ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

8th Annual Report 2002

Danish Polar Center
Ministry of Science, Technology and Innovation
2003

Zackenberg Ecological Research Operations

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Front cover: The micro meteorological station for continuous measurements of energy, carbon dioxide and water vapour exchange between the tundra and the atmosphere is established each year in June, on the heath east of Zackenberg Station. On the photo, GeoBasis Assistant Charlotte Sigsgaard is working with the first calibration of the instrument (Photo Morten Rasch/PolarPhotos).

Back of cover: BioBasis Manager Hans Meltofte and BioBasis assistant Line Kyhn are emptying the different insect traps in 'Gadekæret' just outside Zackenberg Station in early June 2002 (Photo Morten Rasch/PolarPhotos).

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Executive summary

Hans Meltofte and Morten Rasch

In 2002, Zackenberg Station was open 97 days from 28 May to 31 August. Seventeen scientists and four logisticians worked at the station during that period and six other persons paid Zackenberg a visit. Ten scientists and two logisticians used the affiliation in Daneborg from 27 May to 14 June and again from 28 July to 31 August. The total number of bed nights at Zackenberg Station was only 978, which is less than in previous years.

In 2002, Climate Basis continued the measurements of climate at Zackenberg and water discharge in Zackenbergelven, and GeoBasis continued their measurements of different geomorphological and hydrological parameters. No major changes were made to the climate stations at Zackenberg in 2002, but GeoBasis installed equipment for measurements of the physical and chemical environment in the top soil at two of the BioBasis vegetation plots (Salix 1 and Dryas 2). A mast was erected for sampling of precipitation near the climate station.

2002 was a year of extraordinary high temperatures in early spring, *i.e.* late May and early June, and again in late June and early July, weather was warm and sunny. The mean temperatures for the period 21 May – 10 June were the highest recorded at both Danmarkshavn and Daneborg weather stations since computerised data were made available from 1958. For June in general, 2002 was the warmest month recorded at Danmarkshavn since measurements began in 1949, whereas four years had as high or even a little higher temperatures at Daneborg (data since 1958).

In spite of the fact that the snow depth at Zackenberg was the second highest recorded during the ZERO programme (since 1997-98), it was not particularly extensive, and the warm spring resulted in a relatively fast snowmelt. Again, due to the warm weather, ponds and lakes became ice-free early, and the streams started to run earlier than recorded before. The same applies to break up of the fjord ice, which was 1-3 weeks earlier than before. Also the other fjords of Northeast Greenland broke up exceptionally early, and unprecedented little pack ice was found in the East Greenland Current in summer and autumn.

Flowering was generally among the earliest recorded for white arctic bell-heather, arctic poppy and arctic willow together with some of the mountain avens plots, while others were closer to average. Opening of seed capsules showed a more diverse pattern, with arctic puppy close to average or even late, and arctic willow very early. Purple saxifrage was relatively early to intermediate. This diverse pattern may have been due to a relatively cool weather in the second half of July and most of August. 2002 was again a year of many flowers especially in arctic willow, moss campion and arctic cotton-grass, but not quite as many as in 2001 in most white arctic bell-heather and mountain avens plots. Berry production was moderate in the bearberry plots and even poorer in the arctic blueberry plot, while crowberries again appeared in good numbers.

Greening index data from a Landsat-7 satellite image and from hand-held measurements showed values for 2002 that were similar or very close to the values from 2001 and somewhat lower than most other years.

Soil respiration increased during snowmelt and reached a maximum of 0.85 g C per m^2 per day on 28 June during a spell of very warm weather. The growing season, characterised by a daily net C accumulation, began on 2 July, within the range from previous years. During the peak growing season, the CO_2 uptake reached a maximum of 1.0 g C per m^2 per day, and the CO_2 exchange in the 2002 growing season was of the same order of magnitude as found in the two previous years. The end of the growing season on 16 August was within the range from previous years, and the second half of August was characterised by net C loss.

The total number of arthropods collected this year (71,972) was much higher than last year and almost reaches the highest number ever recorded. Butterflies were caught in the highest numbers since 1996, and also the number of larvae was high relative to the last three years. Outside the traps, the most common butterflies, arctic clouded yellow and fritillary sp., were also encountered in very high numbers during bird census work. The warm and sunny weather in 2002 together with the relatively early snowmelt (giving high numbers of trapping days) are the most obvious reasons for the very high numbers of arthropods caught this season. Especially early June was warm, and this is reflected in the earlier build up and peak of many of the arthropods.

Most bird populations were of about the same size as in previous years, but fewer sanderlings and turnstones were found, possibly as a result of three consecutive problematic breeding seasons. The rock ptarmigan population remained low for the third year in succession. Egg-laying in waders was extraordinary early, and some wader clutches were initiated as early as the earliest recorded in high arctic Greenland so far. This was probably the result of the unprecedented high temperatures in late May and early June. Hatching success was moderate due to predation, but generally young production was good. Long-tailed skuas suffered from heavy predation by foxes. More barnacle goose families brought their young to Zackenbergdalen than recorded before, while the brood size was close to average.

After the increase in lemming winter nests from 2000 to 2001, the winter population was expected to peak during the winter 2001-2002, but the density remained at an intermediate level equal to the previous year. Numbers of lemming winter nests depredated by stoat have remained almost the same for three years now.

High numbers of musk oxen were recorded in June, but mainly outside the 40 km^2 census area. Totals decreased towards 1 July, whereupon numbers followed the patterns of previous years, and numbers of 'musk ox days' within the 40 km^2 census area were within the range recorded in earlier years. The maximum number of musk oxen recorded within the census area was 145 individuals in mid August. The calf:cow ratio was 0.32:1, which is in the lower end compared with previous years. On 22 July, an aerial survey covering Wollaston Forland and A.P. Olsen Land gave 234 musk oxen, which including data from the almost simultaneous ground counts, add up to a total of 368 musk oxen. Considering the biases in connection with the aerial survey it was concluded that the musk ox population was within the range of 500-800 animals earlier estimated for the area.

Five fox dens in the study area were partly in use during the summer. Pups may have been present in one den, which in that case might have died in early July. The total number of fox encounters was much the same as in 1997, 1998 and 1999. Three records of single arctic wolfs were made. A minimum of nine arctic hares was recorded within the study area.

A maximum of 48 seals was recorded on the fjord ice in late June, and a maximum of 24 walruses was hauled-out on Sandøen in late July.

Twelve scientific projects were carried out in 2002 based on data from Zackenberg. Of these, three projects were carried out at Daneborg while the remaining were carried out either at Zackenberg or based on data from Zackenberg.

1 Introduction

Morten Rasch

The 2002 field season at Zackenberg Station had the lowest activity since the first year in 1995. Only 26 scientists representing twelve different projects visited the station during June-August, and when we departed from the station on 31 August, the total number of bed nights counted 978. An activity level like that makes the run of Zackenberg Station very expensive due to a high level of general costs. Therefore, several attempts have been made to improve the knowledge about the station in the science community, and already several projects have announced their interest in using the station in 2003. The optimal level of activity at Zackenberg is between 1,500-1,700 bed nights. With less activity it is relatively expensive to serve each scientist at the station and with more activity the capacity of the physical facility is exceeded and the level of disturbance to the ecosystem becomes too high.

Changes in the concept of Zackenberg Basic

Over the last two years, attempts have been made to extend and restructure the monitoring programme, Zackenberg Basic. Until now, the monitoring has consisted of three sub-programmes. ClimateBasis is run by Asiaq, Greenland Field Investigation, and the programme takes care of the run and maintenance of the climate station and the hydrometric station at Zackenberg. GeoBasis is run by Danish Polar Center in cooperation with Institute of Geography, University of Copenhagen. This programme measures the fluxes of water, suspended sediment, organic matter and solutes in the research area, it measures the development of the active layer and it monitors selected geomorphological processes. BioBasis monitors the biotic part of the terrestrial ecosystem incl. the flora and fauna at Zackenebrg. The programme is run by Danish National Environmental Research Institute.

With the planned new concept for Zackenberg Basic it is our intention to extend GeoBasis and to make it a cooperation between Danish National Environmental Research Institute and Institute of Geography at University of Copenhagen. Further, it is our intention to introduce a new marine monitoring programme, MarineBasis, continuing and extending the marine research activities carried out in Daneborg by Danish National Environmental Research Institute since 1994. By these means Zackenberg Basic could become the first programme in the world studying all the different aspects of eco system function in a high arctic environment, and the programme would be an ideal Danish contribution to AMAP's Climate Change Effects Programme. The new concept has been described in a concept paper prepared in cooperation between Danish Polar Center, Danish National Environmental Research Institute, University of Copenhagen and Asiaq, Greenland Field Investigation. The content of the concept paper is given in Chapter 9 in this report. In 2002, the Danish Environmental Protection Agency funded four smaller pilot projects necessary for the extension of GeoBasis and the introduction of MarineBasis.

Extension of the facility

The plans of extending the station with an accommodation building and a combined power station, workshop and garage were not carried out in 2002. The establishment of the two buildings are part of a comprehensive plan for the future development of the National Park of North and Northeast Greenland. At the moment the extension of the Zackenberg facility is waiting for a process of defining the future ownership of all buildings in the National Park. The process of coordinating the future activities in the National Park is carried out in cooperation between the major operators in the National Park, and the process is being led by the Ministry of Science, Technology and Innovation.

In 2002, Zackenberg Station took over a smaller house which originally was build by the Sirius Dog Sledge Patrol as the first building at Zackenberg in 1995. It is our plan to restore the house and eventually use it for accommodation of Zackenberg staff.

Cooperation with Greenland research sites

The cooperation with the other Greenland research facilities, including Arctic Station (central West Greenland), Greenland Institute of Natural Resources (southern West Greenland), Kangerlussuaq International Science Support (mid West Greenland) and Sermilik Station (Southeast Greenland), was continued in 2002. A common brochure telling about the different possibilities at the different stations was published. This brochure will be sent to universities and research institutes with departments for polar research in order to promote Greenland as an excellent research area with very different field stations in very different environmental settings.

International cooperation

Zackenberg Station continued its participation in the two EU-funded networks, ENVINET and SCANNET. In SCANNET, Zackenberg Station is leading a project on Species Performance and Phenology in the North Atlantic region. In ENVINET, Zackenberg Station is taking care of the Station Manager Forum, a forum promoting the experience exchange and cooperation between station managers at different European research stations. To run these two projects, Danish Polar Center has received funding for the employment of two persons, Toke Thomas Høye, employed at University of Copenhagen and taking care of the SCANNET obligations and Gabrielle Stockmann, employed at Danish Polar Center and taking care of the ENVINET obligations.

Zackenberg Station has become involved in the establishment of a circum arctic network of research stations. The network is called Circum-Arctic Environmental Observatories Network (CEON). The initiating institutions are United States National Science Foundation, Abisko Scientific Research Station and Danish Polar Center. The plan will be presented at Arctic Science Summit Week in Sweden early in 2003 and a workshop initiating the network is planned to be held in Stockholm in the autumn of 2003.

Danish Polar Center has in cooperation with the Swedish Polar Research Secretariat, tried to join forces in a Danish-Swedish Biodiversity Project involving six Danish and six Swedish scientists at Zackenberg in 2002. Unfortunately, it was not possible to accomplish the project due to lack of funding for the Danish part of the project. The Swedish part of the project was funded by the Swedish Polar Research Secretariat which in contrast to Danish Polar Center have the possibility of funding strategic research initiatives. Attempts will be made to find funding for the Danish part of the project in 2003.

Late in 2002, the Swedish Polar Research Secretariat offered to a Zackenberg logistician to join their activities in the Antarctic. As a result, logistician Aka Lynge, worked for one and a half month on the Swedish facilities, WASA and SVEA. The purpose of his trip to the Antarctic was to learn from the Swedish experiences about the run and maintenance of a large research station in an extreme environment.

Plans for the 2003 field season

The 2003 field season is expected to be very busy with several large projects both at Zackenberg and at Daneborg. Due to increased activities out of Zackenberg (in the Young Sund/Tyrolerfjord system, on Clavering Ø and on A.P. Olsen Land) it is our plan to buy a large rubber boat for transportation of scientists from Zackenberg to different field sites. Further, it is our intention to improve the toilet facilities, and to finish repairing the house that we bought in 2002 from the Sirius Dogsledge Patrol.

Further information about Zackenberg Station and the study area

Details about Zackenberg Station and its study area are given in earlier annual reports (Meltofte and Thing 1996, 1997; Meltofte and Rasch 1998; Rasch 1999; Caning and Rasch 2000, 2001, 2003). The annual reports can be downloaded from the homepage www.zackenberg.dk where other publications from Zackenberg as well as a description of the facility, the ZERO Site Manual, application forms and other relevant materials are available. The secretariat can be contacted on the address: The Zackenberg Station Secretariat, Danish Polar Center, Strandgade 100H, DK-1401 Copenhagen K, Denmark. Phone: +45 32880100, Fax: +45 32880101, E-mail: mr@dpc.dk.

2 Logistics

Henrik Philipsen

In 2002, Zackenberg Station was open for 97 days, from 28 May to 31 August. Seventeen scientist and four logisticians worked from the station. The station received five official guests. Zackenberg´s branch facility in Daneborg was used by 10 scientists and one logistician from 27 May to 14 June and again from 28 July to 31 August. The total number of person days at Zackenberg and Daneborg was 978.

Transportation

The runway at Zackenberg was covered by snow and ice on our first arrival 27 May and was ready to welcome the first plane on 1 June.

The number of landings with fixed winged aircrafts was 24, twelve landings with personel and twelve landings with cargo. One helicopter landed to pick up guests for transport to Mestersvig.

Local transportation of heavy equipment was done with our ATV, on marked roads. One trip was made off road during the night between 28 and 29 May over the sea ice to Daneborg to pick up cargo and provision. Another off road trip was made during the night between 3 and 4 June to Store Sø to deliver heavy equipment for a scientific project.

Houses

At Zackenberg, guests and scientists are accomodated in Weatherheaven shelters. The shelters need repair, but are still usable for one or two years. The condition of the houses at Zackenberg is good because of continuous maintenance. In 2002, a hut formerly owned by the Sirius Dog Sledge Patrol was purchased by Zackenberg Station and upgraded to allow for accommodation of two persons in single rooms. In the mess room a data projector was installed to allow for scientific presentations, as well as a DVD with surround sound for the weekly transformation of the mess room to "Zackenberg Cinema".

Electrical power supply

Two 14.8 kW generators supply the station with electricity and five small generators are used for power supply in the field. The large generators are still working very well.

The power supply in two houses was converted from AC 230 V to AC 400 V to allow installation of two new electrical water heaters.

Water supply

In 2000 and 2001 we installed aluminium tanks for water storage and in 2002 we bought an integrated water pump system. The new water supply system is expected to work from the beginning of the 2003 field season.

Telecommunication

External communication is performed by a satellite phone (Inmarsat-M), fax and e-mail. This year 751 e-mails were sent and received through a dial-up connection to a server at the Institute of Geography, University of Copenhagen. Telephone communication totalled 1,368 minutes.

To communicate with other stations in Northeast Greenland a HF-radio is used. VHF-radios are used for local communication at the station and surroundings.

Boats

A 2.4 m rubber boat, Suzumar RIB with a 15 HP engine, was bought. The old Zodiac rubber boat is still in use, but will need repair during the winter 2002-3.

3 Zackenberg Basic: The GeoBasis and ClimateBasis programmes

Morten Rasch (editor)

The GeoBasis and ClimateBasis programmes collect data describing the physical and geomorphological environment at Zackenberg. This includes the climate in the Zackenberg area, the water balance of the Zackenbergelven river drainage basin, the sediment, solute and organic matter yield of the Zackenbergelven drainage basin, the dynamics of selected physical landscape elements, and the seasonal development of the active layer, its temperature conditions and its soil water chemistry.

GeoBasis is operated by Institute of Geography at University of Copenhagen and Danish Polar Center in cooperation.

ClimateBasis is operated by Asiaq, Greenland Field Investigations, who takes care of the run and maintenance of the climate station and the hydrometric station

The GeoBasis and ClimateBasis installations have been described in previous annual reports (Meltofte and Thing 1996; Meltofte and Rasch 1998; Rasch 1999; Caning and Rasch 2000, 2001, 2003a). Data from the two programmes are available free of charge from Institute of Geography, University of Copenhagen (mr@dpc.dk).

3.1 The meteorological station

Dorthe Petersen

The meteorological station at Zackenberg was constructed in the summer of 1995. The technical specifications of the station are described in Meltofte and Thing (1996). In 1997 the radiation sensors were moved to a separate mast and a mast for snow depth measurements was erected (see Meltofte and Rasch 1998).

In 2002, no major changes to the station were conducted. The sensors were calibrated and checked by ASIAQ, Greenland Field investigations.

Meteorological data from 2001

Table 3.1 shows a summary of climatic pa-

	Mean	Max.	Min.
Air temperature, 2 m above terrain (°C)	–9.7	12.6	–35.1
Air temperature, 7.5 m above terrain (°C)	–9.2	12.4	–33.0
Relative air humidity 2 m above terrain (%)	71.2	99.6	21.6
Air Pressure (hPa)	1008.8	1042.5	972.2
Incoming shortwave radiation (W/m2)	112.1	818.0	0.0
Outgoing shortwave radiation (W/m2)	56.5	619.8	0.0
Net Radiation (W/m^2)	13.2	601.8	–123.7
Wind Velocity, 2 m above terrain (m/s)	2.7	20.6	0.0
Wind Velocity, 7.5 m above terrain (m/s)	3.2	25.0	0.0
Precipitation (mm w.eq.), total	236		
Ground temperature, 0 cm below surface (°C)	–7.6	21.0	–19.5
Ground temperature, 2.5 cm below surface (°C)	–7.7	13.0	–18.0
Ground temperature, 5 cm below surface (°C)	–7.1	11.6	–17.0
Ground temperature, 10 cm below surface (°C)	–6.3	11.4	–16.3
Ground temperature, 20 cm below surface (°C)	–7.7	7.6	–16.9
Ground temperature, 40 cm below surface (°C)	–8.3	3.1	–16.0
Ground temperature, 60 cm below surface (°C)	–6.5	2.6	–13.0
Ground temperature, 80 cm below surface (°C)	–6.2	1.1	–12.2
Ground temperature, 100 cm below surface (°C)	–7.6	–0.6	–13.3
Ground temperature, 130 cm below surface (°C)	–7.9	–2.2	–12.8

Table 3.1. Summary of selected climate parameters, 2001.

	Air temperature		Rel. humidity	Air press.	Net Rad.	Shortwave Rad.		Wind Velocity		Dominant
	°C	°C	%	hPa	W/m²	W/m²	W/m²	m/s	m/s	wind dir.
	2.0 m	7.5 m	2.0 m			In	Out	2.0 m	7.5 m	7.5 m
2001 Jan	–20.5	–19.2	69.0	1003.6	–16.6	0.3	0.2	2.8	3.1	–
2001 Feb	–21.1	–20.1	68.6	1010.0	–19.1	6.8	6.1	3.1	3.6	–
2001 Mar	–23.7	–22.3	64.4	1017.5	–26.9	61.7	54.4	1.9	2.2	–
2001 Apr	–19.5	–18.2	61.6	1013.2	–26.1	179.5	151.6	2.2	2.4	–
2001 May	–6.3	–6.1	77.3	1011.7	–8.3	274.2	223.6	2.1	2.4	–
2001 Jun	2.1	2.0	79.2	1010.6	67.5	293.1	167.5	1.9	2.1	–
2001 Jul	4.9	4.5	75.7	1007.5	146.5	230.9	26.6	2.6	2.9	–
2001 Aug	5.8	5.6	79.7	1006.6	83.6	179.8	19.9	2.4	2.8	SE
2001 Sept	–0.4	–0.2	72.9	1009.7	12.1	96.3	15.4	2.2	2.7	NNE
2001 Oct	–9.3	–8.8	74.1	1006.1	–19.8	16.0	10.6	3.6	4.3	NNE
2001 Nov	–16.5	–15.8	63.0	1001.3	–24.7	0.5	0.5	4.1	5.3	NNE
2001 Dec	–13.2	–12.4	68.2	1008.0	–21.4	0.2	0.2	3.8	4.9	N
2002 Jan	–21.7	–	63.6	1001.7	–22.3	0.3	0.2	3.0	3.6	NNE
2002 Feb	–21.0	–	64.9	1003.5	–	8.4	7.7	3.6	4.0	NNE
2002 Mar	–22.7	–	58.8	1009.8	–	67.9	59.7	2.9	3.7	NNE
2002 Apr	–14.6	–	64.6	1011.4	–	154.0	144.3	2.4	2.2	NNE
2002 May	–4.1	–	71.5	1016.6	–	260.2	219.5	2.1	2.6	NNE
2002 Jun	2.6	–	83.7	1007.2	113.0	344.4	150.9	1.4	1.6	SSE
2002 Jul	5.7	–	86.8	1004.5	104.6	204.5	23.3	2.3	2.6	SSE
2002 Aug	5.0	–	80.5	1007.5	50.9	127.7	15.5	2.4	2.8	SSE

Table 3.2. Monthly mean values of selected climate parameters, January 2001 – August 2002

rameters measured in 2001. Tables 3.2 and 3.3 show monthly mean values (January 2001 – August 2002) of climate parameters and ground temperatures, respectively. The variations of selected climate parameters and wind parameters in 2001 are shown in Figures 3.1 and 3.2, respectively.

In 2001, the mean air temperature measured 2 m above terrain was –9.7°C. The maximum temperature was 12.6°C (early August), and the minimum temperature was –35.1°C (early March). 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 (Figure 3.1).

The total amount of precipitation in 2001 was 236 mm. The snow depth reached a maximum of 0.68 m in the winter 2000/2001.

The mean air pressure was 1,008.8 hPa. The air pressure was generally more stable during summer than during winter.

The relative humidity was highest during the summer period. Mean relative humidity was 71.2%.

The monthly mean net radiation was positive in June, July, August and September and negative in the remaining months. The same distribution has been seen in the previous years. The mean net radiation was 13.2 W/m². The last snow melted away in late June resulting in a large increase of the net radiation due to decreased albedo.

Mean wind speeds 2 and 7.5 m above ground were 2.7 and 3.2 m/s, respectively. The highest 10 minutes mean value was 20.6 m/s at 2 m above ground and 25.0 m/s at 7.5 m above ground. The wind speeds are generally higher during winter than during summer.

The wind direction sensor was unfortunately out of order from late January until the measuring station was inspected in late July. The distribution of wind from different directions is therefore not calculated for 2001. In the autumn and winter period, the dominant wind direction was between N and NNE (Table 3.2 and Figure 3.2).

Meteorological data from 2002

Monthly mean values of climate parameters are given in Tables 3.2 and 3.3. The variations of selected climate parameters and wind parameters are shown for the period January until August in respectively Figure 3.3 and Figure 3.4.

The monthly mean values of the climat-

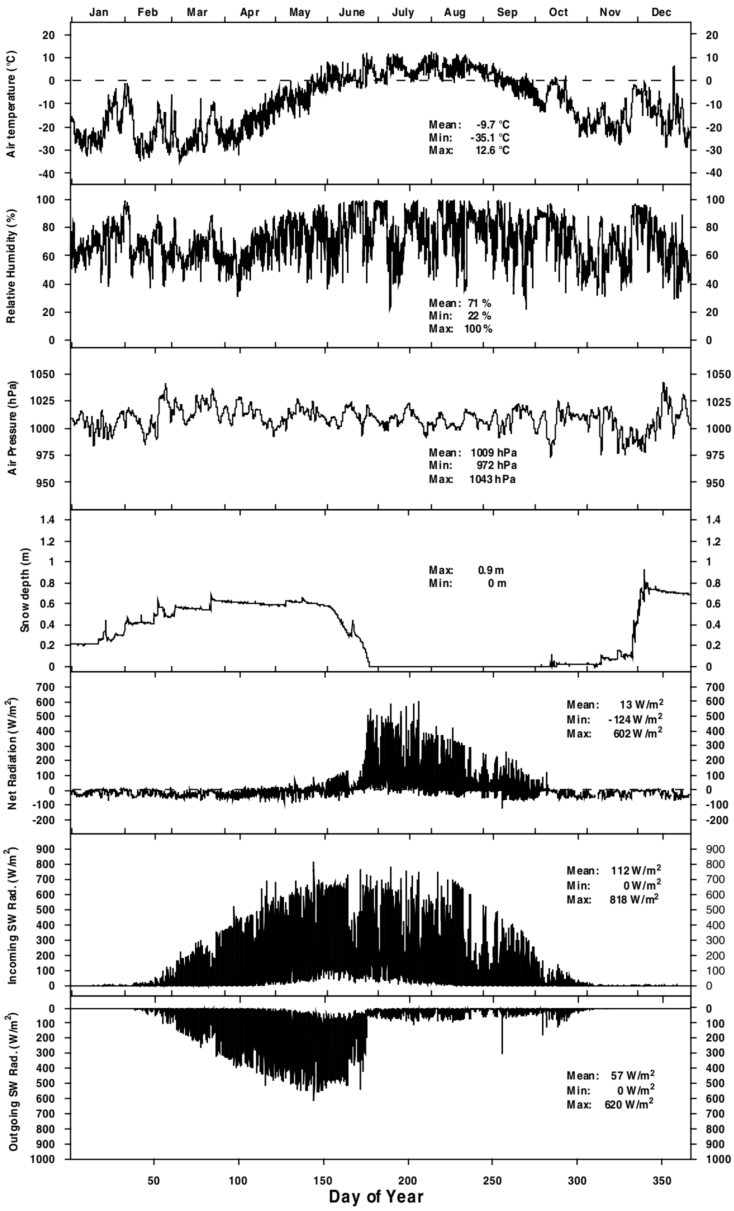

Figure 3.1. Variation in 2001 of selected climate parameters. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation and outgoing short wave radiation. All parameters are measured two meters above terrain.

ic parameters show the same trend as in previous years. The monthly mean temperatures became positive in June. The monthly mean relative humidity exceeded 70% in May.

The snow depth reached a maximum of 1.30 m during the winter 2001-2002. The last snow disappeared from the measuring station in late June giving a large positive net radiation in the following period (see section 4.1).

The dominant wind direction was NNE from January to May and SSE during the summer months (June-August). In previous years (before 2001) the dominant wind direction has been NNW during the winter period and ESE to SE in the summer period. This might indicate a relatively large shift in the wind field. However, as the shift coincides with a change of wind sensor, the change could also be the result of a technical error made during the change of the sensor. A detailed check of the sensor is planned in the coming field season. In case the shift in wind direction is a result of a technical error during the mounting of the new sensor it will be relatively easy to correct the data.

3.2 TinyTalk/TinyTag dataloggers

Morten Rasch and Charlotte Sigsgaard

GeoBasis operated a total of 33 dataloggers in 2001-2002 for measurements of air temperature at soil surface at three sites, soil temperature profiles (incl. air temperature at soil surface) at six sites, water temperature at one site and air temperature in- and outside a snow patch at four sites. The purpose of the measurements has been described together with the position of the dataloggers, the interval between measurements and the period of operation in Table 3.2.1 in Meltofte and Rasch (1998). Statistics from the period 1996-2001 are given in Table 3.4. Unfortunately there were serious problems with the TinyTag dataloggers in 2001-2002. Thirteen out of 33 dataloggers did not work well throughout 2000. This is definitely not satisfying and as a result we started in 2001 when the problems first occurred to improve the set up by making the casings for the dataloggers more resistant towards water and moisture.

3.3 The hydrometric station

Dorthe Petersen, Håkon Gjessing Karlsen, Morten Rasch and Charlotte Sigsgaard

The hydrological measurements started at Zackenbergelven in 1995. The hydrometric station is described in details 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 km². Glaciers cover 106 km².

At the station, the water level is logged automatically with a sonic range sensor. This sensor determines by the use of sound the distance between the sensor

	0 cm	–2.5 cm	–5 cm	–10 cm	–20 cm	–40 cm	–60 cm	–80 cm	–100 cm	–130 cm
2001 Jan	–16.5	–16.2	–15.4	–14.6	–15.5	–14.9	–12.1	–11.0	–12.0	–10.9
2001 Feb	–15.3	–15.1	–14.3	–13.6	–14.5	–14.3	–11.8	–11.0	–12.0	–11.4
2001 Mar	–15.9	–15.8	–15.0	–14.3	–15.3	–15.0	–12.5	–11.7	–12.8	–12.2
2001 Apr	–15.3	–15.3	–14.5	–13.8	–14.9	–14.8	–12.6	–11.9	–13.1	–12.6
2001 May	–10.9	–11.2	–10.5	–9.9	–11.3	–12.1	–10.6	–10.5	–11.8	–11.9
2001 Jun	1.7	0.5	0.6	1.0	–1.5	–3.8	–3.3	–4.4	–6.2	–8.2
2001 Jul	8.3	6.8	6.9	7.3	4.7	1.2	1.2	0.2	–1.7	–4.0
2001 Aug	6.9	5.6	6.0	6.7	4.5	2.1	2.3	0.9	–0.8	–2.9
2001 Sept	–0.8	–0.6	0.3	1.3	0.2	–0.5	1.0	0.9	–0.7	–2.4
2001 Oct	–8.0	–7.0	–5.9	–5.0	–5.5	–4.7	–2.0	–1.1	–2.4	–2.9
2001 Nov	–15.6	–14.7	–13.8	–12.9	–13.4	–12.7	–9.4	–7.8	–8.7	–7.2
2001 Dec	–10.7	–10.6	–9.8	–9.0	–10.2	–10.5	–8.4	–7.8	–9.0	–8.5
2002 Jan	–13.1	–12.8	–11.9	–11.2	–12.1	–12.1	–9.7	–8.9	–10.0	–9.3
2002 Feb	–13.6	–13.4	–12.6	–11.9	–12.9	–13.1	–10.8	–10.0	–11.1	–10.4
2002 Mar	–14.4	–13.9	–13.4	–12.3	–13.6	–13.4	–11.3	–10.2	–11.6	–10.8
2002 Apr	–12.7	–	–12.0	–	–12.4	–	–10.9	–	–11.6	–
2002 May	–9.4	–	–9.1	–	–9.9	–	–9.4	–	–10.6	–
2002 Jun	3.5	2.3	2.1	2.6	–0.3	–2.6	–1.6	–2.6	–4.6	–6.5
2002 Jul	9.3	8.0	8.1	8.5	5.6	1.8	2.0	0.5	–1.5	–3.5

Table 3.3. Monthly mean values of ground temperatures, January 2001 – July 2002.

and the water surface. This signal is transformed to a water level, which can be transformed to a discharge, using an established relation between water level and discharge (a Q/h-relation)

The Q/h-relation

Discharges and corresponding water levels have been measured during all field seasons from 1995 to 2002. The function that describes the relation between water level and discharge is shown in Figure 3.5. The Q/h-relation is based on discharge measurements performed in the years 1995 to 1998 and discharges ranging from 5.98 to 70 m^3/s. The good correlation of the Q/h-relation indicates that the cross profile at the hydrometric station was stable in the period 1995 to 1998. Manual discharge measurements in 1999, 2000, 2001 and 2002 indicate that the cross profile also was stable during that period.

The Q/h-relation is only valid when the riverbed and -banks are ice- and snow free because snow covering the banks changes the cross profile of the river, and ice layers at the bottom of the river gives at false water level.

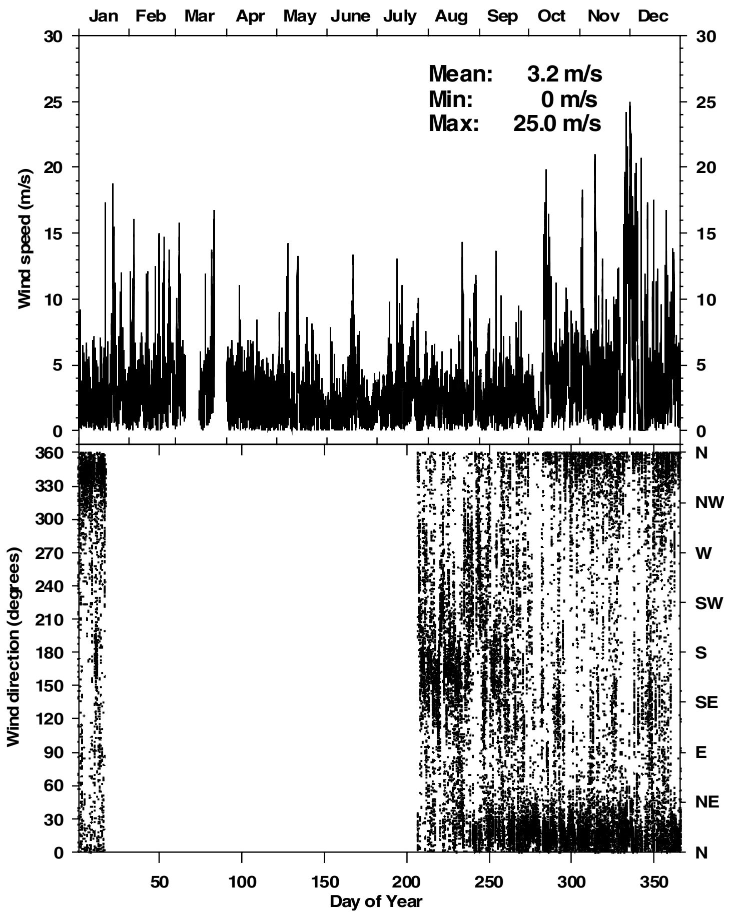

Figure 3.2. Variation in wind speed (m/s) and wind direction, 2001. Parameters are measured 7.5 meters above terrain. The wind direction sensor was out of order from late January until late July.

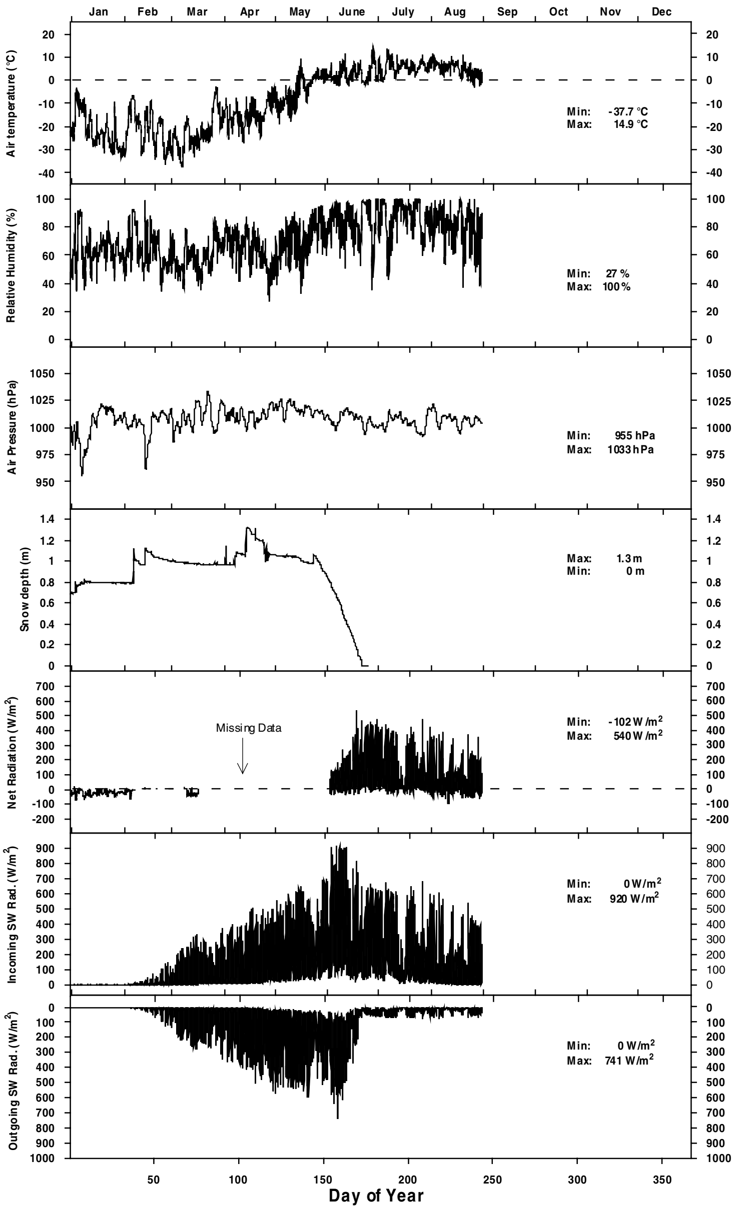

Figure 3.3. Variation in 2002 of selected climate parameters. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation and outgoing short wave radiation. All parameters are measured two meters above terrain.

River water discharge

The water discharge in Zackenbergelven in 2002 is shown in Figure 3.6. In 2002, water was first observed in the river on 4 June. A torrent was seen on 6 June. The flow consisted of thick brash ice. Until 12 June, the riverbanks were covered with snow and ice. For this period the Q/h-relation is therefore not considered valid. No manually measured discharges are available from this period. The sonic range sensor measurements are used to calculate the discharge from 10 June and onwards (Figure 3.6). In the period 4-10 June, the discharges calculated from the sonic range measurements are considered unrealistic.

The total measured amount of water drained from the catchment area in 2002 was approximately 306 mio. m^3. With a drainage area of 514 km^2 this corresponds to a total water loss of 595 mm from the area. The precipitation in the hydrological year 2002, *i.e.* 1 October 2001 – 30 September 2002, was 154 mm.

Sediment, solute and organic matter yield

Sediment concentrations, solute concentrations (Na, K, Ca, Mg, Fe, Al, Mn, Cl, NO_3, SO_4, HCO_3) and organic matter concentrations are measured in samples of river water taken from Zackenbergelven near its mouth (where it passes Zackenberg Station) once every day at 8:00 in the morning. Water samples are analysed for alkalinity (concentration of HCO_3), pH, sediment concentrations and conductivity at Zackenberg. All other chemical analyses on water samples from Zackenbergelven are carried out at Institute of Geography, University of Copenhagen.

As an example of data from 2002, the time series for June – August of sediment concentration, pH, conductivity and temperature are shown in Figure 3.8. The high concentrations of sediment during the first flood is probably due to the sediment that settled on the river bed during the recession in the late part of the 2001 season being washed out of the system during the first event of high water level and current velocities (Rasch *et al.* 2000). The high conductivity during the first days of water discharge (the so-called “ion pulse”) is due to solutes being washed out of the snow package during the first snow melt (Rasch *et al.* 2000).

All water concentration data from 2002 and earlier years (1997-2001) are available from Institute of Geography, University of Copenhagen (mr@dpc.dk).

Due to financial reasons (lack of manpower) it has still not been possible to calculate the annual fluxes of sediment, solute and organic matter in Zackenbergelven.

3.4 Landscape monitoring

Morten Rasch, Charlotte Sigsgaard and Jørgen Hinkler

GeoBasis performs the following monitoring of landscape elements and dynamics at Zackenberg:

1. photomonitoring of 24 different dyn-

	1996			1997			1998			1999			2000			2001		
	Mean °C	Min. °C	Max. °C	Mean °C	Min. °C	Max. °C	Mean °C	Min. °C	Max. °C	Mean °C	Min. °C	Max. °C	Mean °C	Min. °C	Max. °C	Mean °C	Min. °C	Max. °C
P1																		
0 cm	–7.7	–37.6	29.9	–9.8	–40.7	30.7	–9.1	–40.7	28.1	–9.3	–40.7	30.3	NV	NV	NV	NV	NV	NV
10 cm	NV	NV	NV	–9.6	–39.1	19.1	–8.8	–37.6	17	–8.7	–36.3	19.5	–9.4	–36.3	19.5	–8.7	–36.3	20.2
50 cm	–6.7	–25.2	7.3	–9.0	–29.4	8.8	–8.3	–28.4	7.3	–8.3	–27.5	8.8	–9.0	–27.5	8.0	–8.7	–27.5	8.0
118 cm	–5.9	–15.6	–0.1	–8.1	–18.3	–0.1	–7.8	–17.6	–0.1	–8.0	–17.0	0.4	–8.1	–18.2	0.4	–8.3	–18.3	–0.1
P2																		
0 cm	–5.6	–30.5	34.1	–7.8	–29.4	25.9	–7.5	–24.1	22	–7.1	–26.6	22.7	NV	NV	NV	NV	NV	NV
10 cm	–6.1	–24.6	12.4	–8.4	–25.7	12.8	–7.9	–21	18.8	NV	NV	NV	NV	NV	NV	NV	NV	NV
70 cm	–6.0	–19.1	2.3	–8.1	–19.6	2.3	–7.2	–17	3.1	NV	NV	NV	NV	NV	NV	NV	NV	NV
155 cm	–6.5	–14.6	–1.4	–8.6	–16.4	–1.8	–8.0	–14.6	–1.8	NV	NV	NV	NV	NV	NV	NV	NV	NV
P3																		
0 cm	–6.2	–31.5	25.2	–9.6	–36.3	23.4	–7.6	–34.8	23.4	–10.5	–36.8	19.8	–8.3	–39.2	32.1	–9.6	–28.8	19.4
10 cm	–5.9	–27.5	18.1	–8.6	–32.6	18.8	NV	NV	NV	–9.0	–26.5	15.6	–7.5	–28.3	21.5	–9.0	–25.6	16.5
66 cm	–5.5	–20.3	6.9	–8.7	–23.3	6.5	NV	NV	NV	NV	NV	NV	–7.4	–21.5	8.4	–8.5	–20.3	5.9
P4																		
0 cm	–8.5	–33.7	27.0	–10.7	–39.1	27.4	–8.2	–27.5	30.7	–10.9	–32.0	26.3	NV	NV	NV	–9.5	–31.5	22.2
10 cm	–8.0	–28.4	16.3	–10.5	–33.7	14.9	–8.0	–24.9	19.1	–10.4	–28.3	14.2	–9.2	–29.4	19.1	–9.4	–28.3	14.8
85 cm	–7.6	–18.9	1.9	–10.4	–22.5	1.1	–8.6	–20.3	2.7	–9.7	–19.7	1.0	–9.4	–20.5	1.7	–9.5	–20.2	1.9
P5																		
0 cm				–9.2	–36.0	20.4	NV	NV	NV	–9.9	–33.7	19.1	NV	NV	NV	–9.4	–31.5	18.4
75 cm				–8.9	–22.4	11.0	NV	NV	NV	–9.2	–19.6	9.5	NV	NV	NV	NV	NV	NV
140 cm				–8.6	–21.7	11.3	NV	NV	NV	–14.8	–27.5	0.6	NV	NV	NV	NV	NV	NV
P6																		
0 cm				–10.1	–37.6	19.1	–9.5	–32.6	18.4	–8.2	–32.6	24.1	NV	NV	NV	NV	NV	NV
10 cm				–9.9	–25.7	10.6	NV	NV	NV	NV	NV	NV	NV	NV	NV	–9.0	–35.0	12.4
30 cm				NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
60 cm				NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
P6-New																		
0 cm																–9.1	–26.9	19.6
10 cm																–8.7	–24.1	12.7
30 cm																–9.1	–22.8	5.4
50 cm																–9.3	–20.1	–0.1
S1																		
Plateau	–8.1	–35.6	25.3	NV	NV	NV	–12.5	–39.1	18.1	–10.0	–39.1	33.3	–10.0	–40.7	31.1	–9.3	–39.1	29.2
Slope/slope high	NV	NV	NV	NV	NV	NV	–5.8	–21.7	22.3	–6.5	–17.6	24.1	–5.3	–11.2	21.6	–5.4	–13.0	23.8
Snow/slope low	–5.9	–35.2	24.5	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	–5.5	–13.6	15.5
Below/front	NV	NV	NV	NV	NV	NV	–8.0	–32.6	22.3	–13.0	–35.0	14.5	–11.7	–36.3	16.7	–9.9	–32.6	16.7
T1																		
air	–7.3	–33.6	21.6	–9.8	–37.2	23.6	–9.2	–39.1	19.1	–9.8	–37.6	18.4	–10.2	–39.1	24.5	–10.0	–36.3	16.3
T2																		
air	–7.9	–35	20.6	–10.3	–39.1	21.6	–9.8	–40.7	24.5	–11.1	–40.7	18.8	–10.0	–36.3	20.9	–10.5	–39.1	19.5
T3																		
air	–9.2	–36.0	19.8	NV	NV	NV	–10.2	–40.7	20.2	NV	NV	NV	NV	NV	NV	NV	NV	NV
V1																		
water	–2.5	–11.9	8.4	–5.1	–11.8	20.2	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
V2																		
water	–10.8	–23.8	15.9	–8.0	–27.4	19.4	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV

Table 3.4. Statistics on time series from the TinyTag/TinyTalk dataloggers operated by GeoBasis. In 2000 new loggers were installed at site P6 (P6-New). These loggers have now produced their first calendar year (2001) of temperature measurements.

amic landforms (e.g. rock glaciers, coastal spits, gullies, frost boils),

2. monitoring of the snow cover in Zackenbergdalen with automatic digital cameras,
3. active layer depth measurements on a horizontal site (ZEROCALM-1) and on a sloping site (ZEROCALM-2),
4. soil water chemistry measurements at both active layer depth sites,
5. ice wedge growth measurements at two sites,
6. measurements of cross shore landscape changes (accretion or erosion) at six sites, and
7. measurements of vertical salt marsh accretion at two sites.

Monitoring photos

GeoBasis includes repeated photos of dif-

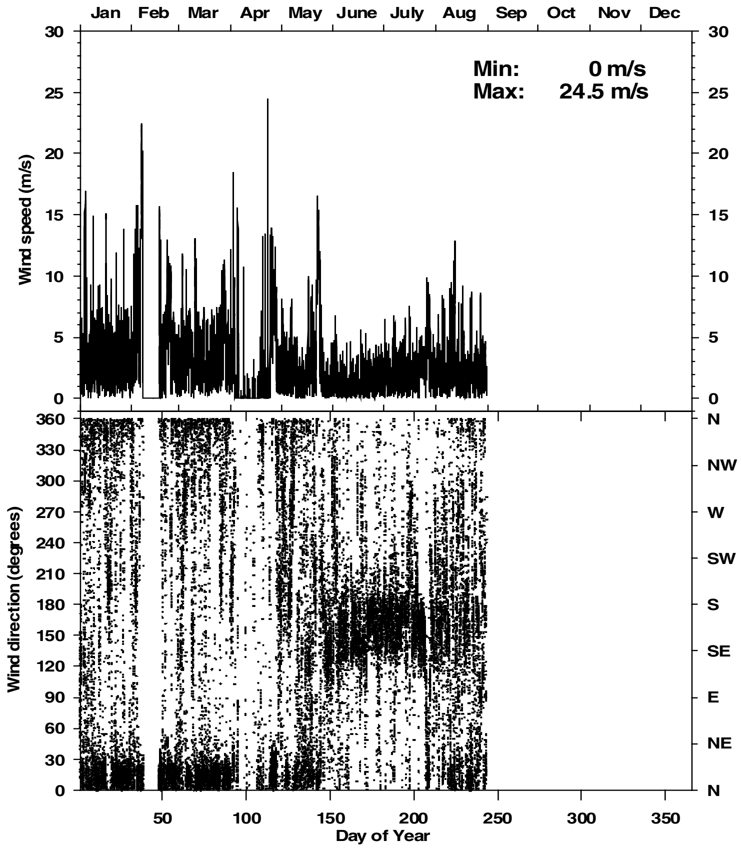

Figure 3.4. Variation in wind speed (m/s) and wind direction, 2002. Parameters are measured 7.5 meters above terrain.

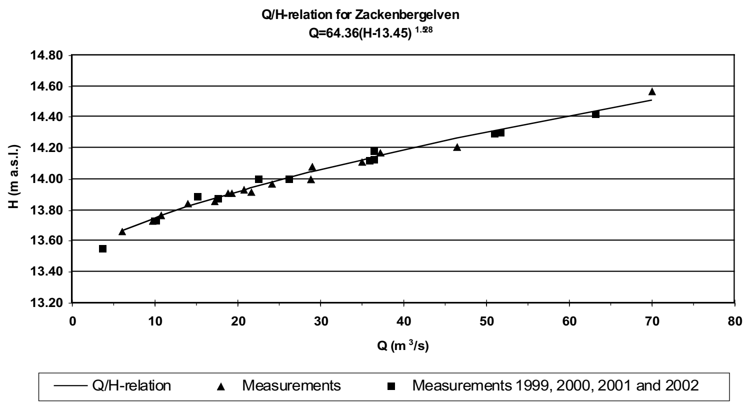

Figure 3.5. Water level – discharge relation curve (Q/h-relation) for Zackenbergelven at the hydrometric station, 1995-1998. The coefficient of correlation (R^2) for the curve is 0.99. Measurements from the period 1999-2002 indicate that no major changes have occurred to the Q/h-relation since 1998.

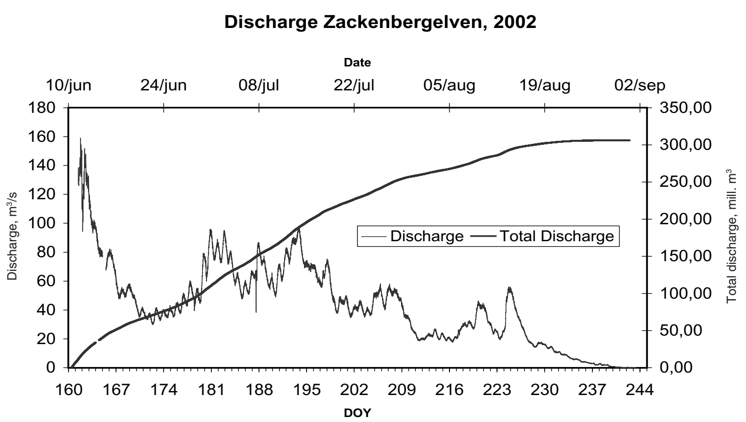

Figure 3.6. Variation of river water discharge in Zackenbergelven, 2002.

ferent dynamic landforms at 24 sites. This part of the photo monitoring has now been running for seven years and except for the pictures of landforms in the coastal zone, there are still no signs of significant (visible) landscape changes in any of the pictures taken. However, the working effort in taking the pictures is very limited, and the photo monitoring of dynamic landforms will therefore be continued at the same time interval as originally decided (pictures are taken once every one or two years). All 24 monitoring photos of dynamic landforms were taken in 2002.

The automatic photo monitoring of the snow cover in the lower part of Zackenbergdalen was continued in 2002. The photo monitoring is carried out with automatic cameras situated on the rock Nansenblokken at 477 m a.s.l. on the mountain Zackenberg west of Zackenbergdalen. The techniques used for transformation of the oblique photos into ortho-photos, the identification of snow in the photos, and the actual measurements of snow cover were described in details in Sections 3.4 and 5.1 in Caning and Rasch (2000) and in Hinkler *et al.* (2002).

In the beginning of the 2002 season two of the cameras were out of order. The camera taking pictures of the northern part of lower Zackenbergdalen had a defect in its power supply, and the camera taking pictures of the southern part of lower Zackenbergdalen had falled c. 10 meters down from the rock where it is normally situated, during one of the heavy winter storms. Fortunately, it was possible to repair the cameras in the early part of the season and to continue measurements. In 2003, it is planned to improve the set-up of the cameras by building a permanent platform for the cameras and by improving the internal power supplies with larger external power supplies charged with solar panels.

Figure 3.10 shows the snow depletion curves for 1998-2002. As can be seen, the snow cover melted away from Zacken-

Figure 3.7. A mast for sampling of precipitation was erected near the climate station in 2002 (Photo Morten Rasch/ Polar Photos).

bergdalen early in 2002 compared to all previous years except 2000.

Active layer depth

For different reasons, most of the active layer depth curves for 2001 (Figures 3.13, 3.14 and 3.15) and the reporting of the active layer measurements for 2001 in Canning and Rasch (2003) were erroneous. As a result this section contains a new reporting of the active layer depth measurements for both 2001 and 2002.

The development of the active layer is being monitored at a horizontal, well-drained *Cassiope* heath at the climate station (ZEROCALM-1) and at a southerly exposed slope with a snow patch (ZEROCALM-2). ZEROCALM-1 consists of 121 measuring points in a 100 m x 100 m grid while ZEROCALM-2 consists of 208 measuring points in a 120 m x 150 m grid. A detailed description of the plots was given in section 5.1.12 in Meltofte and Thing (1997). The actual measurements of the active layer is carried out by hand using a metal spear with a centimetre division. Data from the active layer measurements are reported to the circumpolar monitoring programme CALM (Circumpolar Active Layer Monitoring) which is being run by International Permafrost Association.

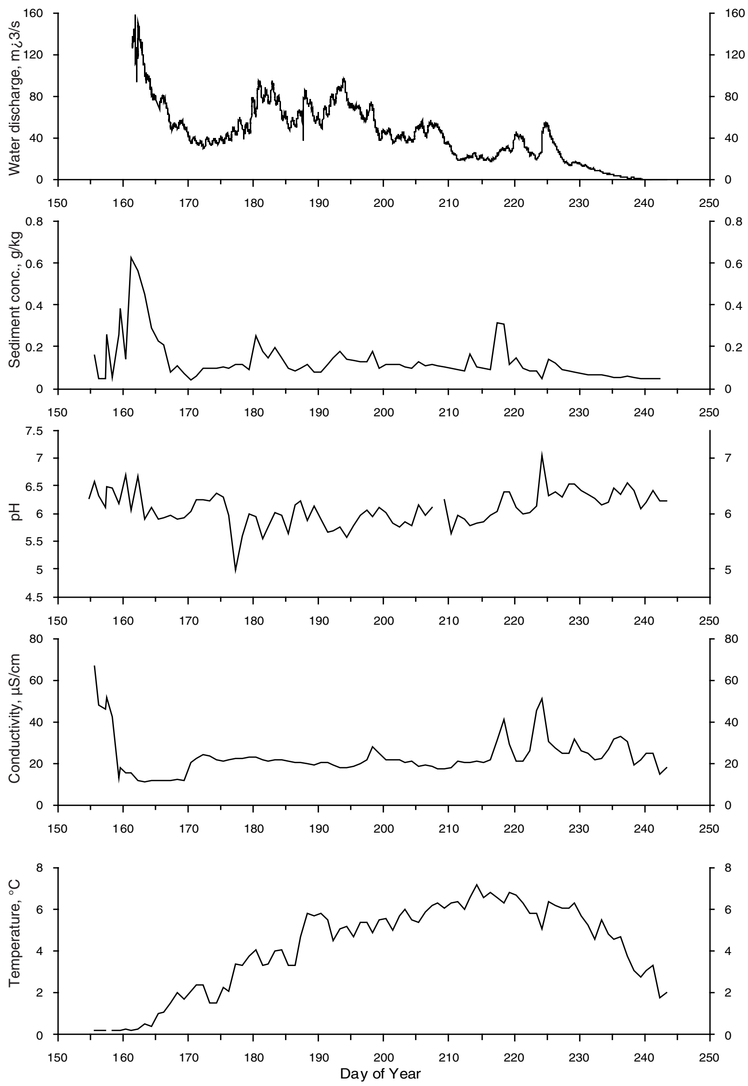

Figure 3.8. Water discharge, sediment concentration, pH, conductivity and temperature in Zackenbergelven during the summer of 2002. Note the high sediment concentration during the first flood and the high conductivity during the first period of water discharge.

Figure 3.9. Photos from the period 1 May – 17 July (one-week intervals) of the lower part of Zackenbergdalen taken by one of the snow cover monitoring cameras situated on the rock Nansenblokken 477 m a.s.l. On 8 May and 5 June fog covered Zackenbergdalen below the camera and on 26 July fog covered the camera.

Figures 3.11 and 3.12 shows the active layer development in respectively ZEROCALM-1 and ZEROCALM-2 in the summers 1997-2002.

Figures 3.13 and 3.14 show the 2001 situation with maximum active layer depths at the two sites, measured on respectively 29 August 2001 (ZEROCALM-1) and 22 August 2001 (ZEROCALM-2). Figures 3.15 and 3.16 show the 2002 situation with maximum active layer depths at the two sites, measured on 30 August 2002. Maxi-

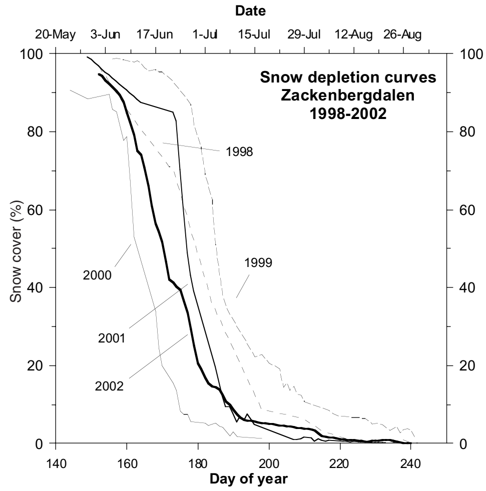

Figure 3.10. Snow depletion curves for the southern part of Zackenbergdalen, 1998-2002.

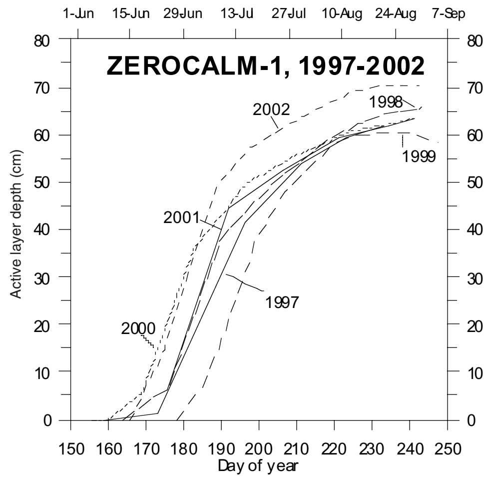

Figure 3.11. Active layer development in ZEROCALM-1, 1997-2002.

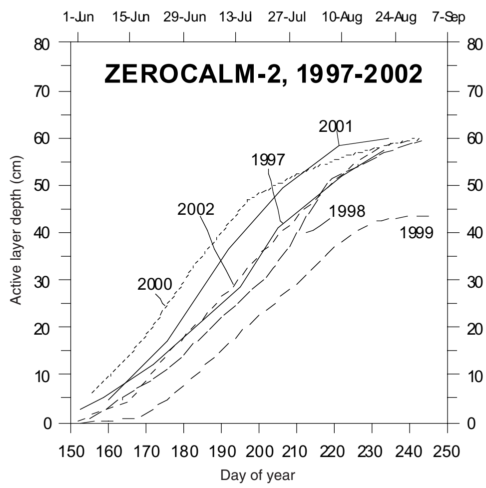

Figure 3.12. Active layer development in ZEROCALM-2, 1997-2002. Please note that Figure 3.13 (active layer development in ZEROCALM-2, 1997-2001) in Caning and Rasch (2003) was erroneous.

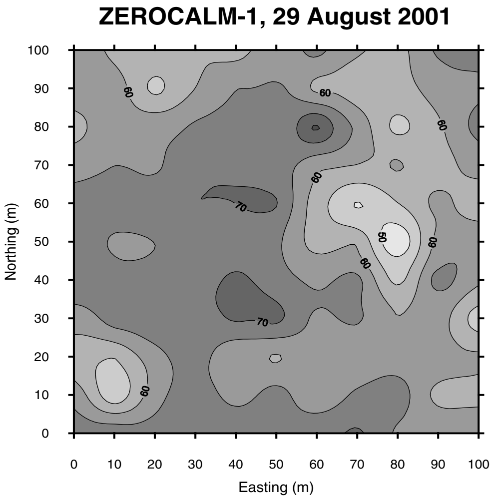

Figure 3.13. Maximum active layer thickness in ZEROCALM-1, 29 August 2001. Depths are given in cm. Distances between curves are 10 cm. This figure replaces Figure 3.14 in Caning and Rasch (2003).

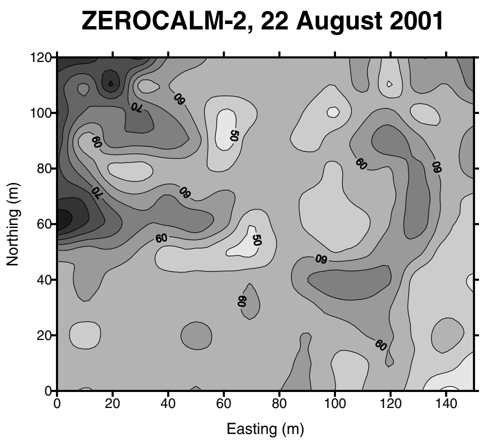

Figure 3.14. Maximum active layer thickness in ZEROCALM-2, 22 August 2001. Depths are given in cm. Distances between curves are 10 cm. This figure replaces Figure 3.15 in Caning and Rasch (2003).

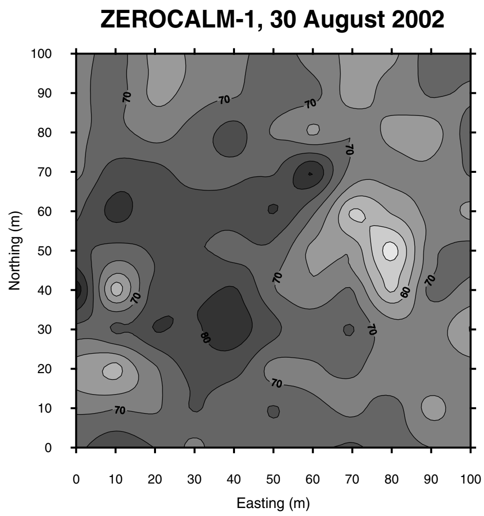

Figure 3.15. Maximum active layer thickness in ZEROCALM-1, 30 August 2002. Depths are given in cm. Distances between curves are 10 cm.

mum active layer depth in 2001 was 0.63 m in ZEROCALM-1 (29 August) and 0.60 m in ZEROCALM-2 (22 August). In 2002, the maximum active layer depth measured on 30 August was 0.71 m in ZEROCALM-1 and 0.60 m in ZEROCALM-2.

The maximum active layer depth in ZEROCALM-1 was the highest ever measured, while the maximum active layer depth in ZEROCALM-2 was average. The two sites react very differently, mainly because ZEROCALM-2 is affected by the presence of a large snow patch while ZEROCALM-1 is not.

Soil water chemistry

Soil water samples are collected at different depths in the active layer at two sites. One site is situated on an *Eriophorum* fen immediately south of the ZEROCALM-2 site. At this site water is sampled from the depths 5, 10, 15, 20, 30, 40, 50 and 60 cm below the surface. The other site is situated on a *Cassiope* heath close to the climate station. At this site water is sampled from the depths 5, 10, 15, 20, 30, 40, 50, 60 and 70 cm below the surface. The water samples from the two sites were analysed for pH, conductivity and alkalinity (HCO_3-concentration) at Zackenberg and for concentrations of Na, K, Ca, Mg, Fe, Mn, Cl, NO_3 and SO_4) at Institute of Geography at University of Copenhagen. A thorough description of the seasonal changes in soil water chemistry at the two sites was given in the annual report for 1999 (Caning and Rasch 2000).

In 2002, the water-sampling site at the *Cassiope* heath was supplemented with an almost identical set-up situated c. 20 meter away from the original site and with sampling at 5, 10, 15, 20, 30, 40, 50 and 60 cm below the surface. Also at the *Eriophorum*

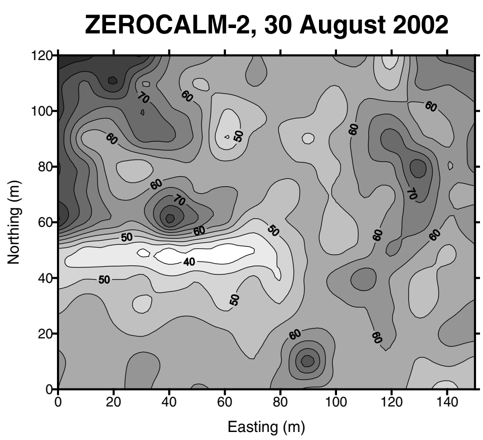

Figure 3.16. Maximum active layer thickness in ZEROCALM-2, 30 August 2002. Depths are given in cm. Distances between curves are 10 cm.

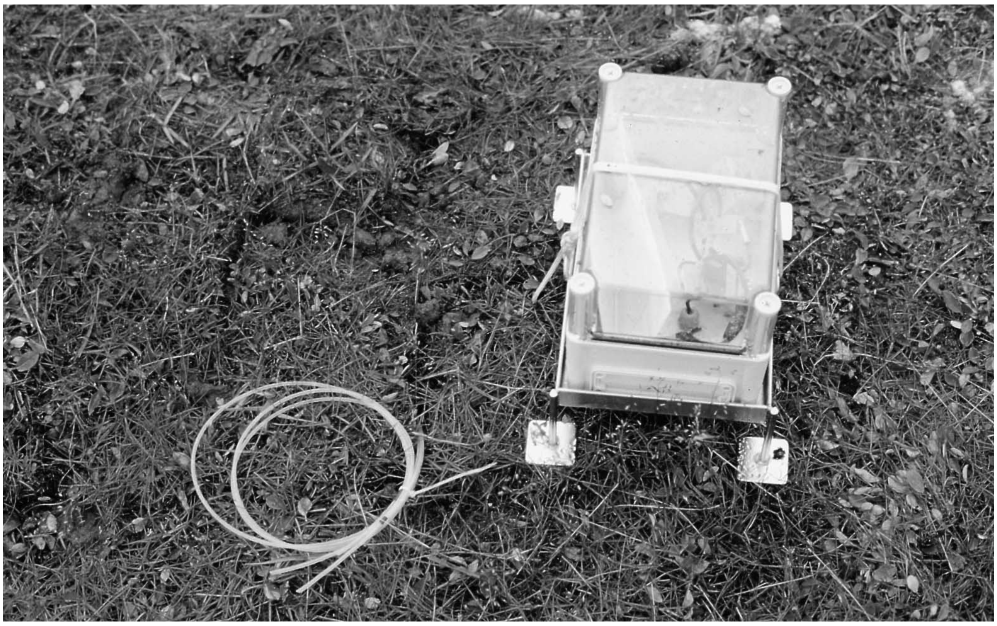

Figure 3.17. In 2002, monitoring of water content, temperature and water chemistry in the top soils at two of the BioBasis vegetation plots were initiated by GeoBasis. The set-up will be ready for measurements in the 2003 field season (Photo Morten Rasch/Polar Photos).

fen, a new site was installed, but here only with sampling at 10, 20, 30 and 50 cm below the surface. It is necessary once in a while to change site for the soil water sampling due to the water suction probes clogging. When we change sites we normally collect water from both the old and the new sites for at least one year to make sure that the results are comparable.

Two identical sites for monitoring of water content, temperature and water chemistry in the top soils at two of the BioBasis vegetation plots (Salix 1 and Dryas 2) were established by GeoBasis in 2002. At these sites, we will in 2003 and onward measure soil water content twice every week at 5, 10 and 15 cm below the surface, we will measure soil temperature once every hour at 0 and 15 cm below the surface, and we will take water samples once every fourteen days at 5, 10 and 15 cm below the surface.

All water chemistry data from 2001 and earlier years (1996-2000) are available and can be ordered from Institute of Geography, University of Copenhagen (mr@dpc.dk).

	Recession (m)			
	Site 1	Site 2	Site 3	Site 4
1996-1997	0	0	0.3	1.0
1996-1998	0	0	0.3	1.3
1996-1999	0	0	0.3	1.3
1996-2000	0	0	0.5	1.4
1996-2001	0	0	0.5	1.4
1996-2002	0	0	0.7	2.8

Table 3.5. Total coastal recession at the south coast of Zackenbergdalen in the period 1996-2002.

Coastal geomorphology

A map indicating the GeoBasis coastal monitoring sites are given in Figure 3.4.4.1 in Meltofte and Rasch (1998).

Coastal cliff recession is measured at four sites along a coastal cliff on the south coast of Zackenbergdalen, and changes of cross shore profile on an accretionary part of the same coast (a coastal spit) are measured in two cross shore profiles. In 2002, extensive coastal cliff recession was measured in the eastern part of Zackenbergdalen (Table 3.5). This was probably due to the extremely low extent of drifting pack ice outside Northeast Greenland in 2002 allowing swell to arrive at the shores without being dampened by sea ice. Coastal recession was reported from several locations in Northeast Greenland during 2002, and on Hochstetter Forland it resulted in the old trapping station Mønstedhus (founded in 1938) being washed out into the sea.

The cross-shore profiles were not surveyed in 2002. The vertical salt marsh accretion will not be measured before ten years after the sites were established (in 1996) due to expected very low rates of vertical salt marsh accretion.

4 Zackenberg Basic: The BioBasis programme

Hans Meltofte (editor)

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Details on BioBasis methods and sampling procedures are presented in a manual (Meltofte and Berg 2003), which is available from the home page of NERI (http://biobasis.dmu.dk). A map with locality names used in this chapter is found at the same place. Also, a synopsis of the entire BioBasis programme and primary data are presented on the website.

Station	1998	1999	2000	2001	2002
0	–	>101	44	79	131
2	–	–	–	177	265
3	–	–	–	–	205
4	81	118	48	61	110
5	–	–	–	–	–
6	–	–	–	–	90

Table 4.1. Snow depth at six permanent stations in Zackenbergdalen in late May 1998-2002 given as the highest daily average during 21-31 May. Station nos 0 and 3 are the sonic range sensors at the hydrometric station and the climate station, respectively.

4.1 Spring snow cover, ice conditions and streams

Hans Meltofte and Jørgen Hinkler

The amount of snow at the start of the melt in late May 2002 was the second highest recorded during our monitoring in Zackenbergdalen (Table 4.1), but the extent of the cover was close to average in early June. In the lowland, the cover was a bit more extensive than average, while on the slopes of Aucellabjerg, cover was less extensive (Table 4.2). Due to the unprecedented warm weather in late May and June, the clearance of the lowland was as fast as in 'normal' years (see also sections 4.2 and 4.3).

Section	Area (km²)	Area hidden (%)	1995	1996	1997	1998	1999	2000	2001	2002	Mean
1 (0-50 m)	3.52	3.5	78	74	65	77	91	60	73	77	74
2 (0-50 m)	7.97	1.2	89	88	90	85	91	57	87	87	84
3 (50-150 m)	3.52	0.0	88	81	83	83	94	51	89	82	81
4 (150-300 m)	2.62	0.0	73	74	68	66	86	33	79	56	67
5 (300-600 m)	2.17	0.0	16	54	73	43	85	31	56	36	49
6 (50-150 m)	2.15	75.3	86	86	84	87	98	55	84	78	82
7 (150-300 m)	3.36	69.3	90	81	76	90	97	54	84	74	81
8 (300-600 m)	4.56	27.5	49	55	66	64	84	37	45	52	57
9 (0-50 m)	5.01	6.2	92	87	96	91	97	54	96	96	89
10 (50-150 m)	3.84	2.9	94	85	95	97	98	60	97	93	90
11 (150-300 m)	3.18	0.2	91	72	86	92	96	77*	97	88	89
12 (300-600 m)	3.82	0.0	40	66	89	68	89	65	73	65	69
13 (Lemmings)	2.05	1.0	89	80	76	80	87	58	83	83	80
Total area	45.70	12.9	76	77	81	80	92	54	82	77	77

* Partly cloud covered, giving too high snow cover

Table 4.2. Area size and snow cover on 10 June in 13 bird and mammal study sections in Zackenbergdalen and on the slopes of Aucellabjerg 1995-2002 (see Figure 4.1 in Caning and Rasch 2003 for map of sections). Photos were taken from a fixed point 477 m a.s.l. on the east facing slope of Zackenbergfjeldet within +/- 3 days of 10 June. Photos were analysed and data extrapolated according to the methods described by Pedersen and Hinkler (2000). Furthermore, the proportions of the areas not visible from the photo point are given. Data from 1995 and 1996 are from satellite images

Table 4.3. Visually estimated dates of 50% ice cover on selected ponds and lakes around the research station, together with start of running water in rivers and break up of the fjord ice in Young Sund during 1995-2002. "West pond" and "East pond" are the two ponds in Gadekæret north of the runway, "South pond" is the major pond in Sydkærene south of the runway, "Rivulets" are the streams draining the slopes of Aucellabjerg through Rylekærene, "Zackenbergelven" gives the initial date of major flow in the river, and "Young Sund" is divided between break up of the fjord ice off Zackenbergdalen and in all of the fjord. The 50% ice cover date for Lomsø is tentative, as it is estimated from the research station.

	1995	1996	1997	1998	1999	2000	2001	2002
West pond		4.6	Dry	5.6	10.6	30.5	8.6	2.6
East pond		3.6	Dry	6.6	16.6	1.6	6.6	3.6
South pond		<3.6	30.5	7.6	12.6	1.6	8.6	3.6
Lomsø		4.7	2.7	8.7	10.7	1.7	4.7	30.6
Rivulets		6.6	11.6	11.6	15.6	4.6	10.6	4.6
Zackenbergelven	<26.5	<3.6	4.6	10.6	20.6	8.6	8.6	4.6
Young Sund (Zac.)		13.7	19.7	14.7	14.7	8.7	13.7	1.7
Young Sund (all)	12.7	13.7	22.7	22.7	24.7	17.7	23.7	8.7

The melt of the ice on the ponds north and south of the research station and on Lomsø together with start of running water in the rivulets and Zackenbergelven were among the earliest recorded so far (Table 4.3). Already at our arrival on 31 May, 10-20% open water was present in the ponds in Gadekæret, and by 10 June the monitored ponds were ice-free. Due to the very dry weather during the rest of June and all of July, the most shallow ponds south of the station started to dry up during late July.

On 8 July, all ice had disappeared from Lomsø. The ice melt on Sommerfuglesø and Langemandssø in Morænebakkerne was relatively early, but not as early as in the very early season of 2000 (Table 4.48). On 10 July, Store Sø was 70% covered in ice, but it was breaking up, and on 17 July it had all gone. This is very early.

Already on 1 June, Aucellaelv and some of the streams north-west of it had started to run on the slopes of Aucellabjerg. This is much earlier than recorded before. On 4 June, Zackenbergelven began to run past the research station, and later the same day, both Tørveelv and one of the tributaries of Kærelv were running (Table 4.3). During the following days, the remaining rivulets began to run.

When we flew up to Zackenberg on 31 May it was estimated that the edge of fast ice was at least 10 km east of Sandøen. From around 20 June, an open water area formed in Young Sund off Zackenbergelven, and already on 1 July the fjord ice off Zackenbergdalen had broken up. This is about 1-3 weeks earlier than in previous years (Table 4.3). On 6 July, the open water almost reached Basaltø, and two days later the ice in outer Young Sund had broken up to the extent that it was possible to go by boat out of the fjord. Also the other fjords in Northeast Greenland broke up exceptionally early. Hence, during a flight on 2 July it was seen that the fjords between Scoresby Sund and Young Sund were either completely or at least predominantly ice-free.

Only a little polar drift ice entered Young Sund during the second half of July, and pack-ice was absent off Wollaston Forland for much of the summer. In fact, during a sea research cruise in September, polar pack-ice was not found until 81°N on 15. September (S. Rysgaard pers. comm.). So little ice has not been recorded before during more than 100 years of record (K. Q. Hansen, Ice Charting and Remote Sensing Division, Danish Meteorological Institute).

4.2 Vegetation

The weekly records on amounts and phenology of flowering etc. were made by Line Anker Kyhn during the entire season. This year, boardwalks were established at small plots, where our traffic during six seasons had started to be visible on the vegetation around the plots. The boardwalks are removed after each visit to avoid change of the local microclimatic environment.

Reproductive phenology, amount of flowering and berry production

Hans Meltofte

Due to high spring temperatures (see sections 3.1 and 4.4), snowmelt in flower plots was close to average (Table 4.4) in spite of large amounts of snow (see section 4.1). Flowering was generally among the earliest recorded for white arctic bell-heather *Cassiope tetragona*, arctic poppy *Papaver radicatum* and arctic willow *Salix arctica* (except 2000) together with some of the mountain avens *Dryas* sp. plots (Table 4.5). Opening of seed capsules showed a

Plot	1996 50% snow	1997 50% snow	1998 50% snow	1999 50% snow	2000 50% snow	2001 50% snow	2002 50% snow
Cassiope 1	14.6	9.6	13.6	27.6	2.6	7.6	13.6
Cassiope 2	19.6	21.6	27.6	4.7	<4.6	21.6	20.6
Cassiope 3	15.6	21.6	20.6	3.7	13.6	20.6	20.6
Cassiope 4	20.6	15.6	20.6	4.7	13.6	21.6	17.6
Dryas 1	<3.6	<27.5	23.5	6.6	<4.6	<31.5	<30.5
Dryas 2	26.6	27.6	4.7	12.7	21.6	3.7	28.6
Dryas 3	6.6	<27.5	7.6	19.6	<4.6	6.6	6.6
Dryas 4	1.6	3.6	13.6	21.6	<4.6	7.6	6.6
Dryas 5	6.6	31.5	4.6	14.6	<4.6	5.6	6.6
Dryas 6	21.6	4.7	5.7	11.7	20.6	28.6	30.6
Papaver 1	20.6	18.6	21.6	3.7	1.6	20.6	18.6
Papaver 2	20.6	20.6	21.6	4.7	14.6	21.6	20.6
Papaver 3	21.6	15.6	20.6	3.7	13.6	21.6	19.6
Papaver 4	21.6	4.7	5.7	11.7	20.6	27.6	30.6
Salix 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5
Salix 2	14.6	20.6	23.6	1.7	13.6	21.6	14.6
Salix 3	7.6	8.6	12.6	24.6	<3.6	7.6	7.6
Salix 4	20.6	5.6	21.6	22.6	7.6	11.6	10.6
Saxifraga 1		<27.5	<27.5	<1.6	<3.6	<31.5	<30.5
Saxifraga 2		<27.5	<27.5	27.5	<3.6	<31.5	<30.5
Saxifraga 3		<27.5	27.5	6.6	<3.6	(27.5)	<30.5
Silene 1	<3.6	<27.5	<27.5	<1.6	<3.6	<31.5	<30.5
Silene 2	<3.6	<27.5	<27.5	27.5	<3.6	<31.5	<30.5
Silene 3		<27.5	27.5	6.6	<3.6	(27.5)	<30.5
Silene 4	24.6	28.6	20.6	6.7	21.6	28.6	25.6

Table 4.4. Inter- and extrapolated dates of 50% snow cover 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 *plots 1996-2002. Brackets denote extrapolated dates.*

more diverse pattern, with arctic puppy close to average or even late, and arctic willow very early. Purple saxifrage *Saxifraga oppositifolia* was relatively early to intermediate (Table 4.6). This diverse pattern may have been due to a relatively cold weather in the second half of July and most of August (see section 3.1).

2002 was again a year of many flowers especially in arctic willow, moss campion *Silene acaulis* and arctic cotton-grass *Eriophorum scheuchzeri*, but not quite as many as in 2001 in most white arctic bell-heather and mountain avens plots (Table 4.7).

Only a few female arctic willow pods in our *Salix* plots were infested by fungus this year (Table 4.8).

The alpine bearberry *Arctostaphylos alpina* plot was split into four separate plots, because the former A, B, C and D sections were actually positioned apart from each other from the very beginning in 1998. Comparing with the previous years, it shows that moderate numbers of bearberries were produced in 2002 (Table 4.9). Berry production was even poorer in the arctic blueberry *Vaccinium uliginosum* plot, while crowberries *Empetrum nigrum* again appeared in good numbers. The extremely poor arctic blueberry production was in marked contrast to the large number of flowers recorded in the plot this year (cf. Table 4.7), and skuas may have contributed significantly to this poor result. A pair had a nest and young nearby, and the young are fed by flowers and berries during their first weeks. Alpine bearberries were only produced from 2.4% of the flowers, and almost none from the blueberry flowers.

Table 4.5. Inter- and extrapolated dates of 50% open 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 *1996-2002. Brackets denote interpolated dates based on less than 50 buds and flowers.*

Plot	**1996 50% flowers**	**1997 50% flowers**	**1998 50% flowers**	**1999 50% flowers**	**2000 50% flowers**	**2001 50% flowers**	**2002 50% flowers**
Cassiope 1	2.7	6.7	6.7	13.7	(28.6)	4.7	3.7
Cassiope 2	6.7	20.7	(21.7)	(26.7)	–	12.7	7.7
Cassiope 3	9.7	18.7	(19.7)	(26.7)	–	11.7	9.7
Cassiope 4	15.7	15.7	(21.7)	(26.7)	–	19.7	7.7
Dryas 1	19.6	22.6	26.6	3.7	26.6	22.6	25.6
Dryas 2	13.7	4.8	8.8	–	24.7	1.8	29.7
Dryas 3	2.7	26.6	6.7	13.7	27.6	6.7	28.6
Dryas 4	27.6	6.7	(9.7)	14.7	26.6	6.7	28.6
Dryas 5	30.6	5.7	1.7	7.7	22.6	5.7	28.6
Dryas 6	19.7	9.8	(7.8)	19.8	21.7	29.7	1.8
Papaver 1	14.7	20.7	24.7	2.8	4.7	12.7	12.7
Papaver 2	14.7	23.7	26.7	30.7	15.7	14.7	13.7
Papaver 3	14.7	19.7	26.7	1.8	10.7	17.7	13.7
Papaver 4	15.7	7.8	11.8	15.8	(20.7)	(27.7)	2.8
Salix 1	6.6	6.6	12.6	14.6	11.6	8.6	9.6
Salix 2	21.6	29.6	10.7	17.7	28.6	29.6	28.6
Salix 3	20.6	25.6	(28.6)	5.7	11.6	24.6	16.6
Salix 4	29.6	23.6	2.7	3.7	17.6	28.6	26.6
Saxifraga 1		31.5	5.6	7.6	6.6	8.6	3.6
Saxifraga 2		2.6	7.6	14.6	9.6	8.6	6.6
Saxifraga 3	5.6	1.6	9.6	16.6	7.6	9.6	7.6
Silene 1	20.6	24.6	21.6	28.6	26.6	28.6	23.6
Silene 2	23.6	29.6	1.7	30.6	2.7	30.6	27.6
Silene 3	30.6	26.6	23.6	6.7	28.6	4.7	28.6
Silene 4	26.7	10.8	20.8	–	28.7	29.7	28.7

Table 4.6. Inter- and extrapolated dates of 50% open seed capsules for arctic poppy Papaver radicatum, *arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia *1995-2002. Brackets denote interpolated dates based on less than 50 flowers+open capsules.*

Plot	**1995 50% open**	**1996 50% open**	**1997 50% open**	**1998 50% open**	**1999 50% open**	**2000 50% open**	**2001 50% open**	**2002 50% open**
Papaver 1	5.8	15.8	–	30.8	>26.8	9.8	16.8	20.8
Papaver 2	15.8	15.8	24.8	–	>26.8	(17.8)	16.8	17.8
Papaver 3	6.8	13.8	19.8	–	29.8	14.8	18.8	20.8
Papaver 4	20.8	–	>27.8	–	(>26.8)	(16.8)	24.8	(26.8)
Salix 1	8.8	8.8	8.8	5.8	13.8	12.8	2.8	29.7
Salix 2	12.8	9.8	19.8	30.8	25.8	20.8	18.8	11.8
Salix 3	2.8	8.8	16.8	(19.8)	16.8	12.8	14.8	5.8
Salix 4	12.8	17.8	14.8	21.8	16.8	13.8	13.8	12.8
Saxifraga 1		20.7	10.8	11.8	13.8	9.8	8.8	4.8
Saxifraga 2		23.7	16.8	24.8	15.8	15.8	14.8	1.8
Saxifraga 3		7.8	9.8	23.8	16.8	7.8	13.8	12.8

Plot	Area	1995	1996	1997	1998	1999	2000	2001	2002
Cassiope 1	2	1321	1386	1855	322	312	28	1711	1510
Cassiope 2	3		1759	550	19	16	8	1353	952
Cassiope 3	2	256	844	789	35	18	0	771	449
Cassiope 4	3	456	1789	391	24	6	3	578	164
Cassiope 5	2.5			1224	455	474	50	3214	3208
Cassiope 6	2			>350	16	3	1	544	736
Dryas 1	4	(936)	(797)	138	223	852	607	1016	627
Dryas 2	60	534	1073	230	42	49	46	172	290
Dryas 3	2	603	522	123	255	437	266	577	235
Dryas 4	6	(325)	(164)	155	69	356	55	301	187
Dryas 5	6	(654)	(504)	123	191	655	312	506	268
Dryas 6	91	809	1406	691	10	25	140	550	430
Dryas 7	12			787	581	1355	574	1340	1483
Dryas 8	12			391	240	798	170	403	486
Papaver 1	105	302	337	265	190	220	197	237	277
Papaver 2	150	814	545	848	316	315	236	466	456
Papaver 3	90	334	238	289	266	183	240	259	301
Papaver 4	91	196	169	192	80	30	35	65	59
Salix 1 mm.	60		807	959	63	954	681	536	1454
Salix 1 ff.		520	1096	1349	149	1207	900	1047	1498
Salix 2 mm.	300		790	1082	132	416	55	803	1206
Salix 2 ff.		617	1376	1909	455	418	95	1304	1816
Salix 3 mm.	36	239	479	412	32	52	330	1196	344
Salix 3 ff.		253	268	237	38	68	137	1009	315
Salix 4 mm.	150		1314	831	509	718	965	680	1589
Salix 4 ff.		1073	1145	642	709	880	796	858	1308
Saxifraga 1	7		(1010)	141	163	584	1552	558	542
Saxifraga 2	6		513	387	432	158	387	515	617
Saxifraga 3	10		529	322	288	707	403	558	318
Silene 1	7		(251)	403	437	993	1327	674	766
Silene 2	6		493	524	440	400	692	568	1094
Silene 3	10		348	211	127	313	274	348	480
Silene 4	1	466	270	493	312	275	358	462	470
E. scheuz. 1	10		395	423	257	309	229	111	582
E. scheuz. 2	6		537	344	172	184	201	358	581
E. scheuz. 3	10		392	545	482	587	38	367	260
E. scheuz. 4	8		260	755	179	515	117	121	590
E. triste 1	10		0	3	1	1	1	0	3
E. triste 2	6		98	59	21	16	43	56	67
E. triste 3	10		0	0	0	0	0	0	0
E. triste 4	8		0	0	0	0	0	0	0
Arctostaphylos 1									1865
Arctostaphylos 2									215
Arctostaphylos 3									387
Arctostaphylos 4									996
Vaccinium 1									2521

Table 4.7. Area size (m^2) and pooled numbers 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 flower plots in 1995-2002. Numbers in brackets have been extrapolated from 1995 and 1996 data to make up for enlarged plots (see Meltofte and Rasch 1998).*

Table 4.8. Peak ratio (per cent) of female Salix *pods infested by fungi in* Salix *plots in 1996-2002.*

Plot	1996	1997	1998	1999	2000	2001	2002
Salix 1	5	4	0	22	4	1	3
Salix 2	0	1	2	2	0	0	1
Salix 3	0	0	0	6	0	0	2
Salix 4	16	3	0	6	0	0	0

Species	Area	1998	1999	2000	2001	2002
Arctostaphylos 1	1.5	148	240	30	99	33
Arctostaphylos 2	1.5	50	17	2	36	18
Arctostaphylos 3	1.5	28	91	4	100	32
Arctostaphylos 4	1.5	139	107	0	14	44
Vaccinium 1	4	240	532	9	0	1
Empetrum 1	4	27	1	17	3081	1034

Table 4.9. Area size (m²) and numbers of berries recorded in alpine bearberry Arctostaphylos alpina*, arctic blueberry* Vaccinium uliginosum *and crowberry* Empetrum nigrum *plots in 1998-2002.*

Vegetation greening in mammal, bird and flower study plots

Mikkel Tamstorf and Hans Meltofte

Greening index data from a Landsat-7 ETM+ satellite image from 2 August 2002 are presented in Table 4.10, and in Table 4.11 they are compared with previous years after extrapolation to simulate 31 July each year (see Figure 4.1 in Caning and Rasch 2003 for location of sections in Zackenbergdalen). All mean values from 2002 were similar or very close to the values from 2001 and somewhat lower than most other years.

Due to drizzle on 12 August, aberrant high greening index values were reached on this date in the flower study plots. Hence, maximum values from days with wet vegetation were omitted for all years (but only occurring for one day in 2000). The resulting data show that 2002 had a culmination of greening that was close to 2001, but lower than both 1999 and particularly the extraordinarily early snowmelt season of 2000 (Table 4.12). We have no immediate explanation for the apparently conflicting data for 1999 between hand held and satellite measurements.

Unfortunately, the RVI meter turned out to produce too high values after repair during the preceding winter, but fortunately this was realised early enough to allow us to use a new meter during the greening peak. Afterwards, the manufacturers calibrated both meters and a correction factor was calculated. Hence, data measured with the "old meter" have been corrected in the databases.

Table 4.10. Area size (km²) and Normalised Difference Vegetation Indexes (NDVI) values for 12 sections of the bird and musk ox monitoring areas in Zackenbergdalen together with the lemming monitoring area (part of Section 2) based on Landsat-7 ETM+ satellite image from 2 August 2002 (see Figure 4.1 in Caning and Rasch 2003 for position of sections). The image has been corrected for atmospheric and terrain influence (humidity, aerosols, solar angle and terrain effects). All negative NDVI values have been changed to 0, so that water and snow covered areas are given similar values from year to year.

Section	Area	Min.	Max.	Mean	Std. Dev.
1 (0-50 m)	3.52	0.00	0.73	0.36	0.19
2 (0-50 m)	7.97	0.00	0.81	0.46	0.18
3 (50-150 m)	3.52	0.00	0.80	0.51	0.14
4 (150-300 m)	2.62	0.00	0.70	0.40	0.15
5 (300-600 m)	2.17	0.00	0.70	0.28	0.15
6 (50-150 m)	2.15	0.00	0.71	0.43	0.17
7 (150-300 m)	3.36	0.00	0.69	0.41	0.16
8 (300-600 m)	4.56	0.00	0.75	0.31	0.20
9 (0-50 m)	5.01	0.00	0.79	0.47	0.17
10 (50-150 m)	3.84	0.00	0.81	0.50	0.13
11 (150-300 m)	3.18	0.00	0.75	0.38	0.18
12 (300-600 m)	3.82	0.00	0.79	0.35	0.19
13 (Lemmings)	2.05	0.00	0.77	0.45	0.16
Total area	**45.70**	**0.00**	**0.75**	**0.40**	**0.17**

Summertime carbon budget for the Zackenberg heath 2002

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During June-August 2002, the measurements of carbon dioxide exchange continued at the Zackenberg heath site located about 100 m north of the climate station. This monitoring is established as a co-operation between the National Environmental Research Institute and the Institute of Geography, University of Copenhagen. During the field season, GeoBasis personnel service the equipment. The measurements were initiated by 3 June and continued until 27 August. From a technical point of view, the collection of flux data was a success in 2002. More than 1900 hours of consistent flux measurements were collected, and less than 1% were lost due to malfunction, maintenance and calibration procedures.

The instrumentation for measuring the vertical fluxes of water vapour and carbon dioxide consists of a three-dimensional (3-D) sonic anemometer (Solent 1012R2, Gill Instruments, Lymington, UK) for measuring wind speed and direction, and an Infrared Gas Analyzer (IRGA) (Li-6262, LI-COR, Nebraska, USA.) for measuring water vapour and carbon dioxide concentrations.

The sonic anemometer and the sampling tube inlet of the IRGA are situated 3 m above ground level. Data collecting and processing is based on the EdiSol software package (Moncrieff *et al.* 1997). As a supplement to the atmospheric fluxes, a number of micro-meteorological parameters are measured simultaneously. These data include air temperature and air humidity (MP100A, Rotronic, Campbell scientific. LTD, UK), soil temperature (thermocouple), IR surface/canopy temperature (KT-17, Heimann, Germany), soil moisture (Delta-T Cambridge, UK).

Figure 4.1 shows the temporal variation in daily air temperature and the daily net exchange of CO_2 also denoted the Net Ecosystem Exchange (NEE) expressed as g C per m^2 per day. Fluxes directed towards the surface are given with negative sign whereas upward directed fluxes are given as positive values. As in previous years, three different periods can be identified:

1. Until 14 June (DOY 165) the CO_2 was still trapped below the snow pack, and the fluxes were very low. During the second half of June (until DOY 182), the snow cover gradually disappeared, and along with the heating of the ground, the soil respiration increased reaching a maximum of 0.85 g C per m^2 per day on 28 June (DOY 179) during a spell of very warm weather. By the end of June, the snow had melted and the vegetation had developed causing a rapid transition to the growing season.
2. The growing season, characterised by a daily net C accumulation, began on 2 July (DOY 183) or within the range from previous years (Table 4.13). During most of the 45 days of growing season, soil respiration was more than balanced by the photosynthetic CO_2 uptake. Only a few spells of poor weather with low photosynthetic rates caused intermediate net carbon loss from the soil-vegetation ecosystem such as 13-16 July (DOY 194-197), when it was overcast and rainy. During the peak growing season, the CO_2 uptake reached a maximum of 1.0 g C per m^2 per day. The transition from melting to growing season only took a few days, whereas the net CO_2 exchange in August gradually approached zero due to leaf senescence and decreasing solar radiation. As it appears from Table 4.13, the CO_2 exchange in the 2002 growing season was of the same order of magnitude as found in the two previous years.
3. The second half of August was characterised by net C loss. However, the C loss in August was only one third of the peak CO_2 emission found during the melting period. The end of the growing season on 16 August was within the range from previous years (Table 4.13).

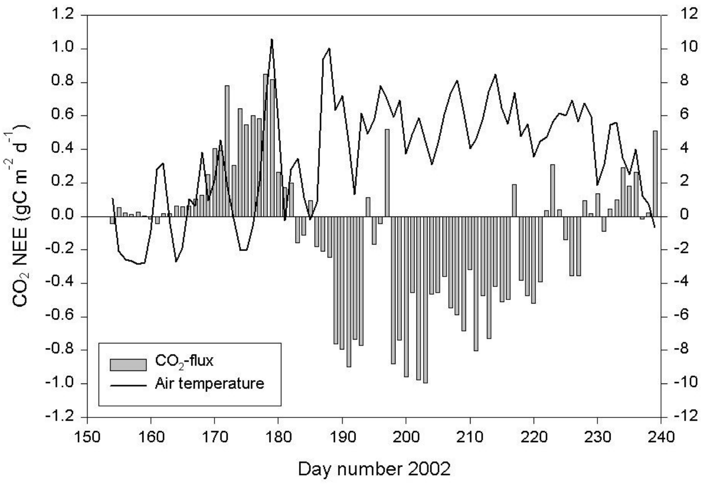


Figure 4.1. Temporal variation in daily carbon dioxide exchange and mean air temperature on the heath north of the climate station in 2002.

Table 4.11. Mean NDVI values for 12 sections of the bird and musk ox monitoring areas in Zackenbergdalen together with the lemming monitoring area (part of section 2) based on Landsat TM, ETM+ and SPOT 4 HRV satellite images 1998-2002 (see Figure 4.1 in Caning and Rasch 2003 for position of sections). The data have been corrected for differences in growth phenology between years to simulate the 31 July value. When comparing values, it should be noted that optimum of the plant communities varies between years with 31 July close to optimum of most years.

Section	1995	1996	1997	1998	1999	2000	2001	2002
1 (0-50 m)	0.37	0.43	0.44	0.44	0.30	0.41	0.34	0.34
2 (0-50 m)	0.43	0.50	0.50	0.51	0.41	0.48	0.43	0.44
3 (50-150 m)	0.54	0.53	0.54	0.53	0.41	0.51	0.47	0.49
4 (150-300 m)	0.46	0.45	0.46	0.44	0.31	0.43	0.36	0.38
5 (300-600 m)	0.36	0.35	0.38	0.38	0.22	0.37	0.26	0.26
6 (50-150 m)	0.48	0.48	0.47	0.46	0.33	0.44	0.39	0.41
7 (150-300 m)	0.48	0.46	0.48	0.45	0.32	0.43	0.38	0.39
8 (300-600 m)	0.42	0.38	0.41	0.42	0.25	0.35	0.28	0.29
9 (0-50 m)	0.42	0.50	0.52	0.51	0.39	0.50	0.44	0.45
10 (50-150 m)	0.52	0.53	0.54	0.52	0.40	0.52	0.48	0.48
11 (150-300 m)	0.47	0.45	0.46	0.42	0.26	0.41	0.35	0.36
12 (300-600 m)	0.42	0.42	0.44	0.45	0.28	0.32	0.34	0.33
13 (Lemmings)	0.42	0.49	0.50	0.49	0.40	0.47	0.41	0.43
Total	**0.45**	**0.46**	**0.48**	**0.47**	**0.32**	**0.43**	**0.38**	**0.38**

Table 4.12. Peak NDVI recorded in 26 flower plots in 1999-2002 together with date of maximum record using a hand held Skye 110 instrument with a 660-730 nm sensor. NDVI values presented are transformed averages of eight hand held RVI measurements in each plot (four in very small plots). Note that the greening measured accounts for the entire plant community, in which the taxon denoted may only make up a minor part.

Plot	1999		2000		2001		2002	
	NDVI	Date	NDVI	Date	NDVI	Date	NDVI	Date
Cassiope 1	0.40	29.7	0.41	29.7	0.37	5.8	0.35	29.7
Cassiope 2	0.41	29.7	0.46	22.7	0.38	22.7	0.38	26.8
Cassiope 3	0.41	19.8	0.36	19.8	0.33	5.8	0.31	26.8
Cassiope 4	0.38	26.8	0.41	22.7	0.35	29.7	0.33	26.8
Mean	0.40		0.41		0.36		0.34	
Dryas 1	0.43	22.7	0.41	22.7	0.37	22.7	0.35	25.7
Dryas 2	0.39	19.8	0.42	22.7	0.39	29.7	0.43	5.8
Dryas 3	0.45	29.7	0.45	22.7	0.42	26.7	0.41	29.7
Dryas 4	0.34	19.8	0.32	22.7	0.33	22.7	0.28	29.7
Dryas 5	0.34	29.7	0.33	22.7	0.31	22.7	0.28	29.7
Dryas 6	0.35	26.8	0.41	22.7	0.34	26.7	0.37	5.8
Mean	0.38		0.39		0.36		0.35	
Papaver 1	0.41	19.8	0.41	22.7	0.38	29.7	0.39	29.7
Papaver 2	0.44	19.8	0.45	22.7	0.41	29.7	0.40	5.8
Papaver 3	0.37	26.8	0.41	22.7	0.35	29.7	0.34	5.8
Papaver 4	0.35	26.8	0.41	22.7	0.34	26.7	0.37	5.8
Mean	0.39		0.42		0.36		0.37	
Salix 1	0.57	29.7	0.59	22.7	0.54	8.7	0.54	22.7
Salix 2	0.52	29.7	0.52	22.7	0.49	29.7	0.51	22.7
Salix 3	0.41	29.7	0.44	22.7	0.39	29.7	0.38	29.7
Salix 4	0.46	29.7	0.47	22.7	0.43	2.8	0.45	29.7
Mean	0.49		0.50		0.46		0.47	
Saxifraga/Silene 1	0.28	29.7	0.34	7.8	0.27	8.7	0.19	22.7
Saxifraga/Silene 2	0.36	29.7	0.38	22.7	0.34	19.7	0.31	22.7
Saxifraga/Silene 3	0.23	29.7	0.26	22.7	0.27	15.7	0.20	29.7
Silene 4	0.32	26.8	0.36	22.7	0.27	29.7	0.26	5.8
Mean	0.30		0.34		0.29		0.24	
Eriophorum 1	0.57	5.8	0.60	14.7	0.60	29.7	0.57	29.7
Eriophorum 2	0.58	29.7	0.58	22.7	0.53	26.7	0.50	29.7
Eriophorum 3	0.54	19.8	0.56	22.7	0.47	29.7	0.47	29.7
Eriophorum 4	0.73	5.8	0.72	22.7	0.68	29.7	0.64	5.8
Mean	0.61		0.62		0.57		0.54	
Mean of all	0.43		0.45		0.40		0.39	

4.3 Arthropods

Line Anker Kyhn and Hans Meltofte

As usual, two window traps and five pitfall trap stations with eight yellow traps each were operated during the 2002 season, and procedures were concurrent with preceding years. In accordance with the relatively large amount of snow in combination with the warm weather in late May and June, ice- and snowmelt in the arthropod trap plots was early to average (Table 4.14). The first traps were opened on 3 June, and the last trap was opened 24 June.

Line A. Kyhn performed the sampling of arthropods, and she also sorted the samples. All sorted material is kept in 70% alcohol at the Zoological Museum, University of Copenhagen.

The total number of arthropods collected this year (71,972) was much higher than last year and almost reaches the highest number ever recorded (2000: 75,932). As the total number of trapping days (3,227) also almost equals the number from the record year (3,321), part of the ex-

	1997	2000	2001	2002
Beginning of growing season	7 July	25 June	6 July	2 July
End of growing season	21 August	11 August	18 August	16 August
Length of growing season	46 days	47 days	43 days	45 days
Beginning of measuring season	7 June	6 June	8 June	3 June
End of measuring season	25 August	25 August	27 August	27 August
Length of measuring season	80 days	81 days	81 days	86 days
NEE for growing season (g C m^{-2})	(-) 12.5	(-) 22.7	(-) 19.1	(-)18.2
NEE for whole measuring season (g C m^{-2})	(-) 3.1	(-) 19.1	(-) 8.7	(-) 9.5
Avg peak daily accumulation (g C m^{-2} d^{-1})	(-) 0.65	(-) 0.92	(-) 0.94	(-) 1.00

Table 4.13. General characteristics of the CO_2 exchange on the Cassiope *heath north of the climate station in 1997 and 2000-2002.*

planation for the high number of arthropods can probably be inferred from this.

Window traps

The two window traps in Gadekæret were established on 3 June, when the pond was less than 60% ice covered. They remained open until 26 August, and there was no disturbance by musk oxen during this period. Catches from the two traps were pooled for each week, and data are presented in Table 4.15 together with total catches from previous years. The taxa composition of arthropods in 2002 resembles that of previous years, though it is clear that when Ceratopogonidae is separated from Chironomidae it replaces Muscidae as the second most numerous Diptera group represented in the window traps. In 1999, the ratio of Ceratopogonidae to Chironomidae was c. 1:3. This year, it was c. 1:4. If the 2002 ratio is legible for the other years, this year's catch of Chironomidae equals the record of 2000. The fact that Gadekæret did not dry out in 2002 is the most likely explanation for the large occurrence of Chironomidae this year, whereas the early peak of this group probably can be ascribed to the warm weather in late May and early June (see section 4.4 Reproductive phenology in waders).

Also the number of Syrphidae was relatively high, whereas the number of Muscidae was the lowest ever recorded. One *Nysius groenlandicus* was caught for the first time since the first appearance in the window traps in 1996. No additions could be made to the over all taxa diversity this year.

Pitfall traps

The first traps were opened on 3 June and the last on 24 June, which sums up to a total of 3,059 trapping days only proceeded by year 2000 with 3,155. Weekly totals are pooled for all five plots and presented in Table 4.16 with totals from 1997-2001 for comparison.

The number of Chironomidae (5,982) was the second largest recorded (1999: 8,542), which must have been a result of the warm weather in late May and early June, also resulting in their record early peak during 10-17 June (see also section 4.4 Reproductive phenology in waders). Station 2 is situated in a wet fen and captures by far the largest proportion of Chironomidae among the pitfall trap stations. Even though Station 2 is situated very close to the window traps in Gadekæret, there was an apparent delay in peaks between the two stations, as Chironomidae peaked a week earlier at Station 2. Fur-

Station no.	1996	1997	1998	1999	2000	2001	2002
1	3.6	Dry	6.6	16.6	1.6	6.6	3.6
2	<3.6*	28.5	29.5	8.6	<4.6*	<31.5*	<31.5*
3	14.6	19.6	18.6	27.6	9.6	19.6	14.6
4	14.6	22.6	26.6	2.7	7.6	21.6	20.6
5	4.6	<29.5*	1.6	12.6	<4.6*	8.6	3.6
7	–	–	–	<3.6	<4.6*	<30.5	<31.5*

* 0% snow

Table 4.14. Date of 50% snow-cover (ice cover on pond at Station 1) in the arthropod plots 1996-2002.

DATE	10.6	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	19.8	26.8	2002	2001	2000	1999	1998	1997	1996
No. of trap days	14	14	14	14	14	14	14	14	14	14	14	14	168	168	166	153	174	184	182
COLLEMBOLA	6	19	27	21	8	22	20	35	15	8	4	6	191	119	102	61	5	15	65
COLEOPTERA																			
Latridius minutus													0	0	0	2	0	0	0
HEMIPTERA																			
Nysius groenlandicus												1	1	0	0	0	0	0	4
Aphidoidea													0	2	0	0	0	0	0
Coccoidea													0	0	3	0	0	0	14
THYSANOPTERA		1	1						1				3	1	0	0	0	0	8
LEPIDOPTERA																			
Colias hecla				1	3	2							6	0	2	0	0	0	1
Clossiana sp.							1						1	1	2	1	1	1	6
Geometridae								1	1				2	3	0	0	0	1	3
Noctuidae													0	0	0	0	0	2	2
DIPTERA																			
Nematocera larvae								1	1				2	0	0	1	0	0	0
Nematocera undet.													0	1418	0	0	0	0	0
Tipulidae													0	0	0	1	0	0	0
Trichoceridae													0	0	0	0	1	1	0
Culicidae			9	52	65	30	27	13	25	5	2	4	232	209	111	322	138	142	98
Chironomidae	9	1201	1873	1771	358	421	235	127	237	64	59	23	6378	3876	8522	5787	3743	7725	6477
Ceratopogonidae		236	741	343	18	29	101	54	51	9	10	6	1598	168	*	1799	*	*	*
Mycetophiliidae						1	3		2				6	23	22	16	624	240	64
Sciaridae		1	39	8	4		2	1	1				56	33	2	171	*	*	*
Cecidomyiidae			1	1	1								3	4	32	6	0	0	1
Empididae					1								1	8	10	9	9	1	77
Phoridae					1								1	1	2	3	0	0	0
Syrphidae			1		2	1	2	1	1	1	1		10	4	5	1	8	16	4
Heleomyzidae									1				1	2	0	1	0	0	0
Agromyzidae	3												3	0	0	0	0	4	0
Tachinidae													0	2	6	1	0	0	0
Calliphoridae	1												1	1	4	5	7	6	2
Scatophagidae	5		1				1						7	0	2	10	0	30	11
Anthomyiidae	2	2	1			1			1	1			8	2	*	3	26	11	*
Muscidae		2	46	151	70	60	60	29	69	24	30	13	554	1312	1455	754	745	809	1355
HYMENOPTERA																			
Bombus sp.									1				1	0	0	1	2	6	5
Ichneumonidae			1		6	8	5	1		1		2	24	34	48	24	18	44	43
Braconidae													0	0	0	0	1	1	0
Chalcidoidea					1			1					2	14	0	0	0	2	0
ARANEA																			
Lycosidae					1								1	0	2	0	0	1	0
Linyphiidae				1	4	1			2				8	15	10	6	1	1	8
ACARINA	3	5	92	37	44	31	30	43	34	20	6	2	347	358	246	191	826	189	299
TOTAL	29	1467	2833	2386	587	607	487	307	443	133	112	57	9448	7610	10588	9177	6155	9248	8547

Table 4.15. Weekly totals of arthropods etc. caught at the window trap station in 2002. 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 1996-2001 are given for comparison. An asterisk marks that the group was not separated from a related group in that year. The systematic order has been changed in agreement with Böcher [n.d.].

thermore, the peak in the window traps levelled out over 2-3 weeks opposite to the rather sudden drop off at Station 2.

Sciaridae appeared in relatively high numbers and peaked in late June and early July with some delay between the different stations (Figure 4.2). The earliest peak was at Station 7, where they were

DATE	10.6	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	19.8	26.8	2002	2001	2000	1999	1998	1997
No. of active stations	3	3	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
No. of trap days	161	168	217	280	280	280	280	273	280	280	280	280	3059	2954	3155	2706	2702	2797
COLLEMBOLA	648	1457	2238	2300	1296	5353	2049	1491	1852	586	526	516	20312	17970	21726	23443	8957	10830
HETEROPTERA																		
Nysius groenlandicus													0	2	0	1	0	5
Aphidoidea		5	6	12	24	19	19	22	22	11	12	5	157	359	3	11	185	10
Coccoidea			3	35	47	78	93	142	137	48	32	19	634	9	781	431	3	548
THYSANOPTERA							2		1		2		5	0	0	2	0	0
LEPIDOPTERA																		
Lepidoptera larvae			4	13	13	11	6	1	1	3	4	7	63	16	18	21	106	168
Tortricidae													0	1	0	0	0	0
Colias hecla				1	6	5	7		8	1		1	29	0	77	42	12	19
Clossiana sp.				4	14	21	87	16	146	65	24	4	381	49	329	82	56	180
Lycaenidae													0	0	4	1	0	0
Plebeius franklinii						4	3						7	19	0	0	1	1
Geometridae							1	4	1				6					
Noctuidae								1					1	15	4	6	2	45
DIPTERA																		
Nematocera larvae		1		1	1	5	4		12	16	3	3	46	15	279	105	58	39
Tipulidae larvae				1						1		1	3	3	4	1	0	0
Tipulidae			1		1		1	1					4	14	2	4	1	4
Trichoceridae	1												1	7	0	3	0	1
Culicidae				10	27	6	31	10			1	1	86	34	61	83	22	16
Chironomidae	123	2278	847	875	700	384	306	142	137	55	91	44	5982	1958	3666	8542	2402	3337
Ceratopogonidae		1	6	12	16	4	18	22	7		14	2	102	7	0	68	*	*
Mycetophiliidae	5		2	2	4	1	13	11	3	5	2		48	181	820	205	1764	1194
Sciaridae	2	63	69	156	192	129	64	14	12	14	34	13	762	573	4	796	*	*
Cecidomyiidae			1			4		1					6	8	24	0	1	0
Brachycera larvae													0	0	4	3	0	0
Empididae		1		2			1		1	1	6	12	24	28	14	21	10	6
Cyclorrhapha larvae			1	1		7	3	2	1	3	3	1	22	0	7	7	19	75
Phoridae				35	135	51	140	43	30	21	16	18	489	445	1316	435	344	214
Syrphidae					1	2	2	3	8	5	5	4	30	18	43	50	28	81
Heleomyzidae		1			1	2	1						5	6	1	7	0	0
Agromyzidae	1	1	1						1		1	1	6	4	2	0	0	1
Tachinidae					1	2	5	1	6	4	4		23	29	37	37	0	19
Calliphoridae	3	2			3	1			8	2	17	8	44	5	218	26	49	48
Scatophagidae							1		6		14	3	24	0	1	41	0	385
Fanniidae													0	0	0	0	0	1
Anthomyiidae	36	24	24	30	12	2	7	2	26	16	45	14	238	57	*	88	416	573
Muscidae		159	467	1679	1739	1003	802	210	466	270	532	172	7499	6766	12805	10005	5463	6217
SIPHONAPTERA													0	0	0	3	0	0
HYMENOPTERA																		
Hymenoptera larvae													0	0	4	0	2	0
Bombus sp.				1		1	1	4					7	3	10	2	6	12
Ichneumonidae		1	5	33	116	45	63	31	33	31	45	33	436	442	710	386	297	567
Braconidae				1		1	2	1	1		4	1	11	11	15	10	105	59
Chalcidoidea			1	2	10	9	24	11	47	17	41	28	190	106	21	9	2	123
Scelionidae								1	3			1	5	3	0	101	0	0
Ceraphronoidea							3		1		2	2	8	3	15	5	0	0
Cynipoidae													0	1	0	0	0	1
ARANEA																		
Thomisidae	9	18	14	50	27	27	17	4	15	16	14	8	219	177	134	144	89	245
Lycosidae	28	111	96	322	250	158	113	73	133	136	119	221	1760	2618	3254	2118	2123	3806
Lycosidae egg sac				5	3			1	1		1	1	12	85	101	160	160	138
Dictynidae		2	9	13	10	7	16	17	3	11	7	12	107	0	0	79	0	53
Linyphiidae	164	287	217	222	90	50	72	59	71	40	82	84	1438	1833	3523	2243	1108	1644
ACARINA	974	2079	1857	2810	2549	2259	1726	2988	1586	858	918	678	21282	9929	15256	8263	6304	19781
OSTRACODA		2	1						3	1	2		9	0	46	84	0	0
NEMATODA													0	0	3	0	0	0
ENCHYTRAEIDAE										1			1					
UNIDENTIFIED													0	0	2	0	0	0
TOTAL	1994	6493	5870	8628	7288	9651	5703	5329	4789	2237	2623	1918	62523	43811	65344	58174	30095	50446

Table 4.16. Weekly totals of arthropods etc. caught at the five pitfall trap stations in 2002. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous week. Totals from 1997-2001 are given for comparison. Asterisks mark groups that were not separated from closely related groups in that year. The systematic order of arthropods has been changed in agreement with Böcher [n.d.].

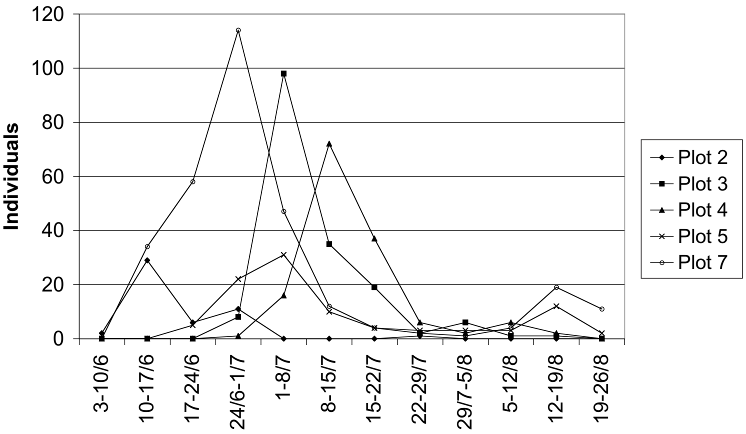


Figure 4.2. Phenology of Sciaridae at the five pitfall trap stations in 2002.

also caught in highest numbers. This could be a result of Station 7 being free of snow the entire winter and therefore having more to offer the mosquitoes early in the season.

The closely related Muscidae and Anthomyidae fly families showed markedly different phenologies. Anthomyidae appeared before any Muscidae and peaked mid June with numbers dropping in July, but showing a second peak in August. Muscidae showed a pronounced peak in the beginning of July. The same tendency was apparent at all open pitfall trap stations and also in the 1998 and 1999 pitfall trap samples. Both families only complete one lifecycle per year. Anthomyidae larvae parasitize different plant species, whereas Muscidae larvae mainly develop in rotten material and defecations from various animals (Böcher [n.d.]). The earlier peak of Anthomyidae might be an adaptation to egg laying in plant species associated with early snowmelt and thereby gaining an earlier start of the season. Also the Anthomyidae family might be relatively more active in warm weather.

Lepidoptera was caught in the highest numbers (424) since 1996, and also the number of larvae was high (63) relative to the last three years. The Geometridae family was caught for the first time in the pitfall traps represented by six individuals. Outside the traps, the most common butterflies, arctic clouded yellow *Colias hecla* and fritillary *Clossiana* sp., were also encountered in very high numbers during bird census work (see below). According to Larsen (2002), no apparent correlation between temperature and fritillary activity was found for the data from 1996-2000, but a negative effect was found from extensive and long lasting snow cover. Wintering larvae and pupae might, however, benefit from the isolation a thick snow cover offers. The large amount of snow, but relatively early melt off due to the warm weather, may therefore partly explain the increase in numbers of butterflies. The unprecedented warm weather, which prevailed most of the time from late May until mid July (see section 4.4 Reproductive phenology in waders), may also have been a very important factor.

The warm and sunny weather in 2002 together with the relatively early snowmelt (giving high numbers of trapping days) are the most obvious reasons for the very high numbers of arthropods caught this season. Especially early June was warm, and this is reflected in the earlier build up and peak of many of the arthropods.

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

One larva of 'black moth' *Sympistis zetterstedtii* was found in Dryas 8 on 9 July, and depredation was recorded in most of the other plots (Table 4.17).

Woolly-bear *Gynaephora groenlandica* caterpillars were not recorded inside the willow plots this year, and Hans Meltofte encountered only eight larvae during bird census work in June and July, which is a small increase from 2001 (Table 4.18).

Sawfly Tenthredinidae larvae were not found this year in ripe female willow pods (Table 4.19).

Bumblebees and butterflies

The first bumblebee *Bombus polaris/hyperboreus* was recorded on 6 June. During bird census work in June and July, a total of 79 individuals were recorded by Hans Meltofte (for effort, see Table 4.21). This is a relatively high figure (Table 4.20), which was a result of the outstandingly fine and warm weather in most of June and the

Figure 4.17. Peak ratio (per cent) of mountain avens flowers depredated by larvae of 'black moth' Sympistis zetterstedtii *in mountain avens plots in 1996-2002.*

Plot	1996	1997	1998	1999	2000	2001	2002
Dryas 1	2	6	3	0	0	0	15
Dryas 2	0	5	0	0	0	0	1
Dryas 3	11	18	3	0	0	0	7
Dryas 4	17	1	7	0	0	0	11
Dryas 5	2	8	2	0	0	0	9
Dryas 6	0	0	0	0	0	0	0
Dryas 7	–	–	0	26	0	0	2
Dryas 8	–	–	0	27	0	0	0

first half of July. During the line transects in mid July, 17 bumblebees were seen in Store Sødal and two between Daneborg and Zackenberg.

Also fritillary *Clossiana* sp. and arctic clouded yellow *Colias hecla* butterflies were recorded systematically during bird census work in June and July. The first fritillary was seen on 12 June and the first arctic clouded yellow on 27 June. This latter date is the earliest so far. Total numbers seen were 52 fritillary in June and 331 in July, as compared to 14 fritillary in June 2001 and 64 in July 2001. Ten arctic clouded yellows were seen in June and 136 in July, again compared to one and 29 in June and July 2001, respectively. These very high numbers in 2002 reflect the fine and warm weather in most of June and the first half of July, when up to 49 fritillary and 20 arctic clouded yellow butterflies were recorded in one day (see also the section on Pitfall traps above).

	1996	1997	1998	1999	2000	2001	2002
June	1	2	7	7	10	2	4
July	0	1	4	17	2	2	3
Total	1	3	11	24	12	4	7

Table 4.18. 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 1996-2002.*

Plot	1996	1997	1998	1999	2000	2001	2002
Salix 1	+	0	0	43	2	0	0
Salix 2	3	0	0	6	0	0	0
Salix 3	9	0	0	3	5	0	0
Salix 4	0	0	0	1	7	0	0

Table 4.19. Peak ratio (per cent) of female arctic willow pods infested by sawfly larvae in 1996-2002.

	1999	2000	2001	2002
June	–	59	12	48
July	35	34	15	31
Total	–	93	27	79

Table 4.20. Numbers of bumblebees Bombus polaris/hyperboreus *recorded by one observer (Hans Meltofte) in Study area 1A (the bird monitoring area) in June and July 1999-2002.*

	West of river	East of river	Total
June	4; 17	18; 74	22; 91
July	9; 27	17; 61	26; 88
Total	13; 44	35; 135	48; 179

Table 4.21. 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.

4.4 Birds

Hans Meltofte

Bird observations were made by Hans Meltofte during 31 May – 5 August and by Thomas B. Berg during 2 July – 31 August. Valuable observations were provided by other researchers and staff during the entire season.

During June, the main effort was to census the breeding birds within the 19 km^2 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.

For scientific names in this chapter, see section on Other observations.

Breeding populations

The 18.8 km^2 census area in Zackenbergdalen was covered on almost daily trips between mid June and late July (Table 4.21). The total effort in both June and July was similar to recent years, but fewer days and hours were spent on the western side of the river. The initial complete census of waders took place between 12 and 20 June, but the higher and western slopes of Aucellabjerg were not covered until 25 June due to weather conditions. The census took 36 hours to complete. During the census, most waders had eggs (see section below), and few individuals appeared to be unsettled. The weather was fine or at least acceptable during the census days.

Based on records made during the initial census supplemented by records during the rest of the season (see Meltofte and Berg 2003), population estimates for five sections of the census area are presented in Table 4.22, and in Table 4.23 they are compared to previous years. Most populations were within the range estimated for earlier years, but sanderlings and turnstones appeared in lower numbers, while dunlins continued their increase. I feel confident that the low numbers of sanderlings and turnstones are real, and they may be the result of three consecutive problematic breeding seasons at Zackenberg: extraordinary much snow and late snowmelt in 1999, a snowstorm during hatching and chick rearing in 2000 and a snowstorm during egg-laying and early incubation in

Table 4.22. Estimated numbers of pairs/territories in five sectors of the 18.8 km^2 census area in Zackenbergdalen, 2002.

	West of river <50 m (3.39 km^2)	East of river <50 m (7.52 km^2)	East of river 50-150 m (3.34 km^2)	East of river 150-300 m (2.49 km^2)	East of river 300-600 m (2.06 km^2)
Red-throated diver	0	3	0	0	0
Pink-footed goose	1	0	0	0	0
Common eider	1	0	0	0	0
King eider	0	4-6	0	0	0
Long-tailed duck	0	6-7	0	0	0
Rock ptarmigan	0	1	2	0	0
Common ringed plover	7-8	4-6	1	13-14	12
Red knot	3-4	10-11	6	5-6	0
Sanderling	9	25-29	0-1	12-13	3
Dunlin	30-33	71-79	15-16	2	2
Ruddy turnstone	3-4	18-23	10	0	0
Red-necked phalarope	0	1-2	0	0	0
Red phalarope	0	0	0	0	0
Long-tailed skua	4	11	7-9	1-2	0
Snow bunting	20	13	16-19	3	5

2001 (see Caning and Rasch 2000, 2001, 2003). However, the high number of dunlins contradicts this. The increase in numbers of this species is probably mainly the result of a better coverage during the years, especially of western Rylekærene, but at least they did not decrease in 2002. Due to the warm weather in late May and early June this year (see below), few pre-breeding ringed plovers were feeding in the lowland, and numbers recorded are probably closer to real numbers than in some previous years.

Like in 2000 and 2001, the ptarmigan population was low, but broods were recorded in innermost Store Sødal and on the outer coast of Wollaston Forland (see Other observations below).

Reproductive phenology in waders

Since snow-cover was close to average in early June (Tables 4.2 and 4.25), I expected to find average egg-laying dates this year. However, surprisingly I found dunlin and turnstone nests, where egg-laying had been initiated around 1 June, and median 1st egg dates even earlier than in the very early breeding season of 2000 (Tables 4.24 and 4.25). Only a few records exist of equally early egg-laying in High Arctic

	1996	1997	1998	1999	2000	2001	2002
Red-throated diver	1-2	2	3	2-3	2-3	2	3
Pink-footed goose	0	1	0-1	2	1	1	1
Common eider	0	0	0	0	1	1	1
King eider	2-3	2	1	2-3	2-4	3-4	4-6
Long-tailed duck	5-8	4-6	6-8	7-8	5-8	5-7	6-7
Rock ptarmigan	3	11-15	4-6	7-8	1-3	2-4	3
Common ringed plover	54-56	40-48	38-45	51-65	41-43	51-54	37-41
European golden plover	0	0	0	0	0	1	0
Red knot	33-43	35-44	27-32	25-33	24-27	27-30	24-27
Sanderling	50-63	55-70	62-70	60-67	59-67	58-70	49-55
Dunlin	69-82	75-91	75-94	81-95	98-103	104-110	120-132
Ruddy turnstone	42-52	49-58	56-63	43-49	48-50	45-51	31-37
Red-necked phalarope	0-1	0-2	1-2	1-2	1-2	1-2	1-2
Red phalarope	0	0	0-1	0	0	1	0
Long-tailed skua	25-29	22-25	21-24	19-24	21-28	22-25	23-26
Northern wheatear	0	0	1	0	0	0	0
Snow bunting	45-55	45-56	41-46	52-64	42-47	48-58	57-60

Table 4.23. Census results from the 18.8 km^2 census area in Zackenbergdalen, 1996-2002.

Greenland (Meltofte 1985). Also, sanderlings were a little early, but more in accordance with other early years. One sanderling clutch initiated on 30 June, two dunlin clutches from 30 June and 1 July, respectively, and one turnstone clutch from 19 June were almost certainly relaid clutches.

The most obvious explanation for the early egg-laying is extraordinary high temperatures in late May and early June. Mean for this period was +0.9°C as compared to between –0.9 and –2.2°C in previous years. Normally, more or less continuous positive daily maximum temperatures do not begin until late May, but average remains below zero even into June. This year showed for the first time a positive mean for 21-31 May at Zackenberg, and average was about 3°C higher than during each of the years 1996-2001. At nearby Daneborg Weatherstation, positive mean temperatures for late May have only been recorded twice since computerised data were made available in 1958, and only once since 1949 at Danmarkshavn Weatherstation, 300 km further north. Early June was also warmer than normal, and for the entire period 21 May – 10 June, mean temperatures were higher than ever recorded at the two weatherstations in the region.

This is the first time that temperatures have been shown to have an overriding impact on egg-laying in High Arctic Greenland, since snow cover has been found to be the main governing factor in regulating egg laying probably working both directly as an ultimate factor and indirectly through invertebrate food availability and predation risk (Meltofte 1985). In the common feeding area for pre-breeding waders in Gadekæret, catches of insects and spiders at Arthropod station 2 during 3-17 June were 2.7-12.7 times higher than recorded before.

Species	Median date	Range	N
Common ringed plover	26 June	–	1
Sanderling	17 June	11-30 June	11
Dunlin	8 June	1 June – 1 July	13
Ruddy turnstone	9 June	1-19 June	13

Table 4.24. Median first egg dates for waders at Zackenberg 2002 as estimated from incomplete clutches, egg floating, hatching dates and weights of pulli.

Reproductive success in waders

The weather was warm and fine during most of the incubation period, with particularly high temperatures in late June and early July. No severe events influenced the incubating waders. We found fewer wader nests than in most other years, partly because relatively short time elapsed between the end of the wader census and hatching, and partly because few other researchers were active in the field this year. But in those found, mean clutch size was normal. In turnstone, for the first time none out of ten clutches held less than four eggs.

Nest predation was recorded in about one third of the nests found. Hence, 2002 was in the upper end of the range of predation experienced during previous years (Table 4.27). This is further reinforced by the fact that most nests were discovered late in the incubation period and hence

	1995	1996	1997	1998	1999	2000	2001	2002
Snow cover on 10 June	84	82	76	80	91	53	84	79
Sanderling		(16 June)	18 June	18 June	23.5 June	16 June	22.5 June	17 June
Dunlin	(18 June)	11.5 June	13 June	16.5 June	22 June	11.5 June	25 June	8 June
Ruddy turnstone	(12 June)	18.5 June	13 June	12.5 June	24 June	11 June	23 June	9 June

Table 4.25. Snow cover on 10 June together with median first egg dates for waders at Zackenberg 1995-2002. Data based on less than 10 nests/broods are in brackets, less than five are omitted. The snow cover is pooled (weighted means) from sections 1, 2, 3 and 4 (see section 4.1), from where the vast majority of the egg laying phenology data originate.

Species	1995	1996	1997	1998	1999	2000	2001	2002
Common ringed plover	(4.00)	(4.00)	(3.50)	(4.00)	(3.50)	(4.00)	(3.5)	(4.00)
Red knot				(4.00)	(4.00)		(4.00)	
Sanderling	(4.00)	4.00	3.86	4.00	3.67	4.00	3.43	3.83
Dunlin		(4.00)	(3.75)	3.90	3.70	3.93	3.63	(4.00)
Ruddy turnstone		3.71	3.79	3.81	3.58	3.75	3.75	4.00

Table 4.26. Mean clutch sizes in waders at Zackenberg 1995-2002. Samples of less than five clutches are given in brackets.

Table 4.27. Predation rate on wader nests at Zackenberg 1996-2002 expressed as minimum and maximum per cent nests depredated of those found with eggs throughout the nesting period. Partially depredated nests 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 total numbers of fox encounters in the bird census area during June-July and the number of fox dens holding pups. Foxes seen on the research station proper are omitted.

Species	1996	1997	1998	1999	2000	2001	2002
Common ringed plover	(100)	(0-25)	(0)	(25)	(0-25)	(25-50)	(0)
Red knot			(0-100)	(50)		(100)	
Sanderling	17	0-40	0-11	21-29	17-33	57	50
Dunlin	(0)	(0)	11-33	0-33	13	13	(25)
Ruddy turnstone	0-29	0-8	27-47	18-55	33-38	20	13-38
Red-necked phalarope				(100)			
All species pooled	13-27	0-17	14-34	20-39	22-28	30-33	26-37
N	15	24	35	41	46	30	19
Fox encounters	14	5	7	13	11	14	21
Fox dens with pups	2	0	1	0	2	2	1?

had to survive relatively short to succeed. By far, most predation must have been by foxes, of which an estimated total of at least two individuals were hunting inside the bird census area during June and July. One den apparently held pups inside the area, but it was deserted in early July. In total, 16 fox encounters took place in June and five in July, in accordance with the estimate that the fox den was deserted in early July. According to the number of winter nests and tracks found in the snow, lemmings were common in June, but they apparently decreased during the summer (see section 4.5 and the section on long-tailed skuas below).

Besides those wader nests found or estimated to have been depredated, one ringed plover nest was apparently depredated after hatching of the first two pulli. In those nest that hatched, one out of four eggs in a sanderling nest held no embryo, while another sanderling egg in a clutch of three had a tiny hole and contained an almost fully developed, but dead embryo. Similarly, one out of four dunlin eggs held no embryo, while two turnstone eggs with almost completely developed embryos had been stepped upon by a musk ox. At least one of the remaining two eggs hatched successfully. Two further turnstone eggs in four egg-clutches only contained small embryos, when the others had hatched.

Numbers of juvenile waders recorded on the tidal delta flats at the coast of Zackenbergdalen were higher for dunlin and ruddy turnstone than recorded previously, while sanderling numbers were relatively low (Table 4.28). The accumulated grand total of 1,040 juveniles may indicate that 2002 was a favourable breeding season for waders in central Northeast Greenland. This particularly applies to turnstones, of which groups of juveniles were recorded almost daily in late July and during August (see also Waders under Other observations below).

Reproductive phenology and success in long-tailed skuas

Lemmings were common in June (see section 4.5), and most likely, all skua pairs produced eggs. That only 14 of the 23-26 pairs (see Table 4.23) were found with eggs, was probably the result of a very efficient fox hunting east of the river during June and early July. Hence, only three pairs hatched young east of the river, while all five breeding attempts west of the river succeeded in hatching young.

The egg laying phenology was the second earliest recorded so far (Table 4.29). The first eggs were laid on 6 June, and the last original clutch was initiated on 14 June. Four re-laid clutches were initiated between 18 and 26 June. Four pairs west of the river succeeded in fledging one young

Table 4.28. 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 20 July – 31 August, 1995-2002. In case of missing counts etc., data have been interpolated.

Species	1995	1996	1997	1998	1999	2000	2001	2002
Common ringed plover	96	126	249	42	44	142	320	140
Sanderling	304	726	149	333	445	366	540	156
Dunlin	325	360	323	232	509	273	326	554
Ruddy turnstone	80	108	82	109	23	73	162	183
Waders total	810	1342	803	722	1021	854	1351	1040

	1996	1997	1998	1999	2000	2001	2001
Median first egg date	–	7.6	12.6	17.6	18.6	15.6	9.6
No. of clutches found	8	17	23	7	5	21	14
No. of young hatched	1	25	16	1	2	18	14
No. of young fledged	0	5	6	1	0	5	4
Lemming winter nests	161	366	721	331	192	326	282

Table 4.29. Egg laying phenology together with breeding effort and success in long-tailed skuas at Zackenberg 1996-2002. Median egg laying date is the date, when half the original clutches were laid, thus excluding clutches estimated to have been replacements. Number of clutches found includes replacement clutches, while number of young fledged is the estimated maximum breeding output of the season. Also given are numbers of lemming winter nests within our 2.16 km^2 lemming monitoring area (see section 4.5).

each, while no breeding attempts east of the river apparently succeeded.

Breeding barnacle geese

Like last year, the first barnacle goose pair with two small goslings appeared at Lomsø on 28 June. This means that egg laying must have started around 27 May, or close to the date in other 'normal' years. On 5 July, seven pairs were present here, and on 9 July the number had grown to 15 families besides six adult pairs without young. On the goose count along the coast to the east on 17 July, 23 pairs with goslings and two pairs without were recorded in Kystkærene, together with nine pairs with goslings and one pair without on the coast between Grænseelv and Halvøen. This means that a total of at least 32 pairs brought their goslings to Zackenbergdalen this year, or more than in any previous year (Table 4.30). On top of this, three pairs apparently lost their broods. Mean brood size of successful families was close to average and decreasing slightly during the season (Table 4.30). Later in August, 13 broods held an average of 1.8 goslings on 16 August, and seven broods held an average of 1.9 on 20 August. Most likely, the families in Kystkærene were scared out into the fjord by a polar bear on 26 July, and they were not back until 2-3 days later.

On a boat trip along the north coast of Clavering Ø from Lerbugt to Djævlekløften and Basaltø on 12 July, a total of five pairs with goslings were encountered on Clavering Ø together with one pair with three newly hatched goslings on the ice-foot below the breeding cliffs on Basaltø. No other barnacle geese were present in the colony, so the span of hatching around Young Sund was probably c. 25 June – 11 July this year.

On the line transect through Store Sødal during 26-28 July, no barnacle geese with goslings were found (see below), but during the aerial musk ox count on 22 July (see section 4.5), five families were recorded in lower Svejstrup Dal. Many more families may have been overlooked in Wollaston Forland and A.P. Olsen Land, however.

The brood size and juvenile percentage on the wintering grounds in Scotland also document a good breeding season for Greenland barnacle geese (Table 4.30), in fact the best since our comparisons started in 1995.

See further below under Other observations.

Line transects

The results of the line transect counts in late July through Store Sødal and between Daneborg and Zackenberg are generally in good accordance with the records from previous years (Tables 4.31 and 4.32). Numbers of moulting immature pink-footed and barnacle geese in Store Sødal were very low, however, and no barnacle goose broods were found this year (see further in section above and on Other observations). The censuses were a bit late in

	1995	1996	1997	1998	1999	2000	2001	2002
Primo July		(3.0)	3.1	(2.9)	1.9	(3.2)	(1.8)	2.4
Medio July		(2.3)	2.7	2.3	1.8	(3.1)	(1.7)	2.4
Ultimo July	(2.0)	(3.0)	2.6	2.2	1.7	3.1		2.3
Primo August	(2.3)	(2.3)	2.4		1.8		(2.0)	2.2
No. of broods	>7	6-7	19-21	>18	29	11	4	32
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23
Per cent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5

Table 4.30. Average brood sizes of barnacle geese in Zackenbergdalen during July and early August, 1995-2002, 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 (Ogilvie 2003).

Table 4.31. Birds recorded (adults; young) during line transect surveys through Store Sødal and from Daneborg to Zackenberg (see map in Meltofte and Thing 1997) in late July 2002.

	Store Sødal 26-28 July	Daneborg 23 July
Red-throated diver	5; 1	
Pink-footed goose	37	
Barnacle goose	138	
Common eider		7
Rock ptarmigan	1; 2	
Common ringed plover	54	7
Sanderling	4; 4	21
Dunlin	20; 4	13; 4
Ruddy turnstone	4; 2	1
Arctic skua		2
Long-tailed skua	6	6
Glaucous gull	10	91
Arctic tern	6	
Common raven		7
Snow bunting	43; 10	5

relation to waders, and a flock of 13 sanderlings was involved in the results for this species. 91 of the glaucous gulls were found in flocks at the outlet of Isdal river.

Sandøen

The arctic terns and Sabine's gulls on Sandøen probably had a poor breeding season. On 16 and/or 26 July, a polar bear visited the island, and most likely it took eggs and young. Anyway, only few tern and gull young were apparently present on the island, when visited by Nette Levermann and Lars Heilmann on 1-3 and 7-21 August (N. Levermann pers. comm.). On 3 August, one eider nest with two eggs, and on 8 August, two tern nests with one egg each was found as the only nests this year. A total of 16 arctic tern pulli were ringed on 3 and 8 August, but further ringing was given up due to cold and wind. Two live Sabine's gull pulli and at least six dead tern pulli were found on 8 August. From 9 August, three days of inclement weather prevailed, and young terns were covered in drifting sand or blown around. At that time both small and larger pulli were present, but most had feathers. On 21 August, flightless young were still present.

Other observations

This section deals with bird observations not reported in the previous chapters. When nothing else is stated, observations refer to the census area in Zackenbergdalen.

Red-throated diver *Gavia stellata*

Already on 1 June, a red-throated diver was sitting on Teltdammen (Table 4.33). This is the earliest observation of birds 'on ground', since the birds in 1997 were just flying over. Two days later, the first bird landed on the breeding pond in Sydkærene, and from 3 June the pair was present and displaying intensively. From then

Table 4.32. Total numbers of birds recorded (adults; young) during line transect surveys through Store Sødal and from Daneborg to Zackenberg, mid-late July 1997-2002. Brackets denote interpolated figures.

	1997	1998	1999	2000	2001	2002
Red-throated diver	3	2		2	3	5; 1
Great northern diver				2; 1		
Pink-footed goose	263	123	27	56	85	37
Barnacle goose	182	250; 23	227; 23	261; 14-16	260; 1	138
Goose sp.	25					
Common eider	390	119; 5	55; 6	10	11; 6	7
Long-tailed duck	13		2			
Rock ptarmigan	2	1				1; 2
Common ringed plover	71	70	(78)	(105; 4)	63; 1	54
Red knot	1			3		
Sanderling	14; 1	10	33	11; 6	12	25; 4
Dunlin	64; 1	62; 1	(56)	48	62	33; 8
Ruddy turnstone	6	8	8	6	2	5; 2
Arctic skua						2
Long-tailed skua	13	9	14	4	21	12
Glaucous gull	11	11; 2	8	(7)	10	101
Arctic tern	3	9	1	3	8	6
Snowy owl					1; 3	
Common raven	10	9	2	(5)	4	7
Snow bunting	104	64; 2	(54)	(30; 6)	110; 1	48; 10

	1996	1997	1998	1999	2000	2001	2002
Red-throated diver	4.6	30.5	3.6	4.6	6.6	3.6	1.6
King eider	12.6	4.6	15.6	16.6	22.6	9.6	11.6
Long-tailed duck	1.6	30.5	2.6	6.6	6.6	7.6	3.6
Red-necked phalarope	5.6	30.5	5.6	10.6	7.6	4.6	5.6

Table 4.33. Dates of first observation of selected bird species at Zackenberg 1996-2002.

on, they were on and off, until a bird was sitting on the small nest mound in the middle of the pond on 16 June. The joy was short, since a fox emptied the nest on 24 June, whereupon the birds were seen irregularly on the ponds until August. Most likely, the same birds visited the ponds in Gadekæret at least two times in June, where they checked out the nest mounds.

Strangely, an adult with one young appeared on the large pond in Sydkærene on 7 August, and they were still present three days later. This family, at least theoretically may have been the birds from Lindemanssø (see below). We have one more similar observation of an adult with a large "pull." in Tørvedammen on 1 August 1997, but this observation has so far been considered doubtful.

On 10 June, a pair was seen for the first time on Lomsø. They were on and off until a bird was sitting on a mud nest on 23 June, but already on 26 June the place was deserted. On 7 July, a bird was sitting on a new nest, but none were seen on the nest again. Up to three birds were seen regularly on the lake until early August.

On 20 June, a pair was building on a nest in Ryledammene, and on 2 July a bird was sitting on the nest, but already on 4 July, no birds were present.

On 18 July, a bird was sitting on a small islet in the lake north of Halvøen, and one further bird was present on the lake, but none were found here on 29 July.

On 24 July, a bird was incubating two eggs on the shore of Vesterport Sø, where no divers had been present on 24 June. It was recorded again on 28 and 30 July and on 5 August, and on 15 July, an adult with two pulli were present on the lake. No birds were seen on nearby Hestehalesø this year.

Finally, on 26 July a pair had a large pull on Lindemanssø, and on 5 July they were seen again.

Hence, a total of 5-6 pairs of red-throated divers nested in Zackenbergdalen this year, and at least two of these pairs probably succeeded to raise three young. The rest were most likely depredated by foxes.

During all of the summer, singles, pairs and groups of up to five red-throated divers were seen flying over Zackenbergdalen, and the first birds – a pair – were feeding in the mouth of Zackenbergelven on 21 June. During the waterbird counts in the deltas of Zackenbergelven in late July and all of August, up to eight red-throated divers were seen on the fjord (3 pairs +1 +1). Since one more pair was present in Sydkærene at the same time, and at least two other birds were attending eggs or young, a total of at least six pairs must have been present in the area, in accordance with the records presented above. Birds from further up Store Sødal may, however, be among the birds on the fjord.

Northern fulmar *Fulmarus glacialis*

Fulmars were seen in the outer part of Young Sund several times in August (N. Levermann pers. comm.).

Pink-footed goose *Anser brachyrhynchus*

On 1 June, a pair of pink-footed geese flushed from the old nestsite west of the river. They were not seen again, when checked on 14 June, nor later in the season.

2-6 birds were seen a number of times on other sites in early June, until the first birds on moult migration – seven flying into Tyrolerfjord – appeared on 17 June. A total of about 400 passed until 3 July and a further 12 latecomers on 11 July. During the same period, an added total of about 125 were staging or rambling in the valley.

11 flightless individuals were encountered on the north coast of Clavering Ø on 12 July, and a total of 30 flightless birds were found around Halvøen during a survey of the coast of Zackenbergdalen on 17 July. A total of 37 was recorded during the line transect count through Store Sødal on 26-28 July (see above). Of these, 27 were found at the large lake in the upper part of the valley, and eight at Store Sø. 16 were able to fly. This means that only about 67 pink-footed geese moulted in the study

area this year, against a maximum of at least 590 in 1995 (Meltofte and Thing 1996). Many hundreds were moulting at a large lake on north-western Storsletten, when passed during an air borne musk ox census on 22 July (see section 4.5). In this area, 1,670 moulting pink-footed geese were recorded during a previous aerial survey in early July 1988 (Bay and Boertmann 1989).

An added total of about 225 staging and migrating birds were recorded in the valley during 17-31 August. The largest flock held 110 individuals.

Two pairs were found in a colony of barnacle geese and glaucous gulls etc. in a ravine about 5 km north of Revet in Payer Land on 4 June (K.O. Lennert pers. comm.).

Barnacle goose *Branta leucopsis*

Up to about 20 barnacle geese were seen almost daily in late May and all of June. In late June, a moulting flock of 86 immature birds began to gather at Lomsø, where the first apparently flightless birds were recorded on 30 June. A further 80 moulting individuals were counted east of Halvøen during the total survey of the coast on 17 June. Of the 138 moulting barnacle geese recorded during the line transect census through Store Sødal on 26-28 July, 81 were found at Store Sø and along Zackenbergelven in the lower part of the valley, while 57 were moulting at lakes in the upper part of the valley. Hence, a grand total of 304 moulting barnacle geese were recorded in our study area this year, which is in the same order of magnitude as in previous years, except for 2001, when a maximum of 500 were found (Caning and Rasch 2003). (See also section on breeding barnacle geese.)

During the air borne musk ox census on 22 July (see section 4.5), flocks of 15+50+100 geese supposed to be barnacles were recorded on western Storsletten. A further 20 barnacle geese were found at Kap Schumacher, 50 in the valley west of the cape and 100 in lower Svejstrup Dal.

The first flying immatures were seen on 26 July, and from early August flocks appeared inland. In late August, flocks of up to 310 were recorded in Zackenbergdalen.

Outside the study area, 10 pairs of barnacle geese were found in a colony of glaucous gulls etc. in a ravine about 5 km north of Revet in Payer Land on 4 June (K.O. Lennert pers. comm.).

Common teal *Anas crecca*

During 11-23 June, a male teal was seen five times on the ponds around the research station. This is one of the northernmost records in East Greenland (Boertmann 1994).

Common eider *Somateria mollissima*

A pair of eiders landed in Sydkærene on 12 June, and from 21 June groups of up to 16 males and females were seen off the mouth of Zackenbergelven. Now and then eiders were seen on lakes, and on 28 July a depredated nest was found west of Zackenbergelven.

About 50 males and females were found along the north and east coast of Clavering Ø on 12 July, and on 17 July the first broods were seen east of Halvøen. More family groups appeared during late July, and in August up to 52 adult females and 37 pulli were counted off the deltas of Zackenbergelven. The last male was seen on 7 August.

The Sirius Military Sledge Patrol counted 2,606 nests in the colony among the tethered huskies at Daneborg. About 10% of the nests were deserted. This is the first time since 1975 that the colony has been counted, and the number was somewhat lower than expected (see section 4.4 in Caning and Rasch 2003). In 1975, the colony held 1,300 nests (Meltofte 1978). Similarly at Danmarkshavn Weatherstation, 300 km further north, at least 100 eiders are nesting among the sledge dogs (weather station personnel pers. comm.).

King eider *Somateria spectabilis*

Two pairs of king eiders were seen on the ponds of Gadekæret and Sydkærene on 11 June, or close to the date of first observation in other years (Table 4.33). A maximum of 3-4 pairs and one male with two females were found on 17 June. On 20 and 23 June, a female 'test-nested' on islets in Gadekæret, but opposite to previous years, no birds were found nesting here, possibly due to fox predation, since a fox swam out to the nesting mound on 26 June.

The last – solitary – male was seen in the delta of Zackenbergelven on 28 June, and in July up to five females were seen on lakes and on the fjord until 17 July. No firm proof of breeding was recorded.

Long-tailed duck *Clangula hyemalis*

A male long-tailed duck arrived on the ponds in Sydkærene on 3 June, or close to average for the previous years (Table 4.33). Pairs and single males were seen almost daily from then on, culminating with seven pairs and four single males on 10 June. Some of these may have been recorded twice, however.

On 3 July, a nest with six fresh eggs were found north of Halvøen, but on 10 July it had been depredated, probably by a fox, since the nest was less than 300 m from Fox den no. 10. On 9 July, an egg predated by a bird was found south of Tørvedammen. On 27 July, a female with four a-few-days-old ducklings were found on Lomsø, where they were seen again on 29 and 31 July and 2 August. In the lake north of Halvøen, a female with three ducklings were found on 8 August.

Up to two pairs plus 4-6 males and 5-8 females were seen on Lomsø and Kystkærene on 9 July and up to 21 on the fjord on 14 and 17 July. In August, up to six long-tailed ducks were recorded in Lomsø and on the fjord.

Gyr falcon *Falco rusticolus*

No gyr falcons were seen in Zackenbergdalen in June and July. However, on 4 June a pair was found in a colony of barnacle geese and glaucous gulls etc. in a ravine about 5 km north of Revet in Payer Land (K.O. Lennert pers. comm.).

An adult was seen over the research station on 6 August and a grey bird on 17 August.

Rock ptarmigan *Lagopus mutus*

A male was seen five times on the slopes of Aucallabjerg, besides a pair at lower Kærelv on 8 June. None were seen in Zackenbergdalen in July and August.

On Basaltø, a male was encountered on 12 July, and on 27 July a female was found with two very small pulli in innermost Store Sødal. A female with 10 "3/4-sized" pulli was encountered at Herschellhus on 2 August (Nanok team pers. comm.).

Waders *Charadrii*

The breeding season of 2002 was quite favourable for the waders at Zackenberg. Snow cleared fast and no severe weather events occurred during the summer (see section Reproductive phenology and success in waders). Common ringed plovers *Charadrius hiaticula*, red knots *Calidris canutus*, sanderlings, dunlins *Calidris alpina* and ruddy turnstones *Arenaria interpres* were all seen during the first days after our arrival, and song and other territorial display was recorded from the same days. No pre-breeding concentrations on communal feeding sites were recorded in early June.

A few post-breeding flocks were seen in early July, such as four knots both on 3 and 6 July, 3+5 sanderlings on 6 July, and six knots, one sanderling and one turnstone on 9 July. On 10 July, flocks of 11 and 17 sanderlings were recorded, and similarly flocks of 20+5+4 on 14 July. From mid July flocks were found feeding on the coast, and the waterbird counts in the old and the present delta of Zackenbergelven every third day from 20 July until 28 August yielded maximum figures of six adult ringed plovers on 7 August, 52 adult sanderlings both on 23 and 26 July, 95 adult dunlins on 1 August and four adult turnstones on 29 July. A further 11 adult ringed plovers were feeding together with nine juvenile turnstones on the dry heath south of the research station on 3 August. The only knots seen after the breeders and post-breeders in early July, were three adults and six juveniles in the deltas of Zackenbergelven on 13 August.

The first independent juvenile waders were seen on 26 July (sanderling, dunlin and turnstone) and 7 August (ringed plover). Maximum numbers of juveniles in the deltas were 34 ringed plovers on 13 August, 27 sanderlings (one with ring from local population) on 1 August, 149 dunlins on 13 August, and 34 turnstones already on 29 July, besides 24 on 10 August, and 28 on 16 August.

European golden plover *Pluvialis apricaria*

On 5 July, a golden plover was heard flying over Zackenbergdalen.

Sanderling *Calidris alba*

Again this year, sanderling nests were checked for the colour of incubating birds (see Caning and Rasch 2001). One nest was checked 31 times between 24 June, when the four eggs had been incubated for three days, and 14 July, when three eggs had hatched (the last egg was infertile). At 29 visits, the adult was present and appeared to be the same female-coloured individual behaving similarly at most visit (sitting tight on the nest or walking around close by). At the remaining two visits, no birds were present. At four other nests, a male-coloured bird was recorded three and four times, respectively, and a female-coloured bird also three and four times, respectively. Hence, two birds were not seen at any nest. Five broods were attended by one male-coloured, three female-coloured and one intermediate adult, respectively.

Pectoral sandpiper *Calidris melanotos*
On 10 July, two female pectoral sandpipers were found north of Lomsø. This is observation no. six of this species in East Greenland (Rasch 1999).

Purple sandpiper *Calidris maritima*
A juvenile purple sandpiper was recorded during the waterbird count in the old delta of Zackenbergelven on 22 August. This is the first observation at Zackenberg, but the species is breeding sporadically along the outer cost north to Germania Land (Meltofte *et al.* 1981).

Red-necked phalarope *Phalaropus lobatus*
On 5 June, the first female red-necked phalarope appeared in Gadekæret (Table 4.33). On 10 June, three were present, and on 12 June they appeared to be one pair plus one male. From then on, only the pair was seen until 30 June. They were not giving alarm calls, and possibly their nest had been depredated. However, on 19 July a male gave alarm calls in the southern part of Sydkærene, but no indication of young was found later. Two males were encountered at Lomsø the next day, and on 30 July a male gave intensive alarm calls at Vesterport Sø, but again, no further signs of young could be found.

Red phalarope *Phalaropus fulicarius*
No red phalaropes were recorded this year.

Arctic skua *Stercorarius parasiticus*
A pair of light-morphed arctic skuas performed intensive distraction behaviour on the coastland off Lille Sødal (north of Daneborg) on 23 July. So, most likely it was single individuals from this breeding pair that were seen at Zackenberg five times between 16 June and 1 August, and both of them chasing an ivory gull at Sandøen on 6 August. Furthermore, one dark bird passed Zackenbergdalen on 29 June, and an immature likewise on 26 July.

The pair at Lille Sødal is one of the northernmost – if not the northernmost – breeding record so far in Northeast Greenland (Boertmann 1994).

Long-tailed skua *Stercorarius longicaudus*
Long-tailed skuas were already present, when we arrived on 31 May, and display, copulation and food delivery was observed from the very first days. Due to the heavy predation by foxes (see chapter above on Reproductive phenology and success in long-tailed skuas), territories started to break down already in late June, and communal flight displays were seen. On 20 July, about 10 joined about 125 glaucous gulls feeding around a pod of about 50 narwhals in the fjord off Zackenbergdalen (see Other observations in section 4.5).

A one year old immature was seen on 6 July, and one probably also one year old on 30 July. The first – poorly – flying young was seen on 24 July, and during late July and early August, most adults left. The last birds – a pair – were seen on 21 August.

Great skua *Stercorarius skua*
On 25 July, two great skuas flew in over Zackenbergdalen, but they returned after heavy mobbing by long-tailed skuas.

Sabine's gull *Larus sabini*
See chapter above on Sandøen.

Glaucous gull *Larus hyperboreus*
During June, up to four glaucous gulls were hunting lemmings on the snow, flying along the river, feeding in the delta, on remains from a shot seal and on a dead musk ox. Similar numbers were recorded in July, when also two immatures were seen on 1 July. However, c. 20 were seen on the coast southeast of Zackenbergdalen on 17 July, and on 20 July, about 125 were feeding around a pod of about 50 narwhals in Young Sund off the valley. Some were feeding very intensively on concentrated spots as if there were fish shoals at the surface. Still, c. 60 were feeding at the river outlet near Pashytten on 31 July and 1 August, and on 13 August, 63 adults and 23 immatures were counted in the deltas of Zackenbergelven. These are the highest figures recorded so far in our study area.

Nine pairs were counted on Basaltø on 12 July, where Rosenberg *et al.* (1970) found six pairs in 1964, but where Pedersen (1934) without any details states 30 pairs in 1931-1933. Outside the study area, about 20 pairs of glaucous gulls were found in a colony of barnacle geese etc. in a ravine about 5 km north of Revet in Payer Land on 4 June (K.O. Lennert pers. comm.).

The first three juveniles were seen in the deltas of Zackenbergelven on 25 August, whereupon juveniles were seen almost daily until our departure on 31 August.

Black-legged kittiwake *Rissa tridactyla*

An estimated total of 200-300 kittiwakes – both adults, immatures and juveniles – were encountered on Sandøen and over outer Young Sund on 24 August (L.A. Kyhn and N. Levermann pers. comm.).

Ivory gull *Pagophila eburnea*

One was encountered at Sandøen on 6 August, where it was mobbed by two arctic skuas until it regurgitated food.

Arctic tern *Sterna paradisaea*

Besides the breeding birds on Sandøen (see chapter above on Sandøen), the only observation was of 30-50 terns fishing at the coast far south-east of Halvøen on 17 July.

Snowy owl *Nyctea scandiaca*

No snowy owls were seen this year.

Northern weathear *Oenanthe oenanthe*

Not a single weathear was seen this summer.

Common raven *Corvus corax*

1-3 ravens were seen more or less regularly in June, and from 1 July, a family of 3-5 was found regularly in the valley during the rest of July and all of August. At least three were juveniles.

Outside the study area, a pair was found in a colony of barnacle geese and glaucous gulls etc. in a ravine about 5 km north of Revet in Payer Land on 4 June (K.O. Lennert pers. comm.).

Arctic redpoll *Carduelis hornemanni*

Besides three in fierce fight on 1 June, only single individuals were heard or seen flying over the valley three times in June.

Snow bunting *Plectrophenax nivalis*

Snow buntings were singing during all of June and early July. A juvenile just able to fly was seen on northern Clavering Ø on 12 July, but in Zackenbergdalen juveniles were not recorded until 18 July. In late August, flocks of up to 30-40 were seen.

4.5 Mammals

Thomas B. Berg

Observations on mammals were recorded by Hans Meltofte (31 May – 5 August), Line A. Kyhn (31 May -31 August) and Thomas B. Berg (2 July – 31 August). Most other personnel supplied additional random observations during the entire field season. The census area for collared lemming was surveyed for winter nests during 6 July – 26 August. Total numbers of musk oxen including age and sex data were censused once a week within the 40 km^2 musk ox census area during 3 July – 28 August. During the entire season, additional counts were made almost daily from the roof of a house on the research station (between 8 pm and 11 pm) scanning the area from Lindemansdalen along the coastline to Lille Sødal north of Daneborg whenever weather conditions permitted. During these counts, arctic hares on the east-facing slope of Zackenberg mountain were also recorded. Similarly, the number of seals on the fjord ice in Young Sund were recorded until the ice became too fragmented on 6 July.

An aerial survey for musk oxen and geese covering most of the relevant musk ox habitats on Wollaston Forland and A.P. Olsen Land was conducted on 22 July. The line transect Daneborg – Zackenberg was walked by Line A. Kyhn and Thomas B. Berg on 23 July, and the transect Zackenberg – Store Sødal was walked during 26-28 July by the same persons.

All 10 known fox dens within our 50 km^2 study area and one just outside the eastern border (Kuhnelv) were checked regularly for occupation, and the only den known between Daneborg and Kuhnelv was checked on 23 July. All observations other than lemmings, foxes and musk oxen are presented in the section on 'Other observations', where scientific names for all species are also given.

Collared lemming population

A total of 282 fresh winter nests was recorded within the 2.05 km^2 census area (Table 4.34). After the increase from 2000 to 2001, the winter population was expected to peak during the winter 2001-2002,

Table 4.34. Annual numbers of recorded winter nests and summer burrows within the 2.05 km² census area in Zackenbergdalen 1995-2002 together with the numbers of animals encountered by one person (same effort each year) within the 19 km² bird census area during June-July. Numbers from previous years have been corrected following a review of the data. Category 1 denotes nests from the previous winter, category 2 are nests from earlier winters that were not recorded previously.

	Nests cat. 1	Nests cat. 2	Summer burrows	Animals seen
1995	285	821	–	–
1996	161	262	–	0
1997	366	113	789	1
1998	721	114	335	43
1999	331	57	455	9
2000	192	69	400	1
2001	326	21	916	11
2002	282	29	–	4

but the density remained at an intermediate level equal to the previous year. Only four lemmings were observed by Hans Meltofte during bird census in June and July (Tables 4.34). Lower numbers of lemming winter nests were recorded during the line transects through Store Sødal and from Daneborg to Zackenberg than in 2001 (Table 4.35). At Karupelv, c. 220 km south of Zackenberg, the lemming population remained at a low density for the third year in succession (Figure 4.3).

Numbers of lemming winter nests depredated by stoat have remained almost the same for three years now, but the proportions of nest predation have changed (Figure 4.3). At Karupelv, the number of nests depredated by stoats doubled from 2001 to 2002 but the proportion remained at about the same level.

Section	Distance km	Winter nests No.	No./km	Summer burrows No.	No./km
Store Sødal					
1996	150	2	0.013	1	0.007
1997	300	11	0.067	9	0.030
1998	150	21	0.140	6	0.040
1999	160	3	0.019	0	0.000
2000	160	1	0.006	0	0.000
2001	160	13	0.081	38	0.238
2002	160	9	0.056	–	–
Daneborg – Zackenberg					
1997	50	22	0.440	21	0.420
1998	50	17	0.340	1	0.020
1999	50	1	0.020	0	0.000
2000	40	0	0.000	1	0.025
2001	40	24	0.600	50	1.250
2002	40	5	0.125	–	–

Table 4.35. Records of lemming winter nests and active summer burrows obtained along the transects Zackenberg–Store Sødal (80 km) and Daneborg–Zackenberg (25 km) 1996-2002. Nests and burrows were recorded within 3 m on each side of the two observers, giving total transect length of 160 km and 50 km, respectively. Deviations from this appear from the table.

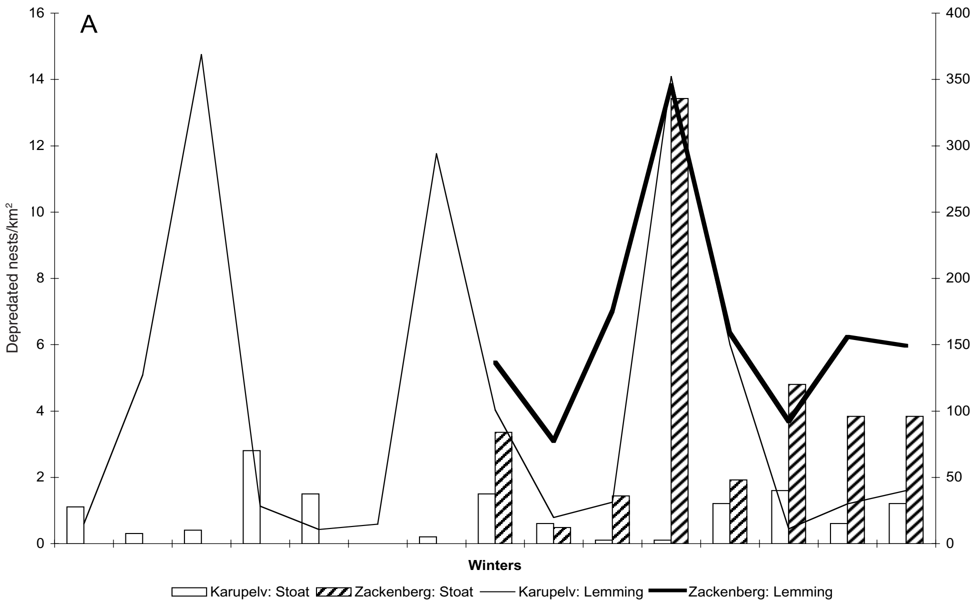
The 29 fixed sampling sites for predator casts and scats were checked on 29 August (Table 4.36). Compared with 2001 data, the number of casts from skuas remained much the same, while numbers of casts from snowy owl, and scats from fox and stoat increased three-, two- and five-fold, respectively. Differences in ecosystem composition between Karupelv valley and Zackenbergdalen and in particular differences concerning densities of snowy owls and stoats have been discussed earlier (see section 4.4 in Caning and Rasch 2000, 2001 and Berg 2002). The increase in the number of casts from snowy owls was expected, as 2001 was the best breeding season recorded so far for snowy owls in Wollaston Forland with two nests within 50 km² and several in other parts. 1997 was the last time a breeding pair of snowy owls was recorded at Zackenberg (see section 4.3 in Meltofte and Rasch 1998) resulting in a high number of snowy owl casts recorded in 1998 (Table 4.36). At Karupelv valley, up to 20 nests within 50 km² can be found in lemming peak years (Sittler 2000). The five-fold increase in the number of stoat scats follows the trend from earlier. At least at Zackenberg, the stoat may respond the same year to an increase in lemming density. The fact that two pairs of snowy owls were present in Zackenbergdalen in 2001 and that stoats were present at relative high densities might be one of the possible explanations for the failure by the collared lemming in reaching a winter population peak during 2001/2002.

Musk ox population biology

The daily censuses of musk oxen in Zackenbergdalen and on adjacent slopes (135

	Skua casts	Owl casts	Fox scats	Stoat scats
1997	44	0	10	1
1998	69	9	46	3
1999	31	3	22	6
2000	33	2	31	0
2001	39	2	38	3
2002	32	6	67	16

Table 4.36. Numbers of casts and scats from predators collected from 29 permanent sampling sites within the 2.05 km² lemming census area in Zackenbergdalen. The samples represent the period from mid/late August the previous year to August in the year denoted.



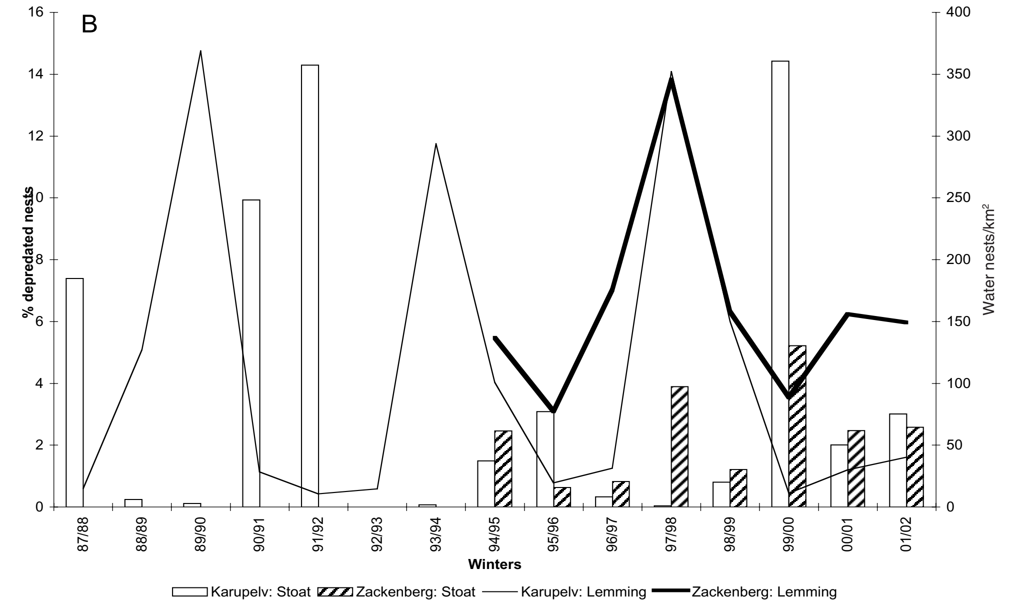


Figure 4.3. Lemming winter nests (right axis) and stoat predation on lemming nests (left axis) at Karupelv, Traill Ø (10 km²; c. 220 km south of Zackenberg) and within the census area in Zackenbergdalen (2.05 km²). Data include nests built from October until May. Nest predation by stoat is given both in actual numbers of depredated nests (A) and as percent of total numbers of lemming nests (B). Benoît Sittler kindly provided data from Karupelv (partly published by Sittler 1995 and 2000).

km²) from a fixed point at the station showed a pattern similar to 2001, which differed remarkably from previous years (1996-2000). High numbers of musk oxen were recorded in June, but mainly outside the 40 km² census area. Totals decreased towards 1 July, whereupon numbers followed the patterns of previous years (Figure 4.4). Inside the census area, densities were at the same level as the average of 1996-2000.

The dynamics of habitat use by musk oxen in Zackenbergdalen varies a lot between years. The timing of immigration by musk oxen from the adjacent valleys into Zackenbergdalen in June/July may differ by 20 days, and the per cent snow cover the previous year correlates significantly

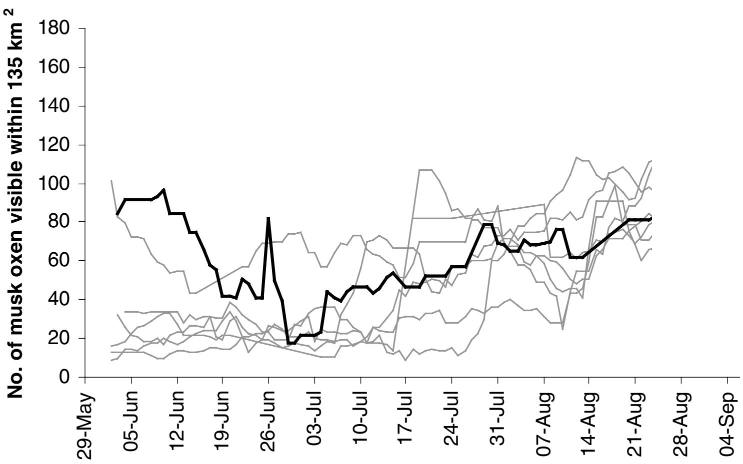


Figure 4.4. Numbers of musk oxen (one week running means) recorded daily during 2002 from a fixed elevated point at the research station (heavy line) compared to similar data from previous years (thin lines). The visible area is about 135 km².

Table 4.37. Accumulated numbers of 'musk ox days' per month counted as one musk ox in one day within the 40 km^2 census area in Zackenbergdalen based on the daily counts from a fixed elevated point at the research station 1996-2002.

	June	July	August	Total
1996	445	445	2412	3302
1997	290	1086	1432	2807
1998	522	635	1121	2278
1999	361	392	1292	2045
2000	478	898	1543	2919
2001	923	1257	1689	3868
2002	418	448	1819	2684

with the preferred altitude for foraging in the beginning of July the following year (Forchhammer 2002).

The water level in Zackenbergelven remained high until the second part of July preventing musk oxen coming from the inland through Store Sødal south of Zackenbergelven to cross the river. Due to this, an unusual big aggregation of 50 musk oxen was recorded west of Zackenbergelven on 19 July.

Numbers of 'musk ox days' within the 40 km^2 census area were within the range recorded in earlier years (Table 4.37). The maximum number of musk oxen recorded within the 40 km^2 census area on the weekly censuses was 145 individuals on 17 August. Including the musk oxen outside the census area (135 km^2 in total) on the same count, the total was 175, which is the highest number recorded so far in one census.

During the two transects Daneborg-Zackenberg and Zackenberg-Store Sødal 23-28 July, a total of 175 animals was recorded (Table 4.38). These records showed a fairly constant proportion of cows over the years (Table 4.39). Data on musk ox observations from the line transects are presented in condensed form for year to year comparison in Table 4.40. The calf:cow ratio was 0.32:1, which is in the lower end compared with previous years (Table 4.39). Considering only the number of cows without a calf recorded in 2001, 'all' cows gave birth to at least one calf that was still alive in August 2002 (Figure 4.5). 66% of the cows present in August 2002 had a reproductive potential (*i.e.* cows without a calf), which is close to the previous six years average of 60% (range 42-83%). It is though noteworthy that data and field observations on flock structure at Zackenberg strongly suggest that cows occasionally have twins and/or occasionally give birth in two consecutive years.

Four fresh musk ox carcasses were recorded inside the 40 km^2 census area, and one carcass of a male calf was recorded outside the area on Palnatoke Bjerg (Table 4.41). Two carcasses – a three year old cow and a 15+ year old bull – were

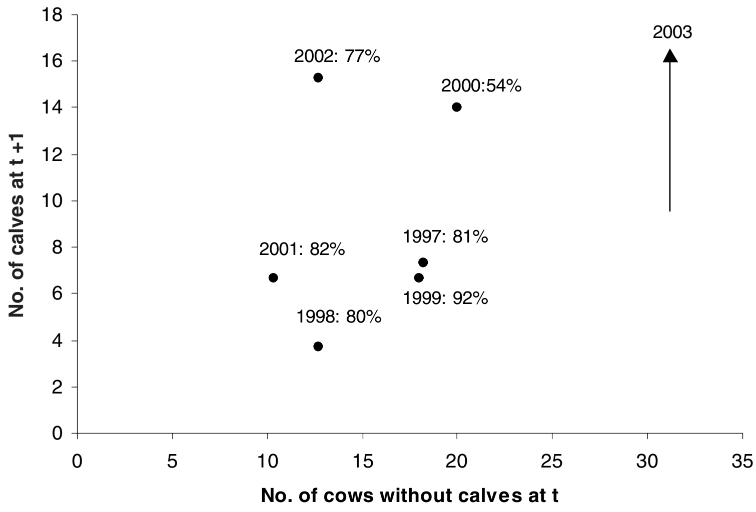
Table 4.38. Sex and age distribution (actual numbers) of musk oxen based on total counts along the two line transects and the related total census in Zackenbergdalen in 1997-2002. All counts were made within 16-30 July and covered an area of about 200 km^2. Possible double counts have been omitted.

Year	Calf	F1	M1	F2	M2	F3	M3	F4+	M4+	Total
1997	13	5	6	13	14	8	2	32	10	103
1998	11	6	7	8	8	8	7	44	23	122
1999	24	0	0	9	8	13	7	58	52	171
2000	25	6	7	4	1	7	6	47	44	147
2001	27	10	7	6	7	6	1	58	38	160
2002	21	11	10	12	10	10	4	56	41	175

	Calf/ cow	1 yr/ cow	2 yrs/ cow	Calf	1 yr	2 yrs	3 yrs male	Ad. female	Ad. male	N
1997	0.32	0.28	0.67	12.6	10.7	26.2	1.9	38.9	9.7	103
1998	0.21	0.25	0.31	9.0	10.6	13.2	5.7	42.7	18.9	122
1999	0.34	0.00	0.24	14.0	0.0	10.0	4.1	41.5	30.4	171
2000	0.46	0.24	0.09	17.0	8.9	3.4	4.1	36.8	29.9	147
2001	0.42	0.27	0.20	16.8	10.7	8.2	0.6	40.1	23.8	160
2002	0.32	0.32	0.33	12.0	12.0	12.6	2.3	37.7	23.4	175

Table 4.39. Proportions of calves, one year old, and two year old subadults in relation to adult cows (three years or older; first three columns), together with the sex and age distribution (per cent) of musk oxen based on total counts along the two line transects and the related total census in Zackenbergdalen 1997-2002. All counts were made within 16-30 July and covered an area of c. 200 km^2. Possible double counts have been omitted.

Figure 4.5. Average numbers of calves during the weekly censuses in August plotted against the number of cows without calves in August the previous year (total number of cows 3 years or older minus the number of calves). The arrow indicates the range of expected number of calves in 2003. The per cent values denote the snow cover in Zackenbergdalen on 10 June of the given year related to the number of calves given on the y-axis.



possibly wolf kills. The variation in numbers of musk ox carcasses from year to year is presented in Table 4.42.

Aerial survey

On 22 July, a survey covering Wollaston Forland and A.P. Olsen Land was conducted using a Twin Otter plane. Flight altitude was 200-300 m above ground, and the ground speed ranged between 150 and 200 km/h. One observer was situated between the two pilots, and two observers were situated in the back covering each side of the plane. The total route was about 400 km, and observation distances were estimated to reach 2 km to each side of the plane depending of light conditions and topography. Unfortunately, the survey took place late in the day (7:30 pm –10 pm), so that low sun prevented observations on several valley slopes, which were in deep shade, or directly towards the sun.

The route was planned to follow valleys and lowlands in order to cover the most important musk ox habitats of the area. The total area of Wollaston Forland and A.P. Olsen Land is about 2,850 km^2, and

	Store Sødal	Zackenberg	Daneborg-Zackenberg	Zackenberg 10 June Snow cover (%)
Musk oxen/km^2				
1996	0.37	0.33	–	77
1997	0.39	1.58	0.13	81
1998	0.62	1.18	0.86	80
1999	0.78	1.20	0.70	92
2000	0.25	2.10	0.22	54
2001	0.31	3.38	0.92	82
2002	0.69	1.68	0.30	77
Faeces piles/km				
1997 winter/summer	1.59 / 0.49	–	4.90 / 0.82	81
1998 winter/summer	1.55 / 0.39	–	1.14 / 0.68	80
1999 winter/summer	6.26 / 1.63	–	3.66 / 2.46	92
2000 winter/summer	2.33 / 0.38	–	0.90 / 0.22	54
2001 winter/summer	5.54 / 1.11	–	2.10 / 0.36	82
2002 winter/summer	4.16 / 1.53	–	3.78 / 0.48	77

Table 4.40. Musk ox densities (animals/km^2) in Store Sødal (92 km^2 in 1996-1998 and 125 km^2 in 1999 and onwards), in the census area in Zackenbergdalen (40 km^2) and in the coastal region between Daneborg and Zackenberg (37 km^2) in mid/late July 1996-2002. The density of faeces piles (no. of piles/km walked) in Store Sødal (150 km in 1997-1998 and 160 km in 1999 and onwards) and from Daneborg to Zackenberg (50 km).

ID. no.	UTM East	UTM North	Sex	Estim. age	General remarks
2002-1	512376	8272095	M	calf	Vertebra removed by fox/wolf
2002-2	513943	8266593	M	12+	No sign of wolf
2002-3	515937	8264622	F	3	In good condition. Eaten by wolf
2002-4	487488	8269605	F	15+	Eaten by wolf
2002-5	512648	8265132	M	15+	Eaten by fox and raven
					Bone filled with fly pupae

Table 4.41. Fresh musk ox carcasses recorded during the summer of 2002.

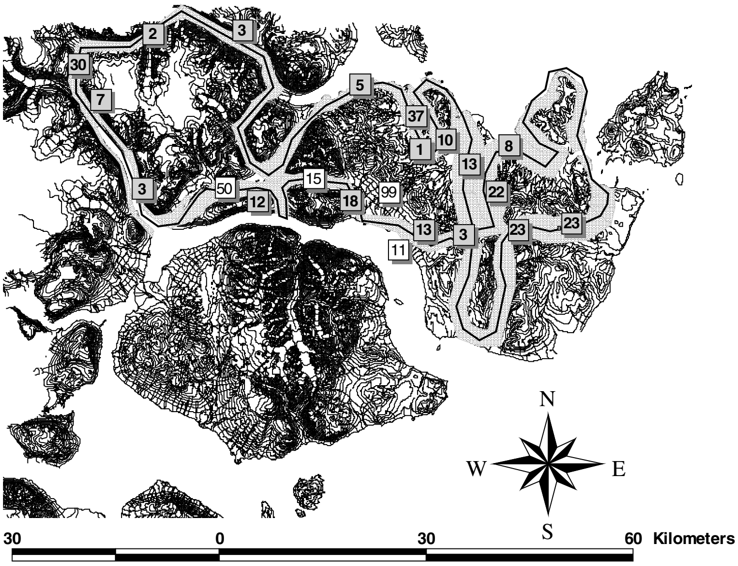


Figure 4.6. Aerial survey of A.P. Olsen Land and Wollaston Forland on 22 July 2002. The 400 km transect is indicated by a black line and the area estimated to have been covered is shaded. Light textboxes show numbers recorded on ground during the two transects: Daneborg-Zackenberg (23 July), Zackenberg-Store Sødal (26-28 July), and the total count in Zackenbergdalen on 30 July. Grey textboxes show numbers recorded during the aerial transect.

850 km² or 30% were covered from the plane (Figure 4.6). The remaining 70% include steep barren mountain slopes, glaciers and a lowland area in the south-eastern corner of Wollaston Forland which unfortunately was not covered. 234 musk oxen were recorded during the two and a half-hours flight (Figure 4.6). The two line transects (23-28 July) and the corresponding total count in Zackenbergdalen (30 July; see Table 4.38) providing a total of 175 musk oxen, covered a minor part of the aerial survey.

Very big differences were found between these ground surveys and the airborn transect (Figure 4.6). In Store Sødal, this difference was mainly due to poor observation conditions from the plane. In Zackenbergdalen, numbers of musk oxen recorded from the plane were low, as we were busy with take off and landing. Hence, none of these areas were well covered. Omitting possible double counts from the air and ground surveys, a combined total of 368 musk oxen were recorded. Considering the biases in connection with the aerial survey we conclude that the musk ox population on Wollaston Forland and A.P. Olsen Land was within the range of 500-800 animals earlier estimated by Boertmann and Forchhammer (1992) based on one aerial survey as well as

Table 4.42. Fresh musk ox carcasses recorded during the field seasons of 1995-2002. F = female, M = male. 'Thaw days' are number of days with positive temperatures and possibly ice crust during the snow covered periods from October to April (>5 cm).

	Snow cover 10 June (%)	Thaw days	Total carcasses	4+ yrs F / M	3 yrs F / M	2 yrs F / M	1 yr F / M	Calf
1994-1995	76	?	2	0 / 1	0 / 0	0 / 0	0 / 0	1
1995-1996	77	5	13	7 / 1	0 / 1	0 / 2	1 / 1	0
1996-1997	81	3	5	0 / 2	0 / 0	1 / 0	1 / 0	1
1997-1998	80	6	2	0 / 2	0 / 0	0 / 0	0 / 0	0
1998-1999	92	5	1	0 / 1	0 / 0	0 / 0	0 / 0	0
1999-2000	54	3	8	0 / 6	1 / 0	0 / 0	0 / 0	1
2000-2001	82	0	4	0 / 4	0 / 0	0 / 0	0 / 0	0
2001-2002	77	1	5	1 / 2	1 / 0	0 / 0	0 / 0	1

Table 4.43. Numbers of known fox dens in use, numbers with pups and the total number of pups recorded at their maternal dens within the 50 km² fox census area in Zackenbergdalen. 'W' and 'D' denote white and dark colour phase pups, respectively.

Year	No. of known dens inside/ outside	No. of dens in use inside/ outside	No. of breed. dens inside/ outside	Total no. of pups recorded	No of muskox carcasses	Lemming winter population
1995	2 / 0	0 / 0	0 / 0	0	2	decrease
1996	5 / 0	4 / 0	2 / 0	5W / 4D	13	low
1997	5 / 0	1 / 0	0 / 0	0	5	increase
1998	5 / 0	2 / 0	1 / 0	8W	2	peak
1999	7 / 0	3 / 0	0 / 0	0	1	decrease
2000	8 / 0	4 / 0	3 / 0	7W	8	low
2001	10 / 2	6 / 1	3 / 1	12W / 1D	4	increase
2002	10 / 2	5 / 1	1? / 0	0	4	intermediate

	White phase		Dark phase		Total number	Number of
	adult	juvenile	adult	juvenile	of records	fox carcasses
1996	3	5	1	0	31W + 3D	0
1997	2	1	1	0	17W + 5D	1W + 1D
1998	3	1	1	2	21W + 3D	1W
1999	3-4	0	1	0	18W + 1D	2W
2000	5-6	3	0	0	28W	2W
2001	3	4-5	1	1	54W +1D	1W
2002	2	0	0	0	23W	0

Table 4.44. Minimum number of individual foxes recorded in Zackenbergdalen (50 km^2, 1 June – 31 August) divided into colour phases (W = white; D = Dark) and age classes 1996-2002, excluding pups at dens. "Total number of records" gives the number of records of all adults and those of juveniles encountered in the field away from their maternal den. Also foxes visiting the research station are included. See further in Table 4.26 for observations in June-July.

counts by scientists and the Sirius sledge patrol.

Arctic fox dens

Five dens in the study area were partly in use during the summer together with one den east of Kuhnelv, just outside the area (Table 4.43). Den no. 4 had fresh diggings, trampled grass in front of entrances and smell of fox during June, but by 7 July the den was abandoned. The closely situated den (no. 3) had clear signs of being used at least during 3-10 July. Den no. 10 was also in use for at least one week (3-10 July). There might have been pups in Den no. 4, which in that case might have died in early July.

Other observations

Collared lemming *Dicrostonyx groenlandicus*

In total, eight adult lemmings were recorded in the field between 3 June and 14 August. Additionally, 10 observations of adult lemmings together with one juvenile were recorded within the station area. Of the six adults recorded in the field, one person using the same amount of effort each year recorded four (Table 4.34). Besides these records, a total of 48 individuals were caught of which 18 adults were tagged with a radio collar and 30 juveniles/subadults were released after examination (see section 5.6). Over the season, nine lemmings were recorded taken by skuas, and one was presumably taken by a stoat, as the radio transmitter and lemming stomach was found side by side.

On 23 July, a subadult female lemming (15 g) was caught between the shelters of the station. She was kept indoor in an open top wooden box and fed daily with fresh plants collected within the station area. She gained 1g body mass per day. After two weeks she was released within the station area. A remarkably observation was made on her forage on arctic puppy (*Papaver radicatum*). She bent the c. 20 cm high flower stalks down in order to reach the seed balls that she bid off and ate. This may explain observations made almost every year within permanent vegetation plots showing that several arctic puppy were without seed balls.

Polar bear *Ursus maritimus*

One animal was recorded on 15 July at Daneborg. An additional fresh track of a young bear was found on 26 July in the old delta south of the research station. On 29 July, tracks were found on Sandøen, probably by one of these bears.

Arctic wolf *Canis lupus*

On 22 July, a seemingly fresh wolf track was found near Fox den no. 5, and on 30 July, a wolf passed south of the research station. On 28 August, a female wolf was recorded resting near Fox den no. 10. It left the place and headed northwards to the slopes of Aucellabjerg. A wolf was also recorded on Storsletten during the aerial survey on 22 July.

Arctic fox *Alopex lagopus*

2002 was the poorest summer so far in terms of arctic foxes recorded (Table 4.44). Based on moult patterns, colour and geographic position of observations, an estimated minimum of only two adult white phase foxes was recorded within the 50 km^2 main study area together with three white adults outside this area. The total number of fox encounters was much the same as in 1997, 1998 and 1999, which is noteworthy since more individuals were estimated to have been involved and more field workers were present in those years.

Arctic hare *Lepus arcticus*

One animal visited the station on 1 June.

Table 4.45. Arctic hares appearing on the east facing slope of Zackenberg mountain during the daily counts from a fixed point at the research station 1 July – 31 August 2000-2002. "Others" denote additional records in the field.

	Average+SD	Range	Counts	Others
2000	2.78 ± 2.90	0-11	16	67
2001	2.36 ± 1.71	0-6	22	72
2002	1.06 ± 0.28	0-4	16	19

	Average+SD	Range	Counts
1997	8.52 ± 4.98	3-21	23
1998	7.42 ± 4.50	0-18	18
1999	25.05 ± 12.32	2-61	22
2000	14.38 ± 7.00	2-28	16
2001	22.06 ± 14.22	3-57	16
2002	28.68 ± 3.82	9-48	13

Table 4.46. Numbers of seals counted daily from a fixed point at the research station from 1 June until the fjord ice became too fragmented in early/mid July 1997-2002. Counts were only made when sight conditions were good.

Daily records on arctic hares were made whenever weather permitted during 2 July – 30 August, when the east facing slope of the Zackenberg mountain was searched by means of a 30x spotting scope. The 16 records obtained during these surveys were distributed between 70 and 1,100 m a.s.l., but most were between 300 and 500 m. A maximum of four individuals was recorded in one count (Table 4.45). Additionally, 18 records were made in the field, of which a maximum of five animals was recorded at one time on Aucellabjerg. This sums up to a minimum of nine individuals within the study area.

Stoat *Mustela erminea*

As in 2001, no animals were seen in 2002.

Walrus *Odobenus rosmarus*

The maximum number of walruses on Sandøen was recorded 30 July, when 24 animals were hauled-out (see section 5.9). Two animals were recorded foraging along the coast between Daneborg and Zackenberg during the line transect survey on 22 July.

Seals Phocidae sp.

Seals on the fjord ice were recorded during the daily musk ox counts from 1 June until the fjord ice became too fragmented on 6 July. On average, 29 seals were recorded per census with a maximum of 48 on 28 June (Table 4.46).

Narwhal *Monomon monoceros*

On 20 July, a flock of at least 50 individuals was recorded swimming out of Young Sund. They were swimming slowly in a relative narrow band about half a kilometre off Zackenbergdalen apparently along the edge of the shallow water outside the deltas. The last records date back to 11 and 13 August 1997, when a flock of 50-100 individuals was recorded in Tyrolerfjord and Young Sund (Meltofte and Rasch 1998).

4.6 Lakes

Kirsten Christoffersen and Erik Jeppesen

The ice-out on the two shallow lakes, Sommerfuglesø and Langemandssø in Morænebakkerne started in mid-June, and an ice coverage of 50% was estimated to have occurred around 3 July and 6 July, respectively. These dates match the situation in the two previous years (see Table 4.48). Langemandssø had a little ice remaining (1% coverage), when sampling started in late July (Table 4.47).

The lakes were sampled three times between 24 July and 15 August 2002. The water temperatures varied little due to the early ice-out, and the mean water temperatures were 8.3°C in Sommerfuglesø and 8.1°C in Langemandssø (Tables 4.47 and 4.48). The conductivity, the total nitrogen and total phosphorus concentration of both lakes were within the range obtained from measurements during the previous years.

The chlorophyll *a* concentrations were remarkably higher in both lakes than in the previous years. Average concentrations of 1.27 and 2.72 µg/l in Sommerfuglesø and Langemandssø were recorded (Table 4.48). These values correspond to a two or more fold increase. Thus, it seems that more nutrients were available for the phytoplankton community during the

Table 4.47. Physico-chemical conditions and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July and August 2002.

Lake	SS	SS	SS	LS	LS	LS
Date	24.7	5.8	15.8	24.7	5.8	15.8
Ice cover (%)	0	0	0	1	0	0
Temperature (°C)	8.2	8.9	7.8	7.6	8.9	7.8
pH	6.0	6.1	6.0	5.7	5.2	5.5
Conductivity (µS/cm)	7	6	10	6	6	5
Chlorophyll a (µg/l)	1.23	1.60	0.97	1.55	2.44	4.16
Total nitrogen (µg/l)	334	261	418	412	217	533
Total phosphorous (µg/l)	17	8	9	15	9	16

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Date of 50% ice cover	ND	9.7	18.7	24.6	2.7	3.7	ND	23.7	21.7	30.6	8.7	6.7
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	6.8	6.4	4.0	9.5	8.4	8.1
pH	6.5	7.4	6.7	5.8	6.6	6.0	6.5	7.0	6.3	5.5	6.4	5.5
Conductivity (µS/cm)	15	13	10	18	18	8	8	9	7	9	8	6
Chlorophyll a (µg/l)	0.84	0.24	0.41	0.76	0.67	1.27	1.04	0.32	0.38	0.90	1.46	2.72
Total nitrogen (µg/l)	ND	130	210	510	350	338	ND	80	120	290	340	387
Total phosphorous (µg/l)	4	9	11	10	19	11	8	7	7	11	20	13

Table 4.48. Average values for physico-chemical conditions in Sommerfuglesø (SS) and Langemandssø (LS) in 1999-2002 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data.

growing season. However, no obvious increases in neither total phosphorous nor total nitrogen were recorded.

The phytoplankton species composition included dinoflagellates (Dinophyceae), chrysophytes (Chrysophyceae), diatoms (Diatomophyceae) and green algae (Chlorophyceae) (Table 4.49). The seasonal average community biomass (expressed in units of biovolume) was dominated by chrysophytes in both lakes (90% of the total biomass in Sommerfuglesø and 71% in Langemandssø). Dinoflagellates constituted almost the entire remaining biomass in both lakes. The most important species in Sommerfuglesø were Chrysophyceae spp. and *Dinobryon bavaricum*, while *D. bavaricum*, *D. hilliardii*, *Kephyrion boreale* and *Ochromonas* spp. dominated in Langemandssø. The remaining biomass in both lakes included several dinophyceans (*Gymnodinium* spp. and *Peridinium umbonatum*-group). These phytoplankton distribution patterns resemble those from previous years with early ice-melt (Table 4.50) and can be explained as climatic related (Christoffersen and Jeppesen 2002).

Zooplankton was sampled in both lakes on 15 August. The zooplankton community in Sommerfuglesø included the cladoceran *Daphnia pulex*, the copepod *Cyclops abyssorum alpinus*, as well as the rotifers *Polyarthra dolicopthera* and *Keratella quadrata* (Table 4.51). In Langemandssø, where arctic char are present, only *C. abyssorum alpinus*, *P. dolicopthera* and *K. quadrata* were found, and with somewhat higher numbers than in Sommerfuglesø. These differences in biodiversity and density are similar to those of previous years and owe to the direct and indirect effects of the predation from fish (see also Caning and Rasch 2000). The early ice-out and the subsequent early rise in water temperature favour the reproduction potential of especially *Daphnia* and *Cyclops*.

Lake	SS	SS	SS	LS	LS	LS
Date	**24.7**	**5.8**	**15.8**	**24.7**	**5.8**	**15.8**
Nostocophyceae	0	0	0	0	0	0
Dinophyceae	0.018	0	0	0.081	0.124	0.262
Chrysophyceae	0.121	0.047	0.031	0.343	0.352	0.436
Diatomophyceae	0	0.001	0	0	0	0
Chlorophyceae	0	0	0.001	0	0	0
Total	0.139	0.048	0.032	0.424	0.476	0.698

Table 4.49. Biovolume (mm^3/l) of phytoplankton species in Sommerfuglesø and Langemandssø during July-August 2002.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Nostocophyceae	ND	0.000	0.005	ND	0.000	0.000	0.000	0.000	0.000	ND	0.000	0.000
Dinophyceae	ND	0.034	0.044	ND	0.015	0.006	0.291	0.185	0.305	ND	0.040	0.156
Chrysophyceae	ND	0.022	0.096	ND	0.358	0.066	0.066	0.187	0.048	ND	0.592	0.377
Diatomophyceae	ND	0.002	0.000	ND	0.001	0.000	0.002	0.000	0.000	ND	0.002	0.000
Chlorophyceae	ND	0.005	0.002	ND	0.000	0.000	0.016	0.000	0.002	ND	0.002	0.000
Others	ND	0.000	0.000	ND	0.004	0.000	0.000	0.000	0.000	ND	0.000	0.000
Total	ND	0.063	0.147	ND	0.377	0.073	0.375	0.372	0.354	ND	0.637	0.533

Table 4.50. Average biovolume (mm^3/l) of phytoplankton species in Sommerfuglesø (SS) and Langemandssø (LS) 1997-2002. ND = no data.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Cladocera												
Daphnia pulex	0.3	10.5	0.3	6.7	8.2	6.8	0	0	0	0	0	0
Macrothrix hirsuiticornis	0.1	0	0	0	0	0	0	0	0.2	0	0	0
Chydorus sphaericus	0.05	0	0	0	0.06	0	0	0.1	0	0.5	0.1	0.07
Copepoda												
Cyclops abyssorum alpinus (adult+copepodites)	0.8	0.5	0.5	0.3	0.5	0.2	3.3	2.9	4.1	22.0	13.4	6.8
Nauplii	5.7	1.3	6.5	1.1	1.4	2.3	5.2	3.8	6.4	3.1	4.5	4.5
Rotifera												
Polyarthra dolicopthera	171	90	185	97	74	11	316	330	274	168	248	22
Keratella quadrata group	4.5	3	17	0	0	0.4	4.5	28	34	0	0	0.3
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.51. Density (no/l) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) in mid August 1997 to 2002.

5 Research projects

5.1 Measuring snow depths in Zackenbergdalen with ground penetrating radar

Jens Nykjær Larsen and Håkon Gjessing Karlsen

From 2-5 June 2002, the snow cover in Zackenbergdalen was measured with georadar. A 500 MHz shielded detection unit was manually dragged over the snow surface and a profile of the snow depth was obtained. The track positions were simultaneously detected with GPS (Figure 5.1).

In order to calibrate the GPR measurements, the snow profiles from the georadar were compared with stake measurements. The snow density was determined in several snow pits along the georadar tracks.

The snow/soil interface was interpreted from the radargrams as a Two-Way-Time curve (TWT). Conversion of TWT into snow depths depends on the density of the snow. Measurements of the snow densities in the period 2–14 June 2002 did not suggest any significant time dependency of the density in that period:

Number of observations	16
Min.	333 kg/m^3
Max.	622 kg/m^3
Mean	517 kg/m^3
Standard deviation	71 kg/m^3

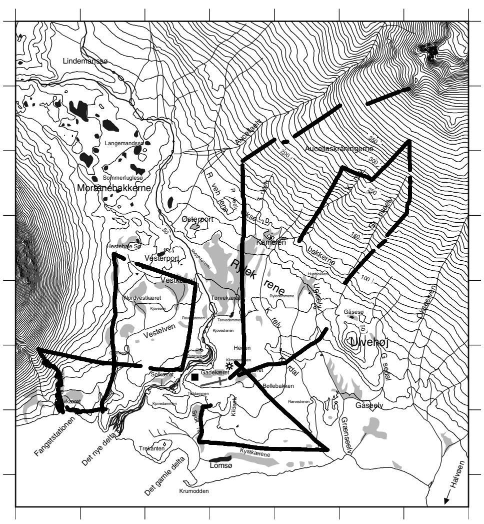


Figure 5.1. Map of Zackenbergdalen. The solid lines indicate tracks where snowdepths were recorded.

Based on theoretical models for deriving radar wave velocities in snow, the above mean snow density suggests a velocity on 21 ± 2 cm/nano second. This result agrees very well with the stake control measurements on the 50 test tracks where the empirically derived radar wave velocity was estimated to 20 ± 2 cm/nano second.

To correct for the melting of the snow during the survey period, a 50-meter long test profile was sampled each day with stakes. Here the melting gradient of the snow was found to be 4.4 ± 0.5 cm/day. This value was used to apply a residual correction to the snow depth data to georadar data from 3-5 June 2002. In this way attempt has been made to make all observations comparable to the snow depths of 2 June.

The observed snow depths have been corrected for the melting effect, and the data along the tracks have been re-sampled at 2 m intervals. The corrected snow depths are suitable for statistical description:

Number of observations	14901
Min.	0 cm
Max.	594 cm
Mean	130 cm
Standard deviation	99 cm

Figure 5.2 displays a histogram of the corrected snow depths. To complete the study of the snow cover in the valley, it is recommended to perform a statistical analysis of snow depth in relation to topographical

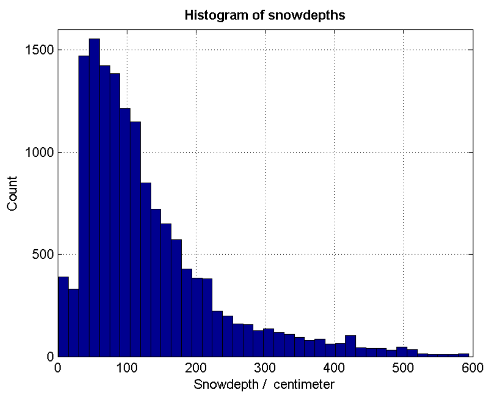


Figure 5.2. Empirical distribution of the snow depths.

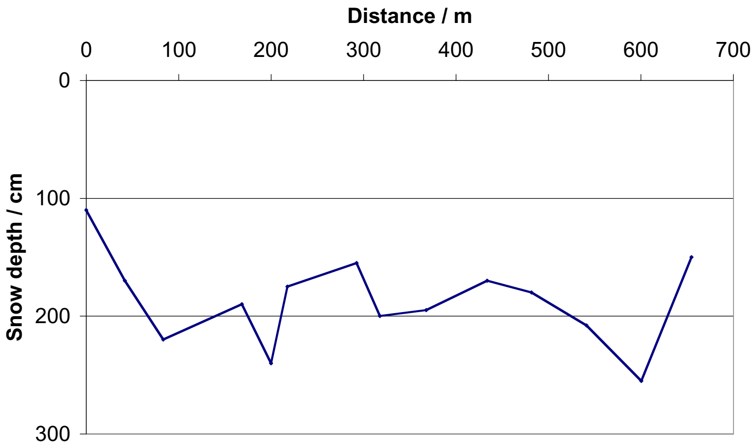


Figure 5.3. Stake measurements. Penetration depths to ice layer representing inter-seasonal surface.

parameters. Furthermore it is of interest to find a method to extrapolate the data and compute the regional snow distribution for the Zackenbergdalen.

Data from this investigation is available on request from Danish Polar Center or ASIAQ – Greenland Field Investigations.

5.2 Glacier pilot study

Håkon Gjessing Karlsen and Jens Nykjær Larsen

To evaluate accessibility to glaciers in the surroundings of the Zackenberg Station, the Palnatoke and the Lindeman glaciers were visited during the period 8-10 June 2002. A walking route was followed along the eastern side of the river Lindemanselven.

Due to heavy melting of the snow in the area, major difficulties were experienced when crossing the rivers. It was therefore not possible to get access to the Lindeman glacier.

The Palnatoke glacier on top of Palnatoke Bjerg is a small plateau glacier (area approximately 3.2 km^2) located at *c.* 1,000 metres above sea level. By means of stake measurements (Figure 5.3) and snow density profiles, the winter precipitation of the 2001/2002-season was estimated to be 1.10 ± 0.25 m water equivalent. At the research station *c.* 35 m above sea level, this number is *c.* 0.5 m water equivalent.

Recommendations for future glaciological projects are available in a detailed report that can be ordered from Danish Polar Center or ASIAQ – Greenland Field Investigations.

5.3 Effects of UV-B radiation on vegetation in Zackenberg

Teis N. Mikkelsen, Helge Ro-Poulsen, Linda Bredahl and Kristian Albert

Emissions of certain gaseous pollutants, like the CFCs, have reduced, especially in polar regions, the stratospheric ozone layer which protects the earth's surface from incoming UV-B radiation. This radiation band is injurious to living cells and can influence growth, development and life cycle of organisms. This project seeks to identify and quantify some effects of UV-B radiation on the performance of high arctic plants under field conditions and on the interactions with microclimate.

Two different methods have generally been applied in the study of UV-effects. One is applying enhanced UV-doses to the plants by means of lamps. The other method is a reduction of the ambient incoming UV-radiation by means of filters placed over the vegetation. The latter method was found most suitable in this project, which is intended to end up with a recommendation of a method for long term monitoring of the impact of UV-radiation on the vegetation in Zackenberg.

The experimental investigation was initiated in the beginning of July 2001. A set of aluminium frames covering 47x60 cm was installed above the ground on two south facing slopes approximately 500 m south of the station. The plant cover was dominated by *Salix arctica*, *Vaccinium uliginosum*, *Cassiope* and *Dryas*. Four types of treatments were applied: UV-A and UV-B absorption (transparent Lexan®), UV-B absorption (transparent Mylar® type D), no UV absorption (transparent Teflon®, control) and no filter (filter control). The treatments were replicated four times at each slope. The plots have now been exposed to the treatments two seasons: July-August 2001 and 2002. The parameter we concentrated on has been chlorophyll fluorescence induction kinetics, but also specific leaf area (SLA), relative content of flavonoids (UV-B absorbing pigments) and species composition have been measured. We further measured air and soil temperatures, soil water content, photosynthetic active radiation (PAR) and relative humidity in the sites.

Besides absorbing different proportions

of short wave solar radiation, the transparent filters affect the temperature conditions underneath. The results show that the different types of foils increase the average air/soil temperature with 0.0/0.4°C (Teflon®), 0.2/0.5°C (Mylar®) and 0.5/0.5°C (Lexan®). This increase should be compared to the average air/soil temperature in the control, which was 4.9/3.5°C.

Chlorophyll fluorescence measurements give information on the functioning of the light absorbing parts of the photosynthetic machinery. From the 2001 measurements it could be seen that the reduction of UV-radiation caused a significant increase in the parameter F_v/F_m, indicating a lower stress level. At the site with the lowest light intensity the removal of both UV-A and UV-B had the most beneficial effect, while at the highest light intensity filtering out the UV-B only had the dominating effect. *Salix* showed effects in the middle of the season while *Vaccinium* showed effects in the autumn.

A large variation in the measurements was observed. To optimise and homogenize the radiation load to the plant leaves an additional *maximum irradiance experiment* was set up in 2002, in which *Salix* leaves were fixed perpendicular to the solar zenith angle, covered with Mylar or Teflon (Figure 5.4). The results showed a general positive effect of reducing the UV-B-radiation, except for the end of the season, where probably some treatment-senescence interactions takes place (Figure 5.5).

Finally, an experiment was conducted, where net canopy CO_2 exchange was measured on 20 cm diameter *Vaccinium uliginosum* plots covered with Mylar or Teflon. The results are not yet analysed.

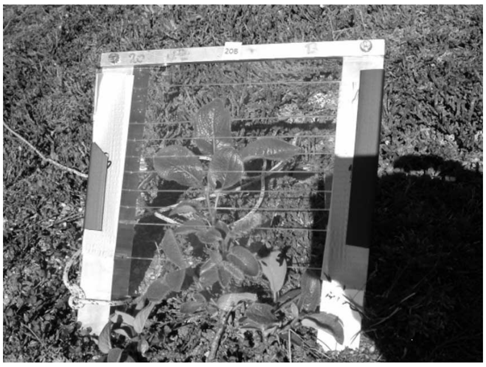


Figure 5.4. Maximum irradiation experiment, in which Salix arctica *leaves are fixed in a position giving them maximum irradiance, covered by either UV-B-absorbing or UV-B-transmitting foil (Photo Teis N. Mikkelsen).*

5.4 High resolution Digital Terrain Model and Hyperspectral data cube for Zackenberg

Mikkel Tamstorf

A hyperspectral campaign was carried out over Zackenberg on 7 August 2000 resulting in a high-resolution digital terrain model (DTM) based on aerial photography and a hyperspectral data set from the HyMap sensor (Caning and Rasch 2001). All data are presented at the website http://hyperzack.dmu.dk from where downloads or request for data can be performed.

DTM and ortho photo

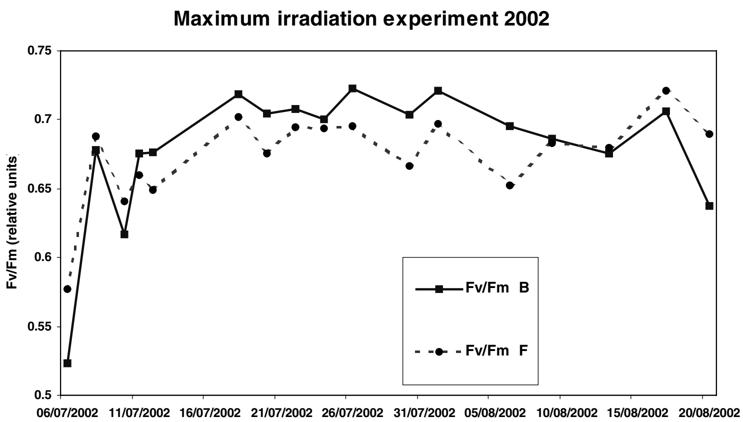
The digital terrain model is based on the aerial photos that were acquired during the campaign. The IMU data from the campaign and ground control positions from the field were used to fix the model in space. The final products are a high-resolution DTM and an ortho photo that can be used directly in geographical analyses.

The DTM is available in two versions, a 2 m resolution model and a 4 m resolution model. The 4 m version is cut to fit the hyperspectral data cube for use in geocoding and analyses of these data. Both models are based on the aerotriangulation with an estimated error at *c.* 3-5 metres.

The 2 m model has been used to extract two sets of contour lines, one with 10 m equidistance and one with 25 m equidistance. The shoreline has been extracted as a separate layer and all contours are supplied in ArcView shapefile format.

The ortho photo has a resolution of 20 cm with the same accuracy as the DTM. An example of the ortho photo is shown in Figure 5.6.

Figure 5.5. Maximum photosynthetic efficiency of Salix *leaves exposed to reduced UV-B (Fv/Fm B) or ambient light (Fv/Fm F).*



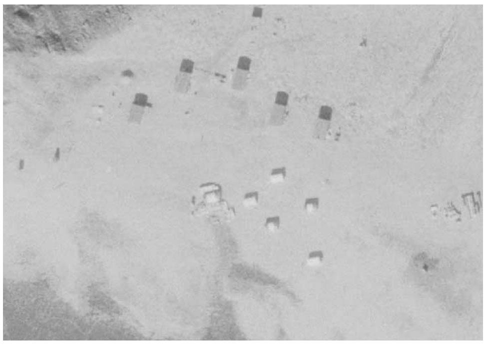


Figure 5.6. Ortho photo close-up of the ZERO station. Resolution of the ortho photo is 20 cm.

HyMap data

The HyMap scanner, built by Integrated Spectronics Inc of Sydney, Australia, has four spectrometers in the interval 0.45 to 2.45 nanometers excluding the two major atmospheric water absorption windows. The bandwidths are not constant, but vary between 15 and 18 nanometers. A subset of the data cube is shown in Figure 5.7.

5.5 Chemistry and genetic variability in arctic plants

Per Mølgaard

This project mainly concerns plant secondary constituents, and the geographical and seasonal variation in these compounds in response to environmental conditions. These compounds are of major importance in relation to protection against herbivory and are probably affected by increased temperatures. Their presence may influence the reproductive success of plants. Main emphasis is put on chemical compounds in *Salix arctica*, *Papaver radicatum*, *Cassiope tetragona*, *Angelica arcangelica* and on plant phenolics in general. Eventually, the genetic diversity will be determined using isozymes and AFLP-markers. As arctic plants have not yet been thoroughly investigated, we have so far been able to identify two genuine compounds new to plants. These may prove important as new leads in the search for plant compounds of potential interest for the technical and pharmaceutical industry, or possibly as herbal drugs.

In particular, the genetic variation in *Papaver radicatum* has shown interesting variations in our preliminary studies of the enzymatic characteristics in plants from Western Greenland. All plants from Disko, West Greenland, were uniform in eight different loci, no matter where on the island the plant populations were collected. In contrast, plants from the Kangerlussuaq, West Greenland, not only differed from those from Disko but they also showed a greater variability. This of course calls for samples from other regions of Greenland. We have had great help from Thomas B. Berg, who supplied a large population sample from Zackenberg to Copenhagen, an excellent sample now awaiting the final analyses at Danish Pharmaceutical University.

The project is linked to ITEX – the International Tundra Experiment (http://www.systbot.gu.se/research/ITEX/itex.html), which is a circumpolar co-operation with stations at more than 20 sites in the arctic area. By observation and manipulation with selected, wide spread plant species, the aims are to anticipate the reaction of these plants and their environment to an eventual global climatic change.

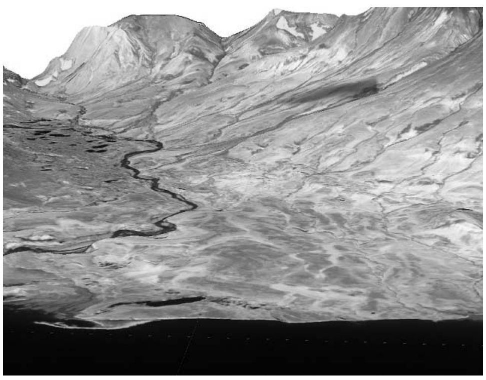


Figure 5.7. Image showing a HyMap colour composite (band 75, 35, 15 in red, green and blue, respectively) draped on the 4 m resolution DTM.

5.6 Behaviour of the Collared lemming *Dicrostonyx groenlandicus* in the arctic summer

Line A. Kyhn

Since 1995 the collared lemming population in Zackenbergdalen has been monitored as a part of BioBasis. Data collection has focused on counting active summer burrows and winter nests (Meltofte and Thing 1997, Meltofte and Rasch 1998). Fluctuations in the collared lemming population have shown a cyclic pattern with summer and winter peaks in a four-year cycle. During the long arctic winter lemmings reproduce in their nests under the snow. Berg (2003) found several differences between the summer and winter conditions which all point toward winter as being the most favourable season from a lemming point of view, especially due to the low number of predators during winter. Therefore, despite a rich selection of palatable plant species, it is likely that the summer constitutes a bottleneck for the lemming population.

To analyse this dilemma between abundant food and greatly enhanced exposure to predators during summer, the behaviour of the collared lemming was investigated using radio telemetry and field observations. 18 adult lemmings were tagged with small radio collars (2 g) and tracked several times each day throughout the summer. All captured animals were sexed and weighted to the nearest gram and their reproductive status checked at every recapture.

It was evident from the capture of subadults in early June that breeding must have taken place in May as of 3 June one female was caught together with two subadults (23 and 26 g) in the same trap. Pregnant females were caught live in traps in June and July and litters were born at least in early and late July. Weight data on a tagged female showed 57 g on 25 June, >100 g on 2 July and 70 g on 25 July. At this last date I found two-three juveniles in the maternal burrow nest using an optical fibre scope.

Traps were placed in the snow on 1 June and six individuals were caught before moving to the snow free summer habitat. Also a total of 17 tracks on the snow were encountered in the Zackenberg area by Hans Meltofte and myself, of which one was followed for 500 m. Moving on top of the snow lemmings followed a strait course and especially sunny days with high temperatures seemed to favour movements. This is most likely due to wet snow conditions in their runways following a rise in temperature. It became clear that it was a risky business moving from the still snow covered winter habitats to the early snow free summer habitats as four of the tracks resulted in a bloody spot and foot prints from a long-tailed skua *Stercorarius longicaudus*. All radio collared individuals moved to already existing burrows from previous years close to the point of first capture.

After movement to the summer habitats individual lemmings could be tracked to their burrows without disturbances using a radio receiver. One-minute scan intervals were used for a minimum of four hours using binoculars and a 30x telescope. A total of 140 observation hours were spend observing the radio tagged lemmings from a distance of more than 30 m. No untagged lemmings were studied. A typical time budget observed during a six hours observation period is shown in Figure 5.8.

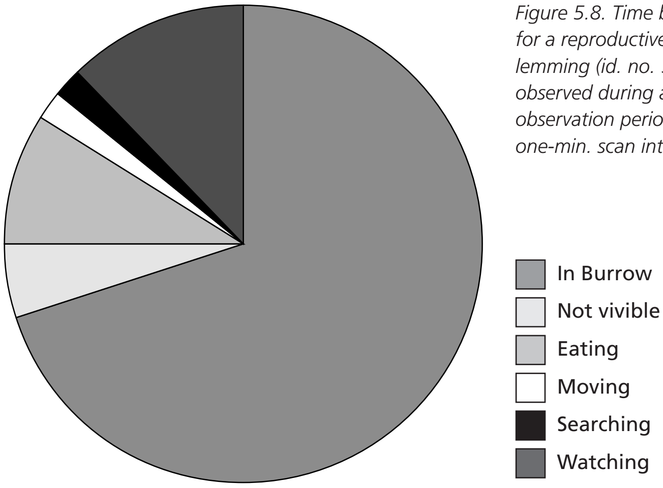


Figure 5.8. Time budget for a reproductive male lemming (id. no. 548) observed during a 6 hours observation period using a one-min. scan interval.

With a few exceptions all individuals observed spent *c.* 70% of their time below ground in their burrows. When above ground *c.* 10% of the time was used for foraging and watching, respectively, regardless of sex. The rest of the time was spent searching or moving. Long consecutive periods in the burrow were followed by shorter intense foraging trips outside the burrow. When the lemming first appeared from a burrow it remained in the entrance for a while watching. It then moved within a radius of less than 1 m from the burrow and started to eat strait away. The lemmings invested very little time in search for specific valuable food items. Instead lemmings ate whatever food plant were available in order to stay within close range of protective cover. Present data supported earlier studies showing that collared lemmings (except pregnant females) loose weight during the summer (Rasch 1999; Berg 2003; Schmidt *et al.* 2002). The threat from predators together with high levels of secondary plant defence mechanisms that lowers the nutritional value of the food, may likely explain the behaviour of collared lemmings and the observed weight loss in the course of the summer (Berg 2003). It seems reasonable to conclude that the arctic summer is a stressful time and might have a bottleneck effect on the collared lemming population in Zackenberg.

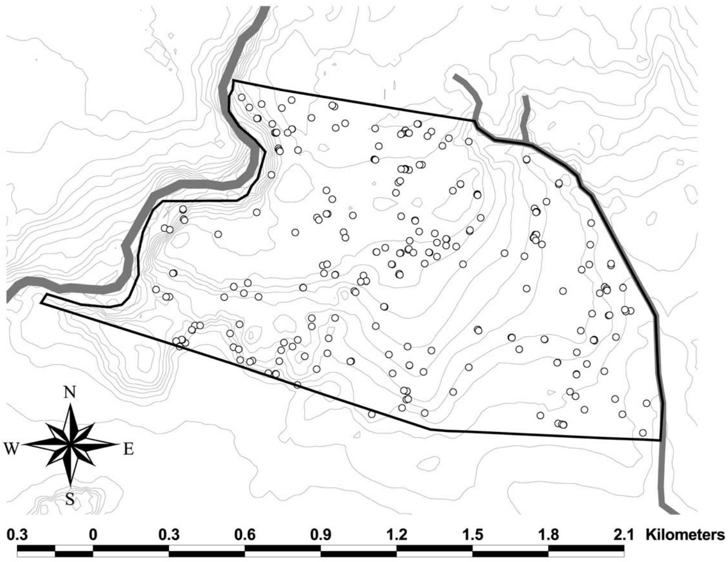


Fig 5.9. Spatial distribution of winter nests.

5.7 Collared Lemming Project – Zackenberg

Thomas Bjørneboe Berg

In contrast to what was expected, the lemming population did not reach a winter peak density during the winter 2001/2002. The number of winter nests remained at an intermediate density equivalent to the previous winter (2000/2001). Spatial distribution of winter nests is presented in Figure 5.9. The Collared Lemming Project terminated in 2002 by the submission of my Ph.D. thesis. Following results can be extracted from the project.

- Optimal winter forage area was more than twice as big as the summer forage habitat given that the estimation of habitat size is valid, but the winter and summer "forage area per day" seems to be equal.
- Differences in herbivory intensities may result in higher levels of secondary plant metabolites in summer forage compared with winter forage.
- Some population phase dependence on habitat use seems to be present, as less preferred habitats are used more than expected only during peak densities.
- *Dryas* spp., Arctic blueberry and female Arctic willow responded positively to simulated herbivory and accumulated more catechin (secondary plant metabolic) during the growing season than the controls.
- Results showed that the plant defences were detectable by the collared lemming and hence that this may affect their forage behaviour.
- As lemmings browse heavily on plants in close proximity to their burrows, and as the simulated herbivory did induce increased levels of catechin, it might be assumed that lemmings experience lower quality of food close to their burrows compared with food plants further away.
- The forage behaviour is hence a trade off between the increased time spent on forage and the risk of predation.
- Male body mass was positively correlated with home-range size.
- Distance moved by both males and females was correlated with body mass, but with opposite trends: male movement distances increased with body mass, while female movement distances decreased.
- Larger males had access to more females, and hence, body mass was indirectly important for individual mating opportunities, but was also associated with higher costs in terms of mass loss, probably as a consequence of increased energy requirements.
- 380 summer burrows were investigated by means of an optical fibre scope. 54 of the burrows (14%) contained a nest of which only two were positively used for breeding. 81% of all burrow entrances were only used for retreat and 36% of the burrows contained faeces.
- By using many burrows as latrines, the lemmings make it difficult for the foxes to determine in what burrow they are. Only around 1 per cent of the active summer burrows had been dug out by fox.

5.8 Marine studies at Daneborg

Søren Rysgaard, Ronnie N. Glud and Egon R. Frandsen

This year we had three projects on the east coast of Greenland. (1) During May-June we investigated bacterial sea ice and sediment processes in Young Sund, (2) during September we investigated biogeochemical processes in different sediments from Scoresby Sund to Nordostrundingen where bacterial processes in sea ice were also included, and (3) a sediment trap was launched in Young Sund in September.

Bacterial sea ice and sediment processes in Young Sund

The investigation covers measurements on sea ice and sediments from Young Sund (74°18′59′′N, 20°15′04′′W – water depth 36 m). Sampling of 1.5 m thick single-year fast ice and sediments was performed during May-June in the fjord. During initial samplings, freezing conditions existed within the sea ice (<–2.5°C) but within a week melting set in and temperatures increased to –0.3°C in the surface and the underside of the sea ice during the first two weeks of June. Measurements within the sea ice covered temperature, salinity, brine volume, Chl. *a*, NO_3^-, NH_4^+, O_2, gas volume, sea ice algal primary production, anaerobic bacterial numbers, bacterial O_2 consumption, denitrification and anammox. Preliminary results show that bacterial activity exceeds sea ice algal production within the sea ice during the investigation period and leads to very low O_2 concentrations in the brine system and in some places anoxic conditions. The anoxic conditions favor the activity of bacterial denitrification and anammox (Figure 5.10). Supplementary investigations of oxygen flux and denitrification activity on 2.2 m thick ice floe and sediment in the Greenland Sea (79°21′16′′N, 11°08′50′′W – water depth 265 m) conducted mid-September 2002 from the Danish military vessel "Vædderen" supported the findings from Young Sund.

Biogeochemical processes from Scoresby Sund to Nordostrundingen

A regional atmosphere-ocean model predicts a temperature increase of 8°C and a 20-30% increase in precipitation-evaporation at the end of this century along the east coast of Greenland (Kiilsholm *et al.* in press). This will lead to an increase in freshwater runoff, thinning of the sea ice as well as an increase in the ice-free period from 2.5 months to 4.7-5.3 months in Young Sund (Rysgaard *et al.* in press). The combined result of the model predictions and the observation from the East Greenland coastline (Figure 5.11) inspired us to perform an investigation along a north-south transect of the east coast of Greenland. The overall idea was that the range of temperatures, ice-free conditions and precipitation patterns that exist along the East Coast would cover the predicted changes in Young Sund within this century. Thus, when studying the effect of climate-induced changes in sea ice conditions on future processes and species composition, the sediment along East Greenland would be an ideal place to look as it will contain a fingerprint of the conditions in the overlying water column representing different ice-cover conditions and hence productivity regimes.

We got the opportunity to join the Danish military vessel "Vædderen" on its tour from Reykjavik and up north during September 2002. Due to exceptionally little sea ice it was possible to sample in Scoresby Sund, Kong Oscars Fjord, Young Sund, off Hochstetter Forland (Haystack), off Danmarkshavn, off Île de France and off

Figure 5.10. Sampling for bacteria in sea ice (Photo Søren Rysgaard).

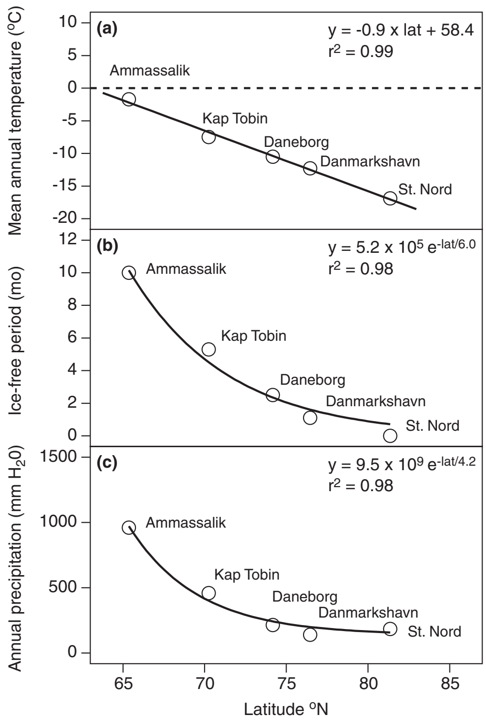


Figure 5.11. (a) Mean annual temperature in Northeast Greenland versus latitude. Data from Cappelen et al. 2001. (b) Annual ice-free period versus latitude. Data from the Danish Meteorological Institute – State of the ice in the Arctic seas, annual reports (1950-1964). (c) Mean annual precipitation versus latitude. Data from Ohmura and Reeh 1991.

Figure 5.12. Sediment trap system is placed at its position (74°18'937"N, 20°16'706"W) in the outer part of Young Sund (Photo Søren Rysgaard).

Nordostrundingen, making it possible to cover the latitudes 70-81°N. At each of these locations, intact sediment cores, together with bottom water, were sampled and brought to the laboratory established on "Vædderen". Cores were incubated under *in situ* conditions, e.g. field temperature, nutrient, oxygen, and flow conditions in specially designed incubators. Measurements were made of sediment-water exchange rates of O_2, DIC and nutrients and of high-resolution concentration profiles of O_2, porosity, density and organic content in the upper 20 cm of the sediment. Furthermore, measurements of nitrogen removal through bacterial nitrification, denitrification and anammox were obtained using different ^{15}N-isotope techniques.

Sediment trap in Young Sund

In the process of designing a long-term marine monitoring program (MarineBasis) to be implemented in Zackenberg Basic (see Chapter 9) we realized that the borders between the involved sub-programs, ClimateBasis, GeoBasis, BioBasis and the coming MarineBasis should be straightened. Especially the coupling between land and sea was obvious and we decided to initiate annual measurements of sedimentation (organic content, ^{13}C and ^{15}N and other elements) in Young Sund using an automatic sediment trap. These measurements will be used to determine how much organic material is imported to the fjord and to distinguish between sources from land and the Greenland Sea by comparing sediment trap data with data from the Zackenberg river and further off the Greenland coast. Thus, it was decided to place a sediment trap close to our previous working area in outer Young Sund. Since there is a sill at the entrance of Young Sund of 45 m water depth we decided to position the trap so that the upper buoyancy would be placed below the sill depth to prevent icebergs from removing or destroying the trap as no icebergs are released from the inner parts of Young Sund. In order to collect the material being produced in the production zone (upper 35-m, Rysgaard *et al.* 1999) the trap was programmed to collect material at *c.* 60 m water depth 21 times until august 2004 where it will be released acoustically from its present position (74°18'937''N, 20°16'706''W). Without help from the military vessel "Vædderen" it would have been very difficult to launch the sediment trap, which weighs over one ton (Figure 5.12).

5.9 Walrus studies on Sandøen

Erik W. Born, Lars Øivind Knutsen, Lars Heilmann and Nette Levermann

Walruses can be individually identified from their genetic profile (e.g. Andersen *et al.* 1998; Andersen and Born 2000), and from natural markings such as scars on the skin and cracks in the tusks (Born *et al.* 1997).

In 2002, the Greenland Institute of Natural Resources, Nuuk, in co-operation with the Danish National Environmental Research Institute, Department of Coastal Zone Ecology (Rønde) initiated a two-year study at the walrus haul-out on the island of Sandøen (Young Sund) with the purpose of

(1) registration of as many individual walruses as possible by means of their genetic profile, and
(2) photo-identification of individual walruses.

The overall objectives of the study are (I) to determine the number of walruses using the Sandøen haul-out and the Young Sund feeding areas based on a "mark-recapture" estimate by use of genetic fingerprints and naturally marked animals, (II) to determine site fidelity of walruses in the area.

Whereas the food ingestion of individual walruses has been estimated (Born *et al.* in press), the parameter 'total number of walruses using Young Sund' is important for calculations of the overall predation by the entire group – thereby the role of walruses in the marine ecosystem in the area can be quantified. Furthermore, by repeating a mark-recapture calculation at *e.g.* 10-years-intervals, the development of the East Greenland population can be monitored.

During the field period (28 July – 31 August), the weather at Daneborg and Sandøen generally was windy and moist. In addition, large swells coming from the east hit the eastern side of Sandøen and eroded those parts of the beach where the walruses used to haul out in previous years (*i.e.* SE tip). Due to the inclement weather and the swells the walruses hauled out in several places on the southern, western and northwestern sides of the island during August 2002. The maximum number of walruses recorded on a single occasions was 19 that rested in two places on Sandøen on 4 August. Among these were an adult female accompanied by a calf of the year (mainly males are usually observed in this area, *e.g.* Born *et al.* 1997).

A dart fired from a cross-bow at a distance of about 15 m was used for taking the biopsies. Usually the animals paid little attention to the presence of the researchers and only reacted little and briefly when being hit by the dart. In total 81 skin biopsies were taken from walruses resting on the island. At the same time efforts were made to obtain ID-photos of all animals that visited Sandøen.

The genetic analyses and the registration of individuals from ID-photos are in progress. Attempts will be also made during August 2003 to obtain skin biopsies and ID-photos of walruses at Sandøen.

5.10 ITACA² – twin 76 magnetic latitude auroral monitors

Stefano Massetti, Maurizio Candidi, Pasquale Cerulli-Irelli, Roberto Sparapani, Marco Maggiore and Henrik Philipsen

The Italian Institute for Interplanetary Space Physics of the National Research Council (IFSI-CNR) started monitoring auroral activity in 1999, by installing an automatic observatory in Ny-Ålesund, Svalbard. Most of the scientific interest in the auroras is due to the deep relationship between this phenomenon and the solar-terrestrial physics.

Just few places are suitable for monitoring the dayside auroras, that is the North of Svalbard and the Northeast coast of Greenland. In particular, Ny-Aalesund and Zackenberg/Daneborg are the settlements that lie closer to the 76° magnetic latitude, and their relative distance (about 950 km) is ideal for joined observations of the same dayside auroral event. Nevertheless, nearly all the past dayside auroral studies were based on optical observations performed only from the Svalbard, because of both the easy accessibility and the extensive logistics support, available all year around. In this sense, we were very attracted by the opportunity to have an automatic observatory at Zackenberg Station. The requirement to operate during the winter season, together with the need of continuous and reliable power supply, forced the station to be installed in Daneborg (7-12 August, 2002). This was possible thanks to an agreement with the Sirius-patrol (Danish Defence Command). The station was placed uphill near the meteorological station in Daneborg, to share the power supply and avoid the lighting of the Sirius outpost as much as possible. The station is a hut with a plastic dome on the top, which hosts all the equipment needed (Figure 5.13): the automatic *all-sky camera* (a); a PC running the acquisition program under the *Linux* operative system (b); an UPS unit to minimise power failures; a GPS receiver used to maintain the system clock synchronised to the Greenwich Mean Time (GMT); an electric heater to maintain the instrument at the appropriate working temperature (*c.* 18°) and to keep the plastic dome free of snow; a satellite phone (c). The all-sky camera is an optical instrument provided with a fish-eye lens that allows a field-of-view of about 180° in

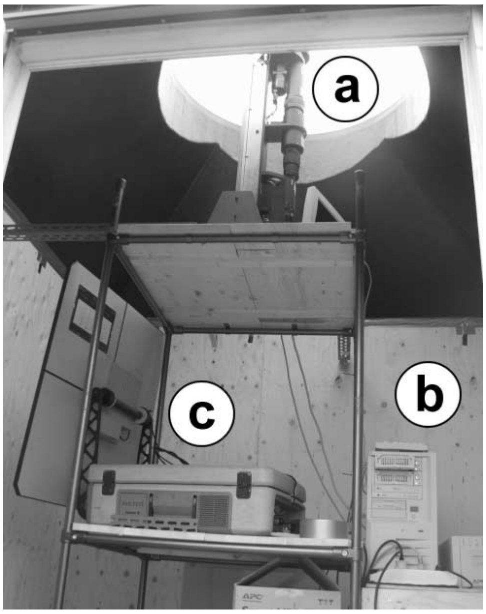


Figure 5.13. Inside view of ITACA-DNB station showing part of the equipment: a) all-sky camera, b) PC and UPS unit, c) Inmarsat-B satellite phone (Photo Stefano Massetti).

the zenith direction, it records digital images (512x512 pixels) on a scheduled basis and saves them on the PC hard-disk. It is possible to chose the wavelength for each image by means of a filter wheel behind the fish-eye lens. In the standard acquisition scheme we take one white-light image (no filter) at the beginning of each hour (to check the seeing of the sky), one red image each minute and one green image every 20 seconds. To overcome the lack of a direct network connection, the station was provided with an Inmarsat-B satellite phone that permits a 9600-baud data connection, which is enough for remote control purpose and to download small amounts of images. At the end of the winter season, the removable hard-disk containing all the data will be collected.

The magnetospheric regions connected to the cusp are expected to map to about 2°-5° degrees in latitude and roughly 30°-90° in longitude, an area that fit within the field-of-view of our twin all-sky camera system (*ITACA*²). A sketch of the field-of-view of the two stations are shown in Figure 5.14, where the great and small circles indicate the ideal boundaries for the red and green emission, assuming an emission height of 120 km and 250 km, respectively. For the first time, contemporary optical observations from Ny-Aalesund (*ITACA-NAL*) and Daneborg (*ITACA-DNB*) will give a comprehensive view of the cusp footprint in the Greenland – Svalbard sector. This will permit to follow the evolution of auroral events for longer periods and/or over a greater area, increasing also the probability to link ground and space observations.

More information on our auroral research activity, together with images, movies and data quick-views, can be found at the *ITACA*² home page (http://sung3.ifsi.rm.cnr.it/~massetti/index.html).

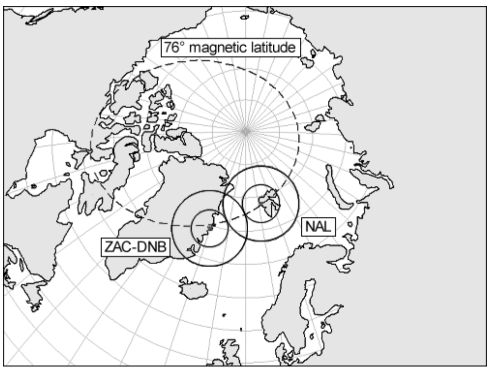


Figure 5.14. Path of the northern geomagnetic cusp footprint (76° magnetic latitude, dashed lines), as the Earth rotates around its axis. The large and small circles indicate the field-of-views of the all-sky cameras located in Daneborg and Ny-Aalesund, calculated for auroral emission at 120 km and 250 km of alti-

5.11 Soil moisture and fluvial geomophology

Bent Hasholt

The TDR soil moisture station, established in 1997 at the climate station, was checked in 2002. The station is working fine and the measurements are continued, now as an integrated part of the GeoBasis Programme.

Field investigations of the fluvial geomorphology along Zackenbergelven showed the influence of different morphological processes. In particular the effect of thermokarst could change the streambed rapidly and provide large amounts of sediment.

A pilot project on the wear and tear of the terrain near Zackenberg Field Station was carried out. Effects of traffic are clearly visible and changes in soil physics are measurable. The area is well suited for studies of traffic impact because the traffic in the area is carefully monitored.

5.12 Spectral Calibration for High Arctic Primary Production Estimation (SCHAPPE)

Mikkel Tamstorf

The project SCHAPPE is based on conclusions from an informal workshop about the Zackenberg BioBasis data. The purpose is to find a method of non-destructive monitoring of the terrestrial primary production in the Zackenbergdalen using spectral measurements and vegetation indices for the estimation of primary production. As an off-spring of the project we will obtain a thorough knowledge about the biophysical variables (chlorophyll, leaf area index, biomass, CO_2-emission, etc.) of the vegetation at Zackenberg.

A pilot project was funded by the Danish Ministry of Environment and carried out during the last two weeks of August 2000. The pilot project successfully established 26 homogenous field sites covering the phenological gradients of five major vegetation types in the area (*Cassiope tetragona* heath, *Dryas* heath, *Salix arctica* snowbed, grassland and fen). Figure 5.15 shows the location of the sites. Each site consists of nine 25x25 cm squares, eight for weekly harvesting and one for CO_2-measurements. Boardwalks were established at the fen sites.

The sites are now ready for harvesting and measurements during an entire field season in order to describe seasonal changes in primary production and the relationship between spectral measurements and primary production for future non-destructive monitoring. Using spectral measurements will not only make it possible to do field measurements of the primary production but also to monitor the primary production on a regional scale using satellite imagery. We hope that a continuation of the project will be funded in 2004.

Further information on the project can be found at: http://schappe.dmu.dk/.

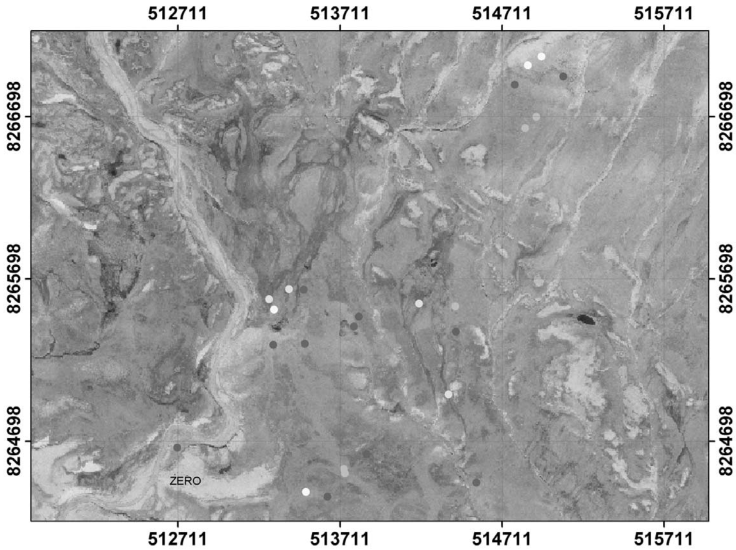


Figure 5.15. Position of the 26 field sites for the SCHAPPE project. Each site consists of nine 25 x 25 cm squares prepared for harvesting and CO_2-measurements. The sites are placed within the five major vegetation types (Cassiope and Dryas heath, Salix snow bed, grassland and fen).

6 Disturbances in the study area

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 not much higher than the low figure of 2001. The number of visits in zone 1b, the 'low impact study area', and in zone 1c, the 'goose protection area', were in the same order of magnitude as in the last few years.

Most trips with the Argo all terrain vehicle were along the 'roads' to the climate station or down to the coast in the delta of Zackenbergelven, where the track was marked up this year. One trip in May was to Daneborg and one in June to Store Sø; both mainly on snow covered ground.

Research zone	May	June	July	Aug.	Sept.	Total
1	11	174	202	162		549
1b		3	20	19		42
1c (20.6-10.8)		1	4	1		6
2	5	6			11	
ATV-trips	1	1		1		3

Table 6.1. 'Person-days' and trips in the terrain with an ATV (all terrain vehicle) allocated to the research zones in the Zackenberg study area 27 May – 31 August 2002. ATV trips on the roads to the climate station and to the delta of Zackenbergelven are not included.

Aircraft activities in the study area

Also the number of fixed-wing aircraft take-off and landings in 2002 (Table 6.2) was almost as low as in 2001. Four helicopter passages 300-600 m a.s.l. were recorded over the valley in July, and in August a helicopter visited the research station.

Discharges

As in previous years, combustible waste (paper etc.) was burned at the station, while plastics, cans, bottles etc. were flown out of the area. Solid but biologically degradable toilet and kitchen waste was poured untreated into Zackenbergelven from 26 June onwards.

During storage of the waste in June, July and August, a total amount of about 500 g 'Vera-flue-safe' was added as a killing agent against fly maggots. The active chemical is cyromazine (N-cyclopropyl-1,3,5-treazine-2,4,6-triamine) in a concentration of 2%. The total amount of untreated wastewater and solid waste let into Zackenbergelven from the toilets, kitchen, showers, sinks and laundry machines equalled *c.* 925 'person-days'.

Table 6.2. Number of flights with fixed-winged aircraft and helicopters, respectively, over the study area in Zackenbergdalen 27 May – 31 August 2002. Each ground visit of an aircraft is considered two flights.

	May	June	July	Aug.	Sept.	Total
Fixed-wing	5	7	10	26		48
Helicopter			4	2		6

Manipulative research projects

At two sites on the slopes south of the research station (site 1: UTM zone 27: 8,264,000 mN, 512,700 mE; site 2: 8,263,800 mN, 513,000 mE) 2 x 12 plots measuring 0.24 m^2 each were provided with transparent filters with different UV-absorbing properties during 5 July – 25 August. Leaves of *Vaccinium* and *Salix* were sampled (100 and 5-10, respectively) during the period, and 2 x 4 soil samples were collected (see Chapter 5.3).

At the slope south of and close to the station workshop (UTM zone 27: 8,264,400 mN, 512,750 mE) 40 *Salix*-branches, each with 2-5 leaves, were exposed to different UV-levels by means of small frames during 5 July – 25 August, after which the leaves were harvested. Three soil samples were collected at the same place. At the bottom of the slope (UTM zone 27: 8,264,350 mN, 512,650 mE) 23 circular plots each with 14 cm diameter were harvested for above-ground biomass, mainly *Vaccinium*, after being exposed to different UV-levels by means of frames with filters during 5 July – 25 August. Three soil samples were collected at the same place (see Chapter 5.3).

Take of organisms

Three samples each of 10 specimens of arctic poppy *Papaver radicatum* were collected on 31 August from three sites: UTM zone 27: 513,800 mE, 8,264,040 mN (800 m southeast of airstrip); 513,250 mE, 8,264,500 mN (near east end of air strip); and 513,000 mE, 8,264,400 mN (south side of air strip) (see Chapter 5.5).

During 28-30 August, 15 x 3 leaves from arctic willow *Salix arctica* were collected on the south facing slope 100 m southeast of the research station (UTM zone 27: 512,700 mE, 8,264,395 mN), 15 x 5 leaves from arctic cotton-grass *Eriophorum scheuzerii* were collected 300 m southeast of the east end of the runway (UTM zone 27: 513,515 mE, 8,264,533 mN) together with 15 x 5 leaves from mountain avens *Dryas integrifolia/octopetala* on the nearby heath (UTM zone 27: 513,611 mE, 8,264,491 mN). All leaves were collected within an area of 10-20 m^2 (see Chapter 5.12).

7 Zackenberg-Daneborg publications 2002

Compiled by Vibeke Sloth Jakobsen

Scientific papers

Borum, J., Pedersen, M.F., Krause-Jensen, D., Christensen, P.B. & Nielsen, K. 2002: Biomass, photosynthesis and growth of Laminaria saccharina in a high-arctic fjord, NE Greenland. – Marine biology 141 : 11-19.

Christensen, T.R., Lloyd, D., Svensson, B., Martikainen, P., Harding, R., Oskarsson, H., Friborg, T., Søgaard, H. & Panikov, N. 2002: Biogenic controls on trace gas fluxes in northern wetlands. – IGBP global change newsletter 51 : 9-15.

Christiansen, H.H., Bennike, O., Böcher, J., Elberling, B., Humlum, O. & Jakobsen, B.H. 2002: Holocene environmental reconstruction from deltaic deposits in Northeast Greenland. – Journal of quaternary science 17(2) : 145-160.

Eyre, B., Rysgaard, S., Dalsgaard, T. & Christensen, P.B. 2002: Comparison of isotope pairing and N2:Ar methods for measuring sediment denitrification – assumptions, modifications and implications. – Estuaries 25 : 1077-1087.

Glud, R.N., Kühl, M., Wenzhöfer, F. & Rysgaard, S. 2002: Benthic diatoms of a high arctic fjord (Young Sound NE Greenland) : importance for ecosystem primary production. – Marine ecology. Progress series 238 : 15-29.

Glud, R.N., Rysgaard, S. & Kühl, M. 2002: Oxygen dynamics and photosynthesis in ice algae communities : quantification by microsensors, O_2 exchange rates, ^{14}C-incubations and PAM-flouremeter. – Aquatic microbial ecology 27 : 301-311.

Hinkler, J., Pedersen, S.B., Rasch, M. & Hansen, B.U. 2002: Automatic snow cover monitoring at high temporal and spatial resolution, using images taken by a standard digital camera. – International journal of remote sensing 23(21) : 4669-4682.

Levinsen, H. & Nielsen, T.G. 2002: The trophic role of marine pelagic ciliates and heterotrophic dinoflagellates in arctic and temperate coastal ecosystems : a cross-latitude comparison. – Limnology and oceanography 47 : 427-439.

Niehoff, D., Madsen, S.D., Hansen, B.W. & Nielsen, T.G. 2002: Reproductive cycles of three dominant Calanus species in Disko Bay, west Greenland. – Marine biology 140 : 567-576.

Post, E. & Forchhammer, M.C. 2002: Synchronization of animal population dynamics by large-scale climate. – Nature 420(6912) : 168-171.

Roberts, R., Glud, R.N., Kühl, M. & Rysgaard, S. 2002: Primary production of crustose coralline red algae in a high arctic fjord. – Journal of phycology 38 : 1-11.

Schmidt, N.M., Berg, T.B. & Jensen, T.S. 2002: The influence of body mass on daily movement patterns and home ranges of the collared lemming (Dicrostonyx groenlandicus). – Canadian journal of zoology 80(1) : 64-69.

Sejr, M.K., Jensen, K.T. & Rysgaard, S. 2002: Annual growth bands in the bivalve Hiatella arctica validated by a mark-recapture study in NE Greenland. – Polar biology 25 : 794-796.

Sejr, M.K., Sand, M.K., Jensen, K.T., Petersen, J.K., Christensen, P.B. & Rysgaard, S. 2002: Growth and production of Hiatella arctica (Bivalvia) in high arctic Young Sound, Northeast Greenland. – Marine ecology. Progress series 244 : 163-169.

Trappeniers, K., Kerckvoorde, A.v., Chardez, D., Nijs, I. & Beyens, L. 2002: Testate amoebae assemblages from soils in the Zackenberg area, Northeast Greenland. – Arctic, Antarctic and Alpine research 34(1) : 94-101.

Reports

Pedersen, S.B. & Hinkler, J. 2002: The spatiotemporal snow cover distribution in Zackenbergdalen, Northeast Greenland mapped using different remote sensing techniques : Master of Science thesis. University of Copenhagen. 118 pp.

General information

Berg, T.B. 2002: Op- og nedture for tundraens lemminger. pp. 61-66. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Christiansen, H.H. 2002: Sne indeholder visdom. – Information, 18 March : 6.

Christoffersen, K. & Jeppesen, E. 2002: Isdækkets varighed har stor indflydelse på livet i søerne. pp. 79-84. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Elander, M. 2002: Det hänger på morrhåret. – Forskning & framsteg 2 : 29-33.

Forchhammer, M.C. 2002: Analyser og modeller i relation til forandringer i klimaet. pp. 15-24. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Forchhammer, M.C. 2002: Moskusokserne i Zackenbergdalen påvirkes af snemængde og plantevækst. pp. 67-72. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

From, L. 2002: Havisen i Arktis smelter. – Jyllands-Posten, 21 December.

From, L. 2002: Isbjørnen er truet. – Jyllands-Posten, 21 December.

Grubbe, K. 2002: Isen holder sig væk fra Østgrønland. – Berlingske tidende, 13 September.

Larsen, S. 2002: Insekter og edderkopper reagerer hurtigt på ændringer i klimaet. pp. 47-52. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland. DMU (Tema-rapport fra DMU ; 41/2002). 88 pp.

Meltofte, H. 2002: "Tropiske" vadefugle i is og sne. pp. 53-60. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Meltofte, H. & Forchhammer, M.C. 2002: Udsigt til mere snerige vintre og mere fugtige somre? pp. 25-28. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Meltofte, H. 2002: Zackenberg – en miljøovervågnings- og forskningsstation i højarktisk Grønland. pp. 7-14. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Mølgaard, P., Forchhammer, M.C., Grøndahl, L. & Meltofte, H. 2002: Blomsterne må vente på sneen og på varmen. pp. 43-46. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Philbert, P.-E. 2002: Grønlandske søer : et simpelt og sårbart liv. – Polarfronten 3 : 8-9.

Sayers, S. 2002: Moskusokser trues af mildere vintre. – MetroXpress, 9 April : 13.

Schmidt, N.M., Meltofte, H. & Berg, T.B. 2002: Prædatorerne i højarktisk Grønland foretrækker lemminger. pp. 73-78. In: Meltofte, H. (red.): Sne, is og 35 graders kulde : hvad er effekterne af klimaændringer i Nordøstgrønland.

Schultz-Lorentzen, C. 2002: The walrus – giant among seals. – Suluk 1.

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Thornbjerg, J. 2002: Grønland undrer sig over unormalt klima. – Politiken, 22 December

8 Personnel and visitors

Compiled by Morten Rasch

Research

Zackenberg

Kristian Albert, Botanical Institute, University of Copenhagen (UV-B radiation, 2 July – 1 September).
Thomas Bjørneboe Gomes Berg, National Environmental Research Institute (BioBasis, 2 July – 1 September).
Svend Danbæk, Botanical Institute, University of Copenhagen (UV-B radiation, 2-16 July).
Jørgen Bille Hansen, Asiaq, Greenland Field Investigations (ClimateBasis, 31 May – 14 June).
Bent Hasholt, Institute of Geography, University of Copenhagen (Hydrology, 16 – 25 July).
Jørgen Hinkler, Institute of Geography, University of Copenhagen (Snow cover and BioBasis, 31 May – 14 June).
Lotte Illeris, Botanical Institute, University of Copenhagen (NDVI, 20 August – 1 September).
Håkon Gjessing Karlsen, Asiaq, Greenland Field Investigations (ClimateBasis, 31 May – 14 June).
Line Anker Kyhn, National Environmental Research Institute (BioBasis and lemming ecology, 31 May – 1 September)
Jens Nykær Larsen, Asiaq, Greenland Field Investigations (ClimateBasis, 31 May – 14 June).
Hans Meltofte, National Environmental Research Institute (BioBasis, 31 May – 6 August).
Teis Nørgaard Mikkelsen, Risø Research Center (UV-B radiation, 2-16 July).
Morten Rasch, Danish Polar Center (GeoBasis, 31 May –14 June, 20 August – 2 September).
Tommy Nielsen, Asiaq, Greenland Field Investigations (ClimateBasis, 31 May – 14 June).
Helge Ro-Poulsen, Botanical Institute, University of Copenhagen (UV-B radiation, 2 – 16 July).
Charlotte Sigsgaard, Danish Polar Center (GeoBasis, 31 May – 1 September).
Mikkel P. Tamstorf, National Environmental Research Institute (NDVI, 20 August – 1 September).

Daneborg

Erik Born, Greenland Institute of Natural Resources (marine ecology, 25 July – 13 August).
Pasquale Cerulli-Irelli, IFSI/CNR, Italy (aurora, 6 – 13 August).
Lars Heilman, Greenland Institute of Natural Resources (marine ecology, 6 August – 1 September).
Ronnie N. Glud, Marine Biological Laboratory, University of Copenhagen (marine ecology, 25 May – 14 June).
Marco Maggiore, CNR Network Support, Italy (aurora, 6 – 13 August).
Stefano Massetti, IFSI/CNR, Italy (aurora, 6-13 August).
Nette Levermann, Greenland Institute of Natural Resources (marine ecology, 25 July – 1 September).
Søren Rysgaard, National Environmental Research Institute (marine ecology, 25 May – 14 June).
Roberto Sparapani, IFSI/CNR (aurora, 6 – 13 August).
Lars Øyvind Knutsen, Greenland Institute of Natural Resources (marine ecology, 25 July – 13 August).

Logistics

Zackenberg

Aka Lynge, Logistician, Danish Polar Center (25 May – 14 June).
Marc Overgaard Hansen, Cook, Danish Polar Center (31 May – 1 September).
Henrik Philipsen, Logistics Manager, Danish Polar Center (25 May – 5 August, 14 August – 1 September).
Bjarne Schmidt, Logistician, Danish Polar Center (16-27 July, 1 August – 1 September).

Daneborg

Henrik Philipsen, Logistics Manager, Danish Polar Center (6 – 13 August).
Bjarne Schmidt, Logistician, Danish Polar Center (28-31 July).

Others

Zackenberg

Jens Morten Hansen, Director, Danish Research Agency (18-20 August).

Per Ravn Hermansen, Principal, Greenland Home Rule (22-23 August).

Anders Karlqvist, Director, Swedish Polar Research Secretariat (18-20 August).

Thorkild Meedom, Head of Office, Ministry of Science, Technology and Innovation (18-20 August).

Naja Mikkelsen, Geological Survey of Denmark and Greenland (18-20 August).

Hanne Katrine Petersen, Director, Danish Polar Center (18-20 August).

Further contributors to the annual report

Kirsten Christoffersen, Freshwater Biological Laboratory, University of Copenhagen.

Egon R. Frandsen, National Environmental Research Institute.

Erik Jeppesen, National Environmental Research Institute.

Per Mølgaard, Royal Danish School of Pharmacy.

Henrik Søgaard, Institute of Geography, University of Copenhagen.

9 Zackenberg Basic. Climate Change Effects in a High Arctic Ecosystem at Zackenberg, Northeast Greenland. The concept

Morten Rasch, Søren Rysgaard, Hans Meltofte and Jørgen Bille Hansen

A marine monitoring programme, MarineBasis, has been added to the terrestrial Zackenberg Basic monitoring programmes, ClimateBasis, GeoBasis and BioBasis. This chapter contains part of the 2002 application for funding of Zackenberg Basic to the Danish Environmental Protection Agency, and describes the concept of the monitoring programmes.

Climate change, high arctic ecosystems and Zackenberg Station

Global circulation models of future climate indicate larger than average warming of the colder regions, and registrations of global air temperature development during the last decades indicate significant and higher than average warming of the Arctic with up to *c.* 1°C per decade (according to Hadley Centre for Climate Prediction and Research, 2001). In this respect, the climate development in the North Atlantic region is of special interest, especially changes in large-scale atmospheric forcing and oceanic cold water circulation.

The largest expanses of high arctic tundra on the Earth are found in Greenland and north-easternmost Canada. With the forecasted temperature changes, the high arctic zone may shrink significantly on a global scale or even disappear altogether and with it its unique biodiversity and other features. Continued focus on processes and dynamics in this area is of the utmost importance and crucial in illuminating direct as well as cascading effects of climate on northern ecosystems.

At Zackenberg in Northeast Greenland, Danish and Greenlandic institutions have established a field station as a logistic base for environmental research, and a monitoring programme, Zackenberg Basic, within the framework of Zackenberg Ecological Research Operations. The field station is situated in an area highly sensitive to global warming due to its high arctic position on the border between permanent sea ice cover to the north and open-water summer conditions to the south.

In Zackenberg Basic, high-resolution measurements are performed in time and space of the climate and its effects on the biotic and abiotic parts of the terrestrial and the marine ecosystem. By merging the intra- and inter-annual variations in these data to form coherent analytic models, it will become possible with time to quantify the processes linking the dynamics of climate with the dynamics of a high arctic ecosystem. It is well known that climate-ecosystem interactions are two-way processes (feed back mechanisms), that is, ecosystem changes also affect climate. Therefore, the biotic-abiotic process links established by Zackenberg Basic are important to the continuous general improvement of global climate models.

Carrying out research and monitoring in the high arctic regions generally involves expensive logistics. Consequently, previous research in the Arctic has been carried out mostly as short field campaigns in projects with a typical duration of maximum three years. This is probably the main reason that limited knowledge exists of the function, climatic control factors and climatic feed back mechanisms of arctic ecosystems. With the establishment of Zackenberg Station it has become possible and economically feasible to carry out even quite sophisticated research activities in association with long-term baseline monitoring in a remote high arctic ecosystem. So far, the monitoring programme at Zackenberg constitutes one of few integrated, cross-disciplinary study programmes of global climate change effects in Arctic and Antarctic regions. As such, Zackenberg is an invaluable reference point for circumpolar arctic studies in general but indeed also an important Northern Hemisphere reference for antarctic studies.

As part of the comprehensive Effects Monitoring Programme, AMAP has identified a number of specific climatic factors and their potential ecological consequences to be monitored in the Arctic. At present, Zackenberg Basic is the only monitoring programme in the entire Arctic, which almost completely fulfils the recommendations given by AMAP (Appendices 1-3). According to the national AMAP implementation plan for Denmark (AMAP Phase II), the monitoring at Zackenberg is considered the core Danish input to this work.

Increased interest in the Arctic during the last decades has resulted in heightened research activity in arctic areas. For instance, the Norwegians have established an extensive research facility in Ny Aalesund and a university (UNIS) in Longyearbyen (both in Svalbard), and the Swedes are running a large field facility at Abisko, and they frequently organise research expeditions on icebreakers operating in the entire circumpolar area. Compared to such initiatives the project at Zackenberg is small in the sense of economic investment, but in spite of this, Zackenberg Basic is in the international lead when it comes to establishment of an improved understanding of arctic landscape and ecosystem dynamics. Continued and more permanent financing of the work at Zackenberg will make it possible to maintain this position in the future.

Zackenberg Station and the Zackenberg study area

Zackenberg Station is situated in high arctic Northeast Greenland, and the station is maintained by the Danish Polar Center. Compared to other research stations in the High Arctic, Zackenberg Station offers relatively advanced facilities, e.g. electric installations, deionised water, dry and wet laboratories, field equipment, accommodation facilities and a kitchen managed by a cook. The station consists of a large facility at Zackenberg and a smaller one in Daneborg. The facility at Zackenberg is used mainly for terrestrial and limnic studies while the facility at Daneborg is used mainly for marine studies. The Danish Polar Center handles all logistics related to transport of persons and equipment to and from the station and accommodation at the station. The maintenance of and transport to and from the station is supported by the Ministry of Science, Technology and Innovation with an annual contribution of *c.* 1.6 mio. DKK.

The Zackenberg study area comprises the drainage basin of Zackenbergelven (terrestrial investigations) and the Young Sund-Tyroler Fjord complex with connected drainage basins (marine investigations). The area is completely undisturbed by humans since the nearest town is 450 km away. The climate is high arctic and relatively dry, with a mean annual temperature of *c.* –10°C, an annual precipitation of *c.* 200 mm and only three months with mean temperatures above 0°C. The drainage basin of Zackenbergelven has an area of *c.* 500 km^2 with glacier coverage of *c.* 20%. The area encompasses a wide variety of physical landscape types including glacial, periglacial, coastal and fluvial landscapes and many different biotopes such as fens, heaths, fellfield plateaus and grasslands. Collared lemmings, arctic hare, arctic fox, stoat and musk ox are the most common terrestrial mammals while common ringed plover, red knot, sanderling, dunlin, ruddy turnstone and snow bunting are the most frequently occurring birds. The total length of the fjord system of Young Sund and Tyroler Fjord is *c.* 100 km, with a surface area of 396 km^2 and a maximum depth of 350 m. A threshold/sill is found at a depth of 40-50 m at the mouth of the fjord. The water in the fjord is stratified during the ice-free period with almost fresh and relative warm surface water and cooler and more saline water in the deeper strata. The fjord is ice covered for *c.* ten months of the year, normally from late September to mid-July. Walrus and seals occur frequently in the fjord and arctic char is present during the ice-free period.

According to global circulation models, one possible future scenario suggests that the climate at Zackenberg may become more maritime, following a decrease in extent and coverage of the drift ice along the coast of East Greenland. As a result, winter temperatures and precipitation will increase, with above-zero air temperatures occurring more frequently, and hence formations of ice crust during winter. Snowmelt in spring will be delayed, and the summers will become more foggy and cloudy and the frequency of cyclonic weather will increase. Such changes may profoundly affect most organisms in the high arctic ecosystem, and a number of species may disappear altogether.

Zackenberg Basic

Zackenberg Basic is the monitoring programme at Zackenberg Station. It comprises four fully integrated sub-programmes:

- ClimateBasis (monitoring of the climate) – ASIAQ, Greenland Field Investigations
- GeoBasis (monitoring of abiotic processes in the terrestrial ecosystem) – University of Copenhagen and Danish Polar Center
- BioBasis (monitoring of biotic processes in the terrestrial and limnic ecosystems) – National Environmental Research Institute
- MarineBasis (monitoring of biotic and abiotic processes in the marine ecosystem) – National Environmental Research Institute

Zackenberg Basic collects long-term series of baseline data on the function of the marine and terrestrial high arctic ecosystems at Zackenberg. As such, Zackenberg Basic provides multi-disciplinary data, which describe the variation in different parameters within each year as well as the year to year variations of these parameters. The monitoring at Zackenberg Station comprises both the terrestrial and the marine environment, and in both environments, biotic as well as abiotic parameters are measured.

The major questions to be addressed are:

1. How and why does climate variability influence the dynamics of high arctic ecosystems?
2. How do high arctic ecosystems affect climate?

To answer the first question we simply look at how normal annual variations in the physical environment, mainly the climate, affect the selected ecosystem components (both biotic and abiotic) and their interactions. The second question is related mainly to the potential feedback mechanisms from ecosystem to climate. A large number of possible feedback mechanisms exist. Some of these are related to the carbon balance of the ecosystem, some are related to the water, sediment and nutrients being washed out of the system and others are related to the changes in snow and sea ice cover. The necessary parameters selected for continuous monitoring are listed in Appendices 1-3.

The Zackenberg Basic is a fully integrated monitoring programme. However, due to the highly specialised expertise needed to provide the inputs required from different science disciplines, the programme maintains four sub-programmes at different agencies serving under central coordination by the programme manager. Integration and coordination is accomplished by:

1. Clearly defining the major questions to be answered in cooperation between the programmes.
2. Clearly defining who should monitor what to answer the questions.
3. Clearly defining the flow of information/data between the programmes.
4. Establishing a working group (Zackenberg Basic Working Group) with participitation of all the monitoring programmes and with scheduled regular meetings among the managers of the individual programmes.
5. Appointing a programme manager responsible for overall coordination of the monitoring.

The monitoring at Zackenberg cannot be viewed as an isolated activity. It must be supported by short-term but detailed research focusing on analyses of interactions among the abiotic and biotic elements themselves and between the abiotic and the biotic environment. The central integration of the monitoring in Zackenberg Basic and focussed research projects is facilitated and maintained by the ZERO Working Group and the Zackenberg Basic Working Group.

Since 1995, a large number of research projects have made use of Zackenberg Basic data. At present, the Danish Meteorological Institute is developing a local climate models for the Zackenberg area, and Geological Survey of Denmark and Greenland is planning to do intensive glaciological monitoring in the area. Further, a large number of research groups are planning either to continue or to start up research in the Zackenberg area. Thus, the potential for even further increasing the synergy between research and monitoring is present.

The ClimateBasis and GeoBasis programmes

ClimateBasis and GeoBasis will provide long-term data that are:

- Necessary for describing all aspects of the regional climate at Zackenberg
- To be used to quantify and model the variation in snow cover at Zackenberg
- To quantify the freshwater, sediment and nutrient transport from the terrestrial system to the marine system
- To quantify, together with BioBasis and MarineBasis, the carbon balance of the terrestrial part of the high arctic ecosystem
- To improve current understanding of the effect of climate variability on the physical landscape dynamics

These five items will be used to improve current model predictions for future changes in the abiotic part of the arctic terrestrial ecosystem and to quantify the feedback mechanisms from the high arctic ecosystem to climate.

It is well known that high arctic ecosystems may be more influenced by global climate change than other parts of the Earth, but it is uncertain to what extent the high arctic areas affect climate. Large areas are covered with tundra underlaid by thick peat formations. These peat formations will either reduce or grow in response to climate changes and consequently either release or absorb the 'greenhouse gases' carbon dioxide and methane. As such, the tundra can either enhance or diminish climatic perturbations. Similar feedback mechanisms are related to snow cover as well as to the output of freshwater and nutrients from the terrestrial to the marine ecosystem. The monitoring through ClimateBasis and GeoBasis will in cooperation with BioBasis and MarineBasis quantify the most central of these feedback mechanisms. Similar investigations have been carried out in the arctic before, but none have been based on longer time series, and as a result, these investigations do not give a full picture of the process variations caused by climate variations.

Furthermore, GeoBasis will quantify the direct influence of climate variability on the physical arctic landscape. Periglacial landscapes are extremely vulnerable to even small changes in physical conditions, and with a continued warming of the Arctic of up to 1°C per decade, the physical landscape of large areas, both inhabited and uninhabited, will undergo great changes, which may have significant economical implications. Although physical landscapes develop relatively fast in the Arctic, it is generally not possible to establish the link between process and result from year to year. Therefore, it is essential to establish field investigations that can be followed for several years, and the Zackenberg area is ideally suited for such studies of periglacial landscape changes in relation to climate change.

The BioBasis programme

BioBasis will provide long-term data:

- To establish ecological base-line data for evaluating and modelling how climatic changes, directly and indirectly, sum up and affect an entire high arctic ecosystem
- For the fundamental knowledge of the spatio-temporal dynamics of a high arctic ecosystem in a changing climate
- To describe and quantify intra- and intertrophic processes
- To describe and quantify short- and long-term changes in species composition and the communities in which they are embedded
- To describe and quantify short- and long-term changes in individual life history of central floral and faunal species

Climate change is a major environmental concern because of its multiple effects on living conditions and hence its unknown worldwide cascading effects on ecosystems. The main concern is of course related to human interests, pertaining to specific climatic effects on human living resources, but equally important are the climatic effects on species biodiversity and performance and hence the healthy functioning of the Earth's terrestrial ecosystems.

The terrestrial ecosystems of the High Arctic are particularly sensitive to the forecasted climatic changes, because the most pronounced climate changes are expected to occur here rather than in boreal and temperate ecosystems. However, our knowledge of Arctic ecosystem response is still basically non-existent. BioBasis will bridge this gap. By monitoring the seasonal and annual variability in parameters such as species composition, population density and spatial distribution, phenology and reproduction across all trophic levels, BioBasis provides the essential foundation for the description of the inter-annual and decadal performance of individual species and communities. This is necessary for the evaluation and modelling of the manner in which high arctic ecosystems will change following any climatic perturbations with respect to functioning as well as cycling of most ecosystem elements. Hence, BioBasis will be the first extensive programme providing the potential for answering the central question 'why do ecosystem changes occur in response to climate?' rather than, as has been done several times before, simply recording that changes do occur in parallel to climatic changes.

It is well established that an ecosystem will respond only on the individual level to any climatic changes. In other words, any observed changes in ecosystem functioning, from community-level interactions to nutrient cycling, are the immediate results of individual responses to climate. This is why BioBasis monitors the effects of climate change on the individual components of the terrestrial ecosystem, the species and their interactions with the rest of the biotic as well as the abiotic elements of the ecosystem. Only by building up such comprehensive data sets on the effects of inter-annual variation in climatic conditions, is it possible to produce models of the functioning of individual species and thereby predict the future development in the populations and the communities in which they are embedded.

The MarineBasis programme

MarineBasis will provide long-term data:

- Necessary for modelling the coupling between physical oceanography and biological production and consumption
- For use in modelling the regulation of pelagic-benthic coupling (vertical flux)
- To quantify and improve understanding of the lateral coupling (land/fiord/sea)
- To quantify the effect of changing freshwater input, sea ice cover and deep-water formation on biological production and consumption
- To improve current understanding of the effect of climatic changes on selected species composition and adaptation in the arctic marine environment

These five items will be used to improve current model predictions for future changes in the arctic marine environment.

The sustainability of arctic marine ecosystems and their response to climate warming is a matter of international concern since the forecasted temperature increase in the Arctic is predicted to be higher than elsewhere in the world and since a further temperature increase will affect future sea ice cover tremendously. The aim of MarineBasis is to build up a data base in Northeast Greenland, where large changes in deep-water formation, freshwater input and sea ice cover have occurred, and to improve the functional understanding of several biological and physical factors involved in changes in the Arctic Ocean. This will be accomplished by collecting key-parameter data in the lower atmosphere, in sea ice, in water column and in sediments. MarineBasis will generate the data necessary for creating model tools for quantifying the carbon dioxide exchange between atmosphere and ocean, linking primary production and consumption in the pelagic environment, vertical export and benthic mineralization. Furthermore, it will increase current understanding of the effect of climatic changes on species composition and adaptation in the arctic marine environment. Thus, MarineBasis will provide tools for identifying and evaluating key factors regulating food chains and carbon and nutrient cycles, and for understanding the response of arctic marine ecosystems to global warming. This will be particularly important in evaluating effects of climatic changes on natural resources in the Arctic, but will also provide important input data for models predicting future climate in Europe.

International obligations

In Appendices 1-3, the main elements monitored by Zackenberg Basic are listed in relation to elements given by AMAP as appropriate variables to monitor in relation to climate change effects. Zackenberg Basic covers most of the necessary ecosystem components. The only gaps appear either where the parameters are irrelevant in the specific study area, or where the actual measurements are too sophisticated to carry out in the remote field site at Zackenberg/Daneborg.

Similar national monitoring obligations are found in the agreements and conventions of CAFF (conservation of arctic flora and fauna), CBD (global biodiversity), BERN (Europe's species and habitats), RAMSAR (wetlands and waterbirds), CMS (migratory species) and AEWA (waterbird agreement) that Denmark has ratified. The outcome of Zackenberg Basic will be an important Danish contribution to ACIA (Arctic Climate Impact Assessment). Furthermore, Zackenberg Basic provides data for a number of international networks such as SCANNET (species performance and phenology, biodiversity, climatic variability, land use and society interactions, climate change scenarios), ENVINET (coordination between and information about field sites in Europe), CALM (active layer development), ITEX (plant community development and flowering), ABBCS (breeding birds) and PASRN (climate related shorebird research network).

Integration, co-operation and co-ordination

One of the basic and unique concepts behind Zackenberg Ecological Research Operations is the co-operation between research, monitoring and logistics. This is achieved within the ZERO Working Group, which includes representatives from the different groups. Some of the major forces of this concept are:

- Monitoring keeps its focus on state of the art questions, parameters and methods
- Researchers are fully aware of what is being monitored and are able to integrate these parameters in their research
- Research ensures transfer of up to date knowledge on questions, methods and analyses to monitoring
- The logistics are carried out with a high level of consideration to the research area

The working group evaluates the applications from research projects. This is done to make sure that no research projects will damage the area's major purpose of remaining an undisturbed high arctic study site. The ZERO Working Group meets twice every year, and the Zackenberg station manager is secretary of the working group.

To maintain a high level of information among the investors in the Zackenberg work, a Steering Committee has been established. This committee meets annually and acts as advisors for the station manager. The station manager is secretary of the committee.

With the inclusion of MarineBasis in Zackenberg Basic, internal co-ordination of the monitoring within Zackenberg Basic becomes necessary. A coordinator, employed by Danish Polar Center, of the entire monitoring programme will be made responsible for the overall co-ordination, the annual publication of the ZERO Annual Report and providing public information on the monitoring activities (incl. the Internet location). The working group will consist of the managers of each separate monitoring programme. The coordinator of the monitoring programme will chair the group and act as its secretary. The Zackenberg Basic Working Group will be responsible for the flow of information and co-ordination between the individual programmes. It will have two formalised meetings annually and informal meetings whenever necessary. Specialists can be included as advisors of the working group whenever necessary.

Publication and data availability

Data from the monitoring programmes are summarised annually in the ZERO Annual Report. This report series has been published by the Danish Polar Center since 1996.

Each monitoring programme is responsible for contributing to the reports with relevant information on the previous year's monitoring results, and the Danish Polar Center is responsible for editing and publishing the reports.

At the end of each ten-year period, a more extensive synthesis will be published. This synthesis will include major scientific achievements of research projects and monitoring programmes. The Zackenberg Basic Working Group is responsible for planning the publication of these syntheses.

The data produced by the monitoring programmes at Zackenberg are distributed free of charge to all researchers who are interested in the data. At present, the delivery of data to scientists is accomplished by the individual monitoring programmes. In future, we will work towards establishing a common database with direct access to the Zackenberg Basic data through the Internet. The database will be linked to or integrated with the existing Zackenberg home page (www.zackenberg.dk) which among other things also contains information and publications on the concept of and the work at Zackenberg and on facilities and prices.

In the period 1995-2001, a large number of scientific articles for publication in peer reviewed journals and a large amount of popular information for Danish and foreign newspapers, journals and broadcasting concerning the work at Zackenberg have been produced by the established monitoring programmes and by the research group responsible for the new MarineBasis component (bibliography in ZERO 6th Annual Report). It is the ambition of the programme to keep the high publication level in the future.

Financing

The maintenance of Zackenberg Station is supported by The Ministry of Science, Technology and Innovation with an annual frame of *c.* 1.6 mio. DKK. ClimateBasis is being run by Asiaq, Greenland Field Investigations, with an annual turnover of *c.* 0.3 mio. DKK, funded by the Greenland Home Rule. The future financing of BioBasis, GeoBasis and MarineBasis has been applied for from Dancea with at total annual amount of 4.4 mio. DKK per year for the maintenance of the programmes and an investment of 3.3 mio. DKK in 2002 for further establishment of the programmes (MarineBasis and GeoBasis).

Appendix 1. GeoBasis and ClimateBasis in relation to AMAP's Effects Monitoring Programme (Climate Change effects)

Parameter variable	Parameter subdivision	GeoBasis and ClimateBasis Sites	Level by AMAP	Recommended
Radiation	UV-B	1	Micro/Landscape	Yes
	Short wave	1	Micro/Landscape	Yes
	Net	1	Micro/Landscape	No
	PAR	2	Micro/Landscape	Yes
	NDVI	1	Landscape	No
Temperature	Vertical profiles	9	Micro/Landscape	Yes
Precipitation		1	Micro/Landscape	Yes
Wind	Speed	3	Micro/Landscape	Yes
	Direction	3	Micro/Landscape	Yes
Snow cover	Depth	3	Micro/Landscape	Yes
	Extent	1	Landscape	Yes
	Duration	4	Micro/Landscape	Yes
	Quality	1	Micro/Landscape	No
Ice cover	Depth	None	–	Yes
	Extent	1	Landscape	Yes
	Freeze time	None	Landscape	Yes
	Thaw time	1	Landscape	Yes
Glaciers	Mass	None	–	Yes
	Extent	1	Landscape	Yes
Permafrost	Distribution	Irrelevant	–	Yes
	Thermal state	None	–	Yes
Active layer	Thickness	2	Micro/Landscape	Yes
	Water content	6	Micro/Landscape	Yes
	Water quality	6	Micro/Landscape	No
Water table	Depth	Irrelevant	–	Yes
Water outflow	Discharge	1	Landscape	Yes
	Sediment load	1	Landscape	Yes
	Organic matter	1	Landscape	No
	Water quality	1	Landscape	Yes

Appendix 2. BioBasis in relation to AMAP's Effects Monitoring Programme (Climate Change effects)

Variable	Subdivision	Eco-system	Level	Plots	Species	Monitored by BioBasis
Physical preconditions						
Temperature (microclimate)		T/F	Plot	26		Yes
Snow cover	Distribution	T	Landscape	12		Yes
Snow cover	Timing of melt	T	Plot	26		Yes
Ice cover on lakes, ponds and fjords	Timing of melt	F	Plot	6		Yes
Plant properties						
Leaf area index		T	Plot/Landscape			Yes[1]
Peak shoot and root biomass		T	Plot/Landscape			Yes[1]
Net primary production		F	Plot/Landscape			Yes[1]
Surface roughness		T				No
Spectral vegetation greenness		T	Plot/Landscape	26		Yes, throughout growing season
Chlorophyll concentration		F	Plot	2		Yes, three times per season
Nutrient pools in soil and plants		T				Yes, see GeoBasis
Nutrient pools in organic and inorganic matter		F				No
Max. stomatal conductance		T				No
Plant and animal						
Species richness, abundance and distribution	Plants	T	Plot/Landscape	160	>100	Yes
Species richness, abundance and distribution	Plants	F	Plot	2	>10	Yes
Species richness, abundance and distribution	Arthropods	T	Plot	6	>100	Yes
Species richness, abundance and distribution	Arthropods	F	Plot	2	>10	Yes
Species richness, abundance and distribution	Birds	T, F	Plot/Landscape	5	>25	Yes
Species richness, abundance and distribution	Mammels	T	Plot/Landscape	13	>8	Yes
Demographic processes (selected species)	Plants	T	Plot	35	8	Yes
Demographic processes (selected species)	Arthropods	F	Plot	6	1	Yes
Demographic processes (selected species)	Arthropods	T	Plot/Landscape	2	4	Yes
Demographic processes (selected species)	Birds	T, F	Plot/Landscape	1	8	Yes
Demographic processes (selected species)	Mammels	T	Plot/Landscape	1	4	Yes
Phenology (selected species)	Plants	T	Plot	27	6	Yes
Phenology (selected species)	Arthropods	T	Plot	6	>100	Yes
Phenology (selected species)	Birds	T	Plot	1	4	Yes
Phenology (selected species)	Mammels	T	Plot	1	1	Yes
Displacement of ecotones		T, F	Plot/Landscape	1		Yes
Processes						
CO_2, CH_4, and N_2O flux		T, (F)	Plot	2		T: CO_2
Decompostion		T, (F)	Plot	7		Yes, indirectly by GeoBasis
N mineralisation		T	Plot	7		Yes, indirectly by GeoBasis

Legend: T: Terrestrial, F: Freshwater

1. Derived from NDVI

Appendix 3. MarineBasis in relation to AMAP's Effects Monitoring Programme (Climate Change effects)

Variable	Parameter subdivision	MarineBasis Sites	Level	Recommended by AMAP
Radiation	UV-B	2	Micro/Fjord	Yes
	Short wave	2	Micro/Fjord	Yes
	PAR	2	Micro/Fjord	Yes
Air pressure		1	Micro/Fjord	Yes
Wind	Speed	1	Micro/Fjord	Yes
	Direction	1	Micro/Fjord	Yes
Snow cover	Depth	3	Micro/Fjord	Yes
	Extent	3	Outer fjord	Yes
	Duration	3	Micro/Fjord	Yes
Ice cover	Depth	1	Micro/Fjord	Yes
	Extent	10	Outer and mid fjord	Yes
	Freeze time	1	–	Yes
	Thaw time	1	–	Yes
Current patterns	Vertical profiles	2	Micro/Outer and mid fjord	Yes
	Speed & direction	2	Micro/Outer and mid fjord	Yes
Nutrients	Vertical profiles & fluxes	2	Micro/Outer and mid fjord	Yes
Carbon and CO2	Vertical profiles & fluxes	2	Micro/Outer and mid fjord	Yes
Salinity and temperature profiles	Vertical profiles	2	Micro/Outer and mid fjord	Yes
Water table, tides	Depth	Irrelevant	–	Yes
Plankton	Species composition, abundance, distribution	2	Micro/Sea ice/water column	Yes
Primary production	Ice algae/phytoplank-ton/ underwater plants	2	Micro/Outer and mid fjord	Yes
Underwater plants/diatoms	Species composition, abundance, distribution	10	Outer and mid fjord	Yes
Benthos	Species composition, abundance, distribution	10	Outer and mid fjord	Yes
Walrus	Abundance	1	Outer and mid fjord	Yes
Ringed seal	Change in food choice and condition	–	Outer and mid fjord	Yes

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