødemandsbugten, Clavering Ø (Fig. 5.28).

Migration patterns

The general absence of walruses in 1999, and the fact that one individual occurred at the beach twice on one occasion only, indicated that Sandøen was not used by a “local” group of animals that resided there “permamently” during the open water season as has been described for the Lille Snenæs haul-out in Dove Bugt further north (Born and Knutsen 1997).

The activity pattern at Sandøen indicated that the site is used relatively briefly by animals *en route* to other areas. Both in 1998 and in 1999 the highest numbers were recorded in late July and early August. This may indicate that the walruses use Sandøen during migration from south (*i.e.* the areas at the entrance to Scoresby Sund and the Blosseville Coast) for instance to the Hochstetter Bugt. Alternatively, the Sandøen haul-out may be one of several haul-outs used in the area as indicated by the walrus with the satellite transmitter, which apparently has alternated be-

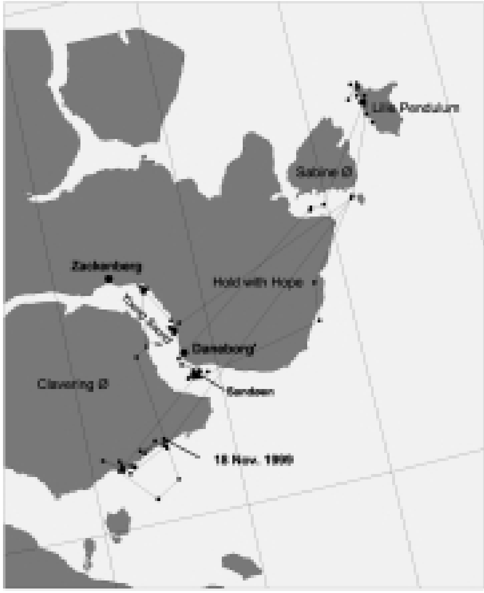


Fig. 5.28. The movement of the male walrus 6481 between 23 August and 18 November. Apart from having hauled out on the Sandøen haulout, relocations indicate that this animal also rested on land on Lille Pendulum and on the southern coast of Clavering Ø. Relocations in the least precise category have also been included. Hence, one may get the false impression that 6481 occurred relatively far inland at certain sites.

tween hauling out on Sandøen, Lille Pendulum, and southern Clavering Ø. The reason for the low number of walruses in 1999 in Young Sund (and along southern Clavering Ø and Wollaston Forland) is not clear. The general absence may reflect (1) natural fluctuations, (2) a reaction to the dense sea ice in the area, and / or (3) a reaction to disturbance from various human activities in the area.

Public relations

Peter B. Christensen, Doug Allan, Gordon Downie and Göran Ehlmé

In response to recent years' public interest in climatic change and Arctic issues, we decided to promote the scientific work undertaken in Young Sund to a broader audience. Thus, several aspects of the CAMP project have been described in c. 10 Danish newspapers and journals during 1999. Furthermore, the scientists video recorded the research activity during June-July, and in cooperation with the National Television Company DR-TV. Those recordings have now been edited to produce a 30 min. program which will be broadcasted nationwide three times in December 1999.

Three photographers from BBC joined the CAMP project in August to film walruses in Young Sund. Their recordings will be broadcasted in the BBC production "Blue Planet". All takes are a valuable and integrated part of the walrus studies in relation to their behavior and feeding activities.

Future studies

The CAMP project continues in 2000, where further investigations of the ecology in Young Sund and the effect of global warming will follow up on the investigations from 1999. The work in 2000 will focus on the short but very dynamic open-water period during late summer. The integrated data-set will make it possible to make mass balance calculations of carbon and nutrient cycling in Young Sund and, furthermore, form the basis of more general sophisticated dynamic models. Finally, the results obtained by the CAMP project will be highly valuable when predicting ecological changes in Arctic marine environment as a consequence of global warming.

Acknowledgements

The work was financially supported by the Danish Research Councils (contracts no. 97000224 and 9802967), The Danish National Research Foundation through the Danish Center for Earth System Science, the Carlsberg Foundation (contract no. 980291 / 10-1241), the Commission for Scientific Research in Greenland (KVUG contract no. 602-53 and 602-65), Knud Højgaards Fond (contract no. 25.728), Prins Joachims og Prinsesse Alexandras Internationale Uddannelses Fond (date 980812).

We thank Egon Frandsen, Jens Larsen and Thomas V. Rasmussen for excellent assistance in the field and laboratory. Michael Stjernholm and Jens S. Laursen are acknowledged for assistance with calculations of bottom topography. Furthermore, the military sledge patrol Sirius is acknowledged for their hospitality and help in general.

5.16 Foraging strategies by muskoxen cows

Nicolai Herman Jørgensen

Data was collected on behaviour, lactation duration, selection of foraging habitat and heard structure of muskoxen cows. Due to

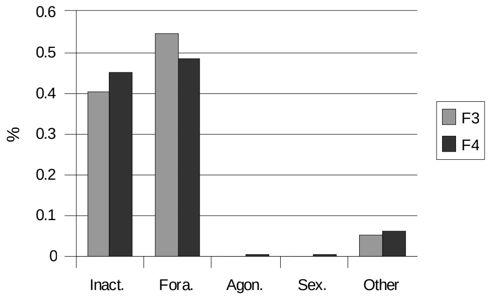


Fig. 5.29. Time allocation in the prerut. F3 = Three years old female, F4 = Four years old or older female.

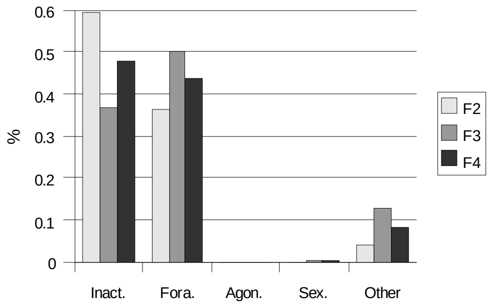


Fig. 5.30. Time allocation in the rut. F2 = Two years old female, F3 = Three years old female and F4 = Four years old or older female.

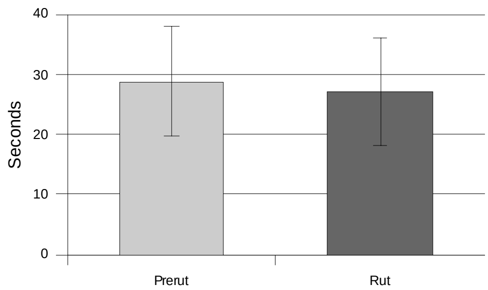


Fig. 5.31. Mean lactation duration in seconds – Prerut (n = 19) and rut (n =18). Vertical lines indicate the standard deviation.

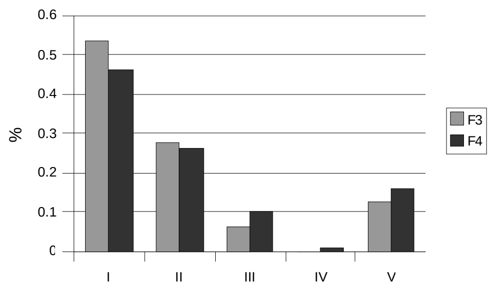


Fig. 5.32. Forage habitat selection – Prerut. F3 = Three years old female, F4 = Four years or older female.

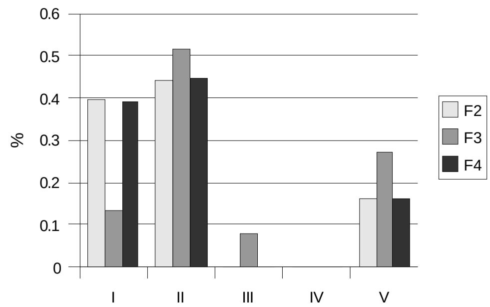


Fig. 5.33. Forage habitat selection – Rut. F2 = Two years old female, F3 = Three years old female, F4 = Four years or older female.

scarcity of cows in the census area during the prerut (5 July to 15 August) data was primarily collected outside the census area. During the rut (16 August to 3 September) data were primarily collected inside the area. Any behavioural data affected by human activity (aerial and ground traffic) were discarded from the analysis. Observations were made with a binocular at a distance of 200-500 m on arbitrarily chosen cows.

Data on behaviour were collected every minute using focal animal sampling (Marin and Bateson, 1993). Behaviour was divided into the categories: inactivity, foraging, agonistic behaviour, sexual behaviour, and other. Data were pooled for the age classes 1) yearling, 2) two years old (F2), 3) three years old (F3), 4) four years or older (F4+).

The F2 group is inactive 59% of the time, is foraging 36% and allocate 4% of the time to other behaviour. The F2 age class shows no agonistic or sexual behaviour. The F3 group shows a decrease in inactivity and foraging from the prerut to the rut, (Figs 5.29 and 5.30), allocating more time in the in the category “other”. In the F4+ age class a decrease in foraging and an increase in inactivity and “other” is noted.

4 cases of sexual related behaviour occur during the prerut, and 19 during the rut, but due to the sampling method these cases do not emerge in Figs 5.29 and 5.30.

The mean duration of lactation was 29 seconds during the prerut (ranging from 12 to 48 seconds) and 27 seconds during the rut (ranging from 12 to 43 seconds) (Fig. 5.31). There is no significant difference in mean duration ($t = 0.58$, $df = 35$, $P > 0.05$) from the prerut to the rut. The cows would terminate the lactation. The calves often attempted to resume suckling but were always denied by the cows.

The foraging habitats were divided into the following classes: 1) meadow (dominated by *Carex* sp. and *Eriophorum* sp.), 2) snowbeds and snow patches (dominated by *Salix arctica* and *Carex* sp.), 3) dwarf shrub heath (dominated by *Cassiope tetragona* and *Vaccinium uliginosum*), 4) steppe (scarcely vegetated), 5) grassland (dominated by *Poaceae*) (Thing 1984, Olesen 1990, Forchhammer 1995). The F3 and F4+ shifted from prefering habitat types containing graminoids (I and V) in the prerut to habitat types containing shrubs (type II and III) in the rut. In 1999, the onset of snow melting was delayed in large parts of the Zackenbergdalen. This may have resulted in delayed plant growth in certain habitat types (type II and III) and prevented the access to *e.g. Salix*.

The focal heard structure was registered (Table 5.4 and 5.5). Sex of calves could not be observed, but the sex ratio is assumed to be 1:1. The proportion of calves in the focal herds increased from 6 to 9.5%. Only one yearling was observed during the field season. The two years old females decreased from 9 to 6%, where as the males in the same age class increased from 2 to 9%. In the 3 years age classes both females and males decreased, from 27 to 11% and from 12 to 4% respectively. In the 4+ years age classes females increased in frequency (22 to 39%) where males decreased 3% from 16 to 13.

Cohort-Prerut	% Females	% Males
Calf	6	6
1 year	0	0
2 years	9	2
3 years	27	12
4+ years	22	16

Table 5.4. Sex and age distribution of focal herds in the Zackenberg valley in the prerut (5 Juli to 14 August). N = 110.

Cohort - Rut	% Females	% Males
Calf	9.5	9.5
1 year	1	0
2 years	6	7
3 years	11	4
4+ years	39	13

Table 5.5. Sex and age distribution of focal herds in the Zackenberg valley in the rut (15 August to 3 September). N = 83.

On several occasions the muskoxen were affected by the noise of flights arriving to the Zackenberg station. Especially when the cargo ship from Denmark arrived and an air brigde from Daneborg to the station was established. The muskoxen in the vicinity of the station airstrip moved to areas further away. A heard 1 km east of the runway started to run, when the first plane landed (out of eight flights) and did not stop until it was about another km further away from the runway.

I thank Thomas B. Berg, Henning Thing, Hans Meltofte and the logisticians on the station for help and advice prior to and during the field season. The field season was financed by G.E.C. Gads Fond and the Zackenberg Scholarship.

6 Disturbance

Hans Meltofte

Surface activities in the study area

The number of person-days (one person in one day) spent in the terrain in the main research zone 1 (Table 6.1) was higher in July and especially in August than in previous years. The total number of person-days spent in Zackenbergdalen was 40% higher than in 1998. Activities in the low impact study area (1b) remained very low, and so did activities in the protection zone for moulting and breeding geese (1c).

Moulting and breeding geese remained very sensitive to our activities. The return of 127 moulting pink-footed geese to the coast around the peninsula to the south-east in spite of the inclement ice conditions, support the suspicion that helicopter flights in early July 1998 has contributed to last year's failure (see section 4.3.8 in Rasch 1999).

Five of the six ATV trips in May and June were on snow. All trips on ground in June, July and August were along the route to Tørvekæret established in 1997.

Aircraft activities in the study area

The number of fixed-wing aircraft take-off and landings in 1999 (Table 6.2) was again higher than the number of flights in 1998, but still lower than in 1997. Some of the many flights in June were caused by a mishap during a landing on 8 June, when a Twin Otter ran off the runway and was damaged.

The number of helicopter flights, that must be considered much more disturbing to wildlife than fixed-wing operations, was much lower than last year. All helicopter flights passed over the fjord and up to the station. No flights went through Store Sødal.

Discharges

As in previous years, combustible waste (paper *etc.*) was burned at the station, while all other waste (plastics, cans, bottles *etc.*) was flown out of the area. However, solid but biologically degradable toilet and kitchen waste was for the first time poured into Zackenbergelven. This included more than 1 ton from 1998 and almost everything from 1999. In August this year, a grinding mill was established at the river shore, so that the waste was comminuted. The total amount of untreated wastewater let into Zackenbergelven from the kitchen, showers, sinks and laundry machines equalled more than 1450 person-days, an increase from 1100 in 1998, 1300 in 1997 and 1200 in 1996. Based on measurements of the natural nutrient transport in the river in 1997, it has been calculated that the impact introduced by dumping toilet disposal in the river is minimal.

Manipulative research projects

On the first plateau south of the station (UTM zone 27: 8,264,564 m N, 512,921 m E), three plots, each measuring 40 x 50 cm, were radiated with infrared heaters during the entire snow free season (see section 5.6).

The 50 m long and 1.7 m high snow fence north of the climate station (UTM zone 27: 8,265,300 m N, 513,700 m E) that was erected in late July 1998 (see section 5.6.1 in Rasch 1999) showed no pronounced effect on the snow regime during snow melt in June-July, probably because snow almost covered the fence in late winter. It is possible, however, that snow accumulated earlier here early in the winter. The fence is made of metal netting with a mesh size of 4 cm carried by iron poles standing in the permafrost (see section 5.13)

The snow fence southeast of the station, erected in August 1996 (see section 6.4 in Meltofte and Thing 1997), was removed this year. There was never any major effect on the snow patterns around it.

Take of organisms

In the valley between the west end of Store Sø and Tyroler Fjord, Arctic char *Salvelinus alpinus* were collected from the larger of the two lakes. A total of 38 land-locked specimens, 3-50 cm long and weighing 3-1307 g, were taken (see section 5.7).

Research zone	May	June	July	Aug.	Sept.	Total
1	3	162	374	562	66	1167
1b			19	14		33
1c (20.6-10.8)			1			1
2			22	12		34
ATV-trips	1	4	3	1	1	10

Table 6.1. Person-days and traffic in the research zones with ATV (all terrain vehicle)

Type of aircraft	June	July	Aug.	Sept.	Total
Fixed-wing	16	8	24	4	52
Helicopter			6		6

Table 6.2. Number of flights over the research area in Zackenbergdalen May-September. Each ground visit of an aircraft is considered two flights.

7 Publications from ZERO 1999

Scientific papers

Christiansen, H.H. 1999: Active layer monitoring in two Greenlandic permafrost areas: Zackenberg and Disko Island. – Danish Journal of Geography 99: 117-121.

Friborg, T., Hansen, B.U., Nordstroem, C. and Søgaard, H. 1999: Controls on the greenhouse gas exchange of a high-arctic ecosystem. – Danish Journal of Geography 99: 19-26.

Friborg, T., Hansen, B.U., Nordstrøm, C., and Søgaard, H. 1999: Seasonal exchange of CH_4 and CO_2 during the short high arctic summer in northern Greenland. In: Proceedings from: Greenhouse gasses and their role in climate change: the status of research in Europe, Orvieto, Italy, 1997. EC Directorate General for Science Research and Development, Climate and Natural Hazards Unit, pp. 66-69.

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Lloyd, C.R., Aurela, M., Hargreaves, K.J. and Nordstrøm, C. 1999: Trace gas fluxes in the Arctic: contribution to proceedings form an international workshop on Greenhouse gasses and their role in climate change: the status of research in Europe, Orvieto, Italy, 1997. EC Directorate General for Science Research and Development, Climate and Natural Hazards Unit, pp. 40-47.

Rysgaard, S., Nielsen, T.G., Hansen, B. 1999: Seasonal variation in nutrients, pelagic primary production and grazing in a high-arctic coastal marine ecosystem, Young Sound, Northeast Greenland. – Marine Ecology Progress Series 179: 13-25

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Trappeniers, K., Kerckvoorde, A.v., Chardez, D., Nijs, I. and Beyens, L. 1999: Ecology of testate amoebae communities from aquatic habitats in the Zackenberg area (Northeast Greenland). – Polar Biology 22: 271-278

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Bøcker, C. 1999: Beregning af NDVI fra Landsat TM, Zackenberg 1999. – Asiaq

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Nordstrøm, C. 1999. Atmospheric exchange of greenhouse gases in arctic terrestrial ecosystems. Ph.D. Thesis. Institute of Geography, University of Copenhagen.

Schmidt, N. M. 2000: Spatiotemporal destribution and habitat use of the collared lemming, Dicrostynyx groenlandicus Traill, in high arctic Northeast Greenland. University of Copenhagen, Department of Zoology, and Danish Polar Center, Copenhagen. 84 pp.

Simonsen, J. 1999: Effekter af kantlyngbevoksning på jordbundsdannelse ved Zackenberg, Nordøstgrønland. Geografisk Institut, Københavns Universitet. 41 pp.

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Christensen, P. B., Rysgaard, S. 1999. Sikup ataani inuuneq. Atuagagdliutit / Grønlandsposten, 2 March.

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Christensen, P. B., Rysgaard, S. 1999. Klimaforandringer i Arktis. Aktuel Naturvidenskab, no. 1: 4-7. Aarhus Universitet, Det Naturvidenskabelige Fakultet.
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Christensen, P. B. 1999. Spændende resultater fra dansk polarforskning. Midtjyllands Avis, 27 June.
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Øksnebjerg B. 1999. De måler isalgernes skjulte liv. Natur & Videnskab, February

8 Personnel and visitors

Research

Zackenberg

Susanne Lildal Amsinck, M.Sc., National Environmental Research Institute, Department of Lake and Estuarine Ecology (fresh water ecology, 3-18 August)

Thomas Bjørnboe Berg, M.Sc., National Environmental Research Institute, Department of Arctic Environment (BioBasis, lemming ecology, 28 June-3 September)

Carsten Böcker, M.Sc., ASIAQ, Greenland Field Investigations, Greenland (ClimateBasis, 8-18 August)

Torben Røjle Christensen, Ph.D., Department of Plant Ecology, University of Lund (trace gas exchange, 28 June-5 July)

Hanne Hvidtfeldt Christiansen, Ph.D., Instute of Geography, University of Copenhagen (nivation, 3 August-9 September)

Kirsten Christoffersen, Ph.D., Freshwater Biological Laboratory, University of Copenhagen (fresh water ecology, 3-18 August)

Bo Elberling, Ph.D., Institute of Geography, University of Copenhagen (pedology, soil water chemistry, 18 July-8 August)

Birgit Hagedorn, Ph.D., Alfred Wegener Institute for Polar and Marine Research, Germany (water chemistry, 29 May-14 June, 8 August-9 September)

Birger Ulf Hansen, Ph.D., Institute of Geography, University of Copenhagen (remote sensing, 14-28 June)

Mark Heuer, M.Sc., Laboratory of Plant Ecology, University of Antwerpen, Belgium (free air temperature increase, 25 July-3 September)

Nanna Høegh, Ph.D. student, Aalborg University, Department of Civil Engineering, The Environmental Engineering Laboratory (trace gas exchange, 25 July-27 August)

Lotte Illeris, Ph.D. student, Botanical Institute, University of Copenhagen (trace gas exchange, 28 June-25 July)

Bjarne Holm Jakobsen, Ph.D., Institute of Geography, University of Copenhagen (pedology, soil water chemistry, 18 July-8 August)

Jens Peder Jensen, Ph.D., National Environmental Reasearch Institute, Department of Lake and Estuarine Ecology (fresh water ecology, 3-18 August)

Anna Joabsson, Ph.D. student, Department of Plant Ecology, University of Lund, Sweden (trace gas exchange, 5 July-27 August)

Frederik Joabsson, Ph.D. student, Department of Plant Ecology, University of Lund, Sweden (trace gas exchange, 3 August-27 August)

Bengt Jonsell, Professor, Bergianska Foundation, Royal Swedish Academy of Science, Sweden (botany, 3-8 August)

Nicolai Hermann Jørgensen, Student, Zoological Institute, University of Copenhagen (muskox behaviour, 5 July-3 September)

Andy Van Keerckvoorde, Ph.D. student, Laboratory of Polar Biology, University of Antwerpen, Belgium (testate amoebae ecology, 8 August-3 September)

Jens Peter Kleist, Technician, ASIAQ, Greenland Field Investigations, Greenland (Climate Basis, 8-18 August)

Fred Kockelberg, Technician, Laboratory of Plant Ecoclogy, University of Antwerpen, Belgium (free air temperature increase, 28 June-18 July)

Frank Landkildehus, M.Sc., National Environmental Reasearch Institute, Department of Lake and Estuarine Ecology (fresh water ecology, 3-18 August)

Sidsel Larsen, Student, Zoological Institute, University of Copenhagen (BioBasis, 5 July-18 August)

Torben Linding Lauridsen, Ph.D., National Environmental Reasearch Institute, Department of Lake and Estuarine Ecology (fresh water ecology, 3-18 August)

Torbjørn Borgen Lindhardt, Paamiut, Greenland (collection of basidiomycetes, 18 July-27 August)

Hans Meltofte, Dr.Sc., National Environmental Reasearch Institute, Department of Arctic Environment (BioBasis, 1 June-8 August)

Inger Nordal, Professor, Department of Botany and Plant Physiology, Institute of Biology, University of Oslo, Norway (botany, 3-8 August)

Ivan Nijs, Ph.D., Laboratory of Plant Ecology, University of Antwerpen, Belgium

(free air temperature increase, 28 June-18 July)
Claus Nordstrøm, Ph.D., Institute of Geography, University of Copenhagen (BioBasis, trace gas exchange,1 June-5 July, 8 August-9 September)
Morten Rasch, Ph.D., Danish Polar Center (station management, GeoBasis, 1 June-7 June, 3 August-9 September)
Åsa Rennermalm, Student, Institute of Geography, University of Copenhagen (trace gas exchange, 28 June-8 August)
Hans-Henrik Schierup, Professor, Department of Plant Ecology, Institute of Biological Sciences, University of Aarhus (fresh water ecology, 3-18 August)
Charlotte Sigsgaard, Student, Institute of Geography, University of Copenhagen (GeoBasis, nivation, pedology, 1 June-18 August)
Ronald Sletten, Ph.D., Quaternary Research Center, University of Washington, USA (pedology, 8 August-9 September)
Willem De Smet, Professor, Laboratory of Polar Biology, University of Antwerpen, Belgium (testate amoebae ecology, 8-27 August)
Koen Trappeniers, Ph.D. student, Laboratory of Polar Biology, University of Antwerpen, Belgium (testate amoebae ecology, 1 June-18 August)
Yvonne Vadebonceour, Ph.D., National Environmental Reasearch Institute, Department of Lake and Estuarine Ecology (fresh water ecology, 3 August-18 August)
Jens Østergaard, M.Sc., ASIAQ, Greenland Field Investigations, Greenland (ClimateBasis, 8-18 August)

Daneborg

Mario Acquarone, Ph.D. student, National Environmental Research Institute, Department of Arctic Environment (marine ecology, 26 July-1 September)
Doug Allan, Photographer, British Broadcasting Corporation, England (tv programme production, 5-27 August)
Erik W. Born, Ph.D., Greenland Institute of Natural Resources, Greenland (marine ecology, 26 July-1 September)
Jens Borum, Ph.D., The Freshwater-Biological Laboratory, University of Copenhagen, (marine ecology, 14-29 June, 5-18 August)
Peter Bondo Christensen, Ph.D., National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 7-29 June)
Gordon Downie, Assistant, British Broadcasting Corporation, England (tv programme production, 5-27 August)
Göran Ehlmé, Photographer, Water Proof Diving AB, Sweden (tv programme production, 5-27 August)
Henrik Fossing, Ph.D., National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 7-29 June)
Egon R. Frandsen, Technician, National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 7 June-5 July)
Ronni Nøhr Glud, Ph.D., The Marine Biological Laboratory, University of Copenhagen, (marine ecology, 7 June-5 July)
David Griffiths, Veterinary, Norwegian College of Veterinary Medicine, Norway (marine ecology, 26 July-1 September)
Benni Winding Hansen, Ph.D., Department of Life Sciences and Chemistry, Roskilde University, (marine ecology, 7-29 June)
Jens Würgler Hansen, Ph.D., National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 7 June-5 July)
Dorte Krause-Jensen, Ph.D., National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 5-18 August)
Michael Kühl, Ph.D., The Marine Biological Laboratory, University of Copenhagen, (marine ecology, 7 June-5 July)
Jens Larsen, Technician, National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 7-29 June)
Kurt Nielsen, M.Sc., National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 5-18 August)
Torkel Gissel Nielsen, Ph.D., National Environmental Research Institute, Department of Marine Ecology and Microbiology (marine ecology, 7-29 June)
Lars Ditlev Mørk Ottosen, Ph.D. student, Institute for Biological Sciences, University of Aarhus, (marine ecology, 7 June-5 July)
Morten Foldager Pedersen, Ph.D., Department of Life Sciences and Chemistry, Roskilde University, (marine ecology, 5-18 August)
Jens Kjerulf Petersen, Ph.D., National Environmental Research Institute, Department of Marine Ecology and Microbiology (marine ecology, 7-29 June)

Thomas Vestager Rasmussen, Student, Institute of Geology, University of Copenhagen, (marine ecology, 7 June-5 July)
Rodney Roberts, Ph.D., Cawthron Institute, New Zealand, (marine ecology, 7-29 June)
Søren Rysgaard, Ph.D., National Environmental Research Institute, Department of Lake and Estuarine Ecology (marine ecology, 7 June-5 July, 5-27 August)
Mikael K. Sejr, Ph.D. student, Institute of Biological Sciensces, University of Aarhus (marine ecology, 7-29 June, 5-27 August)
Bo Thamdrup, Institute of Biology, University of Odense (marine ecology, 7-29 June)

Logistics

Zackenberg

Lars Andreasen, Logistician, Danish Polar Center (logistics, 1 June-25 July)
Karen Egede, Accountant, Danish Polar Center (logistics, 3 August-9 September)
Henrik Lassen, Logistician, Danish Polar Center (logistics, 25 July-8 August)
Aka Lynge, Logistic Manager, Danish Polar Center (logistics, 29 May-18 July, 3 August-9 September)
Henrik Philipsen, Logistician, Danish Polar Center (logistics, 30 May-9 September)
Finn Simonsen, Porter, Danish Polar Center (logistics, 25 July-3 August)
Henning Thing, Special Consultant, Danish Polar Center (logistics, 25 July-8 August)

Daneborg

Lars Andreasen, Logistician, Danish Polar Center (logistics, 29 May-1 June)
Morten Rasch, PhD, Danish Polar Center (station management, 29 May-1 June)

Others

Zackenberg

Per Buch Andreasen, Chairman for the Research Advisory Committee, The Ministry of Environment and Energy (visit, 5-6 August)
Hans Ammendrup, Civil Engineer, Commission for Scientific Research in Greenland (visit, 27 August-3 September)
Vibeke Sloth Jakobsen, Librarian, Danish Polarcenter (visit, 5-18 July)
Finn Lynge, Consultant, Greenland Home Rule, Greenland (visit, 18-22 August)
Morten Meldgaard, Director, Danish Polarcenter, (visit, 5-6 August)
Kurt Nielsen, Director of Research Department, National Environmental Research Institute, Department of Lake and Estuarine Ecology (visit, 5-6 August)
Hanne Petersen, Director of Research Department, National Environmental Research Institute, Department of Arctic Environment (visit, 5-6 August)
Marianne Rønnebæk, Head of Department, The Ministry of Environment and Energy (visit, 5-6 August)
Henrik Sandbeck, Director, National Environmental Research Institute (visit, 5-6 August)

Daneborg

Per Buch Andreasen, Chairman for the Research Advisory Committee, The Ministry of Environment and Energy (visit, 6-8 August)
Finn Lynge, Consultant, Greenland Home Rule (visit, 22-25 August)
Morten Meldgaard, Director, Danish Polarcenter, (visit, 6-8 August)
Kurt Nielsen, Director of Research Department, National Environmental Research Institute, Department of Lake and Estuarine Ecology (visit, 6-8 August)
Hanne Petersen, Director of Research Department, National Environmental Research Institute, Department of Arctic Environment (visit, 6-8 August)
Marianne Rønnebæk, Head of Department, The Ministry of Environment and Energy (visit, 6-8 August)
Henrik Sandbeck, Director, National Environmental Research Institute, (visit, 6-8 August)

Further contributors to the annual report

Inger G. Alsos, Ph.D. student, Botany Department, Tromsø Museum, University of Tromsø, Norway (thermophilous plants)
Christian Brochmann, Professor, Botanical Garden, University of oslo, Norway (thermophilous plants)
Bent Christensen, Ph.D., Zoological Institute, University of Copenhagen (enchytraeid fauna)
Klara Dozsa-Farkas, Ph.D., Department of Systematic Zoology and Ecology, Eötväs Loránd University, Hungary (enchytraeid fauna)
Torstein Engelskjøn, Associate Professor,

Botany Department, Tromsø Museum, University of Tromsø, Norway (thermophilous plants)

Jørgen Hinkler, Student, Institute of Geography, University of Copenhagen (remote sensing)

Erik Jeppesen, D.Sc., National Environmental Research Institute, Denmark (BioBasis)

Marcel Klaassen, Ph.D., Department of Plant-Animal Interactions, Centre for Limnology, Netherlands Institute of Ecology, The Netherlands (ornithology)

Mogens B. Knudsen, M.Sc., ASIAQ, Greenland Field Investigations (ClimateBasis)

Steen B. Pedersen, Student, Institute of Geography, University of Copenhagen (remote sensing)

Jakob Simonsen, Student, Institute of Geography, University of Copenhagen.

Lars Thomsen, M.Sc., ASIAQ, Greenland Field Investigations (ClimateBasis)

9 Acknowledgements

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10 References

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