Zackenberg Ecological Research Operations

3rd Annual Report, 1997

Danish Polar Center
Ministry of Research and Information Technology
1998

Zackenberg Ecological Research Operations, 3rd Annual Report, 1997

Danish Polar Center, Ministry of Research and Information Technology

ISBN: 87-90369-26-2
Editors: Hans Meltofte & Morten Rasch
Layout: Special-Trykkeriet Viborg a-s & Morten Rasch

Impression: 800
Paper: 80 g recycled
Printing: Special-Trykkeriet Viborg a-s

Strandgade 100H
DK-1401 Copenhagen K
Tel: +45 3288 0100
Fax: +45 3288 0101
E-mail: dpc@dpc.dk

Cover photo:
Walrus enjoying the Arctic summer. Photo: Magnus Elander

Citation:
Meltofte, H. & Rasch, M. (eds.) 1998: Zackenberg Ecological Research Operations, 3rd Annual Report, 1997.
– Danish Polar Center, Ministry of Research and Information Technology.

Executive summary

During the summer of 1997, the construction of Zackenberg Ecological Research Station was finalised, and on 14 August the station was officially opened by the Danish Minister of Research and Information Technology together with the Greenland Minister of Health, Environment and Research.

A total of 28 researchers worked at Zackenberg during the summer season, as well as six at the branch facility in Daneborg. A further 10 logistics personnel handled service and construction in Zackenberg.

The environmental monitoring programmes, GeoBasis and BioBasis, had their third season (see sections 3 and 4). The snow melt and the break up of rivers, lakes and the fjord ice were about a week later than in the very early season of 1996, but more important, spells of inclement weather prevailed during parts of June and July. This was clearly reflected in the reproductive phenology of plants and invertebrates. Birds had a good breeding season and the lemming population apparently peaked, while foxes experienced a poor season.

Two multi-disciplinary research projects were running at Zackenberg ('Interactions and feedbacks among physical geographical and biological processes' and 'Lake studies') and one in Daneborg ('Nutrient dynamics in Northeast Greenland waters and sediments').
A further eight research projects on plants, invertebrates and lemmings were allocated to the Zackenberg study area (see section 5).

Table of contents

1. Introduction *Morten Rasch* . . . 6
1.1. The official opening of the Zackenberg Ecological Research Station . . . 6
1.2. New structure of ZERO . . . 6
1.3. The Zackenberg study area . . . 7
2. Logistics *Henrik Lassen* . . . 8
2.1. Transportation . . . 8
2.2. Accommodation . . . 8
2.3. Telecommunication . . . 8
3. The GeoBasis Programme *Morten Rasch* . . . 8
3.1. The meteorological station . . . 9
3.1.1. Meteorological data from 1996 . . . 10
3.1.2. Meteorological data from 1997 . . . 11
3.2. TinyTalk/TinyTag dataloggers . . . 13
3.3. The hydrometric station . . . 14
3.3.1. River water discharge . . . 15
3.3.2. Suspended sediment . . . 16
3.3.3. Water chemistry, pH and conductivity . . . 16
3.4. Landscape monitoring . . . 17
3.4.1. Monitoring photos . . . 17
3.4.2. Active layer depth . . . 17
3.4.3. Soil water chemistry *Bo Elberling, Bjarne H. Jakobsen & Morten Rasch* . . . 18
3.4.4. Coastal geomorphology . . . 19
3.5. General observations on ice conditions *Hans Meltofte* . . . 19
3.5.1. The fjord . . . 19
3.5.2. Lakes and streams . . . 19
4. The BioBasis Programme . . . 20
4.1. Vegetation *Hans Meltofte* . . . 20
4.1.1. ITEX reproductive phenology . . . 20
4.1.2. ITEX quantitative flowering . . . 20
4.1.3. Snow melt in 400 m^2 plant community study plots . . . 20
4.2. Arthropods *Henrik Barner Rasmussen* . . . 21
4.2.1. Yellow pitfall traps . . . 21
4.2.2. Window traps . . . 25
4.2.3. Insect line transect . . . 26
4.2.4. Predation on *Dryas* flowers by larvae of *Sympistis zetterstedtii* . . . 26
4.2.5. Predation on *Salix arctica* . . . 26
4.2.6. General phenological observations . . . 26
4.3. Birds *Hans Meltofte* . . . 27
4.3.1. Breeding populations . . . 27
4.3.2. Reproductive phenology in waders (shorebirds) . . . 27
4.3.3. Breeding success in waders . . . 27
4.3.4. Reproductive phenology and success in long-tailed skuas . . . 28
4.3.5. Breeding barnacle geese . . . 28
4.3.6. Line transects . . . 28
4.3.7. Sandøen . . . 28
4.3.8. Other observations . . . 28
4.4. Mammals *Thomas Bjørneboe Berg* . . . 31
4.4.1. Winter nests and summer burrows of collared lemming . . . 31
4.4.2. Muskox population biology . . . 32
4.4.3. Arctic fox dens . . . 37
4.4.4. Line transects . . . 37
4.4.5. Other observations . . . 37
5. Research projects . . . 39
5.1. The Arctic landscape: Interactions and feedbacks among physical geographical and biological processes . . . 39
5.1.1. Trace gas exchange from plot to landscape scale . . . 39
5.1.2. Controls on soil respiration in tundra peatlands . . . 43
5.1.3. Soil solution and acidification of Arctic brown soils . . . 44

5.1.4. ^{14}C AMS dating of a buried podzol . . . 44
5.1.5. Plant-microbe competition in dry tundra . . . 45
5.1.6. Hydrological and thermal processes in the active layer . . . 45
5.1.7. Hydrology and water quality . . . 47
5.2. Nutrient dynamics in Northeast Greenland waters and sediments . . . 48
5.2.1. Winter campaign . . . 48
5.2.2. Underwater plants . . . 48
5.2.3. Arctic char . . . 49
5.2.4. Porewater concentration profiles . . . 50
5.2.5. Transport mechanisms within the sea bed . . . 50
5.2.6. Walrus feeding behaviour . . . 51
5.2.7. Carbon budget for Young Sund (1996-1997) . . . 52
5.2.8. Acknowledgements . . . 53
5.3. Lake studies . . . 53
5.3.1. Characteristics of the lakes . . . 54
5.3.2. Physico-chemical measurements . . . 54
5.3.3. Biological measurements . . . 54
5.3.4. Sediment analyses . . . 55
5.4. Seed dynamics of Arctic plants . . . 56
5.5. Pollination community ecology . . . 57
5.6. Pollen traps . . . 57
5.7. Collared Lemming Project – Zackenberg . . . 57
5.8. Vegetation mapping of the Zackenberg study area . . . 59
5.9. Herbivore influences on reproductive strategies of Arctic willow . . . 59
5.10. Insect-pathogenic fungi in the Arctic . . . 61
5.11. Behavioural and morphological differentiation among bumblebee *Bombus polaris* workers 61
6. Disturbance *Hans Meltofte* . . . 62
6.1. Surface activities in the study area . . . 62
6.2. Aircraft activities in the study area . . . 62
6.3. Discharges . . . 62
6.4. Manipulative research projects . . . 63
6.5. Take of organisms . . . 63
7. Economic investment in ZERO *Henning Thing* . . . 63
8. Publications from ZERO . . . 63
8.1. Scientific papers . . . 63
8.2. Reports . . . 63
8.3. General information . . . 64
8.4. Supplementary list of publications . . . 64
9. Personnel . . . 64
9.1. Research . . . 64
9.1.1. Zackenberg . . . 64
9.1.2. Daneborg . . . 65
9.2. Logistics and construction, Zackenberg . . . 65
9.3. Guests for the opening of the Zackenberg Ecological Research Station . . . 65
9.4. Participants in the visit by the Danish Parliament's Finance Committee . . . 66
9.5. Other . . . 66
9.6. Further contributors to the annual report . . . 66
10. Acknowledgements . . . 66
11. References . . . 67

1. Introduction

1997 was the most busy year at Zackenberg so far. During summer, 28 scientists worked from the station, the interior of the station buildings was completed, and the station was officially opened. In August, Zackenberg was visited by a large number of notabilities including the Danish Minister of Research and Information Technology, Jytte Hilden, the Greenland Minister of Health, Environment and Research, Marianne Jensen and the Danish Parliament's Financial Committee. 1997 also brought a long-term solution for the future financing of the Zackenberg station and the connected monitoring programmes.

Fig. 1.1.2. The opening of Zackenberg Ecological Research Station was celebrated with an open air banquet. The temperature on the day of the opening approached 0° C. Photo: Henning Thing.

1.1. The official opening of the Zackenberg Ecological Research Station

The Zackenberg station was officially opened on 14 August 1997 by the Danish Minister of Research and Information Technology, Jytte Hilden, and the Greenland Minister of Health, Environment and Research, Marianne Jensen (Fig. 1.1.1). A large number of VIPs from Greenland and Denmark participated in the opening (see section 9.3). The opening was celebrated with an open-air banquet (Fig. 1.1.2).

1.2. New structure of ZERO

From the first pioneer expedition to Zackenberg in 1991 until 1997, the operation of the Zackenberg station and the connected monitoring programmes

Fig. 1.1.1. The Danish Minister of Research and Information Technology, Jytte Hilden, and the Greenland Minister of Health, Environment and Research, Marianne Jensen, officially opened the Zackenberg Ecological Research Station on 14 August 1997. Photo: Henning Thing.

has been financed by short-term grants from the Commission for Scientific Research in Greenland, the Danish Fund for Environment and Disaster Releaf, Ministry of the Environment and Energy, the Danish Polar Center, and the Danish Natural Science Research Council (see section 6 in Meltofte & Thing (1996) and section 7 in Meltofte & Thing (1997) together with section 7 in this volume). In late 1997, a long-term financing system involving a new structure for the station and the monitoring programmes (Fig. 1.2) was negociated. Until now, the Danish Polar Center has been responsible for the operation of both the station and the monitoring programmes (see section 1.2 in Meltofte & Thing 1996). In 1998 and onwards, the responsibility of the Zackenberg station and the monitoring programmes is divided between the following partners: Danish Polar Center, the Danish National Environmental Research Institute, Greenland Field Investigations, the Faculty of Science at the University of Copenhagen and the Greenland Institute of Natural Resources.

- The Danish Polar Center continues to take the responsibility to operate the Zackenberg Ecological Research Station and in co-operation with the Faculty of Science at the University of Copenhagen runs a modified GeoBasis programme (see below). The Danish Polar Center has employed a scientific leader responsible for the management of the station and the GeoBasis programme.
- The BioBasis programme is now financed by the Ministry of the Environment and Energy and run by the Department of Arctic Environment under the Danish National Environmental Research Institute.
- Greenland Field Investigations takes responsibility of the meteorological, hydrological and hydrographic monitoring, formerly part of the GeoBasis programme. This new programme, funded by the Greenland Home Rule, is named the ClimateBasis programme.
- The Danish Minister of Research and Information Technology, Jytte Hilden, has in co-operation with the Greenland Minister of Health, the Environment and Research, Marianne Jensen, donated resources for two Zackenberg grants, *i.e.* two month study tours to Zackenberg or Mestersvig for Greenlandic students (one female and one male) with interest in Arctic and environmental research.
- A ZERO committee including representatives of the Zackenberg partners and representatives of the station staff will be established early in 1998 in order to co-ordinate the activities at Zackenberg.

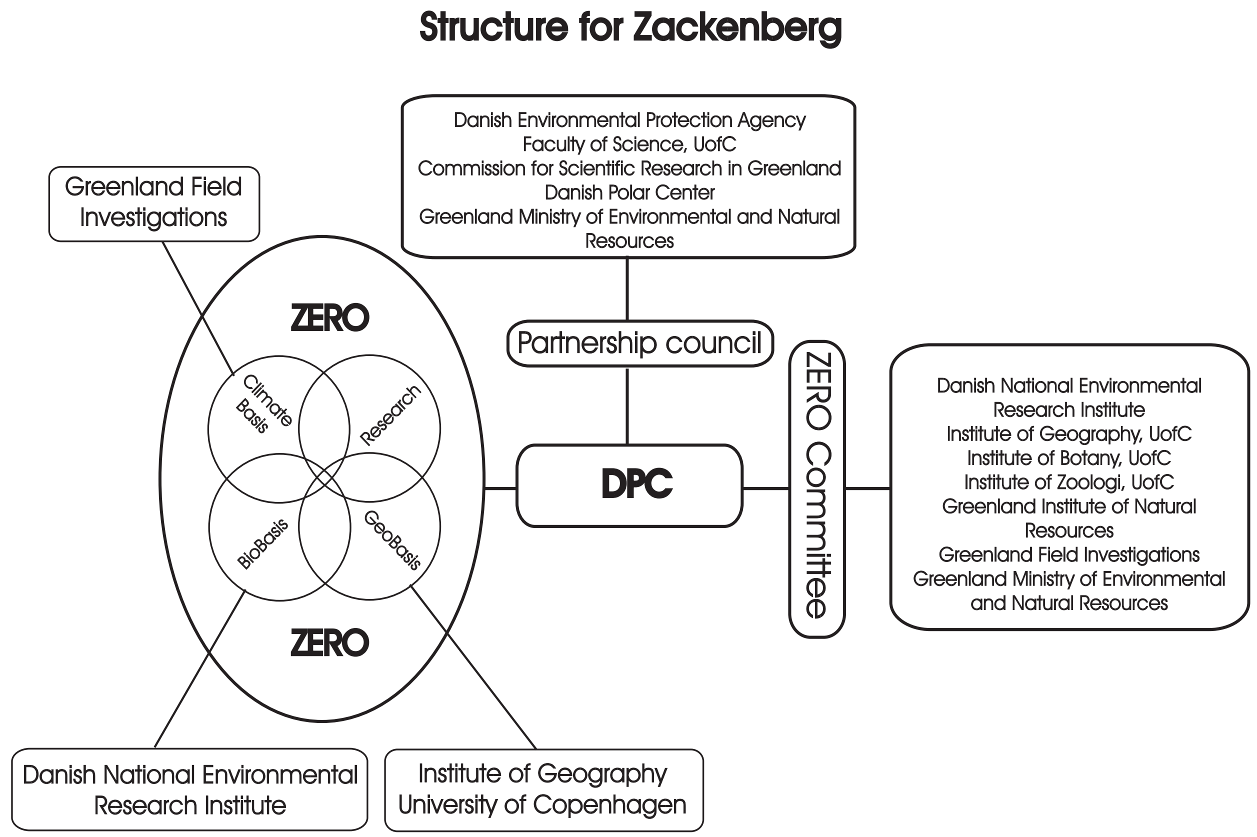


Fig. 1.2. The new structure of ZERO (Zackenberg Ecological Research Operations).

1.3. The Zackenberg study area

The Zackenberg study area comprises the entire catchment basin (514 km^2) of the river Zackenbergelven. The station is located in the valley Zackenbergdalen at the lower reach of Zackenbergelven (74°30' N, 21°00' W). The nearest permanent settlement is Daneborg, 23 km southeast of Zackenberg.

At Zackenberg, positive daily mean air temperatures occur only in June, July and August. In 1996, the mean annual air temperature was –9.2°C, and the total annual precipitation was 223 mm w.e. (see section 3.1.1). Zackenberg is located in the zone of continuous permafrost. Approximately 20% of the Zackenberg study area is glaciated by cirques, valley glaciers and small ice caps. The distance from Zackenberg to the margin of the Greenland Ice Sheet is *c.* 60 km.

A fault through the valleys Zackenbergdalen and Lindemansdalen seperates Caledonian gneiss bedrock along the western sides of the valleys from Cretaceous sandstones and Tertiary basalts along the eastern side of the valleys. Generally, the lower part of the landscape is developed by glacial erosion during the Quaternary glaciations. Tertiary plateaus at *c.* 1400 m a.s.l. are dissected by deep U-shaped valleys. In the lower parts of the valleys, old shore lines at levels up to 50-70 m a.s.l. indicate falling relative sea-level since the deglaciation of the area. One major lake (Store Sø) and a large number of smaller lakes, ponds and tarns are located in the area, which also hosts a large diversity of glacial, periglacial and coastal landscape features and a great variety biotopes like fens, heaths, fellfield plateaus and grasslands.

2. Logistics

The 1997 field season lasted 103 days from 21 May to 1 September. During this period, a total of 38 scientists, construction workers and logistics personnel worked at the station, and a further 20 officials visited the station in connection with the official opening in mid August. In addition, 12 officials from the Danish Parliament's Financial Committee visited the station in late August (see sections 1.1, 8.3 and 8.4). The branch facility in Daneborg was used by two scientists in February-March, and by four scientists and two photographers in August.

The 1997 field season was the first season with the permanent houses in full operation. The completion of dry and wet laboratories together with showers during July was a large step towards more organised and comfortable facilities.

2.1. Transportation

As in 1996, the runway was partly snow covered at the start of the season. Fortunately, the snow covered only the easternmost 150 m of the runway and therefore did not cause any problems. A pioneer team opened the station on 21 May and prepared it for the arrival of the first team of researchers five days later.

Due to the very high level of activity and the large number of visitors the frequency of planes landing at Zackenberg was very high throughout the season. 20 tons of cargo were airlifted to Zackenberg from either Mestersvig or Daneborg. The cargo included equipment for the different research projects and building materials for the completion of two houses. Only a few helicopters operated in the Zackenberg area this season (see section 6.2).

The annual supply ship arrived at Daneborg on 4 August. In addition to supplies for Daneborg and Zackenberg, the ship brought a motorised 8-wheeled amphibious ATV (all terrain vehicle) for Zackenberg. The vehicle exerts an ultra low ground pressure, and therefore has a small impact on the terrain surface. However, the vehicle still damages the surface and the use of it is therefore limited to certain traffic corridors and surfaces with snow cover. The primary purpose of the vehicle is for local transportation inside the station perimeter.

2.2. Accommodation

The Canadian Weatherhaven shelters 'survived' the 1996-1997 winter without major problems. During the 1997 field season, five shelters were used for accommodation, besides one used for workshop.

Lavatories were still mounted in two sheds. A more comfortable and permanent solution will be implemented later.

The 1997 season showed a need for additional buildings for storage, generators, accommodation and recreation.

2.3. Telecommunication

This year, e-mail communication was introduced with some difficulties. Still, e-mailing proved to be a good service, and attempts to improve the service will be made as soon as possible.

3. ZACKENBERG BASIC

The GeoBasis programme

The purpose of the GeoBasis programme is to collect data on the dynamics of physical and geomorphological parameters at Zackenberg. GeoBasis was initiated in the summer of 1995, and the programme was modified to its present form during the summers of 1996 and 1997.

The GeoBasis installations at Zackenberg are described in ZERO 1st Annual Report, 1995 (Meltofte & Thing 1996). Locations of GeoBasis installations and test sites are shown in Fig. 3.

Data collected by the GeoBasis programme can be ordered from the Danish Polar Center (e-mail: mr@dpc.dk) for the price of a CD-ROM.

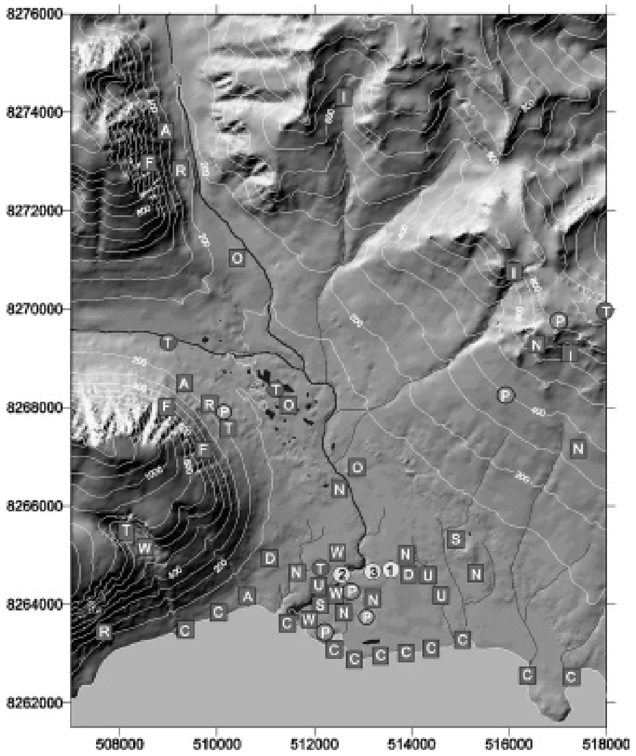


*Fig. 3. Permanent installations and monitoring sites for the GeoBasis programme. **1** Meteorological station. **2** Hydrometric station. **3** Tide gauge. **P** (in circle) Permafrost and active layer profile. **T** (in circle) Air temperature at terrain surface. **W** (in circle) Water temperature. **A** Avalanche track. **C** Coastal landform (see also Fig. 3.4.4.1). **D** Debris island. **F** Free rock face. **T** (in square) Talus slope. **U** Fluvial landform. **R** Rock glacier. **W** (in square) Ice wedge. **I** Snow accumulation. **N** Nivation. **O** Windpolish. **S** Solifluction.*

Fig. 3.1.2. The new snow depth sensor at Zackenberg. The big white box on the mast contains datalogger (Campbell CR500), solar panel and backup batteries. The snow depth sensor is situated at the tip of the horizontal arm. The small white housing on top of the mast contains a temperature sensor used for calibration for changing sound velocity. Photo: Morten Rasch.

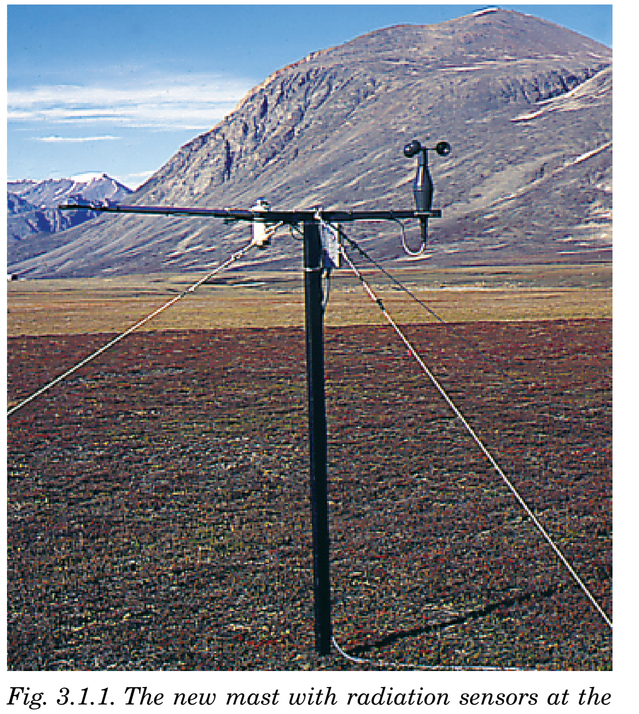


Fig. 3.1.1. The new mast with radiation sensors at the meteorological station at Zackenberg. The wind velocity sensor in the right side of the picture is used for calibration of net radiation. Photo: Morten Rasch.

3.1. The meteorological station

The meteorological station at Zackenberg was constructed in the summer of 1995. The technical specifications of the station are described in Meltofte & Thing (1996). Two major changes have been made to the station during the 1997 field season. The radiation sensors were moved to a separate mast and a mast for snow depth measurements was erected. These changes were made by technician Bent Sørensen.

The vegetation in the nearest surroundings of the meteorological station is in a bad condition due to intense traffic. The resulting change of the terrain surface character is expected to change the albedo of the surface. In order to measure radiation unaffected by traffic, the radiation sensors (including one wind velocity sensor for calibration of net radiation) were moved to a separate mast on a more protected site close to the meteorological station. The new mast with the radiation sensors is shown in Fig. 3.1.1. The change of sensors took place on 24 June 1997.

Most precipitation at Zackenberg fall as snow. The original precipitation sensors at Zackenberg do not measure snow precipitation very accurately. It has therefore been decided to install a number of snow depth sensors at Zackenberg. The registrations by snow depth sensors will be used together with data from an automated digital camera (see section 3.4.1.) to quantify in time and space the volume of snow within Zackenbergdalen. The first snow depth sensor was installed on 24 June near the meteorological station. The snow depth sensor consists of a sonic range sensor measuring, with sound, the vertical distance between the sensor head and the terrain surface. As snow accumulates, the 'terrain surface' moves towards the sensor head. The decreasing distance between the terrain surface and the sensor head is easily converted to an increase in snow depth, which again is converted to mm w.e. The new snow depth sensor is shown in Fig. 3.1.2.

3.1.1. Meteorological data from 1996

In the design of the meteorological station at Zackenberg it was originally planned to transfer

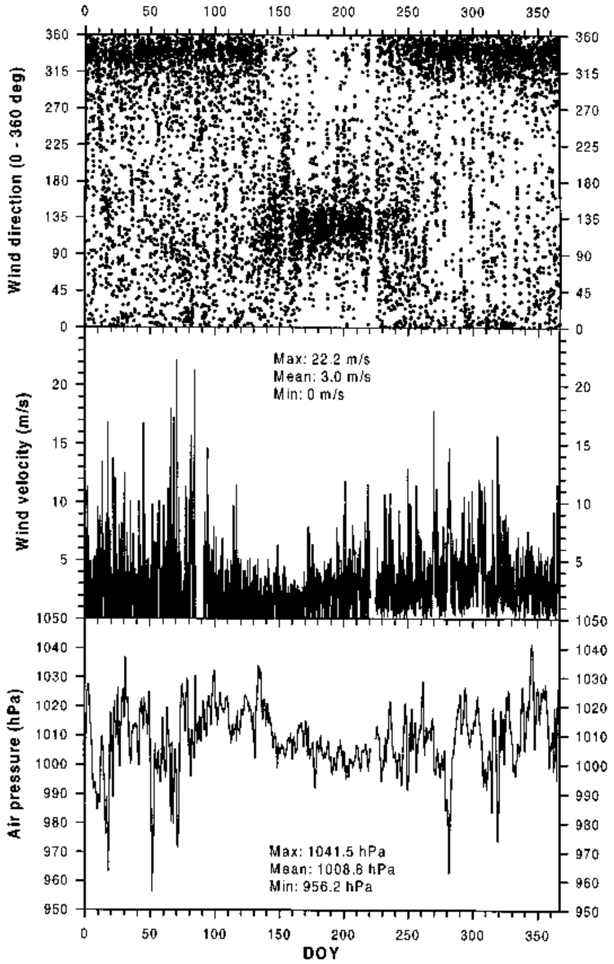


Fig. 3.1.1.2. Variation in wind direction, wind velocity and air pressure at Zackenberg during 1996. Wind direction and wind velocity have been measured 7.5 m above the terrain surface.

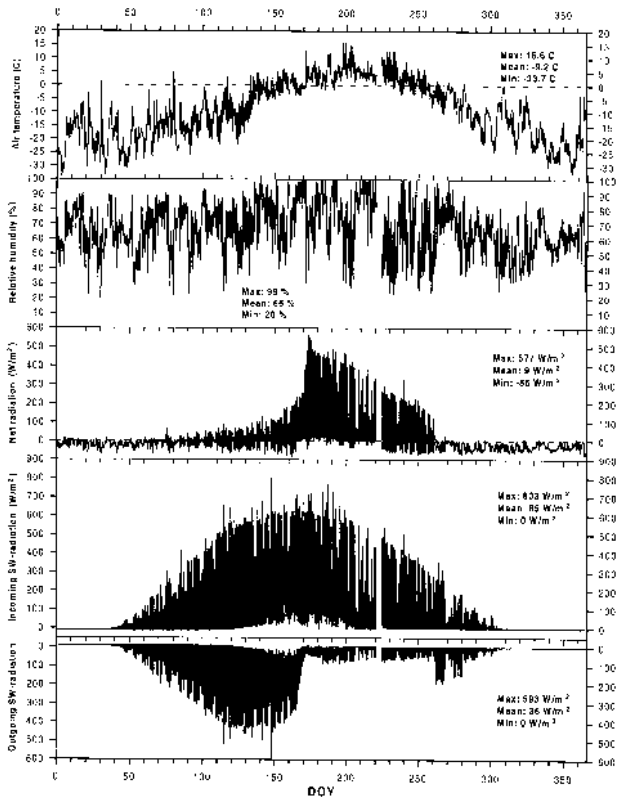


Fig. 3.1.1.1. Variation in air temperature, relative humidity, net radiation, incoming and outgoing short wave radiation at Zackenberg during 1996. All parameters are measured 2 m above the terrain surface.

data from Zackenberg to the Danish Polar Center in Copenhagen once every week throughout the year. It has, however, not been possible to conduct the automatic satellite data transfer from the meteorological station to the Danish Polar Center during the 1996 and 1997 field seasons. Thus, data from the autumn and winter of 1996 were not collected until the beginning of the 1997 field season (end of May 1997).

Data from 1996 represent the first full calendar year of climate registrations from Zackenberg. The variations during 1996 of selected climatic parameters are given in Figs 3.1.1.1 and 3.1.1.2, while statistical values for all the measured climatic parameters are given in Table 3.1.1.

In 1996, the mean air temperature measured 2 m above terrain was –9.2°C, the maximum temperature was 16.6°C (mid July) and the minimum temperature was –33.7°C (mid January). The period with frequent temperatures above 0°C started at the end of May and ended in the beginning of September.

Table 3.1.1. Statistics of meteorological parameters measured at the Zackenberg meteorological station during 1996.

Parameter	Mean	Max.	Min.
Air temperature, 2 m above terrain (°C)	–9.2	16.6	–33.7
Air temperature, 7.5 m above terrain (°C)	–8.5	15.9	–31.9
Relative air humidity, 2 m above terrain (%)	66.4	98.9	20.3
Relative air humidity, 7.5 m above terrain (%)	64.2	99.1	16.3
Air pressure (hPa)	1008.8	1041.5	956.2
Incoming short wave radiation (W/m2)	85	803	0
Outgoing short wave radiation (W/m2)	36	593	0
Net radiation (W/m2)	9	577	–86
Wind velocity, 2 m above terrain (m/s)	2.6	17.6	0
Wind velocity, 7.5 m above terrain (m/s)	3.0	22.2	0
Precipitation (mm w.e.), total	223	–	–
Ground temperature, 0 cm below surface (°C)	–8.4	18.7	–23.7
Ground temperature, 2.5 cm below surface (°C)	–8.3	18.6	–22.6
Ground temperature, 5 cm below surface (°C)	–7.7	16.3	–21.9
Ground temperature, 10 cm below surface (°C)	–7.0	12.9	–20.9
Ground temperature, 20 cm below surface (°C)	–8.2	2.6	–15.4
Ground temperature, 40 cm below surface (°C)	–8.6	3.7	–20.0
Ground temperature, 60 cm below surface (°C)	–6.5	2.6	–15.4
Ground temperature, 80 cm below surface (°C)	–6.1	1.2	–12.9
Ground temperature, 100 cm below surface (°C)	–7.4	–0.7	–14.2
Ground temperature, 130 cm below surface (°C)	–7.6	–2.6	–12.6

The total precipitation in 1996 was 223 mm w.e. Most precipitation came in the period January – April. The period from mid April to the beginning of September was very dry with an accumulated precipitation of only *c.* 15 mm w.e.

The mean air pressure in 1996 was 1008.8 hPa. Air pressure was generally rather stable during late spring – early autumn. During winter, air pressure was much more variable, and periods with air pressure below 980 hPa occurred frequently.

Mean wind velocity 7.5 m above terrain was 3.0 m/s in 1996. The highest gust wind velocity in 1996 was 24.6 m/s. As with air pressure, wind velocity fluctuated more during late spring and early autumn than during the rest of the year. During this period foehn situations with high wind velocity, low pressure, relatively high air temperature (above 0°C) and low relative humidity occurred frequently.

In 1996, the dominant wind direction was south-easterly during summer (early June – mid August) and northerly during winter. The northerly winter winds are probably deflected (by Corioli's force) catabatic winds blowing off the Greenland ice sheet, while the south-easterly summer winds are land-bound breezes caused by warm-up of the terrain surface after snow melt.

The total net radiation during 1996 was *c.* 3300 W/m². During winter, net radiation was consistently negative in the period when the sun was below the horizon. In late spring – early summer, the net radiation increased slowly due to increased short wave radiation as the sun came higher and higher above the horizon. On 21 June, the last snow melted away at the meteorological station, and as a result, the net radiation increased instantly due to decreased albedo (Fig. 3.1.1.1).

3.1.2. Meteorological data from 1997

The variation during the first part of 1997 (1 January – 31 August) of selected climatic parameters are

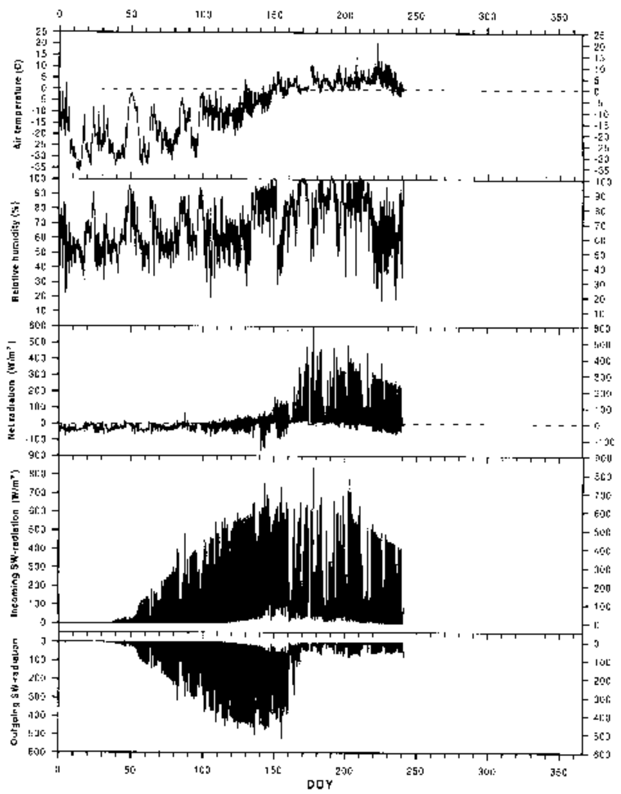


Fig. 3.1.2.1. Variation in air temperature, relative humidity, net radiation and incoming and outgoing short wave radiation at Zackenberg during the first part of 1997 (until 31 August). All parameters are measured 2 m above the terrain surface.

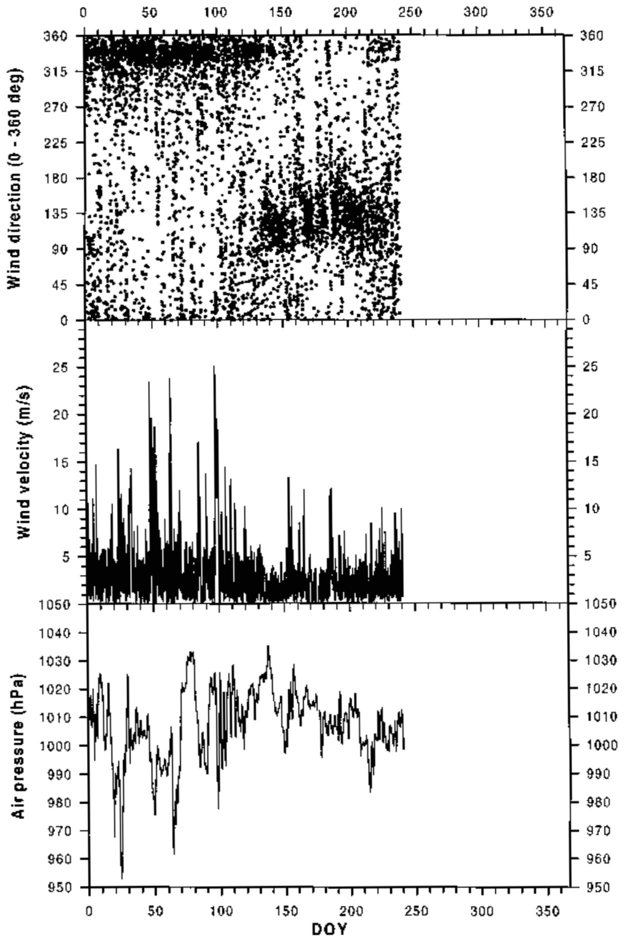


Fig. 3.1.2.2. Variation in wind direction, wind velocity and air pressure at Zackenberg during the first part of 1997 (until 31 August). Wind direction and wind velocity have been measured 7.5 m above the terrain surface.

shown in Figs 3.1.2.1 and 3.1.2.2. For comparison with previous years, monthly mean values from September 1995 to August 1997 of selected meteorological parameters are given in Table 3.1.2.1, while monthly mean values of ground temperatures at the meteorological station for the same period are given in Table 3.1.2.2.

The first months (*i.e.* January – April) of 1997 were generally colder, drier and more windy than the same period in 1996. The coldest month of 1997 was January with a mean monthly temperature of –22.5°C. During the first part of the 1997 field season (*i.e.* late May – early August) the weather at Zackenberg was generally unstable with extensive periods of 100% cloud cover and rain at several occasions, especially in early July. The total precipitation from the beginning of April to the end of August 1997 was 66 mm w.e. In 1996 the precipitation during the same period was 15 mm w.e. In August 1997, the weather at Zackenberg became more stable, and the mean monthly air temperature of August 1997 (5.0°C) was higher than in 1996. The warmest day of 1997 was 12 August with a maximum temperature of 21.3°C

Table 3.1.2.1. Monthly mean values of selected meteorological parameters at the meteorological station at Zackenberg, September 1995 – August 1997.

Year	Month	Air temperature (°C) 2.00 m	Air temperature (°C) 7.50 m	Relative humidity (%) 2.00 m	Relative humidity (%) 7.50 m	Air pres. (hPa) 0.00 m	Net rad. (W/m²) 2.00 m	Short wave rad. (W/m²) In	Short wave rad. (W/m²) Out	Wind velocity (m/s) 2.00 m	Wind velocity (m/s) 7.50 m	Wind dir. (0–360°) 7.50 m
1995	Sep	–1.43	–1.17	74.07	72.13	1005.46	17.08	65.76	7.80	1.95	2.27	194.15
1995	Oct	–12.94	–12.24	60.89	58.13	1012.92	–31.93	5.23	–1.28	2.34	2.85	273.02
1995	Nov	–15.58	–14.61	64.90	62.65	1013.84	–25.65	–10.92	–10.14	2.43	2.85	251.43
1995	Dec	–21.78	–20.66	63.46	60.57	1010.16	–23.11	–11.15	–10.39	2.63	2.98	250.82
1996	Jan	–18.60	–17.85	64.47	62.12	1004.72	–17.59	–10.93	–10.42	2.69	3.24	245.25
1996	Feb	–20.65	–19.48	61.93	57.97	1007.47	–20.83	–4.34	–4.82	2.48	3.11	248.11
1996	Mar	–14.95	–14.13	69.54	67.38	1007.76	–11.64	44.14	33.69	2.46	3.40	218.53
1996	Apr	–11.09	–10.18	68.78	66.72	1017.49	–7.59	144.75	113.19	1.97	2.59	237.60
1996	May	–5.28	–4.91	74.30	73.40	1015.80	3.90	251.40	186.58	1.27	1.48	185.01
1996	Jun	1.90	1.75	76.75	75.45	1006.86	106.58	291.25	106.01	1.39	1.59	142.92
1996	Jul	5.84	5.46	76.96	77.61	1002.14	137.10	207.93	20.09	2.28	2.55	146.13
1996	Aug	4.40	4.57	68.24	67.54	1005.05	68.78	142.08	18.65	2.50	2.88	171.37
1996	Sep	–1.51	–0.90	68.38	65.50	1008.17	0.25	69.79	23.09	2.92	3.44	222.93
1996	Oct	–11.41	–10.31	63.32	59.79	1007.17	–31.54	13.92	10.72	3.75	4.36	281.76
1996	Nov	–17.34	–16.25	57.13	54.56	1010.96	–30.53	–0.99	–0.08	3.00	3.42	266.38
1996	Dec	–20.14	–19.10	61.85	60.07	1012.05	–25.37	–0.96	–0.13	2.57	2.84	249.25
1997	Jan	–22.45	–21.26	56.85	54.20	1001.39	–29.83	–1.08	–0.16	3.07	3.45	240.00
1997	Feb	–21.08	–20.10	62.24	59.49	998.00	–24.59	5.87	5.57	4.16	5.25	279.83
1997	Mar	–18.93	–17.44	64.04	60.79	1005.45	–20.48	58.50	47.40	1.36	3.84	257.59
1997	Apr	–13.01	–11.84	63.94	60.28	1011.21	–18.49	152.89	124.90	3.88	4.50	223.67
1997	May	–6.32	–5.73	74.66	73.47	1017.45	–2.40	264.66	201.76	1.60	1.83	187.99
1997	Jun	2.23	2.36	76.76	74.62	1013.77	80.48	225.69	87.93	2.06	2.40	156.48
1997	Jul	3.72	3.36	84.54	84.75	1007.46	123.35	198.21	21.63	2.40	2.72	155.20
1997	Aug	5.05	5.07	66.51	65.55	1002.48	70.74	142.81	18.76	2.45	2.81	158.90

Table 3.1.2.2. Monthly mean values of soil temperatures at different levels at the meteorological station at Zackenberg, September 1995 – August 1997.

Year	Month	0 cm	–2.5 cm	–5 cm	–10 cm	–20 cm	–40 cm	–60 cm	–80 cm	–100 cm	–130 cm
1995	Sep	–0.61	–0.51	0.41	1.33	0.07	–0.63	0.91	0.80	–0.99	–2.59
1995	Oct	–12.53	–12.18	–11.23	–10.06	–10.63	–8.65	–4.68	–3.54	–4.54	–4.03
1995	Nov	–17.16	–16.99	–16.21	–15.28	–16.17	–14.93	–11.15	–9.87	–10.66	–9.09
1995	Dec	–15.26	–15.17	–14.42	–13.58	–14.63	–14.16	–11.34	–10.50	–11.50	–10.51
1996	Jan	–15.31	–15.25	–14.52	–13.73	–14.86	–14.68	–12.15	–11.43	–12.49	–11.65
1996	Feb	–15.19	–15.20	–14.46	–13.64	–14.72	–14.46	–11.90	–11.20	–12.30	–11.66
1996	Mar	–14.06	–14.09	–13.39	–12.63	–13.85	–13.93	–11.82	–11.29	–12.47	–12.02
1996	Apr	–12.41	–12.48	–11.79	–11.06	–12.36	–12.72	–10.94	–10.57	–11.84	–11.69
1996	May	–9.03	–9.19	–8.52	–7.89	–9.40	–10.38	–9.18	–9.09	–10.51	–10.80
1996	Jun	2.05	2.50	2.13	2.55	–0.34	–2.40	–2.45	–3.06	–5.27	–7.05
1996	Jul	9.12	8.95	8.99	8.67	5.59	2.17	1.55	0.53	–1.53	–3.76
1996	Aug	4.43	4.50	4.91	5.29	3.26	1.47	1.92	1.11	–0.81	–2.75
1996	Sep	–1.20	–0.94	0.03	1.03	–0.12	–0.67	0.92	0.98	–0.78	–2.35
1996	Oct	–10.01	–9.28	–8.36	–7.30	–7.93	–6.58	–2.99	–1.87	–3.06	–3.10
1996	Nov	–17.10	–16.86	–16.12	–15.23	–16.04	–14.96	–10.98	–9.31	–10.12	–8.67
1996	Dec	–20.77	–20.59	–19.91	–19.10	–19.97	–18.99	–14.96	–13.23	–13.94	–12.19
1997	Jan	–21.06	–20.63	–20.01	–19.17	–20.02	–19.15	–15.49	–13.99	–14.79	–13.30
1997	Feb	–17.55	–17.45	–16.80	–16.08	–17.19	–17.16	–14.69	–13.86	–14.89	–14.07
1997	Mar	–16.89	–16.83	–16.12	–15.40	–16.50	–16.46	–13.99	–13.21	–14.29	–13.73
1997	Apr	–14.49	–14.53	–13.79	–13.13	–14.38	–14.78	–12.87	–12.44	–13.65	–13.47
1997	May	–11.93	–12.06	–11.38	–10.73	–12.11	–12.83	–11.31	–11.11	–12.43	–12.57
1997	Jun	1.59	1.30	1.51	1.45	–1.02	–3.31	–3.29	–4.49	–6.51	–8.61
1997	Jul	7.59	7.72	7.78	7.66	4.59	1.17	0.90	0.10	–1.89	–4.24
1997	Aug	4.77	5.77	5.44	5.84	3.72	1.71	2.07	1.00	–0.91	–3.00

3.2. TinyTalk/TinyTag dataloggers

GeoBasis operates 30 TinyTag/TinyTalk temperature dataloggers in the Zackenberg study area. The dataloggers measure soil temperature profiles at six sites (at different elevations and in different soil types), air temperature near terrain surface at nine sites and water temperature in Zackenbergelven and in the pond, Gadekæret, north of the runway. All dataloggers were tapped for data during the 1997 field season. No important operational failures

Table 3.2.1. Position, purpose, interval between measurements and period of operation of TinyTag / TinyTalk dataloggers at Zackenberg.

Purpose	Northing m	Easting m	Elevation m a.s.l.	Depth of sensors cm below surface	Measurements started
Temperature profile in active layer	8263490	512388	20	0, 10, 50, 118	12 August 1995
Temperature profile in active layer near ice wedge	8264257	512713	23	0, 10, 70, 155	12 August 1995
Temperature profile in active layer	8268224	515917	c. 400	0, 10, 66	19 August 1995
Temperature profile in active layer	8269597	516936	c. 820	0, 10, 85	19 August 1995
Temperature profile in active layer in rock glacier	8267457	509964	c. 260	0, 75, 135	25 June 1996
Temperature profile in active layer near ZEROCALM-2 plot	8263921	513068	11	0, 10, 30, 60	26 July 1996
Air temperature near terrain surface in Morænebakkerne	8268397	511090	c. 85	0	26 August 1995
Air temperature near terrain surface in eastern Store Sødal	8269215	509105	c. 130	0	22 August 1995
Air temperature near terrain surface on top of Aucellabjerg	8269902	518023	c. 970	0	19 August 1995
Water temperature in Zackenbergelven at hydrometric station	8264582	512538	c. 10		9 August 1995
Water temperature in Gadekæret, N of runway	8264519	512916	c. 30		
Air temperature at different sites on profile line through snow patch	8264467	512209	16 – 29	varying	30 July 1996

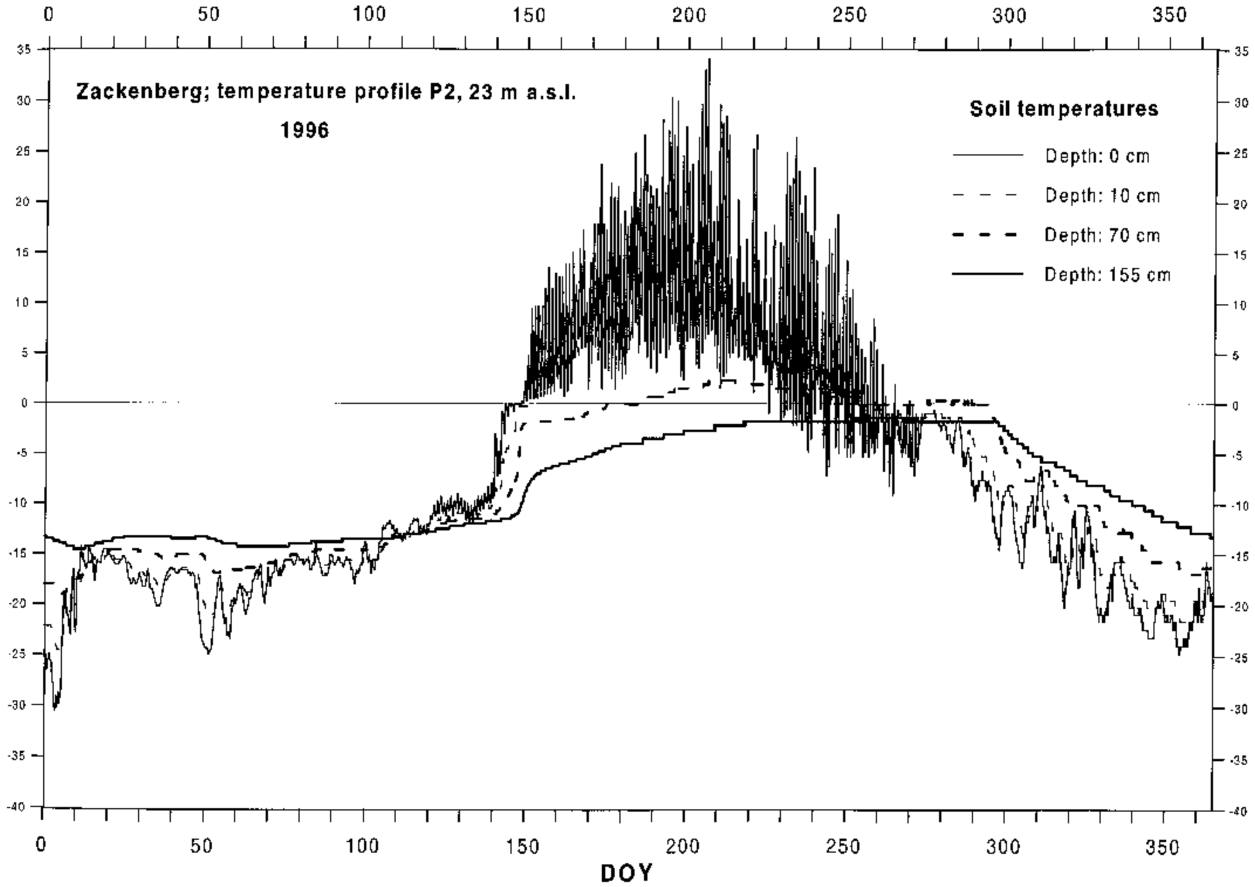


Fig. 3.2. Soil temperature profile from gravel plateau 23 m a.s.l. near the shore in the southern part of Zackenbergdalen, 1996.

with the dataloggers have occurred during the 1996-97 season. The positions, the purpose and the period of operation of the dataloggers are summarised in Table 3.2.1.

Table 3.2.2 shows the variation of the air temperature (near terrain surface) with elevation based on data from the dataloggers, while Fig. 3.2 gives an example of a soil temperature profile from the first part of 1996. More examples of time series from the TinyTag/TinyTalk dataloggers are given in Meltofte & Thing (1997). Data from the TinyTag/TinyTalk dataloggers can be ordered from the Danish Polar Center.

Table 3.2.2. Variation with elevation of mean, maximum and minimum annual air temperature near terrain surface on the slope of Aucellabjerg. Minimum and mean temperature generally decrease with elevation, while maximum temperature decreases with elevation.

Station	Elevation m a.s.l.	Maximum °C	Minimum °C	Mean °C
P2	23	34.1	–30.5	–7.4
P3	400	25.2	–31.5	–7.2
P4	820	27.0	–33.7	–9.4
T3	935	19.8	–36.0	–9.4

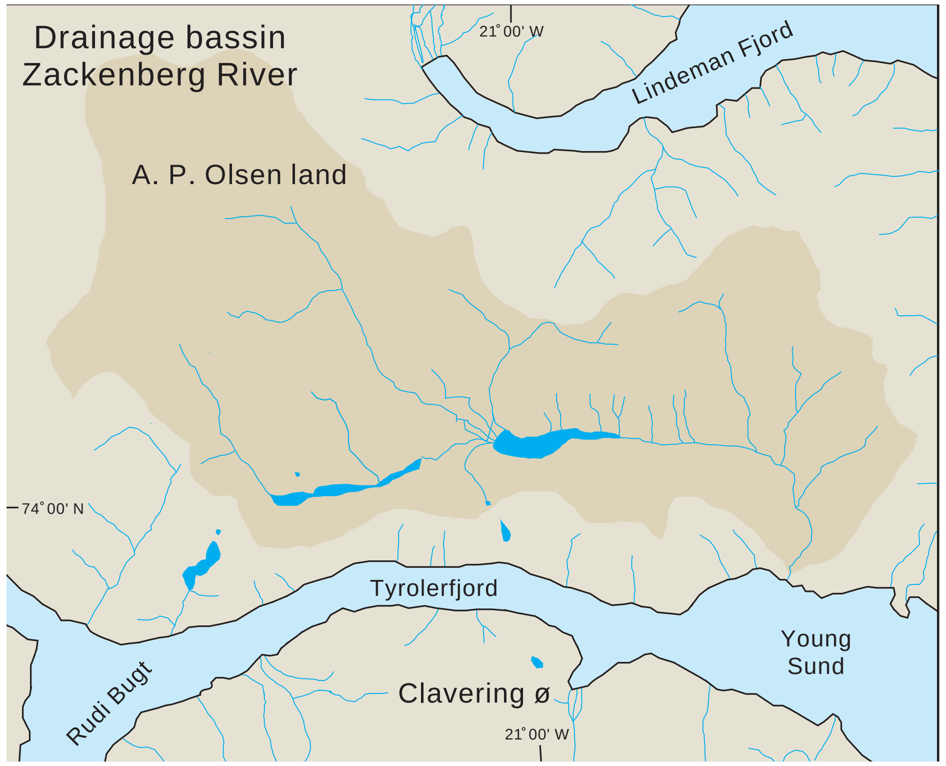
3.3. The hydrometric station

The hydrometric station at Zackenbergelven was established in the summer of 1995. The station records river water discharge from the drainage basin of Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen (Fig. 3.3.1). The technical details of the hydrometric station at Zackenberg are described in Meltofte & Thing (1996).

Water discharge in Zackenbergelven is logged automatically with a sonic range sensor measuring, with sound, the vertical distance from a fixed point to the water surface of the river. The signal is converted to a water depth of the river, which is again converted to a river water discharge by a depth-discharge relation curve based on manual measurements of river water discharge and river water depth (Fig. 3.3.2). River water discharge and river water depth have been measured manually at regular intervals in the field seasons of 1995, 1996 and 1997 (Fig. 3.3.3). The good correlation between data from the three manual measurements in 1997 and the depth-discharge curve for 1995-1997 (see Fig. 3.3.2) indicates that no major changes of the cross river profile at the hydrometric station have occurred since 1995.

The hydrometric station was buried in snow during the first part of the 1997 field season. Problems with snow covering the sonic range sensor during the first part of the season also occurred in 1996.

Fig. 3.3.1. The drainage basin of Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen upstream the hydrometric station at the Zackenberg Research Station. The drainage basin covers an area of 514 km² of which 106 km² (21%) is covered by glaciers.



The station is situated at the foot of a large snow patch, which covers the western river bank during the late spring and early summer (Fig. 3.3.3). The snow patch does not melt away before the river starts to run. Therefore, the position of the hydrometric station is not appropriate, and it has been decided to move the hydrometric station to a less snow rich site at the eastern bank of the river in the 1998 field season.

3.3.1. River water discharge

In 1997, the river started to run at the hydrometric station at Zackenberg Research Station on 4 June (Fig. 3.3.1.1), but the snow below the sensor of the hydrometric station did not melt away until 26 June. In the intervening period, the river water discharge was measured manually almost every day with an OTT C31 current meter. In the last four days before the hydrometric station melted free, the current in the river was however too strong for manual measurements of river water discharge.

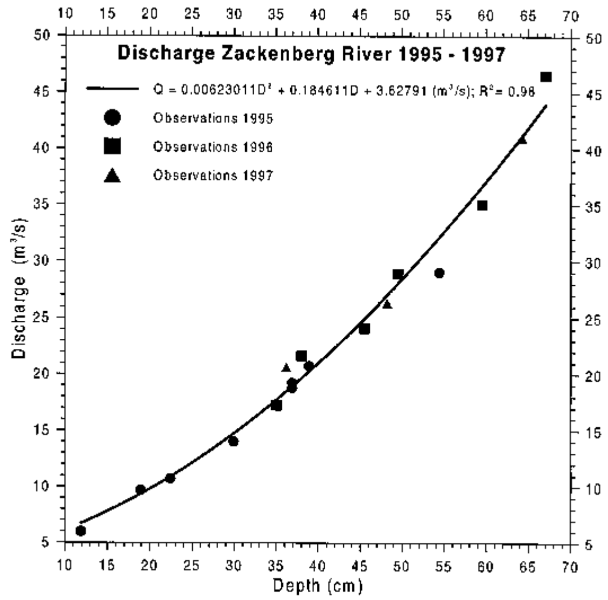


Fig. 3.3.2. Depth-discharge relation curve for Zackenbergelven at the hydrometric station, 1995-1997. The coefficient of correlation for the curve is 0.98.

Fig. 3.3.3. Manual measurements of river water discharge and river water depth are carried out at regular intervals during the field season. In early and mid June 1997 the discharge of Zackenbergelven was very limited. Notice the snow patch that covers the western bank of the river at the hydrometric station. Photo: Morten Rasch.

Fig. 3.3.1.1. Zackenbergelven started to run by the hydrometric station on 4 June 1997. In the first days of water discharge, the river water ran on top of the snow. During this period, the river bottom was extremely smooth, and at several occasions the water discharge suddenly increased by orders of magnitude within few minutes, probably as a result of dams of slush ice being washed away upstream. Photo: Henning Thing.

The river water discharge of Zackenbergelven during the summer of 1997 is shown in Fig. 3.3.1.2. Peak discharge occurred 23-29 June, 5-9 July and 31 July – 8 August. The peak in the period 23-29 June was due to intense snow melt during the first longer period with temperatures well above 0°C, and the peak in the period 5-9 July was due to *c.* 25 mm rainfall on 5-6 July. The peak from 31 July to 8 August can not be explained simply on basis of the climate data from the meteorological station at Zackenberg. The peak succeeded a period with relatively high temperatures culminating at 14.5°C in the afternoon of 28 July (Fig. 3.1.2.1). At that time, the lower parts of Zackenbergdalen were almost free of snow. The temperature peak might, however, have caused snow melting at the high lying plateaus in the western part of the drainage basin. These plateaus are situated *c.* 1300 m a.s.l. With an estimated temperature decrease with elevation of 0.6°C/100 m, the temperature of 14.5°C at Zackenberg corresponds to a temperature of 6.7°C at 1300 m a.s.l. The temperature peaks at Zackenberg before 28 July did not exceed 9.0°C, which corresponds to a temperature of 1.2°C at 1300 m a.s.l. It is therefore probable that the temperature peak on 28 July caused intensive snow melt at the high-lying plateaus and resulted in increased river water discharge at the Zackenberg station during the following days.

The total amount of water drained by Zackenbergelven during the 1997 field season was 1.748334 x 10^8 m^3. With a drainage basin area of 514 km^2, this value corresponds to a water loss of 340 mm w.e. The river water discharge measured during the 1997 field season is probably very close to the total drainage from Zackenbergdalen during 1997. The river water discharge was only 4.3 m^3/s and decreasing rapidly, when the Zackenberg station was closed down on 31 August 1997.

3.3.2. Suspended sediment

Water samples for determination of suspended sediment content and calculation of suspended sediment transport were taken at the hydrometric station twice daily during the field season of 1997. The water samples were filtered at Zackenberg by GeoBasis assistants Henriette G. Anbro and Steen B. Pedersen, and the filters were brought to Copenhagen and analysed for sediment and organic content at the Institute of Geography, University of Copenhagen. The results of the analyses have still not been processed. However, preliminary results suggest that river water sediment content ranges between *c.* 200 and *c.* 500 mg/l and with a mean value close to 300 mg/l. The preliminary mean value of suspended sediment content suggests a total suspended sediment transport of *c.* 50,000 t in Zackenbergelven during the 1997 field season.

3.3.3. Water chemistry, pH and conductivity

Conductivity, pH and temperature of river water in Zackenbergelven were measured twice every day at the hydrometric station during the entire field season. Besides, water samples were taken twice daily for determination of Na, K, Ca, Mg, Fe, Al, Mn, Cl^-, NO^-, SO_4^{2-} and alkalinity. The preparation of samples for transportation to Denmark was carried out by the GeoBasis assistants Henriette Anbro and Steen B. Pedersen at Zackenberg (Fig. 3.3.3.1). The

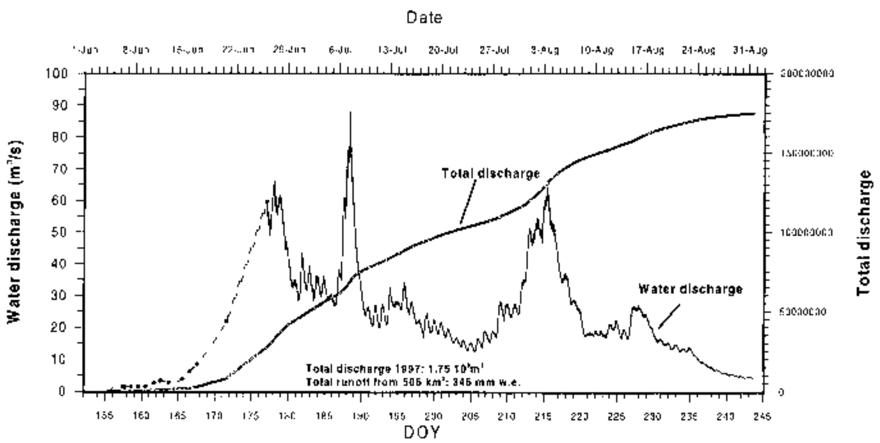


Fig. 3.3.1.2. Variation of river water discharge at 15 minute intervals (black line) in Zackenbergelven during the 1997 field season. The total discharge (grey line) in 1997 was c. 1.75 10^8 m^3.

Fig. 3.3.3.1. GeoBasis assistant Henriette Anbro prepares water samples from Zackenbergelven for transportation to Denmark. In the early part of the 1997 field season, laboratory work was carried out in a preliminary laboratory. Later, permanent laboratory facilities were established. Photo: Morten Rasch.

water samples are now being analysed at the Institute of Geography, University of Copenhagen.

3.4. Landscape monitoring

The landscape monitoring at Zackenberg is based primarily on monitoring photos of characteristic landforms that are expected to change (*e.g.* ice wedges, debris islands, free rock faces, rock glaciers, avalanche tracks, talus slopes, coastal spits and coastal cliffs). Besides, soil water chemistry is measured at two sites, active layer thickness is measured in two plots, growth rates of ice wedges are measured at two sites, cross-shore changes of the shoreline are measured at six sites and vertical sedimentation rate of salt marshes are measured at two sites.

Growth of ice wedges and vertical accretion (sedimentation rate) of salt marshes are expected to occur slowly (<1 mm/year). Measurements of the two processes were carried out in 1996, and it was therefore considered needless to repeat these measurements in 1997.

3.4.1. Monitoring photos

A total of 24 photo monitoring sites of different landscape elements that are expected to change on a short time scale (<10 years) are included in the GeoBasis programme. 21 of these pictures were repeated during the 1997 field season. Besides, each photo site was thoroughly described and the exact position of the sites were measured with GPS.

To allow for a more accurate determination of changes in snow cover in Zackenbergdalen during spring and autumn, a digital camera was installed in August 1997 at the top of a large rock on the south-eastern slope of the Zackenberg mountain at an elevation of *c.* 500 m a.s.l. (Fig. 3.4.1). The camera is programmed to take a picture of the southern part of Zackenbergdalen twice every week throughout the year. The camera is a Kodak DC50 with a 5 MB RAM module for storage of pictures. The automation of the camera (*i.e.* the timer) has been developed by technician Ulf Thomas from Institute of Geography, University of Copenhagen. After retrieving the stored pictures in the summer of 1998, the pictures will be applied for automatic mapping of snow cover in southern Zackenbergdalen using an image processing system and the digital elevation model of Zackenbergdalen.

3.4.2. Active layer depth

Active layer depth was measured at regular intervals (every two weeks) throughout the field season in two plots. One plot (ZEROCALM-1) is situated on horizontal ground in a well-drained *Cassiope* heath *c.* 100 m north of the meteorological station. This plot consists of a 100 x 100 m^2 grid with 121 measuring points. The other plot (ZEROCALM-2) is situated *c.* 500 m south of the runway on a southerly facing slope with *Eriophorum* fen. This plot consists of a 120 x 150 m^2 grid with 208 measuring points.

Fig. 3.4.1. The new digital camera for snow cover monitoring was installed on a rock at 500 m a.s.l. on Zackenberg mountain on 18 August 1997. The picture shows the camera and the area covered by the camera. Photo: Morten Rasch.

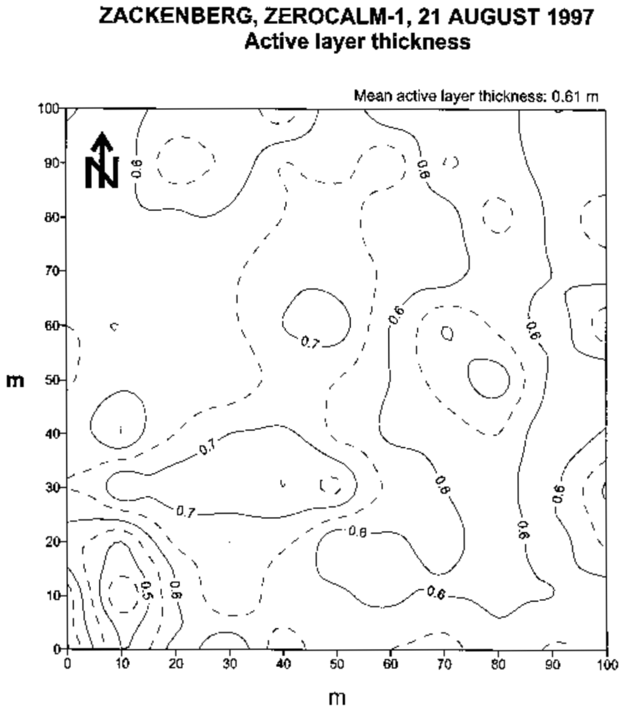


Fig. 3.4.2. Map of active layer thickness at ZEROCALM-1, 21 August 1997.

Both plots were established by Hanne H. Christiansen in 1996 (Christiansen *in* Meltofte & Thing 1997). At each grid point within the plot, active layer depth is measured by pressing a metal rod with scale to the depth of resistance (Nelson *et al.* 1996). Fig. 3.4.2 shows an example of an active layer map based on the measurements from ZEROCALM-1, 21 August 1997. Soil temperature profiles are measured near both plots. Data on maximum active layer thickness of the year are reported to CALM (Circumpolar Active Layer Monitoring Programme) under ITEX (International Tundra Experiment) and IPA (International Permafrost Association) together with soil temperature data. In the 1997 field season, the active layer thickness was at maximum at the last measurement on 21 August. Data from the two plots at Zackenberg can be ordered from the Danish Polar Center (mr@geogr.ku.dk).

3.4.3. Soil water chemistry

In 1996, a soil water chemistry monitoring programme was established by Bo Elberling and Bjarne Holm Jakobsen for characterisation of temporal variations of soil water chemistry at two locations close to the ZEROCALM sites. The two locations include a well-drained *Cassiope* heath soil profile and a fen area dominated by *Sphagnum* and *Eriophorum* vegetation.

Suction probes were installed during the summer of 1996. The suction probes were sampled five times in the 1996 season and twice a week throughout the summer of 1997. Alkalinity, pH and conductivity of the soil solution were measured in the field, whereas Na, K, Ca, Mg, Fe, Mn, Al, Cl, NO_3 and SO_4 were measured in the laboratory after the field season.

Based on preliminary results of soil solution chemistry in 1996 the following characteristics were identified by Bo Elberling and Bjarne H. Jakobsen (see Elberling & Jakobsen 1997): Several processes control the soil solution composition, including climatic (freeze and thawing), biological (CO_2 production) and geochemical (weathering and ions exchange). The interplay between processes gives rise to large spatial and temporal trends in soil solution. Several soil solution types are identified: near-surface dilution by almost distilled water from a melting snowdrift (at the *Eriophorum* fen); leaching of salts (Na^+ and Cl^-) from marine sediments and weathering and concentration of ions below the root zone. Soil acidification is observed in the top 20-30 cm with pH values between 5 and 5.5. Below this level, the pH is between 6 and 7. Weathering of silicate minerals and cation exchange are responsible for soil buffering. Acidification is due mainly to CO_2 production and the acidification (the pH of the soil solution) is observed to vary over summer.

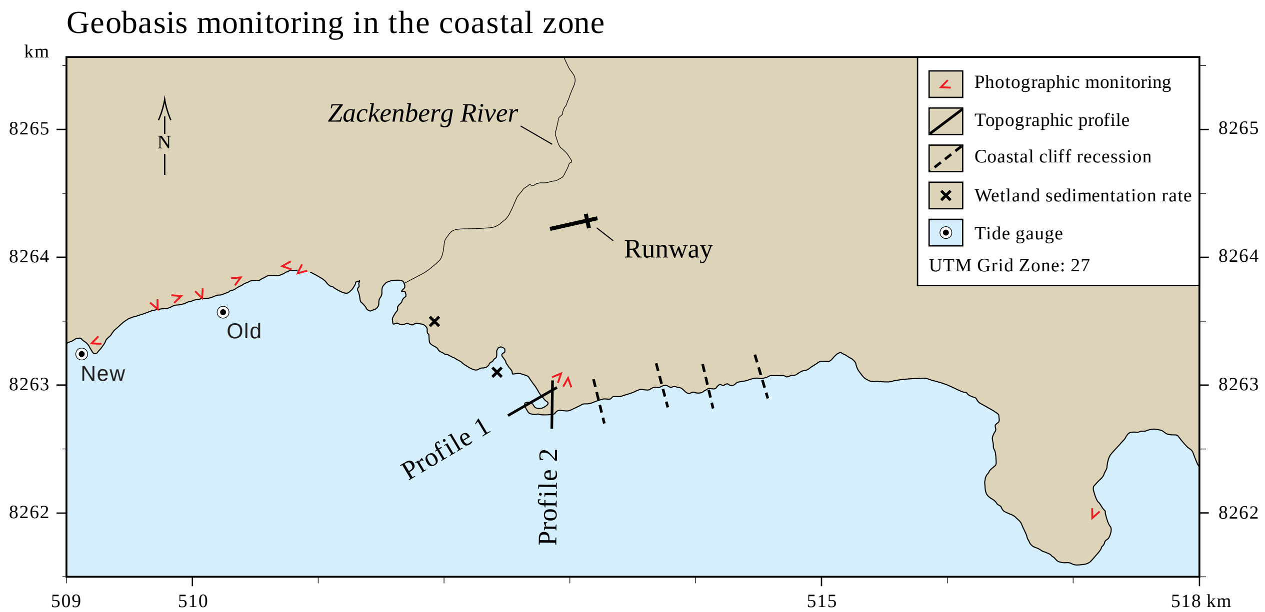


Fig. 3.4.4.1. The GeoBasis monitoring in the coastal zone at Zackenberg includes measurements of different parameters at 19 sites. The tide gauge was moved c. 1 km westwards during the 1997 field season.

3.4.4. Coastal geomorphology

The monitoring programme in the coastal zone includes tide measurements at one site, recurrent photography of characteristic coastal landforms at 10 sites, recurrent surveying of two cross-shore terrain profiles at a recurved spit, measurements of coastal cliff recession at four sites and measurements of the vertical accretion of salt marsh at two sites (Fig. 3.4.4.1).

The tide gauge at Zackenberg was installed in July 1996. The first month of registrations from the tide gauge (July and August 1996) has been used for calculating a tide prediction table for Zackenberg, 1997. A tide prediction table for 1998 will soon be available on the Danish Polar Center homepage (www.dpc.dk). During the winter of 1996-1997, the tide gauge was destroyed by ice pressure on the sensor cable and by foxes chewing the power cords. In the 1997 field season the tide gauge was therefore moved to a more protected site and the cords and cables were protected with iron tubes. Registrations from the first week following re-establishing the tide gauge are shown in Fig. 3.4.4.2.

The two cross shore profiles were established in 1992 and has been re-surveyed in 1995, 1996 and 1997. No significant shore line changes have occurred since 1992. It has therefore been decided to expand the time interval between re-surveying to once every three years.

The four measurements of coastal cliff recession indicate only minor recession of the coastal cliff since 1996. No changes had occurred at the two most westerly sites. At the most easterly sites, the cliff have receded 0.3 and 1.0 m, respectively, since the summer of 1996.

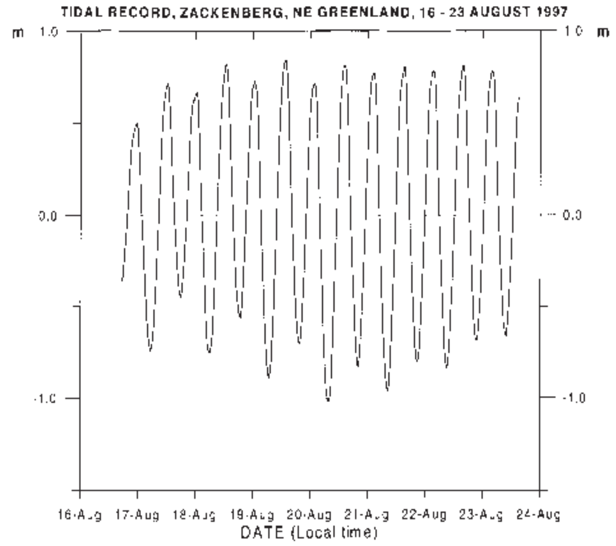


Fig. 3.4.4.2. Tidal record from the tide gauge at Zackenberg 16-23 August 1997. The tide gauge was out of function during the first part of the 1997 field season. The station was re-established at a new site on 16 August.

3.5. General observations on ice conditions

Both the ice on Young Sund and on lakes around Zackenberg broke up at least one week later than in the two previous years. Most likely, this is closer to a long-term average for the area.

3.5.1. The fjord

Like in 1996, the polynya at the mouth of Young Sund extended somewhat into the fjord, and only a narrow ice-bridge connected Sandøen with the fjord ice when the first researchers flew in to Zackenberg on 27 May.

Not until the last days of June, open water formed off the delta of Zackenbergelven, and on 8 July it was estimated to cover about 0.5 km². On 16 July it extended about 1 km², and during the next 3-5 days the ice in the fjord broke up. This was one week later than in 1995 and 1996.

During August, much pack ice entered Young Sund.

3.5.2. Lakes and streams

Open water had started to form in the two ponds north of the runway already when the pioneer team arrived on 21 May. On 27 May, 70% of the western pond and 10-20% of the eastern one were ice free, but very little water was present in the ponds. On 1 June, the largest pond south of the runway was fully ice-free, and the other ponds here were starting to thaw as well. Already on 3 June, the ponds north and south of the runway were almost totally ice-free, but the ponds to the north were not filled with melt-water until 11-13 June. New ice started to form on the ponds on 27 August.

The ice on Lomsø broke up by 30 June, and by mid July all the ice had melted. This is about a week later than in 1996. In mid July, Store Sø was still largely covered with ice, but all ice had disappeared by 7 August. This is about two weeks later than in 1996.

Zackenbergelven started to run on 4 June, which is probably at least one week later than in 1996. Running water appeared in most of the streams on the slopes of Aucellabjerg on 11 June, again almost a week later than in the previous year.

4. ZACKENBERG BASIC

The BioBasis Programme

Details on sampling procedures are presented in a manual (Danish Polar Center 1997), which is available from DPC (tbb@dpc.dk).

4.1. Vegetation

ITEX study plots were sampled by Henrik B. Rasmussen during 27 May – 12 August, and by Thomas B. Berg during the rest of the season. This year, the programme was developed a bit further by dividing each study plot into four sub-areas in order to improve possibilities for statistical analysis of the data. In this connection, three mountain avens *Dryas integrifolia/octopetala* plots (Dryas 1, 4 and 5) and one purple saxifrage *Saxifraga oppositifolia* plot (Saxifraga 1) were extended in size. Furthermore, two new white Arctic bell-heather *Cassiope tetragona* plots (Cassiope 5 and 6) and two new *Dryas* plots (Dryas 7 and 8) were established on the slopes of Aucellabjerg, at an altitude of about 120 m a.s.l.

Neither the ZERO-line, the 400 m^2 plant community study plots, the regional vegetation parameters, nor the cryptogam study plots were checked this year. They are planned to be checked at 5-10 years intervals.

The major plant communities in the study area in Zackenbergdalen were mapped by Christian Bay during late July and August (see section 5.8).

4.1.1. ITEX reproductive phenology

In 1997, snow cleared from exposed plots as early or even earlier than in 1996, while in the latest snow free plots snow cleared up to two week later (*cf.* Dryas 6 in Table 4.1.1; see also section 4.1.3). This is clearly reflected in the flowering phenology, but even more important was the periods of inclement weather especially during the first half of July. Hence, the number of days elapsed between 50% snow cover and 50% open flowers was considerably higher in 1997 than in 1996 for most plots (Table 4.1.1). In four *Dryas* plots the time span was 17-28 days in 1996 versus 33-46 days in 1997, in four *Papaver* plots similarly 23-24 days versus 32-34, in four *Cassiope* plots 17-25 days versus 27-30, in three *Salix* plots 7-13 days versus 9-18, and in one *Silene* plot 32 days versus 43. The cumulative result of these differences was that flowering was up to 23 days delayed in 1997 as compared to the previous year (*e.g.* Dryas 2 and 6, Papaver 4, Cassiope 2 and Silene 4 in Table 4.1.1), while flowering took place 4-6 days earlier in a few exposed plots (*cf.* Dryas 3, Salix 4, Saxifraga 3 and Silene 3 in Table 4.1.1).

4.1.2. ITEX quantitative flowering

Numbers of flowers *etc.* in each study plot are presented in Table 4.1.2. The most pronounced difference as compared to previous years, is the significantly lower numbers of *Dryas* flowers in 1997.

4.1.3. Snow melt in 400 m^2 plant community study plots

Data on snow melt in three 400 m^2 plant community study plots are presented in Table 4.1.3. Plot 1 cleared off 1-2 weeks earlier than in 1996, plot 3 at the same time, while plot 2 cleared off two weeks later than in the previous year. This is in accordance with the general pattern that exposed areas had less snow than in 1996 (plot 1), while snow accumulation sites (plot 2) carried significantly more (see section 4.1.1).

Table 4.1.1. Dates of 50% snow cover and 50% open flowers for white Arctic bell-heather Cassiope tetragona*, mountain avens* Dryas integrifolia/octopetala, *Arctic poppy* Papaver radicatum, *Arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *for ITEX study plots in 1996 and 1997, respectively.*

Plot no.	1996 50% snow	1996 50% flowers	1997 50% snow	1997 50% flowers
Cassiope 1	14.6	2.7	9.6	6.7
Cassiope 2	19.6	6.7	21.6	20.7
Cassiope 3	15.6	9.7	21.6	18.7
Cassiope 4	20.6	15.7	15.6	15.7
Cassiope 6				28.7
Dryas 1		19.6		22.6
Dryas 2	26.6	13.7	27.6	4.8
Dryas 3	6.6	2.7		26.6
Dryas 4		27.6	3.6	6.7
Dryas 5	6.6	30.6	31.5	5.7
Dryas 6	21.6	19.7	4.7	9.8
Papaver 1	20.6	14.7	18.6	20.7
Papaver 2	20.6	14.7	20.6	23.7
Papaver 3	21.6	14.7	15.6	19.7
Papaver 4	21.6	15.7	4.7	7.8
Salix 1		6.6		6.6
Salix 2	14.6	21.6	20.6	29.6
Salix 3	7.6	20.6	8.6	25.6
Salix 4	20.6	29.6	5.6	23.6
Saxifraga 1				31.5
Saxifraga 2				2.6
Saxifraga 3		5.6		1.6
Silene 1		20.6		24.6
Silene 2		23.6		29.6
Silene 3		30.6		26.6
Silene 4	24.6	26.7	28.6	10.8

3rd Annual Report for ZERO

Table 4.1.2. Size and total number of flower buds, flowers and senescent flowers of white Arctic bell-heather Cassiope tetragona*, mountain avens* Dryas integrifolia/octopetala, *Arctic poppy* Papaver radicatum, *Arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia, *moss campion* Silene acaulis *and Arctic cotton-grass* Eriophorum scheuzerii *in ITEX plots in 1995, 1996 and 1997. Numbers in brackets have been extrapolated from 1995-1996 data to make up for enlarged plots (see section 4.1).*

Plot no.	Area (m^2)	1995	1996	1997
Cassiope 1	2	1321	1386	1855
Cassiope 2	3		1759	550
Cassiope 3	2	256	844	789
Cassiope 4	3	456	1789	391
Cassiope 5	2.5			1224
Cassiope 6	2			
Dryas 1	4	(936)	(797)	138
Dryas 2	60	534	1073	230
Dryas 3	2	603	522	123
Dryas 4	6	(325)	(164)	155
Dryas 5	6	(654)	(504)	123
Dryas 6	91	809	1406	691
Dryas 7	12			787
Dryas 8	12			391
Papaver 1	105	302	337	265
Papaver 2	150	814	545	848
Papaver 3	90	334	238	289
Papaver 4	91	196	169	192
Salix 1 mm.	60		807	959
Salix 1 ff.		520	1096	1349
Salix 2 mm.	300		790	1082
Salix 2 ff.		617	1376	1909
Salix 3 mm.	36	239	479	412
Salix 3 ff.		253	268	237
Salix 4 mm.	150		1314	831
Salix 4 ff.		1073	1145	642
Saxifraga 1	7		(1010)	141
Saxifraga 2	6		513	387
Saxifraga 3	10		529	322
Silene 1	7		(251)	403
Silene 2	6		493	524
Silene 3	10		348	211
Silene 4	1	466	270	493
Eriophorum 1	15		395	423
Eriophorum 2	15		392	344
Eriophorum 3	6		537	545
Eriophorum 4	8		260	755

Table 4.1.3. Relative snow cover (%) in three 400 m^2 plant community study plots during the snow melt in 1997.

Date	Plot 1	Plot 2	Plot 3
27.5	70	100	100
03.6	20	100	100
10.6	0	97	100
17.6	0	60	80
24.6	0	45	1
01.7	0	5	0
08.7	0	0	0

4.2. Arthropods

Following last year's experiment with both yellow and transparent pitfall traps as well as yellow pan traps and window traps it was decided to use only yellow pitfall traps and window traps in the future (for comparison between traps, see section 5.6 in Meltofte & Thing 1997). Hence, each of the five pitfall trap stations now holds eight yellow pitfall traps. To increase the strength of statistical analysis, the eight traps at each station was divided into four groups of two traps each. The window trap station was unchanged from 1996.

The use of formaldehyde as trapping liquid was stopped to avoid any kind of contamination of the environment. Now, the liquid used both in the pitfall traps and in the window traps contains only salt (150 g NaCl/l) together with three drops of detergent (Tween 20).

Apart from the traps, insect activity was monitored along a 1660 m line transect. Due to the limited additional information provided by the line transect and to the extreme sensitivity to weather conditions, it was decided not to continue the transect as part of the BioBasis programme in the future.

All field sampling, sorting and data processing was performed by Henrik Barner Rasmussen. Sorted samples are kept available for further examination at the Zoological Museum, University of Copenhagen.

4.2.1. Yellow pitfall traps

All the pitfall traps were already put in place at the end of last field season. Unlike 1996, traps could therefore be activated shortly after the ground was snow free. The first traps were already opened on the day of our arrival on 27 May. All traps were active on 15 July and remained so until 27 August. On one occasion (24 June), two traps on station 5 was destroyed by a fox and the content lost, and at two other occasions (1 and 8 July) a fox had defecated in a trap, thereby increasing the amount of *Cyclorrhapha* larvae.

Total number of arthropods caught each week at the five pitfall trap stations is presented in Table 4.2.1 together with total catches from 1996 for comparison. The phenology of various selected taxa are presented in Figs 4.2.1.1-4.2.1.6.

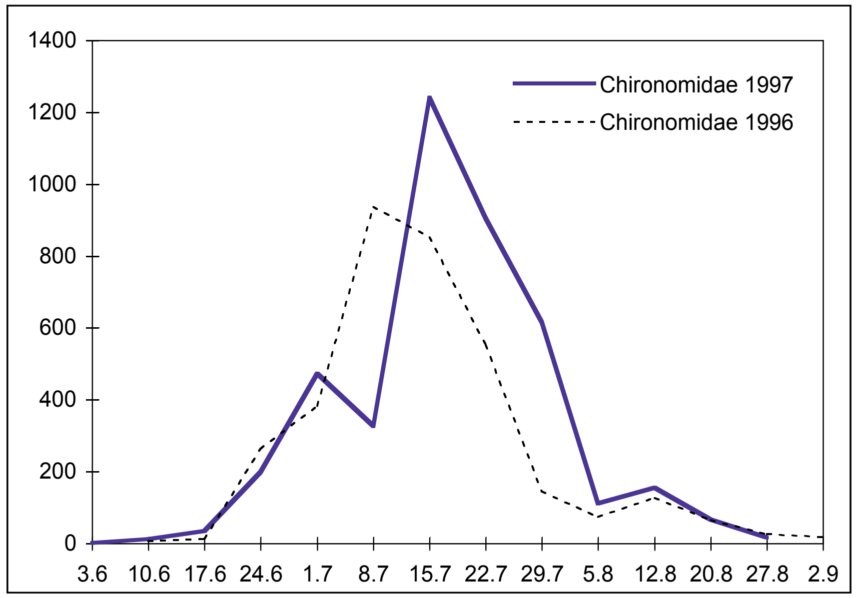


Fig. 4.2.1.1. Phenology of Chironomidae (midges) in 1996 and 1997. Data pooled from all five pitfall trapping stations. Data from 1996 have been extrapolated from half the number of traps.

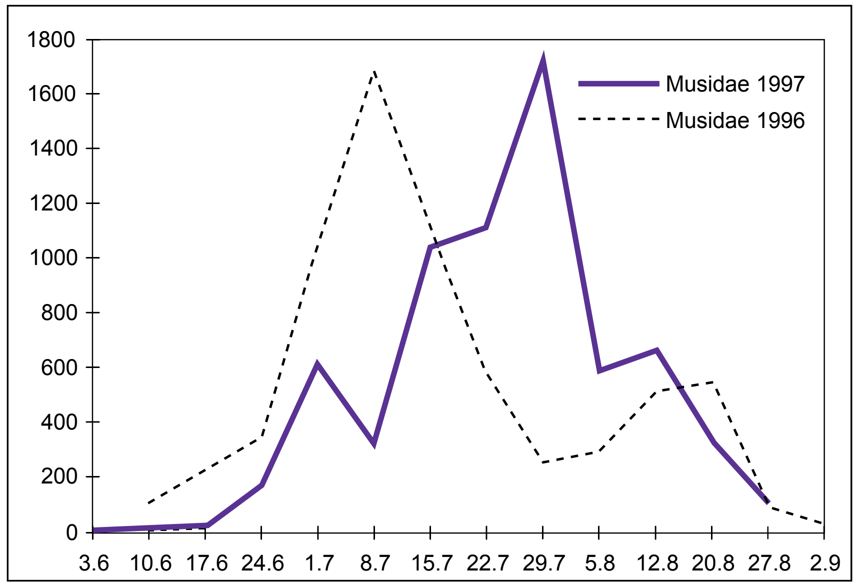


Fig. 4.2.1.2. Phenology of Muscidae (flies) in 1996 and 1997. Data pooled from all five pitfall trapping stations. Note that Anthomyiidae were not separated from muscids in 1996. A pronounced peak on 17 June 1996 has been exchanged with an interpolated value, as it was due to one trap being situated close to a carcass. Furthermore, data from 1996 have been extrapolated from half the number of traps.

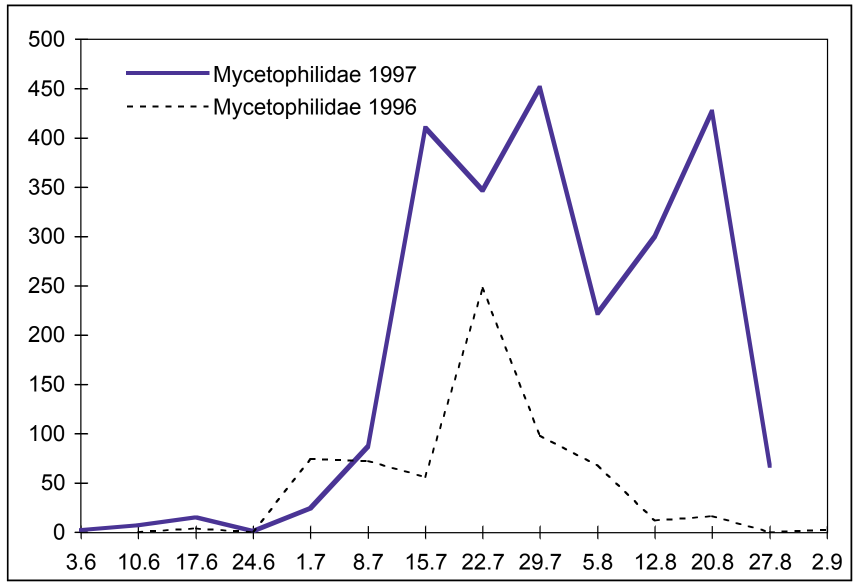


Fig. 4.2.1.3. Phenology of Mycetophilidae (fungus gnats) in 1996 and 1997. Data pooled from all five pitfall trapping stations. Data from 1996 have been extrapolated from half the number of traps.

Fig. 4.2.1.4. Phenology of Ichneumonidae (wasps) in 1996 and 1997. Data summed up from all five pitfall trapping stations. Data from 1996 have been extrapolated from half the number of traps.

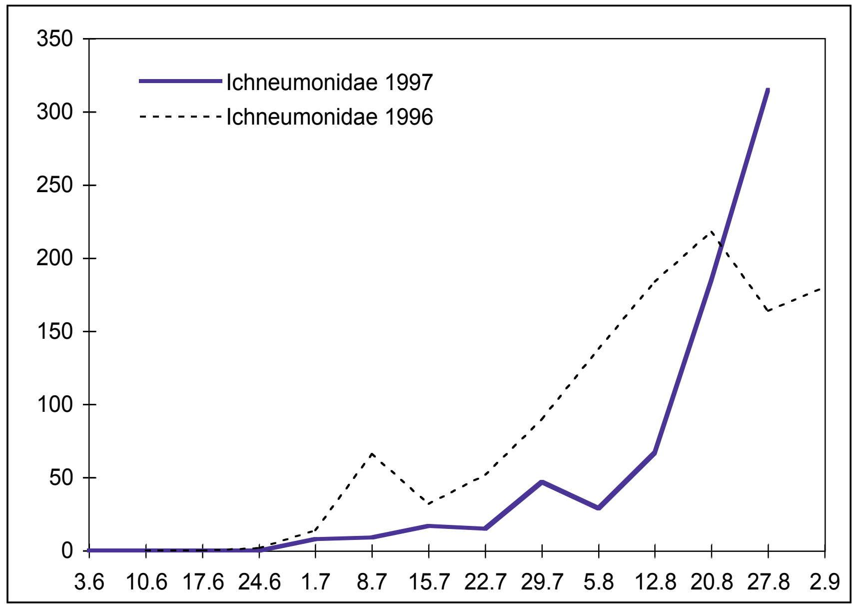


Fig. 4.2.1.5. Phenology of Clossiana sp. (fritillary butterfly spp.) in 1996 and 1997. Data pooled from all five pitfall trap stations. Data from 1996 have been extrapolated from half the number of traps.

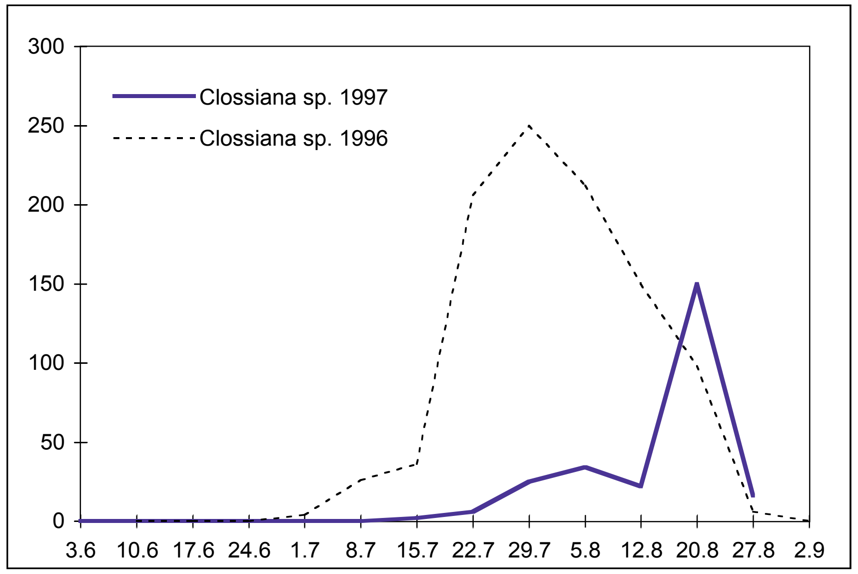
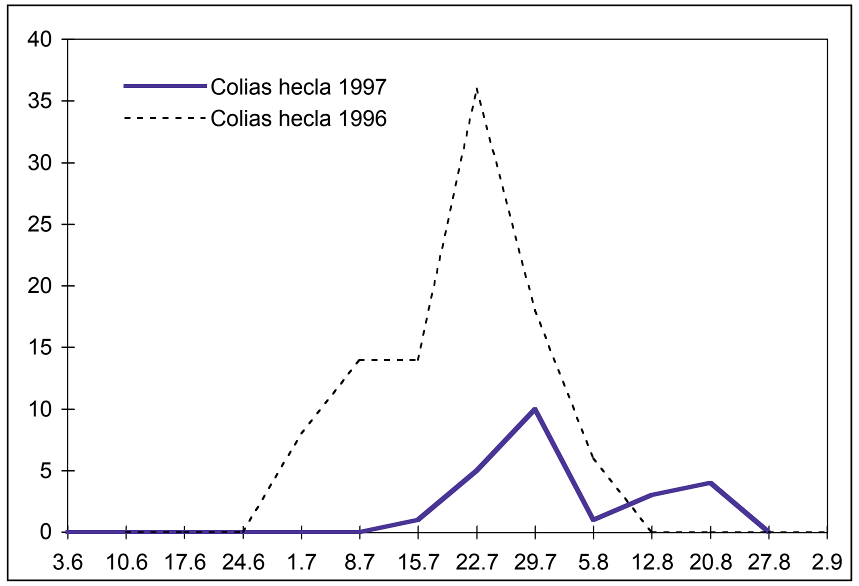


Fig. 4.2.1.6. Phenology of Colias hecla *(northern clouded yellow butterfly) in 1996 and 1997. Data pooled from all five pitfall trap stations. Data from 1996 have been extrapolated from half the number of traps.*



When comparing the results from 1996 and 1997, it should be noted that only four yellow pitfall traps were used per station in 1996. To facilitate comparison, 1996-data have been doubled in Figs 4.2.1.1-4.2.1.6.

Among the most pronounced differences between the two years is that the peak appearance of *Clossiana spp.* (polar & Arctic fritillary) was delayed three weeks in 1997, as compared to 1996, and that the total number of *Clossiana spp.* was reduced

Table 4.2.1. Total number of arthropods caught at the five pitfall trapping stations in 1997. Each station held eight yellow pitfall traps measuring 10 cm i diameter. Values from each date represent catches from the previous week. Totals from 1996 are given for comparison. Note, however, the much lower trapping effort that year. In 1996, Muscidae and Anthomyiidae flies were not separated, neither were juvenile Lycosidae spiders separated from adults.

Date	03.6	10.6	17.6	24.6	01.7	08.7	15.7	22.7	29.7	05.8	12.8	20.8	27.8	S1997	S1996
No. of active stations	2	2	2	3	4	4	5	5	5	5	5	5	5	5	5
No. of trap days	69	112	105	105	196	224	266	280	280	280	280	320	280	2797	1512
COLLEMBOLA	7	234	592	587	1234	704	2042	2514	1513	1227	506	298	139	11597	2794
HETEROPTERA															
Nysius groenlandicus	0	0	0	0	0	0	0	0	0	0	0	2	3	5	20
Aphidoidea	0	0	0	0	0	0	0	0	0	4	2	2	4	12	3
Coccoidea	0	0	0	0	35	12	11	45	131	62	102	82	23	503	102
THYSANOPTERA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
LEPIDOPTERA															
Lepidoptera larvae	0	2	1	3	8	4	3	7	13	2	4	10	3	60	47
Colias hecla	0	0	0	0	0	0	1	5	10	1	3	4	0	24	48
Clossiana sp.	0	0	0	0	0	0	2	6	25	34	22	150	16	255	494
Lycaenidae	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
Plebeius glandon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Noctuidae	0	0	0	0	0	2	5	4	6	8	4	30	6	65	35
DIPTERA															
Nematocera larvae	1	4	0	7	1	17	5	1	2	1	0	0	0	39	26
Tipulidae	0	0	0	1	0	0	2	0	0	2	0	1	0	6	10
Trichoceridae	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
Culicidae	0	0	0	0	0	4	6	2	5	0	0	0	1	18	1
Chironomidae	2	12	35	198	472	327	1241	905	615	112	156	66	16	4157	1728
Cecidiomyiidae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Mycetophilidae	2	7	15	1	24	87	410	347	451	222	300	427	67	2360	325
Empididae	0	0	0	0	0	0	1	0	0	0	0	3	1	5	5
Cyclorrhapha larvae	0	0	5	5	38	1	0	1	1	4	0	0	0	55	7
Phoridae	0	0	0	0	1	0	4	6	10	6	5	30	21	83	55
Agromyzidae	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Syrphidae	1	6	9	7	3	1	6	4	6	7	3	17	5	75	42
Tachinidae	0	0	0	0	0	0	2	0	4	2	2	3	4	17	0
Calliphoridae	26	3	0	1	8	0	1	0	0	0	0	1	3	43	22
Muscidae	4	6	18	172	610	319	1038	1108	1720	585	663	334	102	6679	4133
Anthomyiidae	317	42	22	11	44	3	22	0	0	0	1	9	1	472	
Fannidae	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
Scatophagidae	189	108	12	22	41	0	4	3	2	1	0	4	0	386	13
HYMENOPTERA															
Ichneumonidae	0	0	0	0	8	9	17	15	47	29	67	185	315	692	570
Braconidae	0	0	0	0	4	4	2	6	5	5	8	10	6	50	17
Chalcidoidea	0	0	0	0	0	0	1	1	3	2	8	36	19	70	7
Cynipoidea	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0
Bombus sp.	0	0	0	0	3	0	2	1	1	0	0	3	2	12	1
ACARINA	65	479	1543	1008	2688	1855	1438	2457	2201	1312	1455	1679	986	19166	4554
ARANEA															
Linyphiidae	165	148	109	143	177	103	178	222	139	76	106	147	146	1859	991
Lycosidae	48	114	34	110	290	157	326	486	391	126	141	235	226	2684	1877
Lycosidae egg sac	0	0	0	0	2	4	9	12	42	14	4	24	11	122	34
Lycosidae juv.	0	0	0	0	0	0	0	0	34	63	68	77	624	866	
Thomisidae	8	8	8	6	26	12	22	23	15	3	5	14	6	156	73
Dictynidae	0	0	0	0	0	0	1	6	4	0	2	2	2	17	0
Total	835	1174	2403	2282	5717	3625	6803	8187	7397	3911	3640	3885	2758	52617	18037

to almost a quarter when corrected for number of traps (Fig. 4.2.1.5). *Colias hecla* (northern clouded yellow) showed a similar decrease in numbers, and the time of peak appearance was about one week later than in 1996 (Fig. 4.2.1.6). This reduction and later appearance of butterflies could be due to the generally colder conditions in 1997 (see section 3.1.2). Even the peak in muscid flies was three weeks later in 1997 than in 1996 (Fig. 4.2.1.2).

When corrections are made for the difference in number of traps between 1996 and 1997, the total number of both muscid flies and chironomid midges caught in 1997 are comparable to the amounts caught in 1996, with the first being a little lower and the latter a little higher in 1997 than in 1996 (Table 4.2.1, Figs 4.2.1.1 and 4.2.1.2).

Mycetophilidae (fungus gnats), however, showed an almost four-fold increase in 1997 as compared to 1996, and they occurred in relatively high numbers from mid July (Fig. 4.2.1.3).

The pronounced low seen for most taxa in the catches from 8 July must be attributed to the period of adverse weather in early July (see section 3.1.2).

Apart from the taxa found last year, a few representatives from the following taxa were caught in 1997: Trichoceridae, Cecidiomyiidae, Agromyzidae, Tachinidae, Fannidae, Cynipoidea and Dictynidae. No Thysanoptera nor *Plebeius glandon* were caught this year, however.

4.2.2. Window traps

The window traps were set up on 27 May and remained active throughout the season until 27 August. In two instances a window was broken by muskoxen rubbing their heads against the trap. The catches were however recovered and the broken traps replaced immediately after the incident.

The catches are presented in Table 4.2.2. As in 1996, chironomids (midges) showed a peak already

Table 4.2.2. Total number of arthropods caught at the window trap station 1997. The station held two window traps situated perpendicular to each other, with windows measuring 20 x 20 cm². Values from each date represent catches from the previous week. Totals from 1996 are given for comparison. Note that Anthomyiidae flies were not separated from Muscidae in 1996.

Date	03.6	10.6	17.6	24.6	01.7	08.7	15.7	22.7	29.7	05.8	12.8	20.8	27.8	S1997	S1996
No. of trap days	14	14	14	14	14	14	14	14	14	14	14	16	14	184	182
COLLEMBOLA	0	0	0	0	4	6	0	0	3	1	1	0	0	15	65
HETEROPTERA															
Nysius groenlandicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Coccoidea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
THYSANOPTERA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
LEPIDOPTERA															
Colias hecla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Clossiana sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	1	6
Noctuidae	0	0	0	0	0	0	0	1	0	1	0	0	0	2	2
Geometridae	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3
DIPTERA															
Trichoceridae	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
Culicidae	0	0	0	0	1	2	23	28	22	11	34	18	3	142	98
Chironomidae	63	30	156	3871	1883	200	656	226	327	132	105	51	25	7725	6510
Cecidiomyiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Mycetophilidae	0	7	38	65	82	2	10	6	2	4	18	5	1	240	64
Empididae	0	0	0	0	0	0	0	1	0	0	0	0	0	1	77
Agromyzidae	0	2	2	0	0	0	0	0	0	0	0	0	0	4	0
Syrphidae	4	0	0	1	0	0	0	2	1	1	3	2	2	16	4
Calliphoridae	5	0	0	0	0	0	0	0	0	0	1	0	0	6	2
Muscidae	0	0	1	1	103	32	92	79	147	72	142	92	48	809	1355
Anthomyiidae	0	2	0	0	3	0	1	0	1	1	3	0	0	11	
Scatophagidae	0	2	2	3	16	0	0	0	0	1	1	1	4	30	11
HYMENOPTERA															
Ichneumonidae	0	0	0	0	1	1	13	5	14	4	4	1	1	44	43
Braconidae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Chalcidoidea	0	0	0	0	0	0	1	0	0	1	0	0	0	2	0
Bombus sp.	0	0	0	0	0	0	0	0	1	0	4	1	0	6	5
ACARINA	0	0	0	0	2	1	0	0	125	2	58	0	1	189	342
ARANEA															
Linyphiidae	0	0	0	0	0	1	0	0	0	0	0	0	0	1	8
Lycosidae	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Total	72	43	199	3941	2096	245	796	348	643	233	376	171	85	9248	8623

Table 4.2.3. Total no. of arthropods recorded during six line transects. The 1996 total includes only recordings from a similar number of transects during the same part of the season.

Date	26.6	12.7	20.6	26.7	06.8	09.8	Total 97	Total 96
Snow-cover (%)	10	0	0	0	0	0		
Clossiana spp.		1	2	7	17	24	51	66
Colias hecla						1	1	7
Plebeius glandon				1	1		2	0
Sympistris zetterstedtii			2	3	4	5	13	5
Other moths		2	4	8	26	33	73	23
Tipula arctica	1	4	2	20	1	5	33	11
Bombus spp.	3	1	2	2		5	13	0
Calliphoridae				2			2	7

in the third week of June, or three weeks earlier than in the pitfall traps. This could be due to a difference in species caught by the different kind of traps. The total number of chironomids caught in 1997 is, like in the pitfall traps, comparable with 1996 figures, *i.e.* with the same tendency of a slightly higher number.

Unlike in 1996, no clear peak of *Muscidae* (flies) were seen in 1997. The total number of muscids caught was, like in the pitfall traps, slightly lower than in 1996.

4.2.3. Insect line transect

The insect line transect west of Zackenbergelven was walked for the first time on 26 June, when the snow-cover was reduced to 5-10%. Subsequently, the transect was walked at intervals of about one week until 9 August, or a total of six times (Table 4.2.3). The line transect was walked around mid day on calm, clear days.

Recordings from the line transect indicate a peak of *Tipula arctica* (crane flies) in the last week of July approximately at the same time as last year. Apart from *Tipula arctica,* which was poorly represented in the traps, the recordings from the line transect did not provide additional information.

4.2.4. Predation on *Dryas* flowers by larvae of *Sympistis zetterstedtii*

No larvae of *Sympistis zetterstedtii* were found during the weekly checks of the ITEX *Dryas* study plots.

Table 4.2.4. Peak ratio (%) of Dryas *flowers predated by larvae of* Sympistis zetterstedtii *in 1996 and 1997.*

Plot	Date 1996	Pred.	Date 1997	Pred.
Dryas 1	17.7	2	24.6	6
Dryas 2		0	05.8	5
Dryas 3	01.7	11	24.6	18
Dryas 4	24.6	17	15.7	1
Dryas 5	08.7	2	08.7	8
Dryas 6		0		0

The reproductive organs were however found in some instances to have been predated to a varying extent. In Table 4.2.4, the highest percentage of predated flowers recorded during the season and the corresponding dates are listed together with the figures from 1996.

4.2.5. Predation on *Salix arctica*

Like in 1997, no woolly-bear *Gynaephora groenlandica* caterpillars were observed during the weekly checks of the *Salix arctica* ITEX study plots. One was found west of Zackenbergelven on 23 June, as well as two on the slopes of Aucellabjerg on 24 June and one on 9 July.

The predation on *Salix arctica* pods by an unknown Lepidoptera larvae, observed in 1996, was not seen in any of the *Salix* plots in 1997.

4.2.6. General phenological observations

Dates of first observation of selected insect species are presented in Table 4.2.6. With the exception of bumble bees, all initial observation dates were later than in 1996.

The first (two) *Bombus polaris* queens carrying pollen baskets were seen on 24 June indicating that nest building had started by then. The first *B. polaris* worker was observed leaving a nest on 19 July and the first *B. polaris* male was observed on 26 July.

The first mosquitoes *Aedes nigripes* were encountered on 24 June, but they were not reported to be troublesome until 4 July.

Table 4.2.6. First observation dates of selected insect species in 1996 and 1997.

Species	1996	1997
Colias hecla	26.6	02.7
Clossiana sp.	10.6	16.6
Tipula arctica	12.6	23.6
Culicidae	20.6	24.6
Bombus sp.	06.6	01.6

4.3. Birds

Bird observations were recorded by Hans Meltofte during 27 May – 29 July and by Thomas B. Berg during the rest of the field season. During June, the main effort was to census the breeding birds in the 19 km² census area in Zackenbergdalen (section 4.3.1), while in July emphasis was on breeding phenology, *i.e.* finding nests and young and rechecking these (sections 4.3.2 and 4.3.4). 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 (section 4.3.3). Line transects through Store Sødal were walked by Thomas B. Berg and Henrik B. Rasmussen in mid July and mid August, and between Daneborg and Zackenberg in mid July. In late July Sandøen in outer Young Sund was visited. Valuable observations were provided by several other researchers and staff during the entire season.

For scientific names in this chapter, see section 4.3.8.

4.3.1. Breeding populations

As in 1996, the 19 km² census area in Zackenbergdalen was covered on almost daily trips during most of June and July (Table 4.3.1.1). The main census effort in the extensively covered area east of Zackenbergelven was between 9 and 24 June, while the more intensively covered 'small' area west of the river was covered regularly during the entire period.

By recording the birds present on the relatively limited areas of snow-free land during mid June, the results reflect the population of potentially breeding birds including possible territorial non-breeders. This is considered the best measure for the local 'site claiming' population.

Due to improved maps, better knowledge of the area and more time for the census work, the results from 1997 must be considered more accurate than the 1996 data (Table 4.3.1.2). Hence, the somewhat higher numbers for red knot, sanderling, dunlin and ruddy turnstone are probably due to better coverage, while the lower number of great ringed plovers may be a result of more extensive snow-cover especially on the upper slopes of Aucellabjerg this year. Here, even new snow covered the ground down to 350 m on 11 June, and the estimated number of great ringed plovers found above the 100 m contour was 10-13 pairs lower than in 1996.

The population of rock ptarmigans was significantly higher than last year. Besides more displaying males, a total of 11-13 broods were encountered inside the census area as compared to two in 1996. The populations of waterfowl and long-tailed skuas were very much the same during the two years. (See also section 4.3.8.)

The distribution patterns of the individual species within the census area were very similar to those presented on the maps in the 1996-report (see Meltofte & Thing 1997).

Table 4.3.1.1. Number of trips and hours (trips-hours) allocated to bird censusing and breeding phenology sampling west and east of Zackenbergelven during June and July 1997, respectively.

Month	West of river	East of river	Total
June	9–31	12–50	21–81
July	10–31	14–54	24–85
Total	19–62	26–104	45–166

Table 4.3.1.2. Estimated number of pairs/territories in the 19 km² census area in Zackenbergdalen, 1997.

Species	West of the river (3.39 km²)	East of the river (15.41 km²)	Total
Red–throated diver	0	2	2
Pink–footed goose	1	0	1
King eider	0	2	2
Long–tailed duck	0	4–6	4–6
Rock ptarmigan	2–3	10–12	12–15
Great ringed plover	10	31–39	41–49
Red knot	4–5	31–39	35–44
Sanderling	10	45–61	55–71
Dunlin	22–26	51–63	73–89
Ruddy turnstone	7–9	42–48	49–57
Red–necked phalarope	0	0–2	0–2
Long–tailed skua	3	18–22	21–25
Snow bunting	17–22	27–33	44–55

4.3.2. Reproductive phenology in waders (shorebirds)

As in 1995 and 1996, egg-laying in 1997 peaked around mid June, with the earliest clutches initiated already during the first week of June and a few possible relays initiated in late June (Table 4.3.2). The relatively high consistency in the laying dates recorded during these three years, probably reflects the fact that all three years apparently had relatively little or moderate snow-cover and an early snow-melt.

4.3.3. Breeding success in waders

Due to the low number of foxes at Zackenberg (see section 4.4.3), hatching success of waders was at least as high in 1997 as during the two previous

Table 4.3.2. First-egg dates for waders at Zackenberg in 1997 as estimated from incomplete clutches, egg floating, hatching dates and observations of newly fledged juveniles.

Species	Median date	Range	N
Great ringed plover	15 June	10–24 June	6
Red knot	16 June	6–18 June	4
Sanderling	17 June	12–26 June	12
Dunlin	14 June	8–18 June	17
Ruddy turnstone	13 June	4–22 June	19

Table 4.3.3. Cumulative numbers of juvenile waders recorded at low tide in the old and the present deltas of Zackenbergelven during counts every third day in the period 1-28 August, 1995-1997. For comparison, figures from one missing count in late August 1997 have been extrapolated. The same applies to figures for a number of unidentified sanderlings/dunlins in 1995.

Species	1995	1996	1997
Great ringed plover	90	125	249
Red knot	3	18	0
Sanderling	235	613	144
Dunlin	271	301	285
Ruddy turnstone	58	80	80
Total	657	1137	758

years. Out of 31 wader nests found, at least 22 hatched successfully, while none could be ascertained to have been predated. One sanderling nest failed due to pecking in an egg (perhaps by a turnstone), and the embryos in a turnstone clutch died probably due to water in the nest during the rainstorm in early July. During the same period, the growth rate of two turnstone broods was less than half the normal, while a dunlin brood developed normally. In spite of a critically low growth of a turnstone chick (weight 29.8 g at an age of 11 days as compared to a 'normal' weight of 61 g), this young was recorded on the wintering grounds in the Netherlands on 26 October 1997 (Zoological Museum, University of Copenhagen, in litt.).

The apparently good breeding success is also reflected in the numbers of juvenile waders in the former and the present deltas of Zackenbergelven (Table 4.3.3). Compared to previous years, ringed plover numbers were very high, while sanderling numbers were significantly lower.

4.3.4. Reproductive phenology and success in long-tailed skuas

In accordance with the abundance of lemmings (see section 4.4.1), 17 out of the estimated 21-25 pairs of long-tailed skuas recorded inside the census area (see section 4.3.1) were found with nests. The remaining pairs may as well have attempted breeding. One more pair nested immediately outside the area.

Estimated from hatching dates, egg floating and the weight of a *pullus*, eight out of 16 dated clutches were initiated on 6 and 7 June. One clutch was initiated already on 4 June, while the remaining seven were distributed up to 23 June. Several of the latter may have been relayed clutches.

Of the 17 nests found, 13 held two eggs, the remaining only one. Two more nests found outside the census area held two eggs. 12 clutches hatched successfully, while five apparently were predated (by foxes). Of the 12 broods hatched, at least 4-5 young from different broods were ascertained to have fledged. Hence, apparently no more than one young survived in any brood. At least six broods were predated.

4.3.5. Breeding barnacle geese

Two pairs of barnacle geese with two goslings each were encountered in the fens south of the runway on 29 June. During the following few days more broods showed up, so that in early July a total of 10-11 broods with 30-31 goslings were present here and around Lomsø. On 14 July a total of 14 pairs with 38 goslings were counted in the old delta and around Lomsø. An additional five pairs of which four broods held 13 goslings stayed at Zackenbergelven in the northern part of the census area during the first half of July. On 25 July, a total of 16 broods at Lomsø held 42 goslings. To what extent these included broods from the northern part of the census area is unknown, but at least two families were still present here in early August.

Summarising these data, a total of 19-21 families brought their goslings to Zackenbergdalen this year, which is three times as many as in 1995 and 1996. Average brood size was 3.1 in early July (N=14), 2.7 in mid July (N=14) and 2.6 in late July (N=16).

Lindemansdalen and the south facing cliff of Zackenbergfjeldet were searched for breeding colonies in early June, but no sign of breeding was found.

4.3.6. Line transects

Three line transects were walked through Store Sødal and along the coast from Daneborg to Zackenberg in July and August (Table 4.3.6). The results were very similar to those obtained in 1996. (See also section 4.4.4.)

4.3.7. Sandøen

The island of Sandøen was visited on 27 July, when a total of 450 arctic terns and 150 Sabine's gulls were estimated to be present. 141 tern and gull nests held eggs, and a further 24 *pulli* were counted. Time did not allow further identification. Seven empty common eider nests and two empty long-tailed duck or king eider nests were found as well.

4.3.8. Other observations

This section presents bird records in the study area other than those presented in sections 4.3.1-4.3.7. When nothing else is stated, observations refer to the census area in Zackenbergdalen.

Red-throated diver *Gavia stellata*

On 30 and 31 May the first red-throated divers were circling over Zackenbergdalen, and on 2 June the first pair were seen on a pond. Two pairs were present in the census area from 8 June. On 12 June a pair was building a nest in a pond just south of the runway, and a bird was sitting on the nest already from the next day. On 11 July, a young had hatched, and on 22 August it had flown down to the river delta.

Table 4.3.6. Birds recorded (adults/young) during line transect surveys through Store Sødal and from Daneborg to Zackenberg (see map in Meltofte & Thing 1997).

Species	Store Sødal 16–18 July	Daneborg 21 July	Store Sødal 16–18 August
Red–throated diver	3/0		5/0
Pink–footed goose	203	60	86
Barnacle goose	182		116
Goose sp.	25		
Common eider		390	
Long–tailed duck		13/0	
Rock ptarmigan	2/0		
Great ringed plover	71/0	4/0	29
Red knot	1/0		
Sanderling	11/1	3/0	
Dunlin	56/1	8/0	5
Ruddy turnstone	3/0	3/0	
Long–tailed skua	6/0	7/0	
Glaucous gull	7/0	4/0	4/0
Arctic tern	3/0		12/0
Snowy owl			2/3
Northern weathear			1
Common raven	2	8	
Arctic redpoll			2
Snow bunting	103	3	77

Another pair appeared on the ponds east of Lomsø on 26 June, and on the next day a bird was incubating here too. On 7 July the nest was deserted probably due to flooding during the rainstorm. The pair moved to Lomsø, where they were building on a nest on 13 July. A bird was sitting on the nest from the next day, and on 11 August a *pullus* appeared on the lake, where it was seen again on 16 August.

A third pair bred on a lake just north of the census area west of Zackenbergelven. Here a bird was incubating on 15 and 28 July. On the latter date, the bird was sitting high on the nest, and on 7 August a pair with two 'one-week-old' *pulli* were found here. They were still present when checked on 20 August.

A fourth pair bred on a lake west of the river from Lindemansdalen. Here a bird was incubating on 16 July, but no birds were seen on the lake on 16 August.

The maximum number of divers observed during the season was a flock of nine flying over the delta of Zackenbergelven on 19 August.

Pink-footed goose *Anser brachyrhynchus*

A pair of pink-footed geese were seen in the census area from 28 May. On 2 June a nervous gander was encountered in the westernmost part of the census area, and on 8 June the nest was found with five eggs here. Two eggs hatched probably on 26 June, and on the 29th only three eggs with fully developed and partly hatched goslings remained in the nests. This partial failure may have been caused by human presence in the area. On 2, 25 and 30 July a pair was seen with two goslings at different places along the coast of Zackenbergdalen.

On a point on the coast 5 km west of the station, two pairs were found on 6 June. At least one bird was incubating.

Small numbers of geese (max. 12) were seen in Zackenbergdalen during early and mid June. The moult migration of immature Icelandic geese apparently began on 18 June, when six birds arrived. Including these, a total of 857 birds migrated north up until 30 June, and a further 33 latecomers flew north on 9 July. Several more flocks were heard passing over. Flightless birds were encountered from 8 July, and the last flying birds were seen on 11 July. The entire coast off Zackenbergdalen was surveyed on 25 July, when 181 moulting pink-feet were found between Kærelv and the peninsula to the south-east, and a further 66 east of the peninsula. 15 were moulting at a lake north of Zackenbergelven (lower Lindemansdalen), and about 60 unidentified geese were found on the coast west of the Zackenberg Trapping Station. Hence, a total of 262-322 pink-footed geese moulted in Zackenbergdalen this year, compared to 246 in 1996 and an estimated 550 in 1995.

The first flying geese (unidentified) were seen on 27 July. During August, a maximum of 224 pink-feet were recorded feeding in the valley.

Barnacle goose *Branta leucopsis*

Barnacle geese were present in the study area already at the arrival of our pioneer team on 21 May. During June, up to 14-17 were recorded most days in the census area, while up to 15-30 non-breeders and unsuccessful breeders were present around Lomsø together with the family groups (see section 4.3.5) during the last days of June and all of July. In addition to the family groups staying in Zackenbergdalen, five adults with a brood of two goslings were encountered 2 km west of the trapping station on 27 July.

During a survey for moulting immature geese along the coast on 25 July, 92 barnacle geese were counted around the peninsula to the south-east, and about 60 unidentified geese were found on the coast west of the trapping station.

The first flying geese (unidentified) were seen on 27 July. During August, a maximum of 300 barnacle geese were recorded in the valley. In 1997, the number of family groups, the numbers of non-breeders in June and total numbers in August were all significantly higher than during the previous two years. This may be a result of decreased competition from moulting immature pink-footed geese, that have declined in numbers since 1995, probably due to disturbance (see section 6.1 in Meltofte & Thing 1997).

Common eider *Somateria mollissima*

The first eiders appeared in the colony at Daneborg on 28 May. On 2 June the first five males and three females were seen in the delta of Zackenbergelven.

Similar numbers (max. 7 males, 10 females) were seen regularly during June and July, until the first family parties arrived on 23 July. On 25 July, a total of 88 non-breeding females were counted around the peninsula, and during the waterbird counts in the Zackenbergelven deltas a maximum of 15 adult females and 14 *pulli* were recorded in late July and during August. A further 36 adults and *pulli* were seen east of the old delta on 7 August.

King eider *Somateria spectabilis*

A pair of king eiders appeared in the census area on 4 June, and on 11 June two pairs were present. From 16 June to 23 July, when a female with 5 newly hatched *pulli* appeared at Lomsø, only one pair was seen on 30 June.

Long-tailed duck *Clangula hyemalis*

The first male long-tailed duck arrived in the census area on 30 May, three males were present on the next day, and on 2 June, the first pair was seen. During the rest of June and early July, up to four pairs and two males were recorded almost daily on ponds and in the deltas of Zackenbergelven. A maximum of seven males and females were seen on Lomsø in July, while 37 moulting males were found east of the peninsula on 25 July.

On 1 August, a female with two small ducklings appeared on the ponds just south of the runway, and from 4 to 25 August they were regularly recorded on Lomsø.

Gyr falcon *Falco rusticolus*

Five times during 24 June to 24 August, a gyr falcon was seen in Zackenbergdalen.

Rock ptarmigan *Lagopus mutus*

1997 was probably a peak year for ptarmigan at Zackenberg. Of the 11-13 broods recorded, the first hen with 5 well grown chicks was encountered on 7 July. From then on, females with up to 11 chicks were seen regularly in most parts of the census area. Small chicks (6) were encountered until 7 August.

In August, four flocks with 20-24 ptarmigan were recorded.

Great ringed plover *Charadrius hiaticula*

Ringed plovers were present in the census area from our arrival on 27 May. Four migrated northwest together with seven sanderlings on 12 June.

A maximum of nine adults and 115 juveniles was recorded during the waterbird counts in the deltas of Zackenbergelven on 10 and 22 August, respectively.

European golden plover *Pluvialis apricaria*

A golden plover passed over the census area on 12 June.

Red knot *Calidris canutus*

Knots were singing over Zackenbergdalen already when we arrived on 27 May. An individual in 'winter plumage' was seen on 10 June. On 14 July, a post-breeding flock of seven knots and one sanderling was seen.

Sanderling *Calidris alba*

Sanderlings were present in the census area when we arrived on 27 May. Flocks of 5-7 individuals were seen on migration until 12 June. Post-breeding flocks of up to 12 were seen in mid July. A maximum of 18 adults and 34 juveniles were counted on 22 August during the waterbird counts in the deltas.

Dunlin *Calidris alpina*

Dunlins were recorded already on 24 May by the pioneer team, and on 27 May as many as 20 were feeding at the ponds just north of the runway. Although most of them were dispersed in the valley during daytime, about 10-20 dunlins came to feed in the partially dry ponds north of the runway each evening until 11 June.

A dwarf egg, 16.7 mm wide and 19.5 mm long, was found in a nest with three normal eggs. A maximum of 38 adults and 60 juveniles was counted in the deltas on 29 July and 22 August, respectively, while up to 14 juveniles were regularly feeding at the pond in Tørvekæret during mid and late August.

Eurasian curlew *Numenius arquata*

A curlew was feeding in the fen just north of the station on 7 July. This is only the fifth record in Greenland (Boertmann 1994).

Ruddy turnstone *Arenaria interpres*

Up to 12 turnstones were feeding in the fen area just north of the runway in early June. A post-breeding flock of seven were seen on 24 July, and on the next day four migrated south. A maximum of 2 adults and 29 juveniles were recorded in the deltas on 4 and 29 August, respectively.

Red-necked phalarope *Phalaropus lobatus*

Between 30 May and 24 June, a female red-necked phalarope was seen regularly in the ponds just north and south of the runway. During 11-13 June, two females were present.

Arctic skua *Stercorarius parasiticus*

During the period 8 July to 19 August, 1-3 Arctic skuas were seen six times roaming over Zackenbergdalen. Eleven individuals were light phase birds, and one was dark.

Long-tailed skua *Stercorarius longicaudus*

Long-tailed skuas were present in the census area at our arrival on 27 May, and already on 29 May a total of 25 was recorded. An immature (1-2 y old) was seen on 29 July.

Glaucous gull *Larus hyperboreus*

During the entire summer, a few glaucous gulls were seen almost daily along the river or occasionally hunting lemmings on the tundra. Maximum records were nine in June and six in July, while up to 19 were seen in the deltas in August. Among these were one immature on 27 June, four on 13 August and 10 on 16 August.

A pair nested on a rock in a lake in the south-western part of Morænebakkerne. The nest held three eggs on 2 July, and on 15 July a week-old *pullus* was present on the lake. The first juveniles (three) were seen in the delta on 28 August.

Arctic tern *Sterna paradisaea*

One Arctic tern was observed in the old delta on 29 June.

Snowy owl *Nyctea scandiaca*

A male snowy owl – and at a few occasions even a female – was seen regularly in the upper part of Zackenbergdalen during the entire season. On 16 August, three *pulli* were encountered where Lindemanselven meets Zackenbergelven. Two medium sized young were sitting south of Zackenbergelven, while an almost fully grown young were 'flying' north of the river. The large young was seen a few times more during late August, whereas the two small young hardly survived.

Also on 16 August, a large *pullus* was found at Lerbugt on the north coast of Clavering Ø.

Pied Wagtail *Motacilla alba*

A pied wagtail was seen six times during 10-26 June in the lower part of Zackenbergdalen.

Northern weathear *Oenanthe oenanthe*

Six times between 23 July and 21 August, an adult weathear was seen in the lower part of Zackenbergdalen. On 19 August, three juveniles were recorded at the old trapping station.

Common raven *Corvus corax*

During June, 1-2 ravens were seen regularly in Zackenbergdalen and on the south facing cliff of Zackenbergfjeldet. On 27 June, three juveniles appeared at the old trapping station, and from then on they were seen together with their parents or scattered in the valley during the rest of the season.

Arctic redpoll *Carduelis hornemanni*

Single individuals of Arctic redpolls were recorded 16 times in June and three times in July. On most occasions the birds were passing high over the area, but on a few occasions they were feeding on the ground.

Snow bunting *Plectrophenax nivalis*

The first juvenile was recorded in Morænebakkerne on 15 July. On 30 August, a post-breeding flock of *c.* 100 was seen at the station.

4.4. Mammals

Observations of mammals were made by Thomas B. Berg during 12 July – 2 September, by Hans Meltofte 27 May – 30 July and by Henrik Barner Rasmussen 27 May – 19 August. Additional random observations were made by all other persons at the station and recorded on a sheet placed in the mess. The 2.5 km² census area for collared lemming *Dicrostonyx groenlandicus* was censused for winter nests and active summer burrows. The total number of muskoxen *Ovibos moschatus* was censused once a week within the 39.1 km² census area in Zackenbergdalen and counted daily from a fixed, elevated point at the station. All fresh carcasses of mammals were recorded wherever found throughout the season. The registration of old muskox carcasses was continued. The two line transects Daneborg – Zackenberg and Zackenberg – Store Sødal were walked in mid July and mid August (Daneborg-Zackenberg only in July). One visit on Sandøen was made 27 July. All observations of mammals other than lemmings and muskoxen are included in section 4.4.5.

4.4.1. Winter nests and summer burrows of collared lemming

During snow melt, lemmings were seen daily in the field as well as on the station area. The 2.5 km² census area was searched by transects at 15 m intervals. As in the two previous years, the winter nests were classified into one of the following two categories, I) nests built in the previous winter (1996-1997) and II) older nests. The recorded parameters at each nest were the same as in 1996 (see section 4.4.1 in Meltofte & Thing 1997).

In total, 451 nests were examined. Of these, 342 (*i.e.*, 1.37/ha) were from the previous winter, whereas 109 were of older age (Table 4.4.1.1). The amount of category II nests within the 250 ha census area is continuously decreasing and the census area will most likely be cleared for category II nests in a few years. Compared to last year, the number of summer burrows increased considerably from 80 burrows (0.32/ha) in 1996 to 710 (2.84/ha) this year, an overall increase of 888%. The number of winter nests showed an increase of 212% in the same period. Even though we have not yet followed the lemming population at Zackenberg through a full population cycle, it seems likely that 1997 represented a population peak. This notion is corroborated by a high breeding effort of long-tailed skuas compared to the past two years together with breeding of a pair of snowy owl in the valley (see sections 4.3.4. and 4.3.8). No snowy owl was seen in Zackenbergdalen during the field seasons of 1995 and 1996.

The lemming population in the valley of Karupelv on Traill Ø, about 200 km south of Zackenberg, has shown a cyclic pattern over the past nine years (Sittler 1995 and pers. comm.), and it seems to be out of phase with the population at Zackenberg (Fig. 4.4.1). This figure also indicates a difference in amplitude of the two lemming cycles. The lemming population at Karupelv is favoured by 1.5-2.0 m

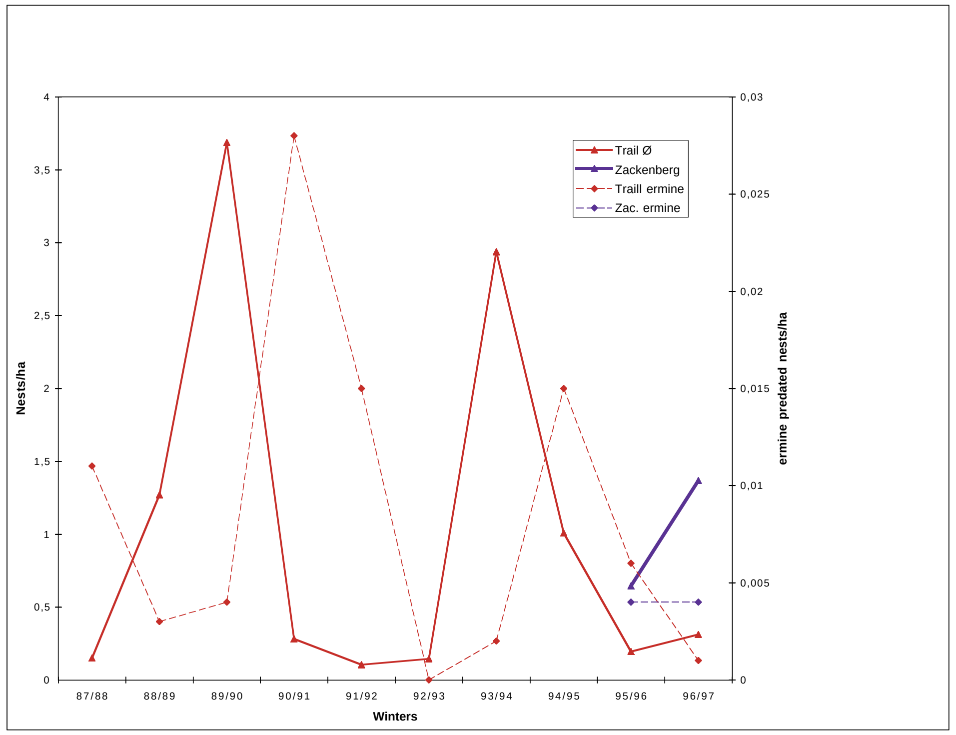


Fig. 4.4.1. Lemming winter nest index and ermine index shown as nest/ha and nest predation/ha, respectively, at Karupelv on Trail Ø and at Zackenberg. Data from Karupelv were kindly provided by Benoît Sittler (in litt.).

thick snow cover, which is three to four times the amount occurring at Zackenberg. This is probably one of the factors affecting the amplitude of the cycles. Lemmings are dependent on a reliable and continuous snow cover throughout the winter.

During the two line transects (Zackenberg – Store Sødal and Daneborg – Zackenberg; see section 4.4.4) fresh lemming winter nests and active summer burrows were recorded (Table 4.4.1.2.). Due to the topography in Store Sødal, it is most likely that the snow cover is more stable and thicker in the lower part of Store Sødal than in the upper part, which the northerly winter storms can keep windblown and dry. The lower part contains more lemming winter nests than the upper part, eight and three, respectively. Compared to 1996, there was an increase in the amount of lemming winter nests from three to eight in lower Store Sødal, indicating the same trend as seen in Zackenbergdalen. This was not the case in upper Store Sødal. Table 4.4.1.2. shows that the coastal plains between Daneborg and Zackenberg are far more important as lemming habitat as compared to the inland habitats.

*Table 4.4.1.1. Annual number of lemming winter nests recorded within the 2.5 km² census area in Zackenbergdalen. * includes nests from the winters of 1993-1995. See the text for further explanation.*

Year	Category I	Category II
1995	279*	830
1996	161	263
1997	342	109

4.4.2. Muskox population biology

An extensive description of the monitoring elements and underlying parameters concerning distribution, phenology and structure of the local muskox population at Zackenberg is described in detail in section 4.4.2 in Meltofte & Thing (1997).

Muskox population dynamics and structure

Distribution and total number, together with size and sex composition of muskox herds within the 39.1 km² muskox census area in Zackenbergdalen were recorded on a weekly basis throughout the field season June-August. In addition, distribution and size of muskox herds were recorded daily from a fixed, elevated point at the station (roof of a hut) between 19.30 and 22.00 hrs. These daily scans were made by a 30x scope and covered the area from Lindemansdalen to Cardiocerasdal (≈ 100 km²). Each observation was given UTM co-ordinates by plotting the observation on a grid map. The daily scans underestimate the number of muskoxen present within the census area due to topography (Fig. 4.4.2.1). Numbers of muskoxen outside the census area (OSCAR) are even more underestimated due to the large distance from the observation point.

In both census procedures, muskoxen were categorised as observations Inside Census Area (ISCAR) and observations Outside Census Area (OSCAR), where OSCAR covers observations in areas both east and west of the census area. Figs 4.4.2.1 and 4.4.2.2 clearly show that the muskox counts within the census area (C-ISCAR) increased dramatically between 3 and 13 July. The same seems to be the case with the C-OSCAR category between 19 and 24 July.

The data in Fig. 4.4.2.3 indicate that the census area and its surroundings may have been used differently at least in 1996. It also appears that the use

Table 4.4.1.2. Records of lemming winter nests and active summer burrows during the transects Zackenberg – Store Sødal (75 km) and Daneborg – Zackenberg (25 km). Recordings are made within 3 m to each side of the track by each of the two persons walking the transect, giving a total length of 150 km and 50 km, respectively.

Section	Winter nests records	Winter nests #/km	Summer burrows records	Summer burrows #/km
Lower Store Sødal				
1996	1	0.007	1	0.007
1997	8	0.053	9	0.060
Upper Store Sødal				
1996	3	0.020	1	0.007
1997	3	0.020	0	0
Daneborg–Zackenberg				
1997	22	0.440	21	0.420

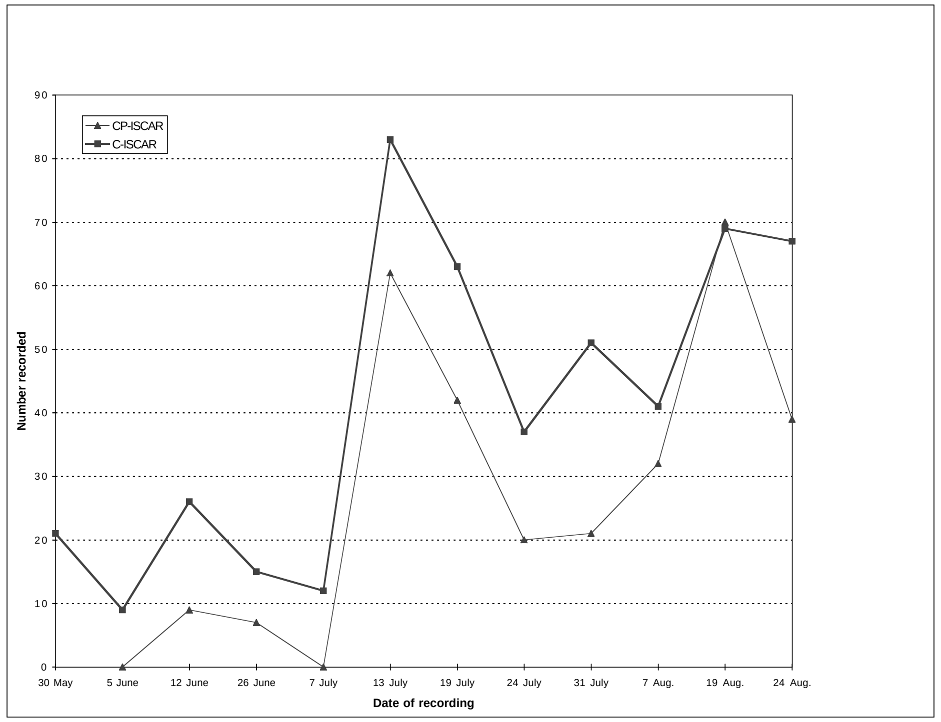


Fig. 4.4.2.1. Total number of muskoxen recorded inside the census area (39.1 km²) from a fixed point at the Zackenberg station (CP-ISCAR) and the weekly census (C-ISCAR) on the same dates.

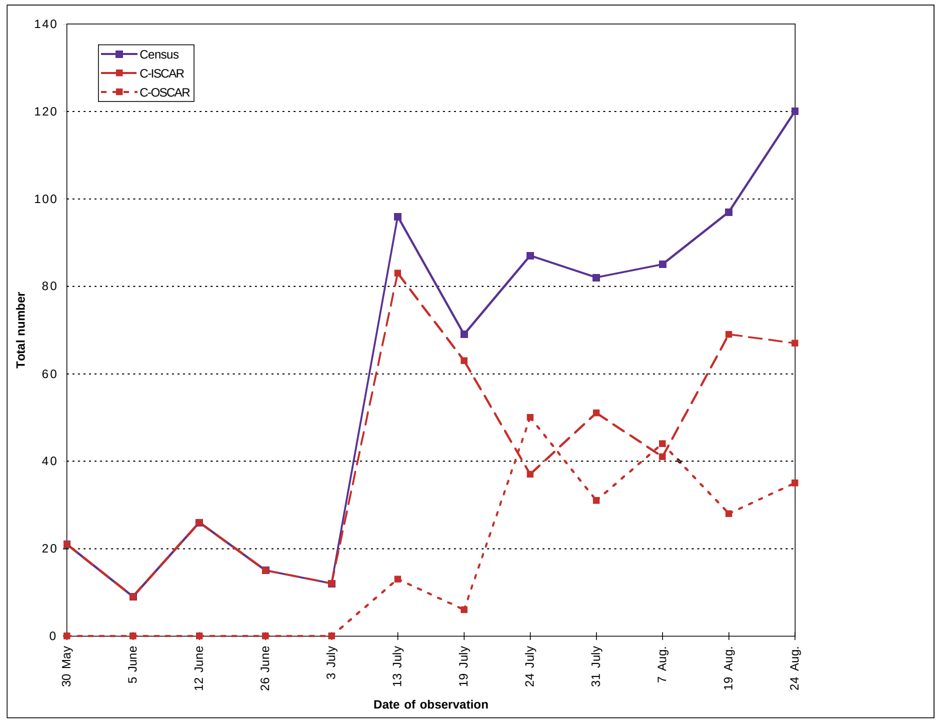


Fig. 4.4.2.2. Number of muskoxen recorded at the weekly censuses. Total number of recorded animals is shown by "Census", recordings inside the census area are shown by "C-ISCAR", and recordings outside the census area are shown by "C-OSCAR".

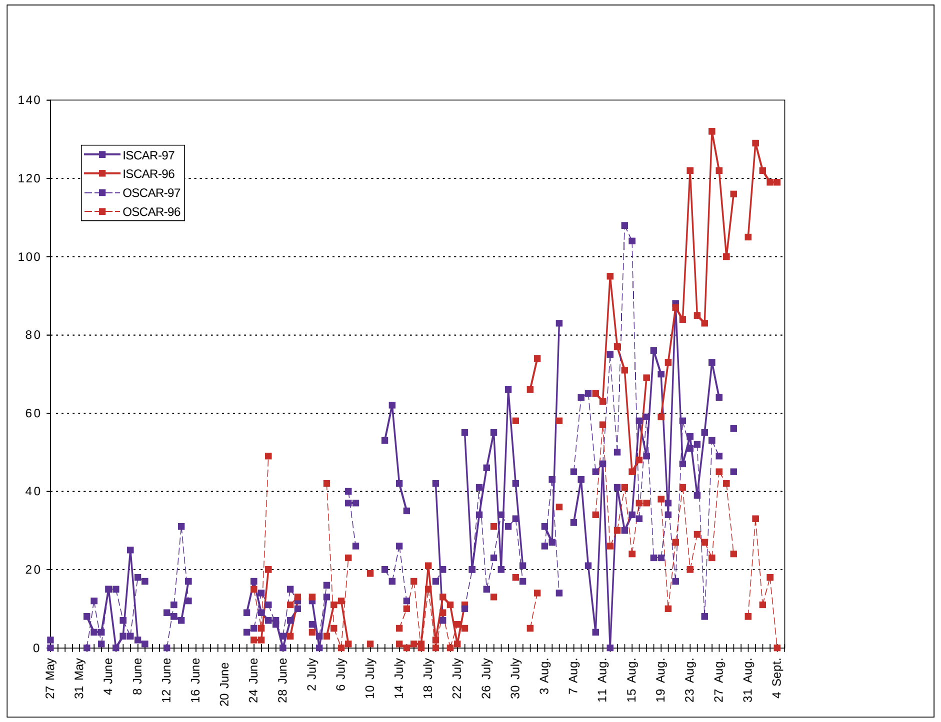


Fig. 4.4.2.3. Daily counts from a fixed point at the Zackenberg station during 1996 and 1997. ISCAR = Inside Census Area, OSCAR = Outside Census Area. Interruptions in the graphs means no observations due to poor weather conditions.

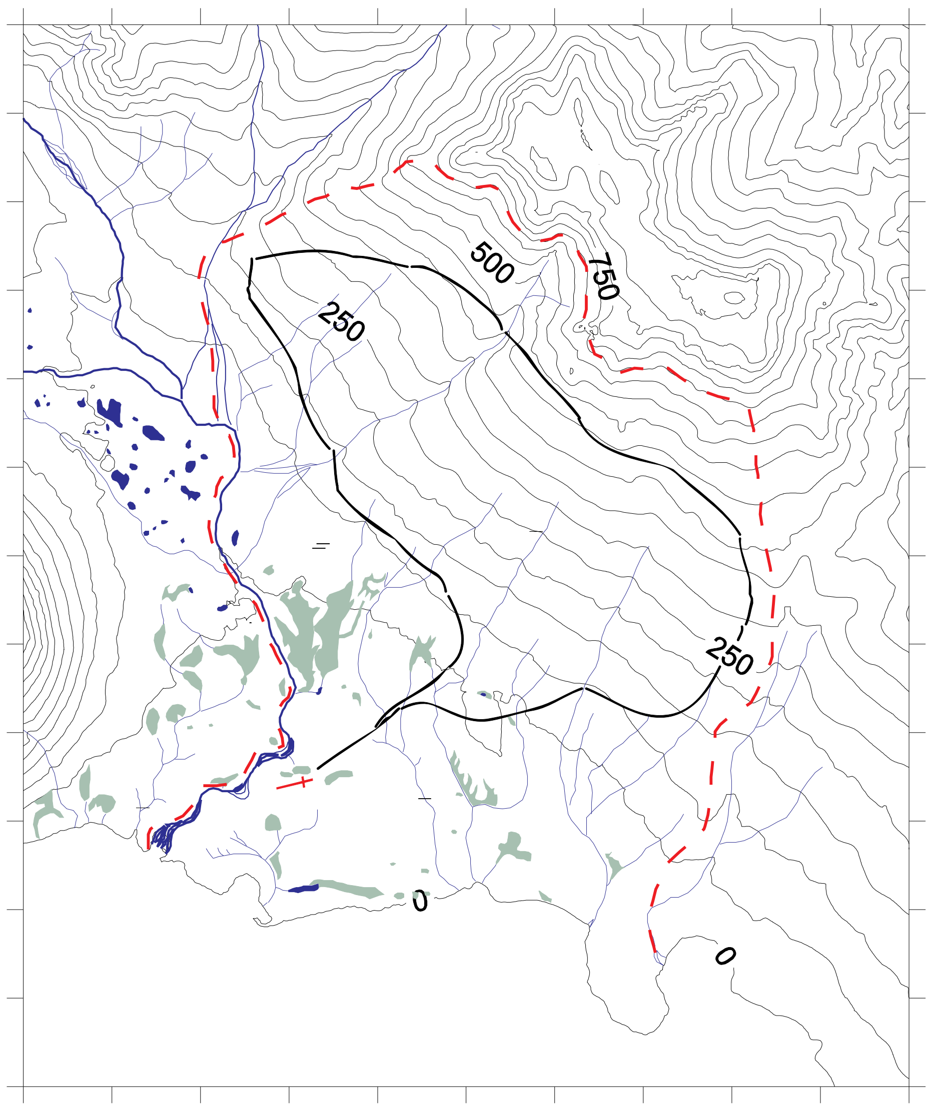


Fig. 4.4.2.4. The muskox census area in Zackenbergdalen, with the location of the point for the daily censuses marked with an asterix.

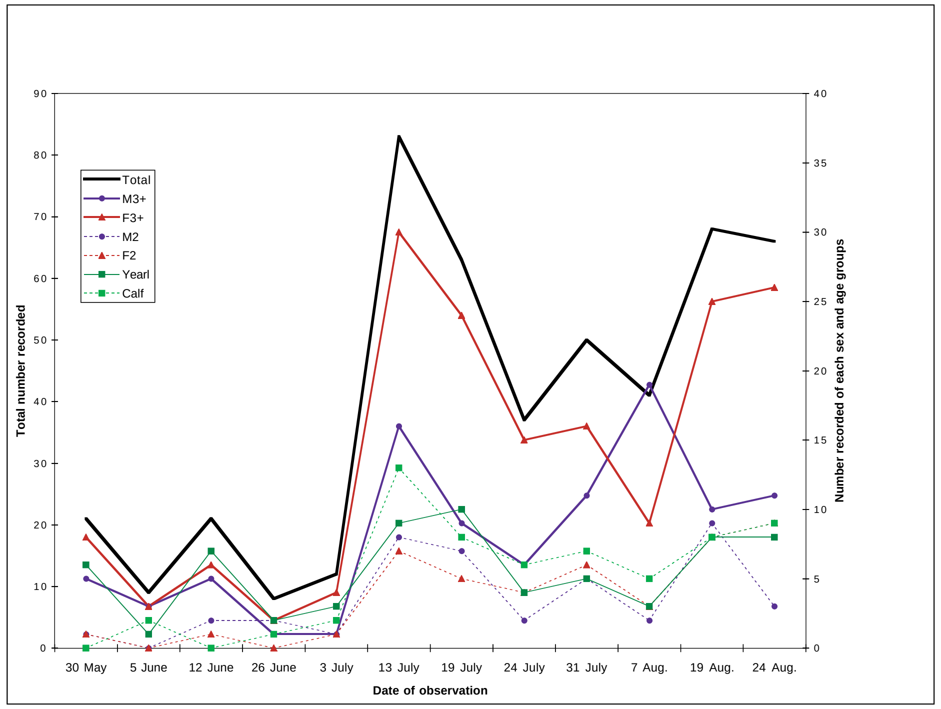


Fig. 4.4.2.5. Sex distribution within age groups of the local muskox population inside the census area in Zackenbergdalen as recorded at weekly censuses. Total = sum of the six underlying graphs, M/F 3+ = males/females ≥ 3 years old, M/F 2 = two years old males/females, Yearl. = one year old males + females, Calf = calves born in 1997.

of the census area may vary from year to year. In 1996, there was a distinctive difference between ISCAR and OSCAR during the rut season from mid August to the end of the field season, while this difference was absent in 1997. There may be several reasons for this, but the increased human activity in 1997 in Rylekærene, an important rutting habitat located centrally in the census area (Fig. 4.4.2.4) may be an explanation.

The composition of the local muskox population varied during the field season as shown in Fig. 4.4.2.5. Immigration of adult females without offspring from previous years as well as immigration of adult males are the main reason for the increase in population size from June to July/August.

Data on flock structure from the weekly censuses were used to calculate the age and sex ratios of the local muskox population (Table 4.4.2.1). The ratio of calves was 13% as compared to 18% in 1996. As discussed by Berg & Forchhammer (section 4.4.2.1 in Meltofte & Thing 1997) the local muskox population in Zackenbergdalen is highly influenced by density independent factors as well as migration

Table 4.4.2.1. Sex and age distribution (%) of the local muskox population in Zackenbergdalen as it appeared from all weekly censuses June-August 1996 and 1997, respectively. Sex of calves could not be accessed in the field but is assumed to be a 1:1 ratio.

Cohort	% males 1996	% females 1996	% males 1997	% females 1997
Calf	9	9	6.5	6.5
1 year	12	12	8	6
2 years	8	2	9	9
3+ year	16	32	20	35

in and out of the area. Keeping this in mind, the 1996 cohort decreased from 18% of the local population in 1996 to 14% in 1997, which gives the same survival rate (0.78) of the 1996 cohort as observed for the 1995 cohort between 1995 and 1996. This cohort decreased from 29% to 22% of the local population between the two years (survival rate = 0.78).

Distribution and social environment of muskoxen

If data from Zackenbergdalen are compared to the results from the two line transects (through the adjacent valley Store Sødal and along the coast between Daneborg and Zackenberg; see section 4.4) it appears, that Zackenbergdalen is used more intensively during the rut season than the two adjacent areas (Zackenbergdalen vs. Store Sødal: *d.f.* = 3; $\chi^2 = 94{,}09$; $p < 0.001$ and Zackenberg vs Daneborg-Zackenberg: *d.f.* = 1; $\chi^2 = 33.417$; $p < 0.001$).

The faecal pile index from Store Sødal and Daneborg-Zackenberg, respectively, shows a clear difference in winter use between the two areas (Table 4.4.2.2). The low lying and highly productive meadows along the coast between Daneborg and Zackenberg are probably an important area for winter foraging, even though the snow depth may be higher here than in the more arid and less productive inland areas of upper Store Sødal.

From June through August there is a shift in altitudinal use of habitats (Fig 4.4.2.6). This change reflects changes in plant growth and snow patterns on the slopes of Aucellabjerg, but may be influenced as well by human activity in Rylekærene. Habitats up to 100 m a.s.l. are the most frequently used (25-61%), but habitats at 201-300 m a.s.l. were also used intensively throughout the field season (26-30%). Altitudes above 300 m were used less in June but more in August 1997 as compared with 1996 (see

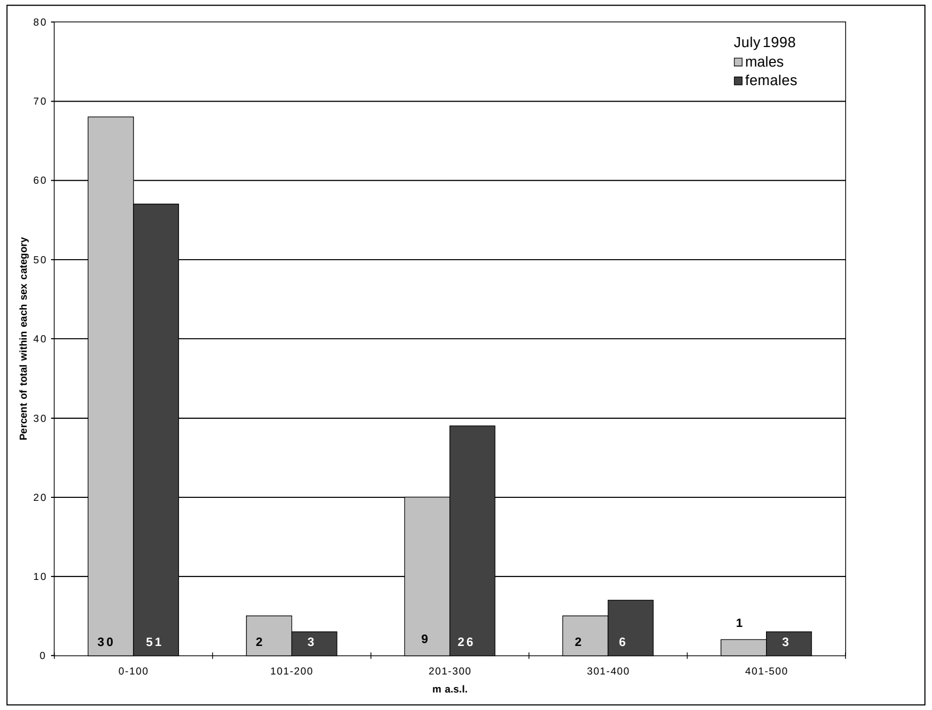


Fig. 4.4.2.6. Altitudinal distribution (%) of adult male and female muskoxen inside the census area June-August 1997. Recorded numbers from the weekly censuses are shown in the base of each block.

section 4.4.2.2 in Meltofte & Thing 1997). Compared with 1996, muskoxen were more often seen at higher altitudes (500-700 m a.s.l.) in August 1997; often concentrated at sites with salt excretion from the soil, even though such sites are also present at lower altitudes. This supports the hypothesis that muskoxen were under anthropogenic influence in Zackenbergdalen in 1997.

The only significant difference between months in use of altitude within each sexgroup, was found among females in June and August (two-tailed *t*-test, *d.f.* = 4, $p = 0.0482$; see Fig. 4.4.2.6). There was no significant difference between sexes (two-tailed *t*-test, *d.f.* = 4, June: $p = 0.7174$; July: $p = 0.0965$; August: $p = 0.3914$). The remarkable difference in August may indicate that females were more affected by human activity in Rylekærene than males.

Table 4.4.2.2. Seasonal changes in muskox densities (#/km²) in Store Sødal (91.8 km²), the census area in Zackenbergdalen (39.1 km²) and the coastal region between Daneborg and Zackenbergdalen (37.4 km²) in 1996 and 1997, respectively. (The Daneborg-Zackenberg area was not censused in mid July 1996 and in mid August 1997.) Density values for Zackenbergdalen are calculated on the basis of total censuses in the census area during the given period. Faeces index was calculated as number of winter and summer piles recorded per km walked (i.e. Store Sødal: #/75 km x 2 and Daneborg-Zackenberg: #/25 km x 2). Store Sødal was walked twice (i.e. July and August), and here the highest number of faecal piles within each transect segment is used.

Period	Store Sødal	Zacken-bergdalen	Daneborg–Zackenberg
12–15 July 1996	0.37	0.35	–
16–19 Aug. 1996	0.13	3.30	0.48
16–21 July 1997	0.39	1.61	0.13
16–18 Aug. 1997	0.19	1.76	–
Winter piles 1997	1.59	–	4.90
Summer piles 1997	0.49	–	0.82

Fig. 4.4.2.7. Carcass ID #97-09, located on the northern slope of upper Store Sødal. Photo: Thomas B. Berg.

Table 4.4.2.3. Fresh muskox carcasses found in 1997. Age is estimated by horn development and tooth wear. Exact age will be determined by analysis of dental cementum layers. Bone marrow is analysed by cross sectioning of the femur.

ID#	Sex	Estim. age (yrs)	Year of death	Bone marrow
97–09*	unknown	calf	1996/1997	present
97–25*	female	1	1996/1997	present
97–29a*	female	2	1996/1997	present
97–32	male	16+	1996/1997	present
97–35	male	10–12	1996/1997	present

* killed by wolf

Fresh muskox carcasses

A total of five fresh carcasses of muskoxen was found (Table 4.4.2.3), all of them outside the census area. This is a remarkable difference from the 13 fresh carcasses found inside the census area in 1996. Three carcasses (ID #97-09, 97-25 and 97-29a) were clearly wolf kills as indicated by throat bite and chewed ribs, whereas ID #97-32 could have died from age. ID 97-09 had been killed within a few hours prior to being found as suggested by the softness of the carcass and the fresh wounds (Fig. 4.4.2.7).

4.4.3. Arctic fox dens

In 1997 there was no breeding at the five known fox dens in Zackenbergdalen, which does seem strange in relation to the abundance of lemmings (see section 4.4.1). Tracks of foxes were seen in June and July at den #1. Den #2 had fresh smell of fox on 29 May but not until 13 August was fresh excavation at one entrance recorded. Den #5 was visited by a wolf prior to 30 May, but no fresh excavations at the entrances was seen until 31 July, when eight active entrances were recorded (Table 4.4.3). Despite this fox activity at den #5, a juvenile lemming was seen at the entrance, indicating that the den was used for breeding by lemmings. One week later there were no signs of activity at all at the den.

4.4.4. Line transects

All transects were walked by Thomas B. Berg and Henrik B. Rasmussen. The transect through Store Sødal was walked 16-18 July and 16-18 August, respectively, and the transect from Daneborg to Zackenberg was walked on 21 July (see map, Fig. 4.4.4 in Meltofte & Thing 1997). For bird observations, see section 4.3.6.

Except for a single adult Arctic hare observed in upper Morænebakkerne the only mammals recorded during the transects were muskoxen. It appears from Table 4.4.4.1, that the number of muskoxen recorded in Store Sødal decreased from July to August. The number of observed winter and summer muskox faeces piles varied a little between the two transects. A total amount of 280 winter piles and 112 summer piles in Store Sødal (Table 4.4.4.1) together with 245 winter and 41 summer piles along the Daneborg-Zackenberg transect was recorded (Table 4.4.4.2). These data may indicate that the coastal area is preferred as compared to the inland. The relatively low number of faecal piles in lower Store Sødal indicates that these parts of Store Sødal are used mainly as migration routes for muskoxen during their migrations between Zackenbergdalen and upper Store Sødal. There is no indication as to whether the north or the south side of lower Store Sødal is preferred as migration route. The number of winter faecal piles exceeds by four times the number of summer piles in upper Store Sødal. If the difference indicates that upper Store Sødal is a more important winter than summer feeding site this can be explained by more stable winter conditions here with relative thin snow cover (as indicated by the dominating xeric habitats) providing access to the sparse vegetation.

Table 4.4.3. Activities recorded at the five known fox dens in Zackenbergdalen in 1997.

Den #	# entrances	# active entrances	Other activity
1	50	0	tracks
2	50	1	tracks, smell
3	22	0	none
4	30	0	none
5	11	8	smell, lemming

4.4.5. Other observations

Arctic hare *Lepus arcticus*

Three Arctic hares were seen 300 m a.s.l. on the east slope of the Zackenberg mountain on 1 June, and single individuals were seen twice in Morænebakkerne (July and August). East of Zackenbergelven, four individuals were seen east of Ulvehøj in May and three were seen on the top of Aucellabjerg in August.

Collared lemming *Dicrostonyx groenlandicus*

Lemmings were seen regularly in the terrain throughout the summer, in total 12 adults, two juveniles and two dead ones (adult and juvenile) were encountered. Single individuals were seen regularly among the buildings as well as at Zackenberg trapping station.

Table 4.4.4.1. Observations of mammals etc. from the 75 km line transect through Store Sødal in July and August, respectively. The number of faecal piles is recorded by two persons, giving a transect length of 50 km per transect segment (lower St. Sødal north and south side and upper Store Sødal, respectively). M = male, F = female, 3+ = 3 years or more. Observations are made by the naked eye and verified by 10x binoculars. Each pile of faeces within 1 meter to each side of the track was recorded.

Section		16–18 July	16–18 August	Total 1997
Lower St. Sødal north side				
Muskox	M3++	1	0	1
	F3+	4	0	4
	M2	3	0	3
	F2	2	0	2
	calf	1	0	1
	unspecified		17	17
	winter piles	4	19	23
	summer piles	4	25	29
Arctic wolf		0	track	0
Lemming	winter nests	0	5	5
	active summer burrows	0	5	5
Bumblebee		5	1	6
Upper Store Sødal				
Muskox	M3+	3	2	5
	F3+	11	0	11
	M2	3	0	3
	F2	3	0	3
	M1	2	0	2
	F1	2	0	2
	calf	2	0	2
	carcass, killed by wolf	2	0	2
	winter piles	185	119	204
	summer piles	35	32	67
Arctic wolf		0	track	0
Arctic fox	fur	1	0	0
Lemming	winter nests	2	1	3
	active summer burrows	0	0	0
Bumblebee		4	0	4
Lower St. Sødal south side				
Muskox	winter piles	45	8	53
	summer piles	13	3	16
Arctic wolf		0	track	0
Arctic fox		0	tracks	0
Arctic hare		track	1	1
Lemming	winter nests		3	3
	active summer burrows		4	4
Bumblebee		3	1	4

Arctic wolf *Canis lupus*

A pack of two wolves was seen on 28 May on the fjord ice at the entrance of Tyrolerfjord and again on 4 June immediately south of the airstrip. Tracks in the snow were seen in Zackenbergdalen in late May as well as in mud in July. A fresh wolf kill of a musk-ox calf was found in upper Store Sødal on 17 July as well as a fresh track in mud at another site in Store Sødal (see sections 4.4.2 and 4.4.4).

Arctic fox *Alopex lagopus*

Although apparently no foxes were breeding in Zackenbergdalen (see section 4.4.3), the station was visited by a juvenile white phase fox in August, indicating that breeding took place in areas adjacent to the valley. Besides this juvenile fox, the station was visited four times by a dark phase and four times by a white phase fox in August. Tracks were seen near the station during June and July.

It was possible to distinguish only two different individuals among the white phase foxes, giving a total record of a minimum of four different individuals, *i.e.* two white adults (one of them a male, the sex of the other unknown), one white juvenile male and one blue adult female.

The white male was seen at Ulvehøj. It behaved trustfully at a close distance, spending much time scratching its fur. It paid a short visit to an old musk-ox skull, chewed on the horn and then defecated on the top of the skull. The white juvenile male was found dead on 16 August south of the airstrip, probably killed by a neck bite. The dark phase female

Table 4.4.4.2. Observations of mammals etc. on the 25 km line transect from Daneborg to Zackenberg on 21 July. M = male, F = female, 3+ = 3 years or more. The number of faecal piles is recorded by two persons, giving a total transect length of 50 km.

Species	Number
Muskox	
M3+	1
F3+	7
M2	6
F2	4
M1	1
F1	0
unspecified yearlings	2
calfs	4
unspecified	4
winter piles	245
summer piles	41
Lemming	
winter nests	22
active summer burrows	21
Bumblebee	5

was found dead 200 meter north of the station on 27 August (probably killed by ravens). Both killed foxes were autopsied and found starved with no body fat, and poorly digested plant material in the stomach.

On 16 August, a white phase fox was seen chasing a juvenile snowy owl. Shortly afterwards the female snowy owl came and chased the fox away.

Additionally, four fresh, white phase fox carcasses in winter fur were found. Two were found on the slopes of Aucellabjerg (280 m and 400 m a.s.l., respectively), one in Rylekærene and one southeast of Ulvehøj.

Ermine *Mustela erminea*

One individual was recorded on 8 June west of the old Zackenberg trapping station, 40 m a.s.l. A lemming summer burrow dugged out by an ermine was found in Kærdal (see also section 4.4.1).

Walrus *Odobenus rosmarus*

One visit was made to the walrus haul-out site on Sandøen by Thomas B. Berg, Henrik B. Rasmussen and Henrik Lassen on 27 July. 17 individuals were found sleeping on the beach at the south end of the island, at the same place as last year. Additionally, two individuals were seen in the coastal waters. The research team working at Daneborg did not see more than a maximum of 20 individuals at any time during the field season. 19 individuals were photographed for future recognition (see also section 5.2.6).

Seals Phocidae

From 29 May until the sea ice broke up in mid July, the abundance of seals visible on the fjord ice in Young Sund was recorded every evening between 21.00 and 21.30. A total of 213 seals were recorded on 26 days giving an average of 8.2, and with a range of 1-21. This is identical to the situation found in 1996. During 8-14 June numbers peaked with a daily average of 13.2 (range 8-21). Only two observations were made after 13 July, both of single individuals seen from the old Zackenberg trapping station.

Narwhal *Monodon monoceros*

Narwhals are migrating northward along the east coast of Greenland during summer and may penetrate into the fjord systems. On 11 August, a flock of 30-40 individuals was seen in Tyrolerfjord from a Twin Otter during a flight to Zackenberg. Two days later a flock of 50-100 individuals was recorded from a Zodiac in the vicinity of Daneborg by the research team there.

5. Research projects

5.1. The Arctic Landscape: Interactions and feedbacks among physical geographical and biological processes

The following reports from researchers affiliated with Institute of Geography and Institute of Botany, Department of Plant Ecology, University of Copenhagen, form an overview of activities at Zackenberg under the auspices of an interdisciplinary project co-ordinated by Professor Sven Jonasson and funded primarily under the Danish Research Councils' Polar Programme (1995-1997) and also with the Faculty of Sciences, University of Copenhagen, and the EU's Environment and Climate Programme as sponsors.

5.1.1. Trace gas exchange from plot to landscape scale

Torben R. Christensen, Martin Sommerkorn, Jed Kaplan, Lotte Illeris, Thomas Friborg Jacobsen, Henrik Søgaard, Claus Nordstrøm, Birger U. Hansen & Sven Jonasson

An integrated study investigating the seasonal dynamics of CO_2 and CH_4 fluxes in contrasting High

Arctic ecosystem types was carried out in 1997 in Zackenbergdalen. Both chamber and micrometeorological techniques were used.

Chamber measurements

Chamber measurements of net CO_2 exchange, respiration, photosynthesis and net CH_4 exchange were carried out at 30 permanent stations in the fetch area for eddy correlation measurements (see below). A portable Li-Cor 6200 transparent chamber system was used for the measurements of CO_2 flux and dark aluminium chambers were used for measuring CH_4 fluxes. Syringe samples were taken in the field and analysed for CH_4 on a gas chromatograph equipped with a flame ionisation detector at Zackenberg Research Station. Daytime measurements took place at all stations approximately every fourth day between 25 June and 27 August. In addition, a number of diurnal campaigns measuring fluxes every third hour were carried out at selected stations. Along with the flux measurements, soil temperature at four depths, water table position, thaw depth and snow depth (when applicable) were monitored at all stations. The above ground biomass in all chambers was harvested on 27-28 August, quantified and grouped by vegetation type. Furthermore, the vegetation composition was mapped in a 270 x 360 m^2 intensive study area encompassing the main 'fetch area' for the eddy correlation tower (see below) and all chamber stations (Fig. 5.1.1.1). The vegetation was divided into the categories *Cassiope* heath, grassland, continuous fen, hummocky fen and *Salix arctica* snow bed, *i.e.* vegetation groups compatible with the larger scale vegetation mapping effort carried out by Christian Bay but here with a higher resolution of 10 x 10 m^2.

The chamber data are being processed and preliminary results indicate the following (Christensen *et al.*, *in prep*.):

- Methane fluxes varied from uptake rates of up to 0.1 mg $CH_4/m^2/hr$ at the *Cassiope* heath to high emission rates in the central fen of 34 ± 19 mg $CH_4/m^2/hr$ both observed during the peak season in August. Net daytime ecosystem exchange of CO_2 (NEE), *i.e.* the flux of carbon in or out of the system, varied from 23 ± 33 mg $CO_2/m^2/hr$ at the *Cassiope* heath to significantly higher accumulation rates of 189 ± 36 mg $CO_2/m^2/hr$ in the central fen.
- Integrated fluxes based on the spatial coverage of the individual vegetation units (Fig. 5.1.1.1), and the measured mean fluxes for those, yielded (Fig. 5.1.1.2) an overall mean daytime CH_4 emission rate for the intensive study area of 6.6 ± 2.6 mg $CH_4/m^2/hr$; a daytime net CO_2 exchange rate (NEE) of 151.8 ± 42 mg $CO_2/m^2/hr$; a mean respiratory loss of carbon at rates averaging 272 ± 42 mg $CO_2/m^2/hr$ and hence estimated mean photosynthesis rates of 424 ± 64 mg $CO_2/m^2/hr$ over this part of the valley.
- The preliminary analyses of controls on temporal and spatial variations in CH_4 efflux rates indicate a strong linkage between mean net ecosystem production and CH_4 flux rates. A linear regression analysis of net CO_2 exchange versus CH_4 fluxes in the central fen area reveals a strongly significant relationship ($N = 16$, $r^2 = 0.73$, $p < 0.01$) and the highest explained variance in CH_4 efflux of any of the measured biotic and abiotic environmental parameters.

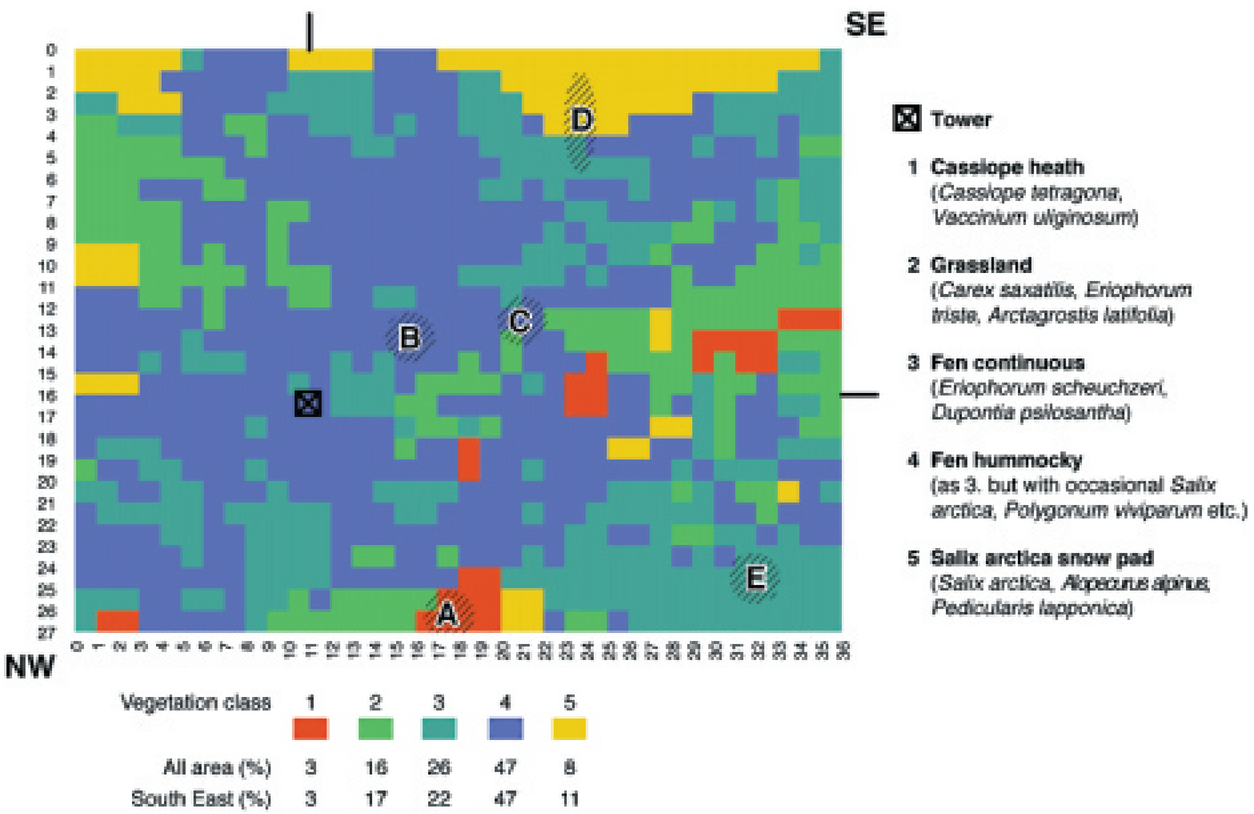


Fig. 5.1.1.1. Distribution of dominant vegetation types in the intensive study area of the central part of Rylekæret. Numbers along axes refer to 10 m pixels i.e. *the area covered is 360 x 270 m^2. Relative area coverage (%) of different vegetation types in the whole area and in the prevailing upwind direction (south-east) from the tower used for micrometeorological measurements is given. Hatched areas with letters A-E indicate zones where chamber measurements were carried out with six permanent bases in each zone.*

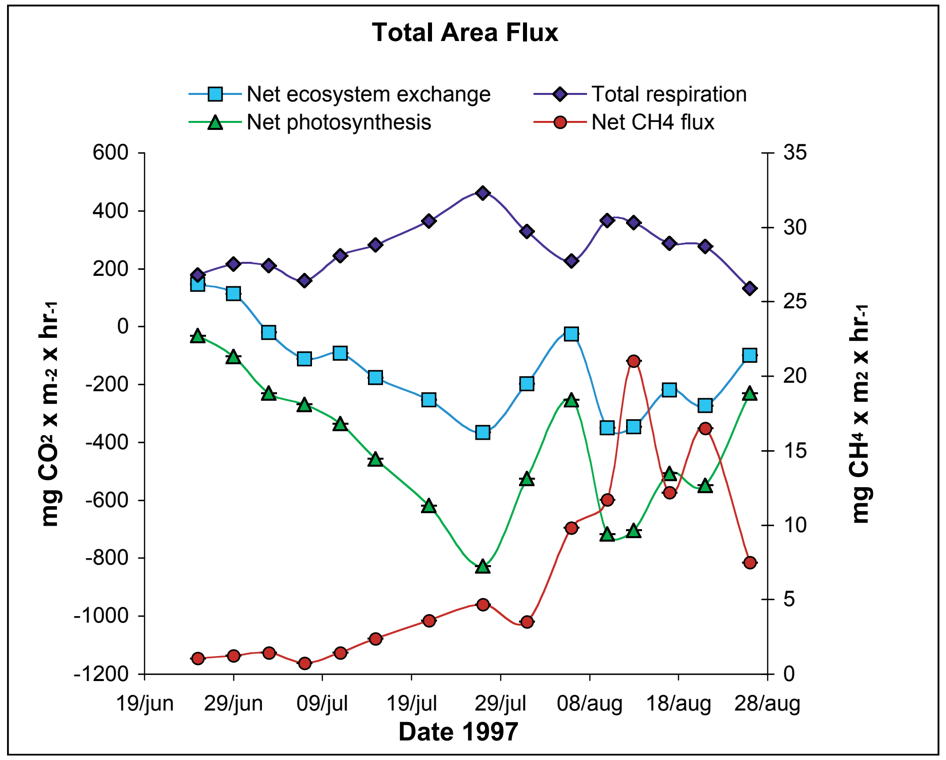


Fig. 5.1.1.2. Integrated mean chamber fluxes of CO_2 and CH_4 through the season for the intensive study area as calculated on the basis of mean fluxes and relative area coverage of the different vegetation types given in Fig. 5.1.1.1.

Micrometeorological measurements

Two experimental sites were established in Zackenbergdalen in order to measure CH_4 and CO_2 exchange from the two dominating ecosystem types in the area. A 'wet site' (UTM zone 27: 513200 m E, 8266200 m N, zone 27) was established within an extensive fen area, Rylekærene, of which most parts were water covered throughout the summer. The 'dry' heath site (513450 m E, 8264950 m N) was elevated by approximately two metres relative to the wet site and was more dry throughout the campaign, with water table below soil surface. Both sites were fully snow covered until the middle of June.

Two identical eddy correlation systems were used at the two sites for flux measurements of CO_2, water vapour, heat and momentum. Measurements of CO_2 and water vapour concentration were done with a Li-6262 (LiCOR, USA) infra red gas analyser. A sonic anemometer (Gill Solent, UK) was mounted at a height of 2.7 m for measurements of vertical and horizontal wind components. A third system with a measuring height of 16 m was operated during three weeks in July (513400 m E, 8266250 m N), as a spatial integration study of the area (data not shown). In addition to this equipment, a tuneable diode laser, TDL, (Aerodyne Inc., USA) was applied for fluctuation measurements of CH_4. CH_4 concentrations were obtained from the 3017.4 cm absorption line at a frequency of 20 Hz. Fluxes of CO_2, water vapour and heat were measured continuously throughout the campaign, along with standard meteorological parameters of *e.g.* soil and air temperatures, soil moisture and radiation. CH_4 fluxes were obtained from the wet site for approximately 40 days. Incoming photosynthetic active radiation was measured using PAR sensors (LiCOR, USA), and soil and air temperatures were measured using thermocouples and resistance thermometers respectively.

Three examples on the obtained fluxes of CH_4 and CO_2 from the summer of 1997 are presented. The selected days represent typical values of CH_4 and CO_2 exchange from the three different periods.

In the first two weeks of the experiment the snow cover was 0.5 to 2 m thick, and fluxes remained small as exemplified in the figures from 4 June (Fig. 5.1.1.3). No distinct diurnal pattern was found in the fluxes, which corresponds well with the fact that the soil layer was frozen and air temperatures were only a few degrees above zero during day-time, leading to slow thawing of the snow. When melt water from the mountains broke through to

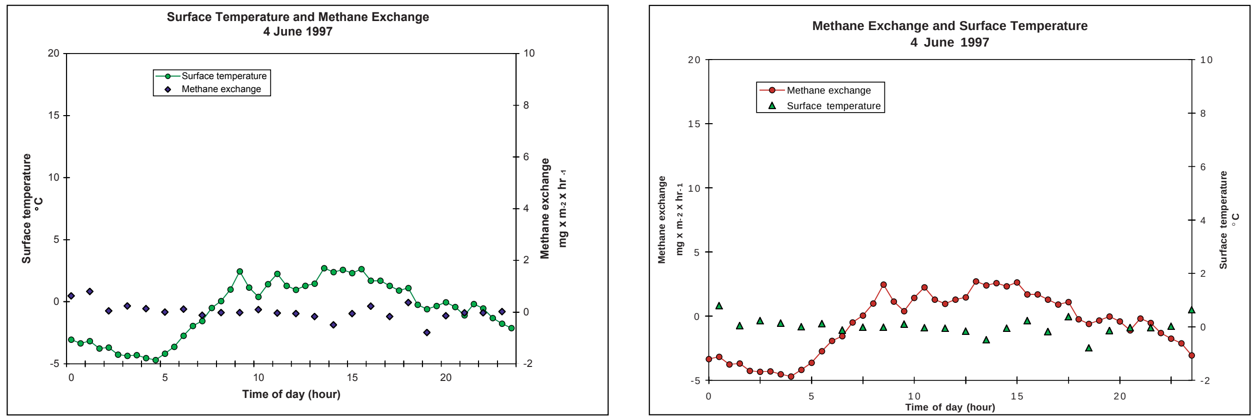


Fig. 5.1.1.3. Methane exchange for 4 June displayed with surface temperatures (left) and carbon dioxide exchange for the same day from both sites displayed with Photosynthetic Active Radiation (right).

the valley bottom on 17 June, the snow melted fast and only patches of snow were left on 1 July. During the last two weeks of June a rapid increase could be measured in the emission of CO_2. The high CO_2 emission during this period can be associated with release of CO_2 from the melting snow, in combination with increased soil respiration and no photosynthetic active vegetation.

The highest exchange rates of CH_4 and CO_2 during the experiment were found around 1 August, reflecting the influence of sunny weather with daytime air temperatures around 10°C. Integrated daily methane emission reached values of 80-100 mg/m^{-2}, which was the highest found during the campaign. A diurnal variation is found in the methane emission with maximum values during afternoon (Fig. 5.1.1.4), indicating the relation to soil temperatures and friction velocity. The relatively low values from 15.00 to 18.00 hrs can be associated with a small change in wind direction during this part of the afternoon.

Carbon dioxide fluxes from 30 July show a net uptake for both sites. Fluxes for the wet site, however, were considerably higher than found for the dry site, reflecting a higher leaf area index on the wet site. During the period with net diurnal uptake of CO_2, diurnal rates were approximately three times the rates found on the dry site. At both sites a net uptake can be observed during hours of daylight indicating photosynthesis dominating over soil/plant respiration. At the wet site, highest uptake rates are found during morning. This can be explained by high radiation rates. During afternoon, uptake generally decreases, reflecting the increased respiration influence on the net flux, with increased soil temperatures.

As the short High Arctic summer turned into autumn, both CH_4 emission and CO_2 uptake declined from mid-August to the end of the campaign. Methane emission still showed a diurnal variation with highest fluxes during early afternoon, but values were considerably smaller than found in the first part of August (Fig. 5.1.1.5). This decline can be associated with lower soil temperatures in combination with a decrease in water table level in the last part of August. Integrated daily fluxes around 20 August showed an emission of 30 mg/m^2. Also in the CO_2 fluxes, decreasing values are apparent for both sites as a result of senescence of the vegetation. The first snowfall in the valley was on 31 August.

Emission of methane showed a clear seasonal variation controlled by soil temperatures and water table level. Carbon dioxide exchange also had a seasonal variation at both sites, together with a clear

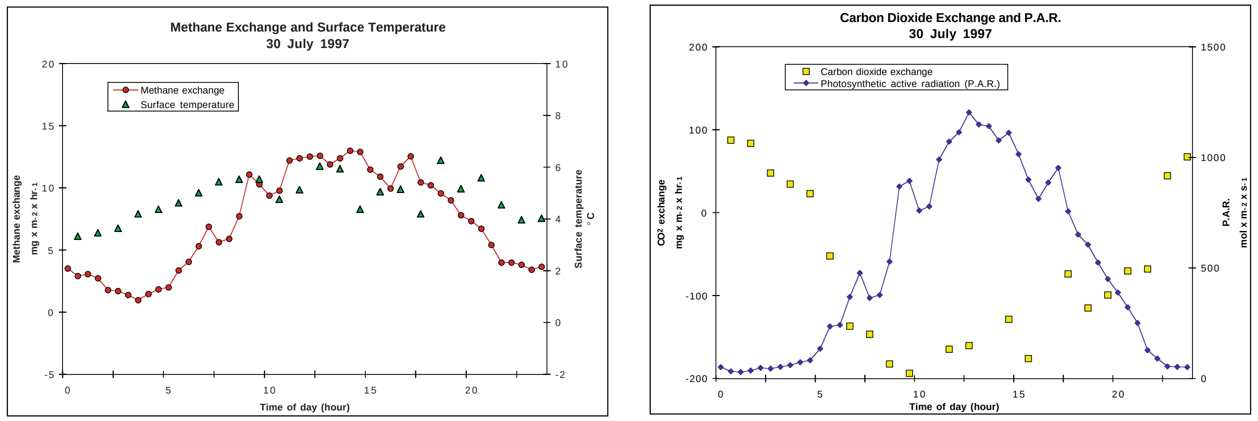


Fig. 5.1.1.4. Methane exchange for 30 July displayed with soil temperatures (left) and carbon dioxide exchange for the same day from both sites displayed with Photosynthetic Active Radiation (right).

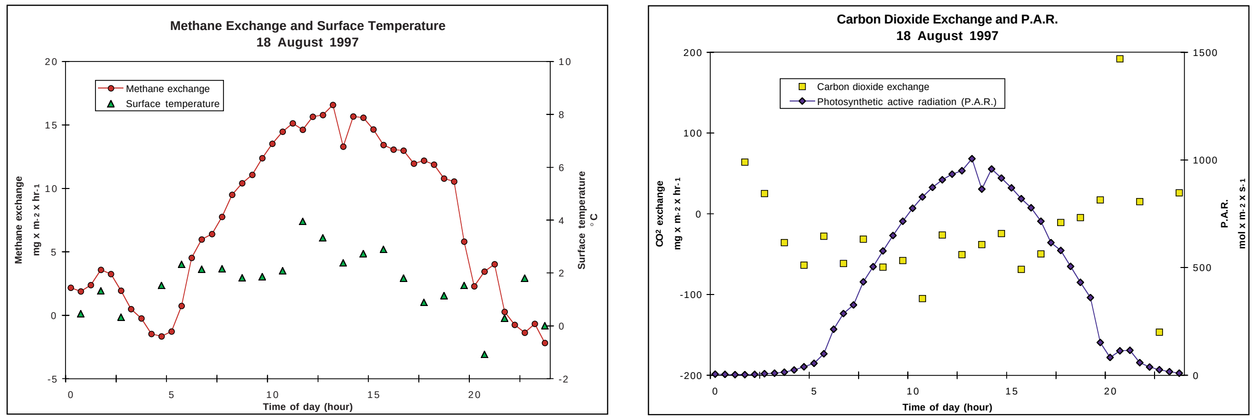


Fig. 5.1.1.5. Methane exchange for 18 August displayed with soil temperatures (left) and carbon dioxide exchange for the same day from both sites displayed with Photosynthetic Active Radiation (right).

difference between the two sites. During the campaign, the fen was a sink of CO_2, whereas the heath site showed balance between uptake and emission.

5.1.2. Controls on soil respiration in tundra peatlands

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

A full factorial experiment adding nutrients to a drained fen, Tørvekæret, was conducted in 1996 (see section 5.1.4.1 in Meltofte & Thing 1997). The purpose of this study was to identify the limiting factors for soil respiration *i.e.* the return of the stored peat carbon as CO_2 to the atmosphere. Results from the fertilisation showed, somewhat surprisingly, no response of soil respiration to inorganic nutrient additions (Christensen *et al.* in press). Combined with results from linked investigations of controls on actual and potential soil respiration rates in Siberian tundra soils this indicated a limitation of soil respiration induced by the lability of the remaining organic material. To test this hypothesis we conducted an additional experiment in Tørvekæret in 1997 adding a labile carbon source (glucose) to the system and monitoring the CO_2 evolution rates by a closed chamber technique. CO_2 was in this experiment analysed from syringe samples on a gas chromatograph equipped with a thermal conductivity detector situated at Zackenberg Research Station. Glucose was added to six plots on 8 August 1997 (250 g/m^2 = 62.5 g/plot). Soil inorganic and microbial nutrients were extracted from soil plugs from control and treatment plots on days 0, 1, 3 and 5 after the start of the experiment. These extracts have not been analysed yet. However, preliminary results from the measurements of CO_2 efflux show a highly significant increase in CO_2 evolution following the glucose addition (Fig. 5.1.2). We may therefore conclude that the lability of the soil organic matter imposes an important constraint on the potential CO_2 release following possible warmer and drier climatic conditions in tundra peatlands. Although the soils

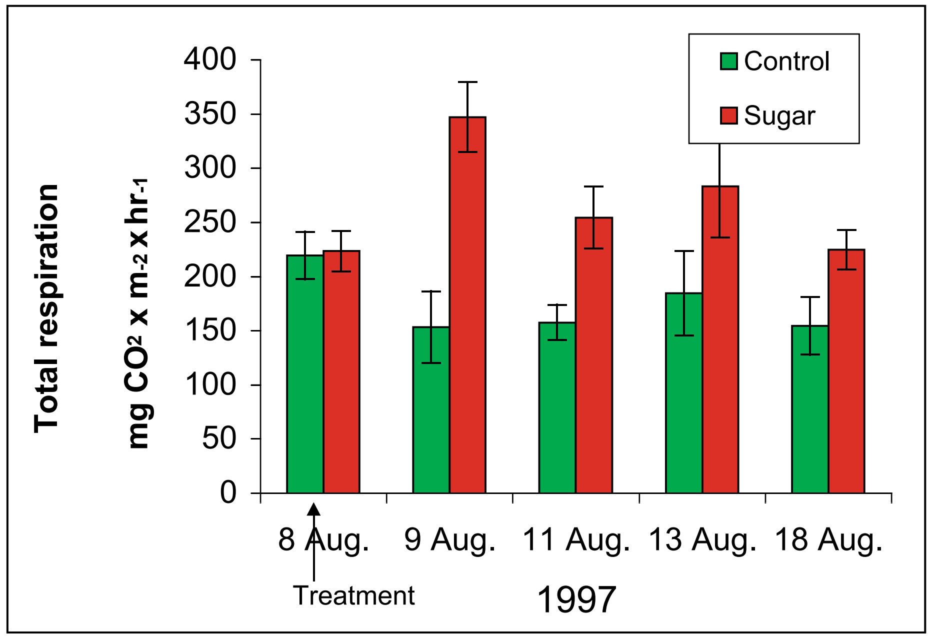


Fig. 5.1.2. Measurements of CO_2 efflux at the experimental drained fen site following the 1997 glucose treatment.

have an organic content of more than 95%, soil respiration may paradoxically be considered as carbon limited.

5.1.3. Soil solution and acidification of Arctic brown soils

Bo Elberling & Bjarne Holm Jakobsen

Soil-forming processes and the dynamics of soil systems have traditionally been evaluated based on the analysis of the solid phase. More recently, interpretation of the soil water chemistry has become important, as several studies have shown that the solution charge balances reflect the present pedogenic processes in response to current environmental conditions (Ugolini *et al.* 1990). Soil-forming processes include both weathering and transport processes which are important for the terrestrial feedbacks from changes in environmental conditions. In the High Arctic, global temperature changes are considered to be a factor, which may change the pedogenic processes over a short and long term. In order to evaluate changes in response to environmental changes, the present research focuses on natural variation in soil solution during the summer months and variations in different vegetation zones.

The collection of soil solution from suction probes initiated in 1996 was continued and expanded in the summer of 1997, as 30 new suction probes were installed at two new sites. The investigations in the summer of 1997 focused on the soil acidification in the area and the importance of CO_2 degassing during pH measurement.

Among the soil-forming processes, the natural production of protons in the top soil is considered among the most important chemical processes, giving rise to acidification, chemical weathering and transport processes within the soil profile. In Arctic environments, carbonic acid is expected to be the single most important contributor of protons, as the atmospheric contribution of stronger acids as nitric acid and sulphuric acid is limited. As a result of subsurface decomposition and plant respiration, the partial pressure of CO_2 (P_{CO_2}) in the soil atmosphere during the Arctic summer has been reported to be more than 10 times above the atmospheric content (Vugakov & Popova 1968). Theoretically, the subsurface P_{CO_2} gives a pH below 4.4, if no soil buffer capacity exists. In the absence of carbonate dissolution, silicate weathering and cation exchange, processes become important buffer mechanisms and thus control the soil acidification.

At Zackenberg, soil acidification is observed in the top 20-30 cm of most soil profiles with pH-values between 5 and 5.5. Below, the pH is between 6 and 7. The pH-lowering in the soil profile coincides with a general increase in dissolved Ca and Mg with depth, indicating that weathering of silicate minerals and cation exchange are responsible for soil buffering. The pH of the soil solution is observed to vary over the summer, with the largest variation in pH in the root zone (depths of 0-10 cm). Here, CO_2 is produced and the cation exchange capacity is low. During spring (May-June) the soil thaws, buffer processes are active but CO_2 production is limited. As a consequence, pH is constant or may increase. As the growing season starts and the soil temperature increases, decomposition and respiration processes produce more acid than the buffer processes can consume, and pH drops.

The preliminary results show that pH-measurements in soil solution are not trivial. Due to the low CO_2 content in the atmosphere as compared to the root zone, CO_2 in the soil solution tends to degas when exposed to the atmosphere. Therefore, the time lag from soil solution extraction to the actual pH measurements becomes critical. A modified sampling equipment was introduced in 1997, which made it possible to measure pH within minutes after extraction. Compared to traditional pH measurements, we observed almost one pH-level lower pH in the field. This suggests that previous pH measurements are too high and that the soil acidification has been underestimated.

5.1.4. ^{14}C AMS dating of a buried podzol

Bo Elberling, Bjarne Holm Jakobsen & Kristian Dalsgaard

A buried well-developed podzol, found at relative well-drained sites in the Zackenberg area, has previously been described by Jakobsen (1992). The podzol consists of distinct soil horizons, including an eluvial horizon (E/B) and two illuvial horizons (Bhs and Bs). Today, the podzol is buried beneath 10-30 cm of sand. A typical profile is shown in Fig. 5.1.4. In the illuvial horizons, organic matter as well as iron and aluminum have been accumulated implying climatic and vegetative conditions presently found in the humid and warmer Low Arctic Greenland. The presence of the buried podzol thus presumably indicates that warmer palaeo-climatic conditions have existed in Zackenberg. A climate optimum in Holocene has previously been described to cover a period in Greenland from about 7000-5000 BP (Jakobsen 1992). Dating of the podzol in Zackenberg may therefore be important for reconstructing Holocene climate fluctuations and different stages of soil development. The Podzol is found in the fossil delta of Zackenbergelven which has been developed around 8000 BP (Christiansen & Humlum 1993), giving a maximum age of the podzol.

Radiocarbon dating of soils goes back to the early 1960'ies. More recent, the method has been improved by Matthews (1980) and by K. Dalsgaard in close collaboration with the AMS Laboratory, Institute of Physics and Astronomy, University of Aarhus, Denmark. As the organic input to a soil does not occur at one point in time, but continuously and is subject to various degrees and rates of decomposition, the organic matter is of mixed age. The ^{14}C age of a buried soil therefore reflects the apparent mean residence time of the soil in addition to the time elapsed since the soil was buried (Matthews 1980). Consequently, the ^{14}C age of a buried soil yields a minimum estimate of the time elapsed since the beginning of soil formation and a maximum estimate of the time elapsed since burial.

Fig. 5.1.4. A buried well-developed podzol is found at Zackenberg. The Podzol consists of a dark A-horizon (rich of organic material), a light-coloured E-horizon of maximum eluviation, two dark B-horizons characterised by accumulation of organic matter and sesquioxides (oxides of iron and aluminium), as well as a C-horizon representing the parent material.

Soil samples from organic-rich (Bh and Bhs) horizons in one profile, collected in Zackenberg in the summer of 1996, have been dated using the ^{14}C AMS method on four organic fractions (acid extract, humic acid, fulvic acid and a residual), at the Institute of Physics and Astronomy, University of Aarhus. The calibrated ^{14}C ages (BP, before present = 1997) indicate a minimum age of the start of the podzolation process of approximately 7425(50 BP based on the age of the humic acid fraction in the Bs-horizon. Development of the Bs-horizon has continued for at least 1360 years based on the time difference between the youngest and oldest fraction of organic carbon. Based on the youngest organic carbon fraction (fulvic acid) in the Bhs-horizon, it can be concluded that the active podzolation in the Zackenberg area has continued until at least 2700 BP, although the intensity of the podzolation may have changed throughout this period due to climate fluctuations.

5.1.5. Plant-microbe competition in dry tundra

Anders Michelsen, Lotte Illeris, Sven Jonasson, Martin Sommerkorn & Heidi Elberling

A complete factorial experiment with nitrogen and phosphorus addition to a dry *Kobresia-Dryas-Salix arctica* heath was initiated in 1996 near the research station (see section 5.1.4.2 in Meltofte & Thing 1997). In 1997, factorial weekly water additions were included in the design. The aim of the experiment is to investigate if plants in a dry, High Arctic tundra are water and nutrient limited, and to determine the importance of plant-microbial competition in tundra soils with low amounts of organic matter. Earlier analyses of tundra soils rich in organic matter have shown that microbes contain a large proportion of the total soil N and P suggesting that small changes in microbial population sizes can lead to large changes in the amounts of soil nutrients available to plants. It is not known to which extent this is the case in Arctic soils low in organic matter although this information is important for our predictions of the capabilities of plants to respond to a warmer climate by enhanced growth.

In mid August, the vegetation cover in each of the 48 0.5 x 0.5 m^2 plots of the experiment was analysed by the pin-point method. Soil samples were taken, and in the laboratory of the research station the soil was sieved and shaken with two different extractants, K_2SO_4 and $NaHCO_3$. After filtering, the samples were frozen and are now awaiting analysis of inorganic and microbial N and P, and microbial *c.* Photosynthesis of three *Salix arctica* leaves was measured with a Li-Cor 6200 system in each of the plots, and leaves of this dwarf shrub species and the graminoids *Kobresia myosuroides* and *Carex rupestris* were collected and dried in the laboratory for later analysis of leaf N and P concentration. The leaf area of individual *Salix arctica* leaves was measured by an image analyser. The combined information on the nutrient content in soils, microbes and plants will show how the nutrients were partitioned after different treatments. These data can subsequently be used for inference of the functioning of the dry heath system.

5.1.6. Hydrological and thermal processes in the active layer

Peter van der Keur & Bent Hasholt

The depth of ground freezing in polar regions is dependent on many factors, such as duration and severity of freezing air temperatures. It also depends on the composition and water content of the soil, as well as heat flow conditions in the ground. Impor-

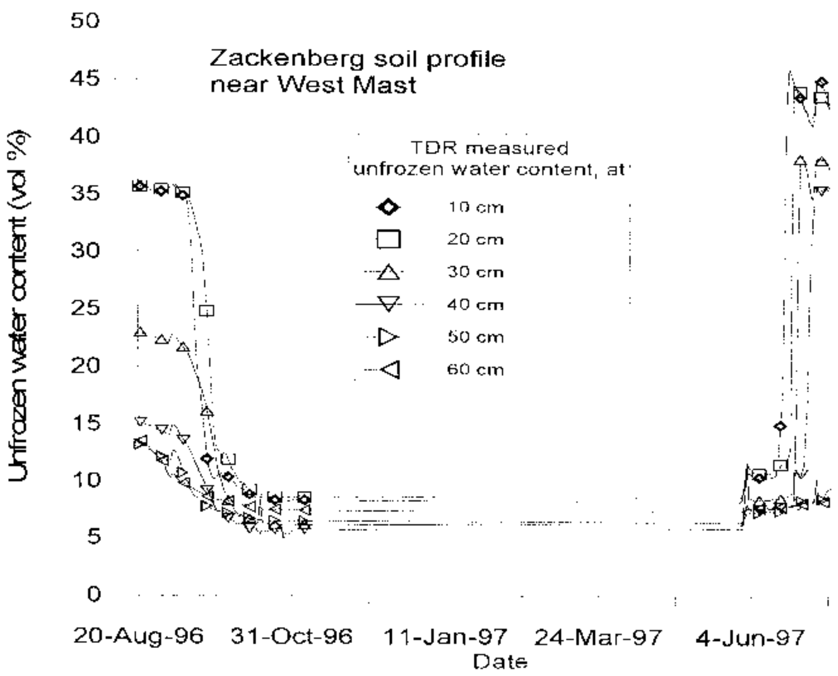


Fig. 5.1.6.1. Unfrozen soil water centent as measured by TDR at 10, 20, 30, 40, 50 and 60 cm depth during 21 August 1996 – 13 July 1997.

tant biological and hydrological processes occur in the active layer, which is limited downwards by permanently frozen soil. Therefore, it is crucial to study the strong links that exist between heat and water fluxes. In the Zackenberg study area, unfrozen soil moisture is monitored by TDR technique that utilises the large differences in dielectricity between frozen and unfrozen water. Unfrozen water content in a soil profile close to the west mast of the meteorological station is measured continuously at depths of 10, 20, 30, 40, 50 and 60 cm, which constitutes the main part of the active layer. Soil temperature is measured with thermistors at the same levels. The combination of data on unfrozen water content and temperature can reveal important information on hydrological and thermal properties of the active layer. Figs 5.1.6.1 and 5.1.6.2 show measured time series of unfrozen water content and soil temperature, respectively, for the period August 1996 to July 1997.

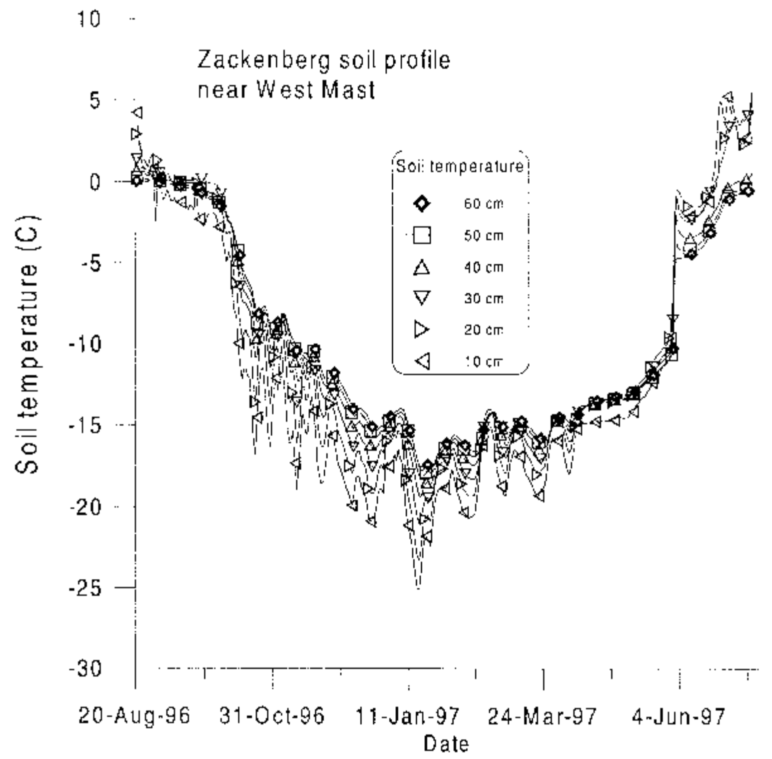


Fig. 5.1.6.2. Soil temperature at 10, 20, 30, 40, 50 and 60 cm depth during 21 August 1996 – 13 July 1997.

5.1.7. Hydrology and water quality

Bent Hasholt & Birgit Hagedorn

The aim of the study this summer was 1) to supplement and confirm findings from last year's reconnaissance of hydrology and fluvial geomorphology in the Zackenbergelven drainage basin (see section 5.1.8 in Meltofte & Thing 1997) and 2) to identify and quantify the source of the components transported by water courses within the basin.

Hydrology and fluvial geomorphology in the Zackenbergelven drainage basin

A significant drainage basin difference in specific runoff from different tributaries to Zackenbergelven was found in 1996. The river from Lindemansdalen had a rather high specific runoff compared to the branch originating in Store Sødal. Therefore, a detailed reconnaissance trip was carried out in Lindemansdalen and its side valleys. It was found that the drainage basin delimited by use of the map in scale 1:250,000 was too small. According to the map, a major part of the runoff originates from a glacier in the north-western part of the valley. In 1997, it was found that also a valley behind Aucellabjerg contributed considerably to the runoff from Lindemansdalen. According to the map, this valley should drain northwards. The case demonstrates the morphological and hydrological effect of alluvial fans. The runoff from the valley oscillates down an alluvial cone. When the cone is situated near the watershed, the shift from one side of the cone to the other may cause a change in the area of the bordering drainage basins (in this case *c.* 10 km^2). The correct specific runoff of the Zackenberg basin upstream of the hydrometric station is therefore lower than originally expected.

Measurements of discharge and runoff were combined with collection of water samples for determination of suspended and dissolved load. It was clearly demonstrated that the Lindemansdalen drainage system has high concentrations of suspended sediment, originating from waterlogged steep slopes with very sparse or no vegetation. Concentration was between 300 and 2500 mg/l in Aucellaelv, and in Palnatokeelv between 137 and 1890 mg/l. In the two main water courses draining Lindemansdalen and Store Sødal, the figures were 72-420 mg/l and 15-18 mg/l, respectively. In this area, significant differences were found in the concentrations of dissolved solids.

Source of the components transported by water courses within the basin

The objective of this part of the study was to identify and quantify the source of the components transported by water courses in the entire Zackenberg catchment area by applying geochemical and isotope (87Sr/86Sr, 18O ^{2}H) methods. For this purpose, water and sediments were sampled from the catchments during the period 12-22 July.

Two main rock types are characteristic for the basin: 1) metamorphic and magmatic basement of Caledonian age outcrops at Dombjerg and Zackenberg; water courses draining this area contribute water to the rivers of Lindemansdalen and Store Sødal, and 2) Tertiary and Cretaceous sediments overlain by Tertiary basalt outcrops at Palnatokebjerg and Aucellabjerg; water courses draining this area contribute water to the rivers of Lindemansdalen and Zackenbergdalen. At low altitudes, Lindemansdalen, Store Sødal and Zackenbergdalen are covered with Quaternary sediments. The different geology of the investigated catchments should lead to characteristic geochemical and Sr-isotope compositions of solutes and solids transported by the different streams.

From each stream, water samples were taken for cation, anion and Sr-isotope measurements. To characterise the water source, samples of snow, rain (event of 13-14 June) and water from streams and two ponds were collected for stable isotope investigations. Before analysis, the suspended matter was collected on cellulose acetate filters with 0.45 microns pore size. As the laboratory analyses are not yet completed, only the first cation and stable isotope analyses of the collected water samples are presented. Streams draining the crystalline rocks had low total solute concentration, *i.e.* between 8 and 10 µS/cm, with relative element abundances Ca > Si > Na > K > Mg. Waters draining the sedimentary rocks had high electrical conductivity, *i.e.* between 100 and 600 µS/cm and element abundances Ca > Mg > Na > Si = K for Lindemansdalen, Ca > Na > Mg > Si > K for Aucellabjerg and Ca ≥ Na > Si > K for Palnatokebjerg.

Zackenbergelven is the confluence of the Store Sødal outlet and the investigated water courses draining the sedimentary rocks. Water from this river had moderate electrical conductivities of about 30 µS/cm and element abundance Ca > Mg = Na > Si >K, indicating the input from waters draining the sedimentary rocks to the Store Sødal outlet. The element abundance of the waters followed the mineral dissolution rates: carbonates > silicate > feldspars > quarts. High amounts of Ca and Mg (85 ppm and 30 ppm, respectively) and high Ca/Si and Mg/Si ratios in water courses draining the sedimentary rocks indicated carbonates as the main source of solutes. On the other hand, the low content of solutes of water courses draining the crystalline rocks could be explained by the low dissolution rate of silicates compared to carbonates.

The change in element abundance between water courses draining crystalline rocks and those draining sedimentary rocks reflects the different geochemical composition of the sources. The high Na content of waters draining Aucellabjerg may be related to the basalt outcrop at the top of the mountain. In addition to the geochemical composition of source rocks, secondary processes like ion redistribution and ion exchange by clay influence the geochemical composition and solute load of water.

When available, the Sr isotope measurements will be sensitive indicators of solute as well as sediment source.

5.2. Nutrient dynamics in Northeast Greenland waters and sediments

Søren Rysgaard, Peter Bondo Christensen, Jens Borum, Jonathan D. Carl, Göran Ehlmé & Magnus Elander

This year's experimental studies consisted of two main tasks:

1. Performing a winter campaign in February-March 1997, repeating all parameters measured in Young Sund during the summer campaign in 1996.
2. Follow-up in August 1997 of questions that arose in both summer and winter field campaigns of the ongoing project 'Nutrient dynamics in northeast Greenland waters and sediments'.

5.2.1. Winter campaign

All measurements performed during the 1996 field campaign at Station A in Young Sund (see section 5.2 in Meltofte & Thing 1997) were repeated during a field campaign in February-March 1997. Despite weather conditions, we succeeded in completing all experiments without any major problems. Sampling of the water column and sediment was performed in darkness before 6 February to ensure true winter conditions (average diurnal light intensity < 1 µmol photons/m^2/s). Air temperature was about –30°C, and the sea-ice was 1.5 m thick with a 0.4 m snow cover above (Fig. 5.2.1). All incubations were performed at *in situ* conditions (–1.8°C) in a temperature regulated room kindly made available to us by the SIRIUS military sledge patrol. During the first three weeks calm wind conditions prevailed, except for a seven day period at the end of February, where we experienced a true Arctic hurricane with wind speeds up to 80 knots. Fortunately, we had completed the field program by then.

5.2.2. Underwater plants

In 1996 we discovered that large areas of Young Sund were vegetated by dense beds of macroalgae. This gave rise to the question of the relative importance of these plants to total primary production in Arctic coastal waters. In 1997 we investigated species composition and spatial distribution of macrophytes along depth transects from Wollaston Forland (74°18.51'N and 20°13.71'W) to Clavering Ø (74°18.38'N and 20°28.36'W). Water column light attenuation and macroalgal photosynthesis were assessed and growth measurements on macroalgae using an *in situ* marking technique were initiated.

Fig. 5.2.1. Drilling a whole in the sea-ice at Station A, on 6 February 1997. Photo: Søren Rysgaard.

Finally, algal specimens were sampled for measuring tissue contents of C, N, and P.

Underwater video and photos were taken along depth gradients by scuba diving. The macroalgae occurred down to a depth of about 20 m, and the community was dominated by species of the genera *Laminaria*, *Alaria*, *Fucus* and *Desmerestia*. Water column light attenuation varied between 0.22 and 0.25 m^{-1} and allowed positive net photosynthesis of *Laminaria saccharina* and *Fucus spiralis* down to about 25 m depth. Apparently, macroalgal growth is very intense in spite of the relatively short growth season. Visual inspection of *Laminaria* morphology suggested annual formation of leaf blades of more than 2 m length. In order to check algal growth rate, specimens of *Laminaria* growing at 6-8 m depth were marked by thalli punching. The plants will be harvested and growth recorded in 1998. Young and old algal tissues were sampled for later analysis of C, N and P in order to characterise food quality of the organic material produced by the macroalgae. In addition, tissue contents of heavy isotopes ($\delta^{13}C$ and $\delta^{15}N$) will be analysed to allow evaluation of internal reclamation of C and N within the algae and evaluation of the macroalgal contribution to sediment pools of organic detritus.

Arctic kelp accumulates nutrients in the tissue during winter, when nutrient concentrations are high, and carbohydrates during summer, when irradiance is high. This strategy enables these macroalgae to efficiently utilise the short Arctic growth season. Other studies have shown that secondary producers (mainly sea urchins) consume about 10% of the net primary production of the kelp, whereas the remaining 90% enters the detritus food chain as particulate or dissolved matter. The fate of this particulate dissolved matter will be investigated in detail in our new project 'Changes in Arctic Marine Production'.

5.2.3. Arctic char

During earlier investigations in Young Sund we have ascertained a large population of anadromous Arctic char *Salvelinus alpinus*. This salmonid is the most northern ranging fish of all freshwater species and historically is found in large densities throughout the circumpolar region leading us to ponder what role this fish species may have in affecting nutrient dynamics in Greenland waters. Probably, the entire population of anadromous Arctic char within Young Sund spends the winter in Store Sø. When the spring thaw comes and Zackenbergelven begins to flow, the anadromous char migrates into the marine environment of Young Sund to spend the summer months (June-August) foraging. Arctic char are known to prey upon zooplankton, fish fry and small fish and thus may have a significant impact on the various trophic levels of Young Sund. If there is a large anadromous char population and these fish have high consumption rates, as anticipated, then Arctic char influences on the numbers of secondary and tertiary producers and consumers could in turn affect primary production and ultimately nutrient sedimentation and re-circulation. To elucidate some of these questions, a series of preliminary investigations of Arctic char in Young Sund was undertaken during this year's field campaign.

In connection with the yearly fishing campaign of the SIRIUS patrol, a total of 294 char (ranging in size from 15 to 70 cm) were captured using both standard and biological survey gill-nets (nets that are divided into sections with a range of different mesh sizes). Nets were set at seven different locations in Young Sund at distances between 0.5 and 25 km from the mouth of Zackenbergelven (see Fig. 5.2.3). Captured char were measured (fork length) and weighed individually to determine length/weight relations and condition factors. Thereafter, stomachs were removed and the contents weighed and examined for ration size and prey selection. Otoliths were removed in a number of char for each cm to calculate age-at-length plots.

Although all data have not yet been processed, preliminary results show that a high percentage of Arctic char stomachs contained prey (average of 92%) indicating that feeding was quite intense. The diversity of prey species consumed was often low (approx. 90% of stomachs had only one or two species) and food items were generally small (<2 cm) possibly due to prey availability and/or selection. The prey most often consumed both with regards to number and weight was amphipods and mysids (in about 50% of the stomach samples), fish and fish larvae (in about 20% of the stomach samples) and copepods (in about 11% of the stomach samples). Although there were some slight variations in the selection of prey according to the area of capture, these did not appear to be significant. Furthermore, overall prey selection did not appear to be influenced by foraging location and/or char size. The sampled Arctic char ranged from around 6 to 14 years of age.

Data from this pilot project have helped create an important basic knowledge of the Arctic char of Young Sund and serve to supplement further analyses of data obtained from our previous studies as well as to give a solid base for future investigations.

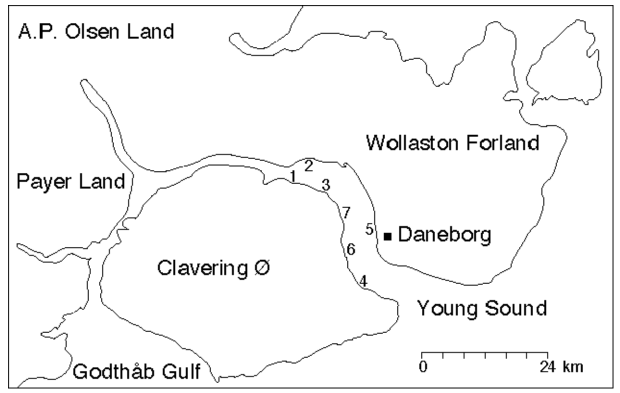


Fig. 5.2.3. Locations for sampling Arctic char.

However, further investigations of Arctic char such as total abundance, length frequencies, recruitment and mortality rates *etc.* are still needed in order to add further to the understanding of direct and indirect influences of Arctic char on production. Continued investigations will also give us more insight in what effects abiotic and biotic changes may have on Arctic char populations and eventually what effect these changes may have on Arctic ecosystems.

5.2.4. Porewater concentration profiles

Investigations carried out during our ongoing project revealed highly interesting data concerning nitrate concentration profiles within the sediment of Young Sund. The nitrate concentration profile is important when modelling nitrogen removal by bacterial denitrification in the sea bed because it reflects the balance between bacterial production and consumption of nitrate.

An unexpected distribution of nitrate within the sediment was found in many sediment cores investigated during the field campaign of 1996. A secondary nitrate concentration maximum was found deeper in the anoxic sediment strata when applying the traditional porewater (water filled space between sediment particles) squeezing technique. This year, we tested a newly developed microsensor for measuring nitrate in marine sediments and no secondary nitrate peak was found in any of the investigated sediments.

We therefore expected the high nitrate concentrations deep within the sediment to originate from other sources than bacterial nitrification. Experiments were conducted applying different amounts of pressure (0.5-6 bar) when extracting porewater. The data obtained suggest that organisms containing an internal nitrate pool are lysed and thus liberate nitrate to the surrounding sediment when pressure is applied. Recently, similar observations have been made in sediments along the continental shelf off Peru and Chile. Here it was found that the sulphur bacterium *Thioploca* assimilates large amounts of nitrate and uses it as an energy source in a previously unknown way of life (Fossing *et al.* 1995). Microscopic investigation of three sediment cores collected in Young Sund have also revealed the presence of *Thioploca*. Further work is required in order to elucidate the role of *Thioploca* in Arctic sediments.

5.2.5. Transport mechanisms within the sea bed

The mathematical model developed during the ongoing project in Young Sund (Rysgaard & Berg 1996, Rysgaard & Berg *in prep*.) is a general dynamic model describing the coupled transport and interaction of solutes and particles in sediments. Using the model, it is possible to simulate the biogeochemical cycle in the sediment on an annual basis using the time dependent sedimentation rates of organic matter as input. Transport is assumed to take place by molecular diffusion, and through bioturbation. The interaction between solutes and particles is described through a set of stoichiometrically coupled reactions where the reaction rates are controlled by approximations of Michaelis-Menten kinetics. The model has been verified using data collected during our summer campaign in June-August 1996, and during our winter campaign in February-March 1997. In various scenarios the model will be used to predict the response of sediment processes to ecosystem perturbations caused by global changes in temperature. The major focus is to predict possible changes in the annual fluxes across the sediment-water interface in response to altered sedimentation rates. Measurements from our 1996 campaign show that pelagic primary productivity in the surface layers becomes limited by nutrients when sea ice cover disappears. Since fresh precipitating material during the summer thaw is rapidly mineralised by bacteria within the sediment and nutrients thereby released into the overlying water column, bacterial mineralisation within the sediment becomes an important factor controlling the pelagic primary production.

Model simulations of bacterial mineralisation in the sediment of Young Sund indicated that molecular diffusion as sole input parameter for transport within the sediment was insufficient to obtain a good correlation between simulated and measured activities of sediment mineralisation. Therefore, in the summer campaign (August 1997) we conducted detailed investigations of transport mechanisms within the sediment. Transport measurements of both sediment particles and porewater were obtained. Results from the analysed data show that bioturbation by benthic animals plays an important role for the transport of both particles and solutes within the sediment. Furthermore, data elucidate that benthic animals are more active during the productive open water period and that their effect on particle and porewater transport is enhanced during this period.

5.2.6. Walrus feeding behaviour

Sandøen at the mouth of Young Sund is a haul-out place for walruses, and small groups are daily seen diving for food near Daneborg. The walruses are assumed to feed on bivalves, especially *Mya truncata*, which are found in great numbers in the soft bottom sediments.

In August 1997, a first attempt was made to do a unique and first-time-ever photographic documentation of walrus activities under water. Because of the animals' potential aggressiveness towards humans in the water, several precautions were taken to assure the personal safety during the diving activities. Specially designed under-water housing, both for digital video and still photography was used. Photography and filming were made not only the normal manual way with the photographer in the water, but also with submerged cameras mounted on a tall pole, and operated with remote controls from a Humber rubber boat propelled by an electrical low noise outboard motor.

The photographic efforts resulted in some novel

Fig. 5.2.5. Sampling sediment cores at Station A. Photo: Jonathan D. Carl.

Fig. 5.2.6.1. Walrus on its way to the sea floor. Photo: Magnus Elander & Göran Ehlmé.

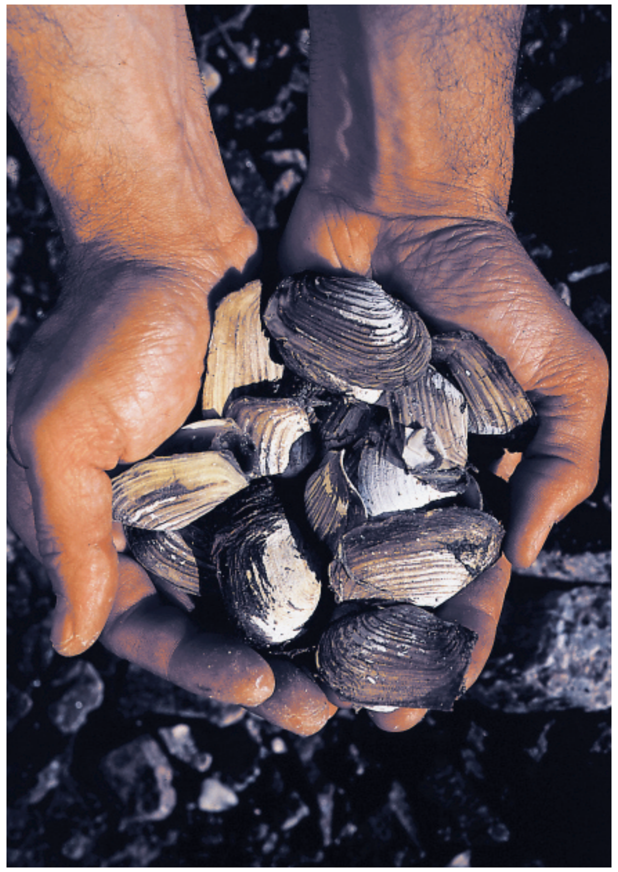


Fig. 5.2.6.2. Empty mussel shells collected from the sea floor after walrus visit. Photo: Magnus Elander.

Fig. 5.2.6.3. Walrus enjoying the Arctic summer. Photo: Magnus Elander.

observations of the feeding behaviour of walruses. Using a combination of GPS and echo sounding instruments to keep the boat exactly above the spot where a walrus was diving, we observed that they exploited the same narrow feeding area during many consecutive dives. The visual result on the bottom was large dug-up 'craters' with great numbers of empty bivalve shells. Because of low visibility in the upper water mass above the pycnocline (down to 25 m) this summer, it was difficult to follow the animals during their dives. Only occasionally it was possible to document a full diving cycle. Single successful observations, however, revealed that the walruses wiped away the soft bottom sediments by powerful beats with the front flippers (like a hovering eagle) to uncover the dense population of *Mya truncata*. It is the very same technique used by human divers to uncover *e.g.* archaeological finds covered by mud on the bottom. This may then be used in combination with other known feeding techniques depending on the quality of the sea floor *e.g.* spraying water with the mouth and possibly also using the tusks to dig. Subsequently it was easy for the walruses to pick up and ingest large numbers of prey. Since walruses must eat 1-4 mussels per minute during a continuous 24 hrs feeding session to consume the estimated daily intake of 50-80 kg, they must be extremely efficient when feeding.

We expect that the walrus population may have a significant impact on the biomass of larger bivalves, at least in regional parts of Young Sund. Based on visual observations during summer (1994-1997) it is suggested that walruses feed very intensively on the same location for days or weeks before moving on to another favourite location. Visual observations made by divers at last year's favourite feeding location revealed a large number of empty *Mya truncata* shells on the sea-bottom. However, more work is required before final conclusions are drawn regarding the feeding behaviour of the walrus and its ecological role in carbon and nutrient cycling within Young Sund.

5.2.7. Carbon budget for Young Sund (1996-1997)

We have obtained a comprehensive data set of carbon and nutrient dynamics in waters and sediments of Young Sund. The data set includes data from several locations during the summer of 1996 and during winter 1997.

Most of these data have been analysed making it possible to construct a carbon (C) and nitrogen (N) cycle for the sound. As an example, the carbon cycle is presented in (Fig. 5.2.7), where 11 sampling events during 1996-1997 are integrated to describe the annual budget. The carbon (and nutrient) cycle can be divided into the following themes:

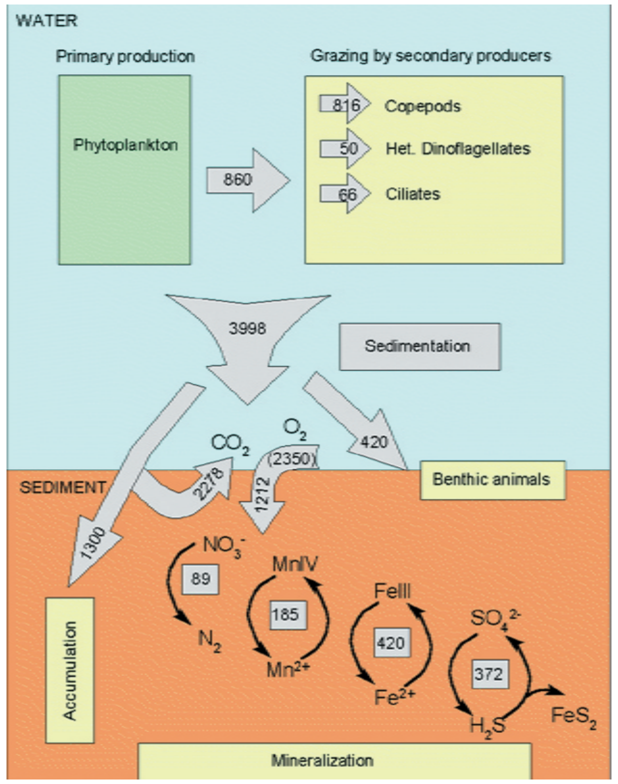


Fig. 5.2.7. Annual carbon budget for Station A (36 m depth) in Young Sund. All units are mmol C/m^2/yr. Further details are given in the text.

- Production of carbon by primary producers
- Consumption of primary producers by grazers in both the water column (zooplankton) and sediment (benthic animals)
- Consumption of grazers by Arctic char – under preparation
- Sedimentation of carbon
- Microbial degradation of carbon in the sediment
- Permanent accumulation of carbon in the sediment

Phytoplankton was primarily composed of diatoms throughout 1996-1997. The primary production of these organisms accounted for 860 mmol C/m^2/yr (or 10.3 g C/m^2/yr). It is possible that sea ice algae also contributed significantly to the total primary production since a green layer in the lower surface of the sea ice was observed in June. Furthermore, underwater plants may also contribute to total primary production. The contribution of sea ice algae and underwater plants to total production will be investigated further in our new project.

The zooplankton community was able to graze the whole phytoplankton community, and approximately 25% of the carbon reaching the sea floor was composed of dead phytoplankton together with zooplankton exuvia and faecal pellets. It is possible that underwater plants and sea ice algae may constitute a similar input to the sediment. The remaining fraction of carbon input to the sediment was imported from land and from the Greenland Sea. Measurements of $\delta^{13}C$ in freshly precipitated material showed that the major fraction of carbon precipitating from the water column may originate from land during the summer period.

The bivalve *Hiatella arctica* dominated the benthic animal biomass, and growth estimates suggested that it consumed about 10% of the carbon reaching the sea-bottom. However, several other benthic animals were present in the sound, and since laboratory analyses of the grazing impact of these organisms have not yet been completed, the consumption estimate of benthic animals is a minimum estimate.

Microbes within the sediment degraded 57% of the precipitated carbon. The microbial mineralisation was complex and degradation of organic carbon involved utilisation of oxygen, nitrate, manganese, iron and sulphate, respectively. Hereby carbon dioxide and nutrients were released to the overlying water column and made available to new primary production.

Approximately 30% of the carbon reaching the sediment was not degraded but permanently accumulated within the sediment. Due to accumulation of carbon and other settling components, the bottom sediment layer of Young Sund increases by 3 mm per year.

5.2.8. Acknowledgements

The Danish Research Councils (grant #9501025) are acknowledged for financial support. Furthermore, we thank the SIRIUS military sledge patrol members for their hospitality and help. We also appreciate their enthusiasm for offering the opportunity for three biologists out of shape to practise body building with 50 m^3 of concrete. Later we discovered that they were constructing a new building.

Egon Frandsen, Anna Haxen, Marlene Jessen and Kitte Gerlich are thanked for skilful technical assistance in the laboratory.

5.3. Lake studies

Erik Jeppesen, Kirsten Christoffersen & Frank Landkildehus

Arctic lakes are useful model ecosystems for evaluation of the effects of climatic changes. They are well-delimited and heavily influenced by the local climatic conditions in their catchment areas. In most lakes there is a continuous deposition of sediment. Analyses of sediment, plant and animal remains may therefore be used to describe the historical development of biological communities, including the effects of climatic changes. Greenland lakes are particularly useful when evaluating the effects of climatic changes as they are often only insignificantly influenced by human-related activities in their catchments.

In Greenland there are a large number of both shallow and deep lakes. Several hundreds of these lakes have been the object of limnological studies, but so far no major investigation at ecosystem level has been undertaken.

Recently, a cross-institutional 3-year research project on Greenland lakes was initiated, comprising the National Environmental Research Institute in Denmark, the Freshwater Biological Laboratory of the University of Copenhagen, the Geological Survey of Denmark and Greenland and the University of Regina, Canada.

The project serves three purposes:

- To increase our understanding of biological interactions in the pelagial of shallow Arctic lakes with special emphasis on the role of fish.
- To establish relations between biological remains in the sediment and contemporary data for a number of variables with the purpose of describing the historical development in the biological communities in Greenland lakes during the past 1,000-10,000 years, including evaluating the effects of climatic changes.
- To develop a monitoring programme for lakes at Zackenberg.

As a part of the project, we studied the biological communities of the pelagial in 19 shallow lakes situated in Zackenbergdalen during 7-19 August 1997. The sampling programme included fish, zooplankton, phytoplankton, ciliates, flagellates, bacterioplankton and a number of physico-chemical parameters. Moreover, we sampled the upper 1 cm of the sediment for zooplankton remains. This first presentation includes physico-chemical data, fish and zooplankton in the water and sediment. The remaining variables have not yet been analysed. The project will be continued in 1998-99.

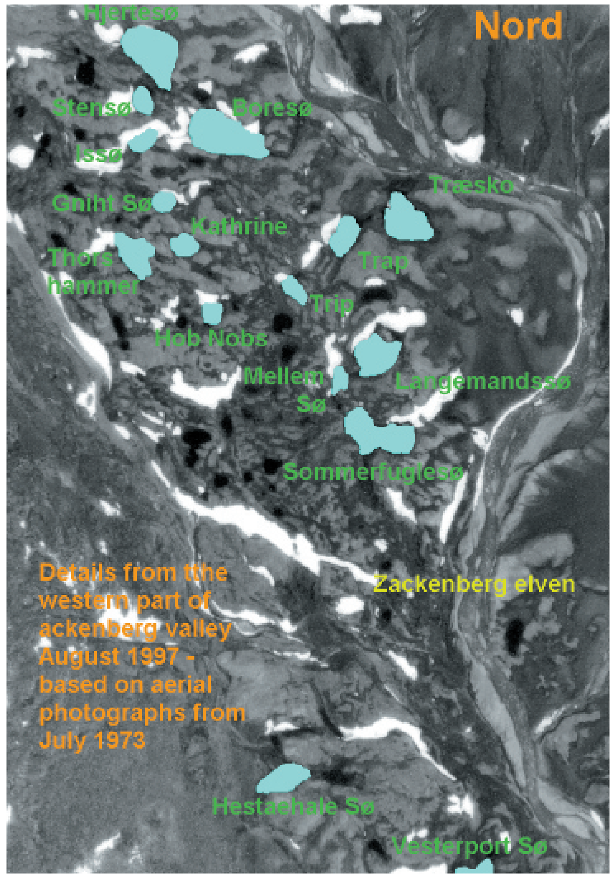


Fig. 5.3.1. Location of the investigated lakes in Morænebakkerne. Based on an aerial photo (from National Survey and Cadastre). Names are tentative.

5.3.1. Characteristics of the lakes

Most of the lakes were situated in the moraine hills (Morænebakkerne) in the north-western part of the valley and in the level area south of the hills (Fig. 5.3.1). Additionally, two lakes south of the research station (Lomsø and one of the lakes of Sydkæret) were included. The position of the lakes was identified from aerial photos and the actual shapes and depths were measured on location. The lakes were numbered and some were given tentative names (Fig. 5.3.1).

The lakes were generally small and shallow with maximum depths ranging from 0.2 to 6.7 m (Fig. 5.3.1, Table 5.3). This implies that most of the lakes freeze to the bottom during winter, as the maximum ice thickness of Northeast Greenland lakes is 2-2.5 m.

5.3.2. Physico-chemical measurements

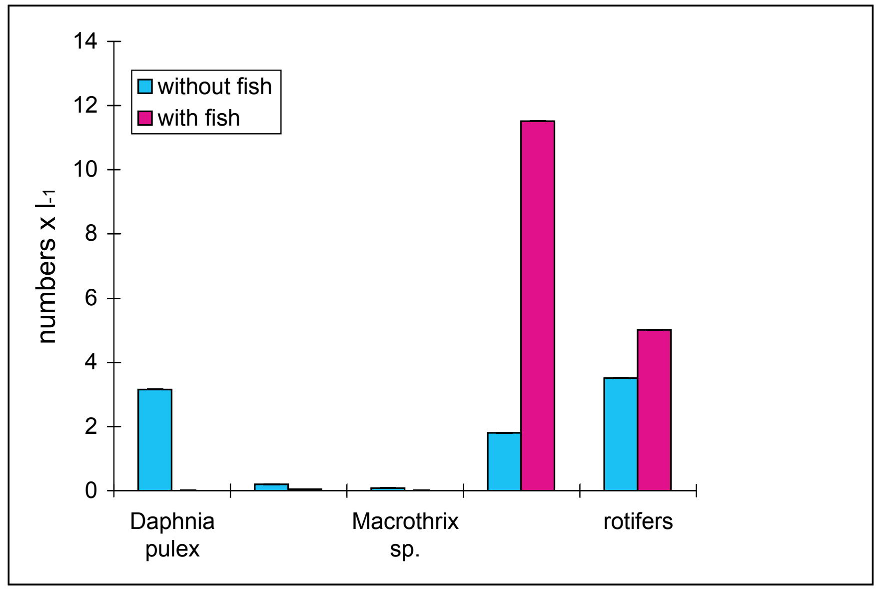
The lakes were generally nutrient-poor as indicated by the specific conductivity (Table 5.3). In most lakes, the total phosphorus (TP) concentration ranged between 2 and 10 (µg/l and total nitrogen between 140 and 830 (µg/l. In comparison, the mean value for Danish lakes is as high as 210 (µg P/l and 2,100 (µg N/l. TP was relatively high (27 (µg/l) in Vesterport Sø where geese periodically rested.

Water temperatures (averages for the water column) ranged from 5 to 13(C during the sampling period, reflecting variations in hydrological conditions (depth, residence time and ice/melt water) and changing weather conditions during the sampling period. All lakes had well oxygenated waters (78% to 101% saturation) throughout the water column. pH ranged between 6.0 and 7.8.

5.3.3. Biological measurements

To study fish populations, biological multi-mesh survey gill nets with 14 different mesh sizes (6.25 mm to 75 mm) were used. The nets were set at the bottom and checked after 18 hours. Between 3 and 10 nets were used in each lake depending on lake size. Fish were caught only in the three deepest lakes with maximum depths of 4.5, 6.1 and 6.7 m, respectively. The fish stock consisted solely of dwarf Arctic char *Salvelinus alpinus* that become sexually mature at a size of only 11-13 cm. The catch per net (CPUE) was as low as 0.5 – 1.4 fish. In comparison,

Fig. 5.3.3.1. Average density ((SE) of various zooplankton in lakes without (N = 16) and with (N = 3) fish.



CPUE typically reaches values as high as 100-400 in nutrient-rich Danish lakes.

The relative importance of the various zooplankton species differed markedly with the presence/absence of fish (Figs 5.3.3.1 and 5.3.3.2). In the fishless lakes, the large species, *Daphnia pulex*, was the dominant cladoceran and occurred in densities as high as 12/l (Lomsø), while *Daphnia* were totally absent in lakes with fish. Also the two other species observed, *Chydorus sphaericus* and *Macrothrix* sp. appeared in somewhat higher densities in fishless lakes. Conversely, the abundance of cyclopoid copepods was considerably higher in lakes with fish and a similar tendency was observed for rotifers.

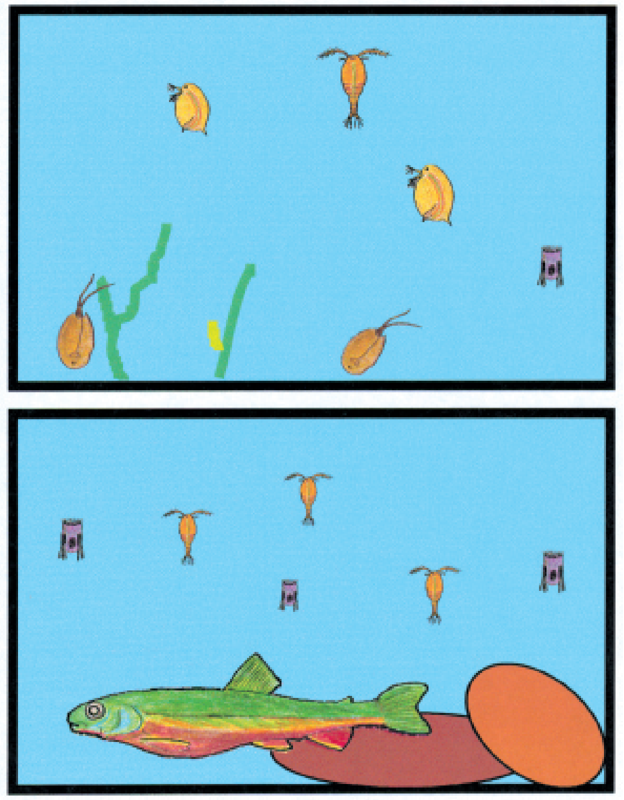


Fig. 5.3.3.2. Different biological structure of lakes with and without fish.

In a number of lakes we found tadpole shrimp *Lepidurus arcticus*. They especially occurred in lakes with soft sediments and were lacking in most lakes with hard bottoms. Moreover, they were completely lacking in lakes with Arctic char. The absence may be ascribed to fish predation. Knowledge about the role of tadpole shrimp in lake ecosystems is poor. They stay near the bottom most of the time, but occasionally forage in the water preying on zooplankton. Tadpole shrimp was especially abundant in the very shallow ponds.

The absence of *Daphnia* spp. and *Lepidurus arcticus* and the low abundance of small cladocerans in lakes with fish indicate a very high predation pressure from fish in these lakes. Despite low fish catches the results suggest that the predation pressure on zooplankton is just as high or even higher than in a nutrient-rich, roach- and bream-dominated Danish lake. This supports a hypothesis presented by Jeppesen *et al.* (1997) that the predation pressure on zooplankton is particularly high in nutrient-poor and nutrient-rich lakes, and not as pronounced in intermediate nutrient-rich lakes. If the results from Danish lakes can be directly transferred, nutrient-poor Greenland lakes with fish will be most sensitive towards changes in nutrient loading, because the nutrients may be funneled directly into growth of phytoplankton, while zooplankton grazing may reduce the growth increase in the fishless lakes.

Phytoplankton abundance was low as indicated by chlorophyll *a* values of 0.6-4.9 (g/l (Table 5.3). Several lakes had an extensive cover of mosses and a few lakes had vascular plants (*Hippuris vulgaris* and *Ranunculus hyperboreus*) in the littoral zone.

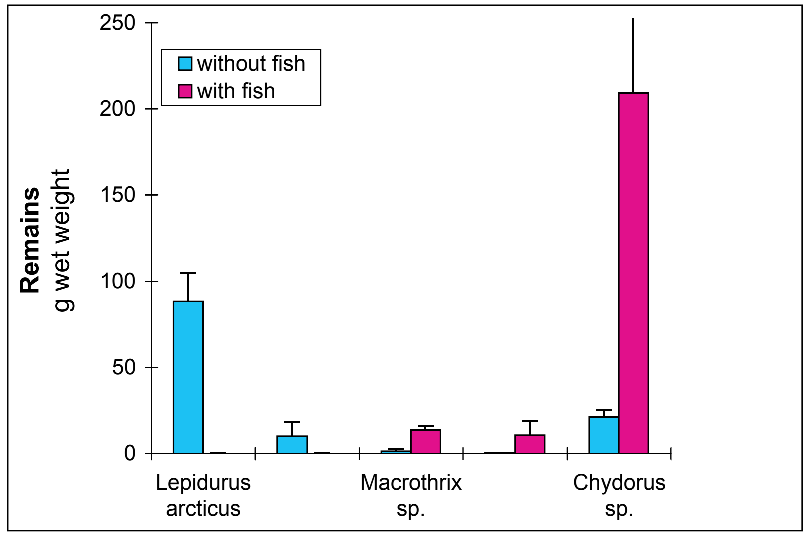


Fig. 5.3.4. Number of remains of benthic and pelagic crustaceans per g wet weight of bottom sediments (upper 1 cm) in lakes without (N = 16) and with (N = 3) fish.

5.3.4. Sediment analyses

We took samples from the upper 1 cm of the lake sediment to determine zooplankton remains. As the sediment preserves remains throughout the whole season, analyses of these provide a seasonally integrated picture of the pelagic communities, although variations in preservation may alter the relative contribution of the various species. These analyses allow us to judge whether the up-to-the-minute account achieved by a single sampling event is representative for the lake as a whole.

Resting eggs of *Daphnia pulex* and a number of skeleton fragments of *Daphnia*, *Lepidurus, Chydorus, Macrothrix* and *Alona* were observed (Fig. 5.3.4). *Daphnia* remains were very abundant in fishless lakes. In lakes with fish, *Chydorus* remains were dominant. Sediment investigations thus yield the same picture of the cladocdran community as do point samplings in the water phase. August samples may therefore give a satisfactory picture of the community of planktonic cladocerans in the lakes.

Apart from planktonic forms, the sediment also contained remains of benthic and plant-associated cladocerans that were otherwise only sporadically recorded in the water samples. It was characteristic that the number of mainly benthic-living forms such as *Macrothrix* and *Alona* was considerably lower in lakes with than without fish. This may be due to predation from the predominantly benthic predator *Lepidurus* which occurred only in fishless lakes.

It is still too early to evaluate to which extent biological remains in the sediment may be used to explain the effects of climate changes in lake ecosystems. The preliminary results suggest, however, that changes in the predation pressure from fish and thus the fish stock abundance may be estimated on the basis of changes in the occurrence of *Daphnia* and *Lepidurus* remains. In addition, variations in *Lepidurus* predation seem to be mirrored in the benthic cladoceran community.

Table 5.3. Physico-chemical measurements. Names refer to the map, Fig. 5.3.1.

Name	Maximum depth (m)	Conductivity (µS cm^{-1})	Temp. (°C)	pH	Total phosphorus (µg l^{-1})	Oxygen (%)
Vesterport Sø (1)	0.7	18	4.9	6.0	27	82
Sommerfuglesø (2)	1.8	15	6.3	6.5	4	87
Langemandssø (3)	6.1	8	6.8	6.5	8	89
Mellemsø (4)	0.2	11	9.4	6.5	2	98
Trap (5)	1.5	17	7.5	7.0	10	101
Træsko (6)	2.7	14	8.6	6.7	15	95
Trip (7)	0.9	19	10.1	7.1	10	93
Hob Nobs (8)	0.6	16	8.9	6.8	13	88
Kathrine (9)	0.5	14	10.5	6.8	2	93
Gniht Sø (10)	1.5	25	9.9	7.3		95
Boresø (11)	4.6	9	8.9	6.7	6	88
Hjertesø (12)	6.7	9	9.5	6.5	7	78
Stensø (13)	0.7	12	13.0	6.7	10	97
Issø (14)	1.7	16	8.6	6.6	15	89
Thors Hammer (15)	3.4	10	10.2	6.6	2	84
Hestehale Sø (16)	0.3	36	10.1	7.3	5	92
Sletten Sø (17)	0.3	22	7.3	6.7	6	87
Lomsø (18)	1.5	77	10.0	7.1	15	93
Sydkær Sø 1 (19)	0.2	44	6.8	7.8	10	88

5.4. Seed dynamics of Arctic plants

Heidi Elberling

During the field season of 1996 a field experiment was initiated on a 50 x 50 m^2 abrasion plateau due south of the Zackenberg station (see section 5.3 in Meltofte & Thing 1997). The project is a detailed study of the seed flow (seed production > seed dispersal > seed bank > seedling establishment) of several plant species with life-strategies considered to be typical of the High Arctic, *i.e. Lesquerella arctica*, *Papaver radicatum*, *Melandrium triflorum*, *Cerastium arcticum*, *Draba arctica* and *Potentilla rubricaulis*. Within the field site, 90 plots of 0.5 x 0.5 m^2 were randomly distributed. Each plot was assigned one treatment out of six to test for the influence of physical parameters such as temperature, nutrients, moisture and disturbance. The measurements of the seed dynamics parameters continued in 1997, and several parameters will also be measured in 1998. The data are currently being processed.

5.5. Pollination community ecology

Heidi Elberling

The community study of Arctic plant pollination which took place within the area south of the Zackenberg station resulted in the collection of approximately 500 insects from both 1996 and 1997 (see section 5.4 in Meltofte & Thing 1997). The 1000 specimens were determined to *c.* 65 species by Verner Michelsen. The insects predominantly belonged to Diptera. The insects were collected from 30 different plant species of which the most visited were *Cerastium arcticum*, *Dryas octopetala*, *Papaver radicatum*, *Potentilla rubricaulis*, *Saxifraga oppositifolia* and *Silene acaulis*. Analyses of pollen deposits on the insects performed by Peter Witt will supplement the resulting matrix of 30 different plant species and 65 different insect species with additional interactions. The data will be used to evaluate the degree of specialisation or generalisation among the pollinators.

5.6. Pollen traps

Bent Fredskild

In order to elucidate the recent pollen deposition, a pollen trap was placed *c.* 2 m above ground at the meteorological station on 3 June. Besides, adjacent to one of the lakes in Morænebakkerne cored in 1996 (see section 5.1.10 in Meltofte & Thing 1997), one trap was placed on top of a ridge and two traps were put on the lake shore on 19 June. When they were removed on 29 August, the trap at the meteorological station was replaced by a new one. A series of soil surface samples from the ridge at the lake were collected in order to record the local pollen deposition in different vegetation types.

5.7. Collared Lemming Project – Zackenberg

Thomas Bjørneboe Berg

Data collection on collared lemming *Dicrostonyx groenlandicus* habitat selection, feeding biology,

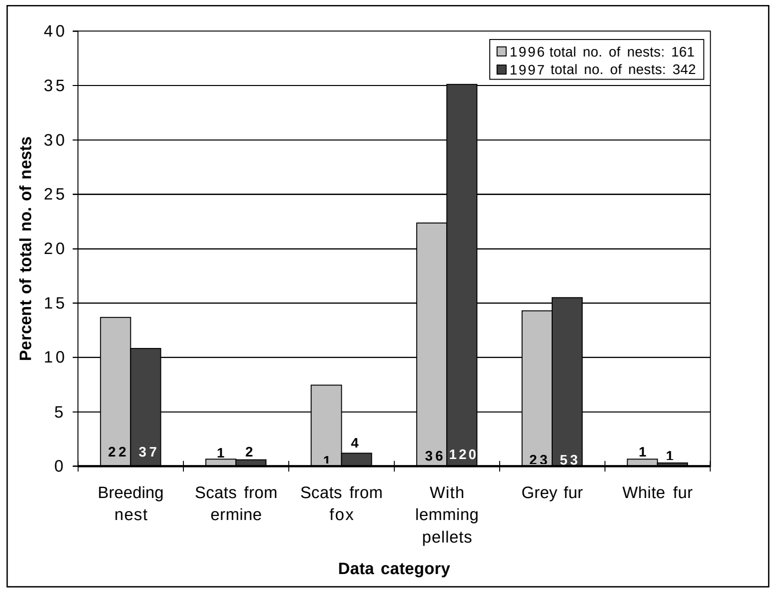


Fig. 5.7.1. Selected data obtained during the examination of lemming winter nests within the 2.5 km^2 census area at Zackenberg. Numbers on top of each block show the actual number of nests in the given category.

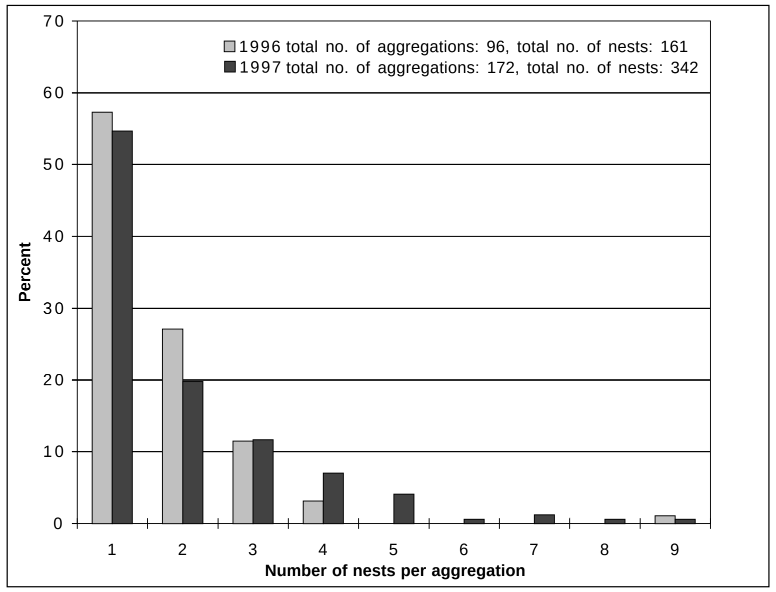


Fig. 5.7.2. Frequency of aggregations within the 2.5 km² lemming census area at Zackenberg. Nests are assumed to be related to each other when the distance between them is ≤ 20 m.

population dynamics and morphology, initiated in 1995, was continued (see also section 4.4.1).

Locations of all 1996-1997 winter nests (342) and active summer burrows (710) within the 2.5 km² census area were marked with flags. Due to shortage of time only half of them were given UTM co-ordinates using an electronic teodolite. The remaining half will be given UTM co-ordinates during the 1998 field season prior to the search for new nests and burrows. Parameters recorded during the examination of nests and burrows were the same as in 1996 (see section 5.7.1 in Meltofte & Thing 1997). Only the number of nests visited by foxes (as indicated by faeces left in the nest) and the number of nests with lemming pellets varied remarkably between 1996 and 1997 (Fig. 5.7.1). This indicates that the breeding effort per nest may be the same in years with increasing lemming population as in years with lemming peaks. Nests with pellets were assumed to have been abandoned as residence and hence used as pellet deposits instead. The difference in the frequency of this category between 1996 and 1997 may reflect an increased activity according to the assumed lemming peak year (see 4.4.1.).

The lemming activity is also illustrated by the number of aggregated nests (Fig. 5.7.2). Although not significantly different (two-tailed t-test, df = 8, p = 0.0686), the difference in number of aggregated winter nests between 1996 and 1997 indicates an increase in 1997. 52.6% of the 342 winter nests recorded in 1997 were within aggregations of three or more nests, as compared to 33.5% of the 161 winter nest recorded in 1996.

Size of winter nests vary from a diameter of less than 10 cm to more than 25 cm (Fig 5.7.3). The proportional distribution on size category did not differ significantly between 1996 and 1997. Nest material found in 1997 showed the same pattern as in 1996. The most frequently used nest material is graminoids, even though this material may be absent in

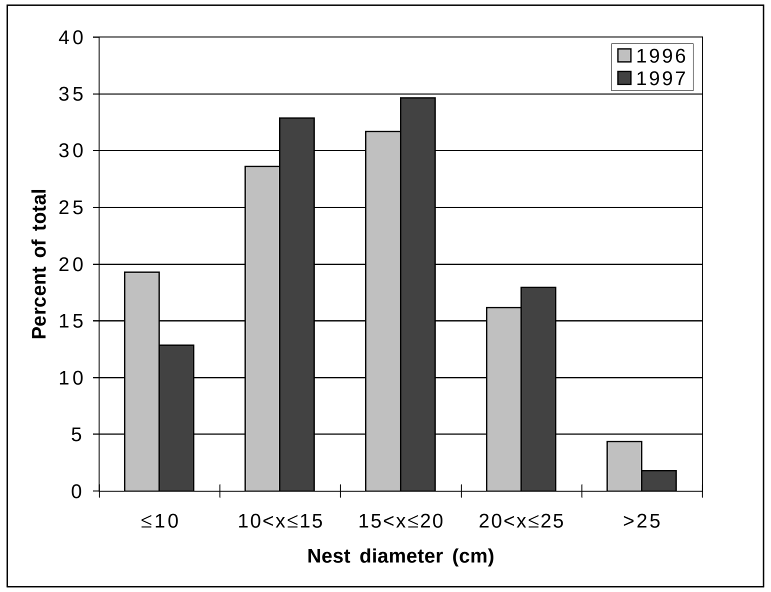


Fig. 5.7.3. Frequency of nest sizes within the 2.5 km² lemming census area at Zackenberg.

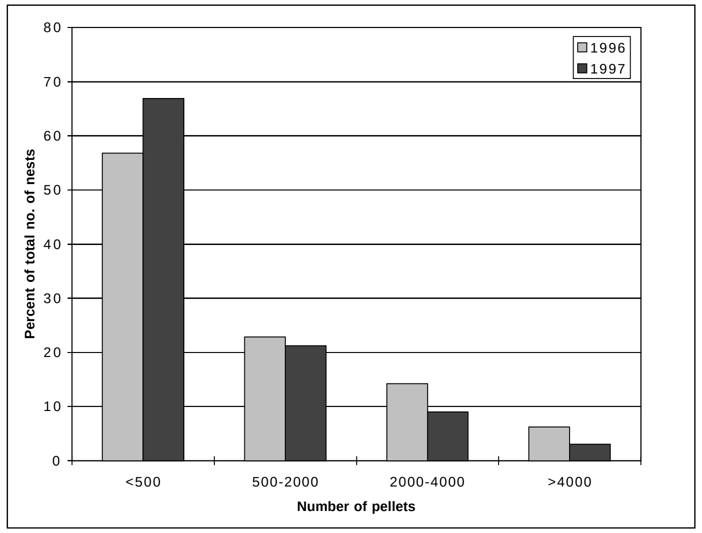


Fig. 5.7.4. Estimated number of lemming pellets per nest within the 2.5 km² lemming census area at Zackenberg.

the immediate vicinity of the nest. Also mosses and leaves of *Salix* and *Dryas* are frequently seen in the nest. Nests are seldom built exclusively of *Cassiope*. Neither was there any difference in the amounts of pellets per nest (Fig. 5.7.4).

Within the 2.5 km² lemming census area, 31 natural lookout sites were checked for casts from long-tailed skuas and snowy owls and scats from Arctic fox and ermine. In 1996, only eight sites (26.7% of the total number of sites) had casts from long-tailed skuas, and these were not necessarily from 1996. In 1997, 52% of the 31 sites contained 44 casts from long-tailed skuas, ten scats from Arctic fox and one scat from ermine. All of the recorded casts and scats in 1997 originated from the period mid August 1996 to mid August 1997. Considering the fact that long-tailed skuas leave the breeding ground between late July and early September, the 44 recorded casts from 1997 were most likely produced between early June and late August 1997. The high number of casts from long-tailed skuas supports in particular the assumption that 1997 was a peak year for lemmings in Zackenbergdalen.

Fig. 5.8. Detailed analyses of species composition, plant cover and biomass in one of the nine types of plant communities discernible on an aerial photo. By using the ITEX concept of vegetation analyses it is possible in the future to record changes of the vegetation structure and species composition. Photo: Fiona Danks.

5.8. Vegetation mapping of the Zackenberg study area

Christian Bay

Mapping of the major vegetation types of the study area at Zackenberg took place from mid July to mid August at the time of plant cover peak development.

A black and white aerial photo from 5 August 1987 in scale 1:25,000 was used to interpretate distribution of vegetation types. Based on a number of initial reconnaissances, vegetation was classified into nine types of plant communities which could be recognised on the aerial photo. Plant communities were characterised by composition and cover of vascular plant species, moss cover and relation to terrain and soil parameters. The main study area – Zone 1a – comprises a *c.* 3 km wide belt stretching in a north-east direction from the shore of Young Sund up the slopes of Aucellabjerg to an altitude of 600 m a.s.l. (see Fig. 4.3.1.1 in Meltofte & Thing 1997). In total, *c.* 19 km² have been ground truthed and mapped.

In each of the nine plant communities, vegetation analyses rendering detailed information on species composition, cover and biomass were completed. The ITEX concept of vegetation analyses was used (Fig. 5.8), making it possible to record changes of vegetation structure and species composition by re-analysing the permanently marked plots in the future. The vegetation is classified into: Fen, grassland, three types of dwarf shrub heath, snow-bed, two types of wind exposed habitats as well as salt marsh. The vegetation is very mosaic-like with homogenous patches of only a few hundred square metres. East of Zackenbergelven the lowland is dominated by *Cassiope tetragona* heath intersected by grasslands and *Salix arctica* snow-beds in the

Fig. 5.9.1. Male catkins of Arctic willow with ripening pollen capsules at the beginning of summer. Photo: David Klein.

Fig. 5.9.3. Fiona Danks and Christian Bay determining the sex ratio of Arctic willow plants along a transect line adjacent to Kærelv. Photo: David Klein.

low-lying depressions. On the west side of the river *Vaccinium uliginosum* heath is more abundant and fens are richer and have a higher species diversity. On the slopes of Aucellabjerg the vegetation changes and grasslands, *Dryas* dominated heaths and wind exposed habitats are dominating.

5.9. Herbivore influences on reproductive strategies of Arctic willow

David Klein, Christian Bay & Fiona Danks

Willows (*Salix* spp.) at high latitudes are a primary forage species for vertebrate herbivores. In the High Arctic of North America and Greenland, *Salix arctica*, the only abundant willow present, sustains heavy herbivory from muskoxen *Ovibos moschatus*, Peary caribou *Rangifer tarandus*, Arctic hares *Lepus arcticus* and lemmings *Dicrostonyx groenlandicus*. Willows are dioecious and Arctic willows show female-biased sex ratios. This research was designed to test the hypothesis that female Arctic willows are better defended against tissue loss to herbivores than male plants as a function of the different reproductive strategies of the two sexes.

Analysis of *Salix arctica* leaf tissues for tannin, nitrogen and *in vitro* digestibility is in progress, as is analysis of plant tissues in collected faeces of muskoxen, Arctic hares and lemmings. Results of data available to date, show that leaf growth of female willow plants was greater than that of male plants in six of seven sites sampled as measured by the weight of comparable numbers of leaves produced on inflorescense shoots (Fig. 5.9.1). This is surprising in that female plants have to support the cost of development of the catkins throughout the growth season, whereas male plants drop their smaller and lighter catkins following anthesis (Fig. 5.9.2). The sex ratio of Arctic willows was found to vary from near equality to 64 females to 36 males in the five sites sampled (Fig. 5.9.3). In the manipulations to simulate increased cloud cover as a function of climate change using shade tarps that reduced solar insolation by 50%, tannin levels of shaded willow leaves were significantly lower than those in the control plots in all three of the paired plots (Fig. 5.9.4). Changes in tannin and nitrogen levels and *in vitro* digestibility of male and female willow plants in relation to phenological progression remain to be analysed.

Christian Bay's mapping of the vegetation and measurement of biomass levels in the research areas in Zackenbergdalen (see section 5.8) provide a basis for assessing herbivore pressure on Arctic willows as part of this project. Samples of male and female willow leaves were also collected for collaborative investigations by Per Mølgaard at the Royal Danish School of Pharmacy in Copenhagen on the chemical nature and importance of secondary chemicals as antiherbivore defences.

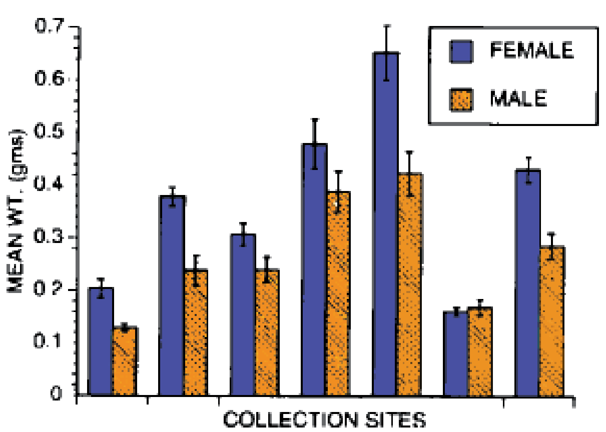


Fig. 5.9.2. Weights of leaves on inflorescense shoots of Arctic willow were greater in female than male plants in six of the seven sites sampled.

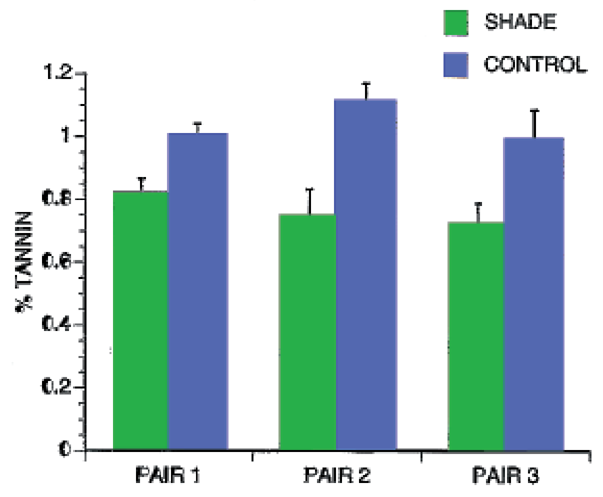


Fig. 5.9.4. Tannin levels were lower in leaves of Arctic willow subjected to simulated increased cloud cover (50% reduction of solar insolation) for a month during the growth season, in contrast to those in adjacent control plots.

5.10. Insect-pathogenic fungi in the Arctic

Jørgen Eilenberg, Heidi Elberling & Verner Michelsen

In temperate ecosystems, insect-pathogenic fungi are well-known. They can be important mortality factors that influence the population dynamics of species of Diptera, Hemiptera, Coleoptera, *etc.* In the Arctic, however, almost nothing is known about the occurrence of insect-pathogenic fungi.

During the summers of 1996 and 1997 adult Diptera were caught by Bo Elberling and Heidi Elberling at Zackenberg (see section 5.4 in Meltofte & Thing 1997 and section 5.5 in this volume). Immediately after capture the insects were preserved in alcohol. Diagnosis showed presence of an insect-pathogenic fungus, *Strongwellsea* sp. (Zygomycotina: Entomophthorales) in eight specimens of *Spilogone dorsata* (1996) and in 4-5 specimens of *S. micans*, S. *sanctipauli* and *S. dorsata* (1997). The fungus has a rather unique life cycle: during infection one or two abdominal holes develop in infected individuals who may survive several days with such holes. Infective spores are projected actively from the holes causing new infections.

The main character for species identification of *Strongwellsea* species is spore morphology. So far, the measured spores are different from the two described species of *Strongwellsea* and the fungus infecting the Arctic *Spilogona* spp. may prove to be an undescribed Arctic species in the genus.

We have recently initiated a search for *Strongwellsea* infected specimens among insects caught in traps by the BioBasis programme in 1996 and 1997 (see section 4.2 in Meltofte & Thing 1997 and this volume). Several other species from the genus *Spilogona* may be infected by the fungus.

Fig. 5.10. Adult Spilogona dorsata *infected with* Strongwellsea *sp. The infection causes two abdominal holes.*

5.11. Behavioural and morphological differentiation among bumblebee *Bombus polaris* workers

Henrik Barner Rasmussen

Bumblebees are a group of social bees showing both advanced and primitive social traits, and they are therefore referred to as being primitively eusocial. One of the more primitive traits is the presence of only one morphologically distinct worker cast. Another primitive trait is that workers do not shift between discrete behavioural classes during ageing. This is known as age polytheism.

There are, however, reports of some degree of behavioural changes among workers during colony ageing (Cameron 1989). Also size of workers has been shown to influence the probability of engaging in foraging *vs. e.g.* nursing (Goldblatt & Fell 1987). All of these studies have dealt with species producing several broods of workers, and none has been on Arctic species.

Two species of bumblebees occur in Greenland, *Bombus hyberboreus* and *Bombus polaris*. The first is a nest parasite of the latter and only rarely produce workers of their own.

B. polaris produces only around 15 workers in one small brood before initiating the production of sexuals. This very limited colony size must be an adaptation to the short Arctic summer, which does not allow for the production of a second worker brood. To elucidate what effect this strongly reduced colony size has on work partitioning among workers, a time study of individual worker activity was carried out.

Three nests were located east of Zackenbergelven. Nest no. 1 contained two dead queens (one *B. polaris* and one *B. hyberboreus*) together with one dead and 17 living *B. polaris* workers. Nest no. 2 contained one *B. hyberboreus* queen and eight *B. po-*

laris workers and nest no. 3 contained one *B. polaris* queen and 11 *B. polaris* workers.

All workers from each nest were captured and given individual colour codes on the thorax.

Each nest was monitored between 14 and 18 hours during a period of 10 days and all individual departures and arrivals were noted, totalling more than 1000 recordings.

Of the 36 marked workers 28 were recaptured after the monitoring period and weight and head width were measured.

Both the *B. hyberboreus* and *B. polaris* queens in nest no. 2 and 3 were engaged in foraging, spending respectively 58% and 90% of the time away from the nest. This deviates from the behaviour seen in other species where queens seldom leave the nest after the appearance of the first workers.

In all three nests there was a clear partitioning between foraging and nursing workers. Foraging workers spent between 40% and 90% of the time away from the nest (average 63%), and nursing workers spent max. 5% of the time away from the nest (17 out of 19 were not leaving the nest at all). Of the 28 workers recaptured, 17 were regarded as being nursing and 11 as being foraging workers.

The average head width of foraging and nursing workers were 5.36 mm and 4.91 mm, respectively (ANOVA $p < 0.001$). Within each nest, there was no size overlap between the two groups.

This indicates two behaviourally and morphologically discrete groups of workers in *Bombus polaris*. This almost subcast differentiation of workers is among the most pronounced seen in bumblebees.

6. Disturbance

6.1. 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 (Table 6.1) increased to 954 days in 1997 as compared to 670 in 1996 and 230 in the initial season of 1995. The number of person-days spent in the low impact study area (1b) and in the protection zone for moulting geese along the coast (1c) is still relatively low. Research zone 2 was visited only in connection with the two line transects (see sections 4.3.6 and 4.4.4).

The most obvious impact of our presence in the area is that moulting pink-footed geese still avoid the areas immediately south of the station, and the family groups of barnacle geese have been displaced to the least disturbed parts of the valley (see sections 4.3.5 and 4.3.8). Also the muskox seemed to some extent to have been displaced from Rylekærene during the rutting season in August (see section 4.4.2.2).

On 8 August, an eight wheeled all terrain vehicle (ATV) was flown in from the cargo ship in Daneborg. The vehicle is constructed to exert minimum impact on the terrain surface. To concentrate future motorised traffic on specific 'roads', a track between the research station and the trace gas exchange study site in the westernmost part of Rylekærene was staked out. 11 ATV round trips were made between the research station and this site, and one trip was made between the research station and the old Zackenberg trapping station at the coast, driving almost exclusively in the river bed and in the littoral zone along the fjord coast.

Table 6.1. 'Person-days' and trips in the terrain (zone 1a) with an ATV (all terrain vehicle) allocated to the research zones in the Zackenberg study area 27 May – 31 August 1997.

Research zone	May	June	July	August	Total
1	35	222	327	370	954
1b	1	4	24	23	52
1c (20.6–10.8)			1		1
2			6	6	12
ATV–trips				12	12

6.2. Aircraft activities in the study area

The number of fixed-winged aircraft take-off and landings was almost twice as high in 1997 (Table 6.2) as in 1996. Part of the increase was caused by the extra flights in connection with the official opening of the research station and by the Danish Parliament's Finance Committee in August (see section 1.1, 9.3 and 9.4).

Table 6.2. Number of flights with fixed-winged aircraft and helicopters over the study area in Zackenbergdalen 21 May – 1 September (two flights on the latter date are included under August). Each ground visit of an aircraft is considered two flights.

Type of aircraft	May	June	July	August	Total
Fixed–wing	12	12	38	58	120
Helicopter		4	3	6	13

6.3. Discharges

Waste was treated in the same way as in 1996 (see Meltofte & Thing 1997). The total amount of untreated wastewater let into Zackenbergelven from the kitchen, showers, sinks and laundry machines equalled 1300 'person-days'.

6.4. Manipulative research projects

In the seed dynamics study plot south of the Zackenberg station (UTM zone 27: 512623 m E, 8264264 m N) a total of *c.* 180 g N, 75 g P and 210 g K was added on 4 August (see section 5.4).

In a study plot in Tørvekæret (513343 m E, 8265440 m N) a total of 375 g glucose was added on 8 August. In a similar study plot just south of the station (512625 m E, 8264159 m N) a total of 22.5 g N and 4.86 g P was added in August. In the plot south of the station, even water was added weekly during July and August (for both plots, see sections 5.1.2 and 5.1.5).

6.5. Take of organisms

A total of 3610 g (dry weight) leaves and twigs of *Salix arctica* were collected close to the station. Furthermore, small samples of leaves from *Dryas sp.* and *Carex ruprestris* were taken here, and leaves of *Poa arctica* were collected in Tørvekæret (see sections 5.1.2, 5.1.5 and 5.9).

In 30 plots, each of 25 x 25 cm^2, situated *c.* UTM 513200 m E, 8266000 m N (zone 27), all vegetation above the soil surface was harvested in late August (see section 5.1.1).

Besides the sampling of invertebrates described in sections 4.2 and 5.5, ten *Bombus hyperboreus* queens were collected in the study area west of Zackenbergelven, and three nests were collected east of the river (see section 5.11).

In three lakes in Morænebakkerne, a total of 19 dwarf (7.5-13.5 cm) Arctic char *Salvelinus alpinus* were collected in August. Ten were taken in Hjertesø (511000 m E, 8268635 m N), seven in Boresø (511455 m E, 8268385 m N) and two in Langemandssø (511935 m E, 8267890 m N) (see section 5.3.3). As in previous years, a few hundred Arctic char were caught off the coast adjacent to the old trapping station.

7. Economic investment in ZERO

With the Zackenberg station established and fully functional it is possible to provide a status for the total economic support that has been funneled into the ZERO programme. Since the start of the pioneering year 1991 and until the end of 1997 a total of DKK 8,400,000 covered logistics in general. During the same period long-term ecosystem monitoring required DKK 6,400,000 whereas research projects in context with the ZERO concept were allocated a total of DKK 15,000,000.

8. Publications from ZERO

8.1. Scientific papers

Buhl, P.N. 1997: Microhymenoptera from Zackenberg, North East Greenland (Hymenoptera: Chalcidoidea, Cynipoidea et Ceraphronoidea). – Ent. Meddr 65: 161-164.

Rysgaard, S. & Berg, P. 1996: Mineralization in a northeastern Greenland sediment: mathematical modelling, measured sediment pore water profiles and actual activities. – Aquatic Microbial Ecology 11: 297-305.

8.2. Reports

Danish Polar Center 1997: BioBasis: Conceptual design and sampling procedures of the biological programme of Zackenberg Basic. Version of April 1997. – Danish Polar Center, Ministry of Research and Information Technology.

Fredskild, B. & Mogensen, G.S. 1997: ZERO Line Final Report 1997. A description of the plant communities along the ZERO line from Young Sund to the top of Aucellabjerg and the common plant communities in the Zackenberg valley, Northeast Greenland. – Greenland Botanical Survey & Botanical Museum, University of Copenhagen.

Meltofte, H. & Thing, H. (eds.) 1997: Zackenberg Ecological Research Operations, 2nd Annual Report, 1996. – Danish Polar Center, Ministry of Research and Information Technology.

Tamstorf, M.P. 1997: Analyse af sne- og vegetationsdækket ved Zackenberg, NØ-Grønland, ved brug af Landsat TM og SPOT HRV images. – Geographica Hafniensia C4.

8.3. General information

Anon. 1997: New Ecological Research Station Increases Arctic Access. – Witness the Arctic 5(1): 17.

Anon. 1997: Zackenberg *p. 85 in:* Logistics Recommendations for an Improved U.S. Arctic Research Capability. – U.S. Arctic Research Commission.

Bondo, P. 1997: Åbningsfest på Zackenberg. – Polarfronten 1997(3): 3.

Böcher, J. 1997: Feature locality: The Zackenberg Ecological Research Station, Greenland. – Arctic Insect News 8: 4-9.

Christiansen, H.H. 1997: News from members. Denmark/Greenland. – Frozen Ground 21: 9-10.

Elberling, B. & Jakobsen, B.H. 1997: Variations in soil solution of Arctic brown soils at Zackenberg, Northeast Greenland. – Abstract and oral presentation at The II International Conference for Cryopedology, Syktyvkar, Russia, Aug 5-8, 1997.

Humlum, O. 1996: Zackenberg; The GeoBasis Programme. – Northern Sciences Network Newsletter 20: 20-22.

Jeppesen, H. 1997: Zackenberg feltstation i nord. – Hovedområdet 26(6): 14-15.

Kjærgaard, J.J. 1997: Zackenberg år 0 til plus 2. – Berlingske Tidende 22. april 1997.

Kjærgaard, J.J. 1997: Zackenberg som alarm i en sart natur. – Berlingske Tidende 19. august 1997.

Knippel, L.O. 1997: Forpost mod nord. – Jyllandsposten 29. april 1997.

Meltofte, H. 1997: Zackenberg Ecological Research Operations (ZERO): A new research facility in High Arctic Greenland. – Wader Study Group Bull. 82: 46-50.

Philbert, P.-E. 1997: 100 dage under midnatssolen. – Polarfronten 1997(2): 10.

8.4. Supplementary list of publications

Andreassen, J. 1991: Miljø-base i Østgrønland. – Berlingske Tidende 30. juni 1991.

Fischer, K. 1984: Der er isbjørne, hvalrosser og polarræve i parken. – Politiken 19. februar 1984.

Fischer, K. 1994: Der sker noget i verdens største nationalpark. – Berlingske Tidende 21. marts 1994.

Nielsen, R.H. 1991: År nul før drivhuseffekten. – Ingeniøren 1991(22).

9. Personnel and visitors

9.1. Research

9.1.1. Zackenberg

Henriette Anbro, student, Institute of Geography, University of Copenhagen (GeoBasis and remote sensing, 27 May – 22 July)

Jonathan D. Carl, M.Sc., National Environmental Research Institute, Denmark (fish ecology, 23 July – 5 August; see also section 9.1.2)

Christian Bay, Ph.D., Botanical Museum, University of Copenhagen (vegetation mapping and plant ecology, 23 July – 19 August)

Thomas Bjørneboe Berg, M.Sc., Danish Polar Center (BioBasis, lemming ecology and station manager, 12 July – 1 September)

Torben Røjle Christensen, Ph.D., Dept. of Plant Ecology, University of Lund (trace gas exchange, 22-26 June and 5-19 August)

Kirsten Christoffersen, Ph.D., Freshwater Biological Laboratory, University of Copenhagen (freshwater ecology, 5-19 August)

Fiona Danks, student, Institute of Arctic Biology, University of Alaska Fairbanks (plant ecology, 12 July – 19 August)

Bo Elberling, Ph.D., Institute of Geography, University of Copenhagen (GeoBasis, pedology, soil solution and plant ecology, 13-23 June and 19-31 August)

Heidi Elberling, Ph.D. student, Botanical Institute, University of Copenhagen (plant ecology, 14 June – 11 August)

Birgit Hagedorn, Ph.D., Alfred Wegener Institute for Polar and Marine Research (water chemistry and sediment transport, 12-21 July)

Birger Ulf Hansen, Ph.D., Institute of Geography, University of Copenhagen (remote sensing, 15 July – 5 August)

Bent Hasholt, Ph.D., Institute of Geography, University of Copenhagen (water chemistry and sediment transport, 12-21 July)

Lotte Illeris, M.Sc., Botanical Institute, University of Copenhagen (trace gas exchange, 5 August – 1 September)

Thomas Friborg Jacobsen, Ph.D., Institute of Geography, University of Copenhagen (trace gas exchange, 27 May – 13 June and 5-31 August)

Bjarne Holm Jakobsen, Ph.D., Institute of Geography, University of Copenhagen (pedology, 13-23 June)

Erik Jeppesen, M.Sc., National Environmental Research Institute, Denmark (freshwater ecology, 5-19 August)

Jed Kaplan, Ph.D. student, Dept. of Plant Ecology, University of Lund (trace gas exchange, 22 June – 5 August)

David R. Klein, Professor, Ph.D., Institute of Arctic Biology, University of Alaska Fairbanks (plant ecology, 12 July – 19 August)

Frank Landkildehus, M.Sc., National Environmental Research Institute, Denmark (freshwater ecology, 5-19 August)

Hans Meltofte, D.Sc., Danish Polar Center (station manager and BioBasis, 27 May – 30 July)

Anders Michelsen, Ph.D., Botanical Institute, University of Copenhagen (plant ecology and trace gas exchange, 5-19 August)

Claus Nordstrøm, Ph.D. student, Institute of Geography, University of Copenhagen (trace gas exchange, 27 May – 31 August)

Steen B. Pedersen, student, Institute of Geography, University of Copenhagen (GeoBasis and remote sensing, 12 July – 19 August)

Morten Rasch, Ph.D., Institute of Geography, University of Copenhagen (GeoBasis, 27 May – 13 June and 11-26 August)

Henrik Barner Rasmussen, student, Danish Polar Center (BioBasis and invertebrate ecology, 27 May – 19 August)

Ronald S. Sletten, Ph.D., Quaternary Research Center, University of Washington (reconnaissance for pedology study, 11-19 August)

Martin Sommerkorn, Ph.D. student, Institute for Polar Ecology, University of Kiel (trace gas exchange, 27 May – 23 June and 4-19 August)

Henrik Søgaard, Ph.D., Institute of Geography, University of Copenhagen (trace gas exchange, 8-26 July)

9.1.2. Daneborg

Allan Bredahl, National Environmental Research Institute, Denmark (logistics, 2 February – 1 March)

Jens Borum, Ph.D., Freshwater Biological Laboratory, University of Copenhagen (marine vegetation, 4-25 August)

Jonathan D. Carl, M.Sc., National Environmental Research Institute, Denmark (fish ecology, 5-25 August; see also section 9.1.1)

Peter Bondo Christensen, Ph.D., National Environmental Research Institute, Denmark (marine biology, 10-22 August)

Magnus Elander, Ph.D., Amarok AB, Sweden (marine biology, 4-25 August)

Göran Ehlmé, Water Proof Diving AB, Sweden (underwater photography, 4-25 August)

Søren Rysgaard, Ph.D., National Environmental Research Institute, Denmark (marine biology, 2 February – 1 March and 4-25 August)

9.2. Logistics and construction, Zackenberg

Aksel Andersen, Venslev Cabins (building, 12-26 July)

Hauge Andersson, Danish Polar Center (logistics officer, 24-26 August)

Niels Kristian Jensen, Danish Polar Center (logistics assistant, 21 May – 23 June)

Kjeld Johnsen, Venslev Cabins (building, 12-26 July)

Henrik Lassen, Danish Polar Center (logistics assistant, 21-22 May, 5-18 August and 25 August – 1 September)

Kresten Mathiasen, Danish Polar Center (logistics manager, 12 July – 1 September)

Kenn Nielsen, Danish Polar Center (logistics manager, 21 May – 30 July)

Henrik Philipsen, Danish Polar Center (cook, 27 May – 1 September)

Bent Sørensen, Nalunngilaa Electronic, Nuuk (technician, 22-26 June)

9.3. Guests for the opening of the Zackenberg Ecological Research Station

Jytte Hilden, Minister of Research and Information Technology

Marianne Jensen, Minister of Health, Environment and Research, Greenland Home Rule Government

Martha Abelsen, Director, Department of Health and Research, Greenland Home Rule Government

N.C. Borck, Captain, Danish Navy Chief of Defence Command

Torben Daltoft, Head of Division for International Programme Cooperation, National Forest and Nature Agency

Jens Peder Hart Hansen, Chairman, The Commission for Scientific Research in Greenland

Mogens Holm, Research coordinator, Greenland Home Rule Government

Henrik Jeppesen, Dean, Faculty of Science, University of Copenhagen

Knud Larsen, Deputy minister, Ministry of Research and Information Technology
Morten Meldgaard, Director, Danish Polar Center
Søren Hald Møller, Director, Department of Environment and Nature Management, Greenland Home Rule Government
Jette Søgreen Nielsen, Personal secretary to the Minister of Research and Information Technology
Palle Norit, Commander, Patrol Branch of the Danish Navy Chief of Defence Command
Klaus Nygaard, Director, Greenland Institute of Natural Resources
Ove Poulsen, Research director, Ministry of Research and Information Technology
Lars Ulsø, Lieutenant, Patrol Branch of the Danish Navy Chief of Defence Command

9.4. Participants in the visit by the Danish Parliament's Finance Committee

Peter Duetoft, Chairman of the Danish Parliament's Finance Committee
Helle Degn, Member of the Danish Parliament's Finance Committee
Tommy Dinesen, Member of the Danish Parliament's Finance Committee
Bjørn Elmquist, Member of the Danish Parliament's Finance Committee
Pia Gjellerup, Member of the Danish Parliament's Finance Committee
Klaus Hækkerup, Member of the Danish Parliament's Finance Committee
Karen Højte Jensen, Member of the Danish Parliament's Finance Committee
Christian Mejdahl, Member of the Danish Parliament's Finance Committee
Peter Bohlbro, Head of secretariat, The Danish Parliament's Finance Committee
Uffe Toudal, Assistent secretary of state, Prime Ministers Office
Poul Henrik Sørensen, Deputy director, Danish Polar Center
Sonia Westall, Secretary, The Danish Parliament's Finance Committee

9.5. Other

Henning Thing, Ph.D., Danish Polar Center (supervision of ZERO, 27 May – 13 June and 5-26 August)

9.6. Further contributors to the annual report

Kristian Dalsgaard, M.Sc., Institute of Geology, University of Aarhus
Jørgen Eilenberg, Ph.D., Royal Veterinary and Agricultural University, Denmark
Bent Fredskild, Ph.D., Botanical Museum, University of Copenhagen
Sven Jonasson, Professor, Ph.D., Botanical Institute, University of Copenhagen
Peter van der Keur, Ph.D. student, Institute of Geography, University of Copenhagen
Verner Michelsen, Ph.D., Zoological Museum, University of Copenhagen

10. Acknowledgements

The activities by the Danish Polar Center at Zackenberg and at Daneborg during 1997 were made possible through generous grants from the 'Commission for Scientific Research in Greenland' to the Center's logistic platform and ZERO.

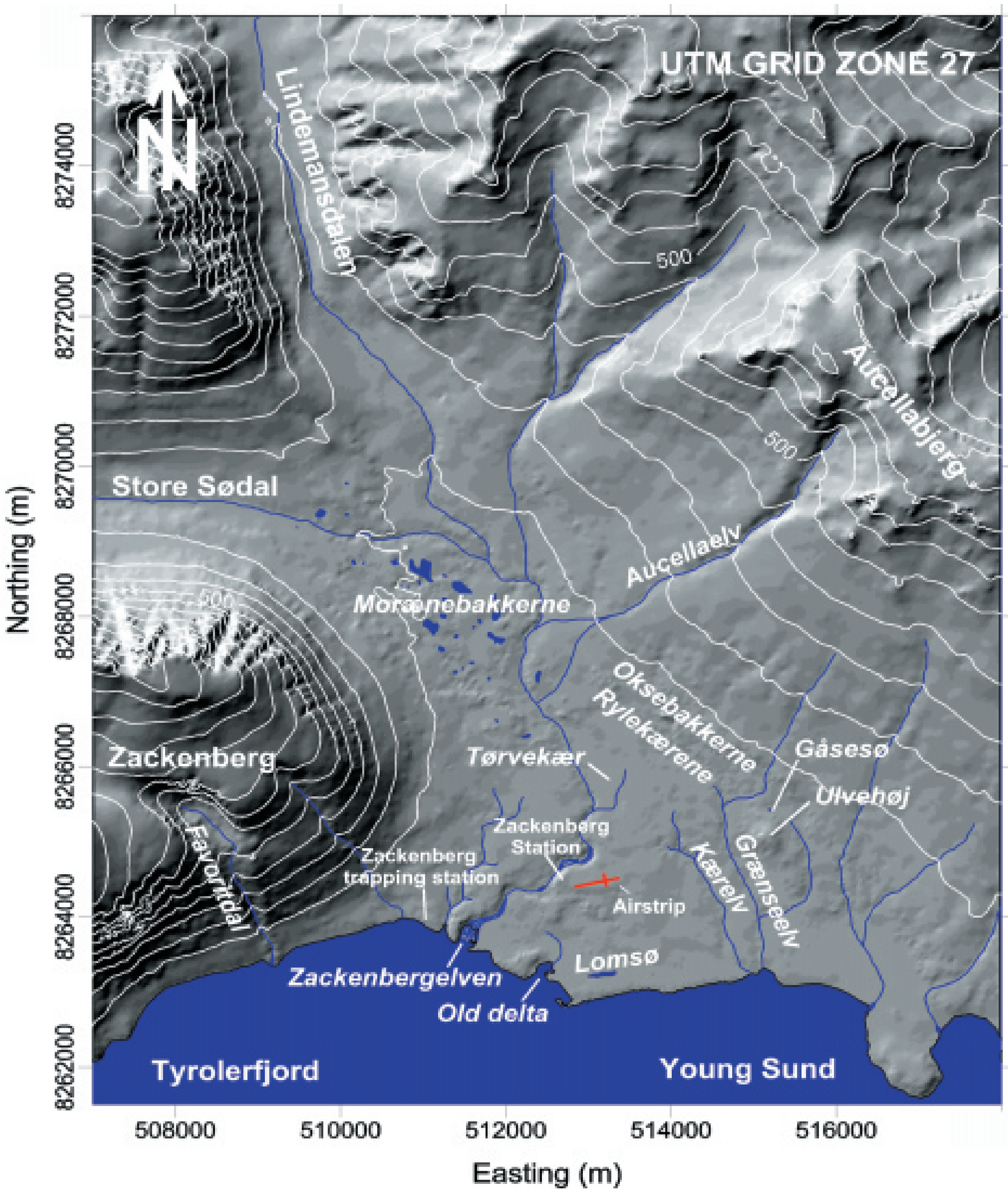
The 'Danish Fund for Environment and Disaster Releaf' (MIKA), Ministry for Environment and Energy, provided economic support for the monitoring programme, Zackenberg Basic.

SIRIUS, the military sledge patrol in Northeast Greenland, readily offered valuable assistance during the field season, and Air Iceland together with Greenlandair provided, as always, a competent and flexible service.

Árni Einarsson, Háskóli Íslands, kindly helped with the production of window traps for insects.

11. References

Boertmann, D. 1994: An annotated checklist of the birds of Greenland. – Meddr Grønland, Biosci. 38, 63 pp.
Cameron, S.A. 1989: Temporal patterns of division of labor among workers in the primitively eusocial Bumble bee *Bombus griseocollis* (Hymenoptera, Apidae). – Ethology 80: 137-151.
Christensen, T.R., Jonasson, S, Michelsen, A., Callaghan, T.V. & Havstrøm, M. in press: Environmental controls on soil respiration in the Eurasian and Greenlandic Arctic. – Journal of Geophysical Research.
Christiansen, H.H. & Humlum, O. 1993: Glacial history and periglacial landforms of the Zackenberg area, Northeast Greenland: Preliminary results. – Geografisk Tidsskrift 93: 19-29.
Danish Polar Center 1997: BioBasis: Conceptual design and sampling procedures of the biological programme of Zackenberg Basic. Version of April 1997. – Danish Polar Center, Ministry of Research and Information Technology.
Elberling, B. & Jakobsen, B.H. 1997: Variations in soil solution of Arctic brown soils at Zackenberg, Northeast Greenland. – Abstract and oral presentation at The II International Conference for Cryopedology, Syktyvkar, Russia, Aug 5-8, 1997.
Fossing, H., Gallardo, V.A., Jørgensen, B.B., Hüttel, M., Nielsen, L.P., Schulz, H., Canfield, D.E., Forster, S., Glud, R.N., Gundersen, J.K., Küver, J., Ramsing, N.B., Teske, A., Thamdrup, B. & Ulloa, O. 1995: Concentration and transport of nitrate by the mat-forming sulphur bacterium Thioploca. – Nature 374: 713-715.
Goldblatt, J.W. & Fell, R.D. 1987: Adult longevity of the workers of the bumblebee *Bombus fervidus* (F) and *Bombus pennsylvanicus* (De Geer) (Hymenoptera, Apidae). – Can. J. Zool. 65: 2349-2353.
Jakobsen, B.H. 1992: Zackenbergområdets naturgeografi. – Naturens Verden 8: 306-313.
Jeppesen, E. 1997: The ecology of shallow lakes – trophic interactions in the pelagial. – DSc-thesis (submitted).
Matthews, J.A. 1980: Some problems and implications of ^{14}C dates from a podzol buried beneath an end moraine at Haugabreen, southern Norway. – Geografiska Annaler 62A: 185-208.
Meltofte, H. & Thing, H. (eds.) 1996: Zackenberg Ecological Research Operations. 1st Annual Report, 1995. – Danish Polar Center, Ministry of Research & Technology.
Meltofte, H. & Thing, H. (eds.) 1997: Zackenberg Ecological Research Operations, 2nd Annual Report, 1996. – Danish Polar Center, Ministry of Research and Information Technology.
Nelson, F., Brown, J., Lewkowicz, T. & Taylor, A. 1996: Active layer protocol. Pp. 14-16 *in* Molau, U. & Mølgaard, P. (eds.): ITEX Manual. Second Edition. – Danish Polar Center.
Rysgaard, S. & Berg, P. 1996: Mineralization in a northeastern Greenland sediment: mathematical modelling, measured sediment pore water profiles and actual activities. – Aquatic Microbial Ecology 11: 297-305.
Rysgaard, S. & Berg, P. in prep.: Annual carbon and nitrogen mineralization in sediments: Mathematical modelling, measured sediment porewater profiles and actual activities from Young Sound (Greenland).
Sittler, B. 1995: Response of stoats (*Mustela erminea*) to a fluctuating lemming (*Dicrostonyx groenlandicus*) population in North East Greenland: preliminary results from a long-term study. – Ann. Zool. Fennici 32: 79-92.
Ugolini, F.C., Sletten, R.S. & Marrett, D.J. 1990: Contemporary pedogenic processes in the Arctic: brunification. – Science du Soil 28: 333-348.
Vugakov, P.S. & Popova, Y.P. 1968: Carbon dioxide regime in soils of the Krasnoyarsk forest steppe. – Sov. Soil Sci. 6: 795-800.



APPENDIX 1.
The core of the Zackenberg study area with place names. All unofficial place names are given in italic.