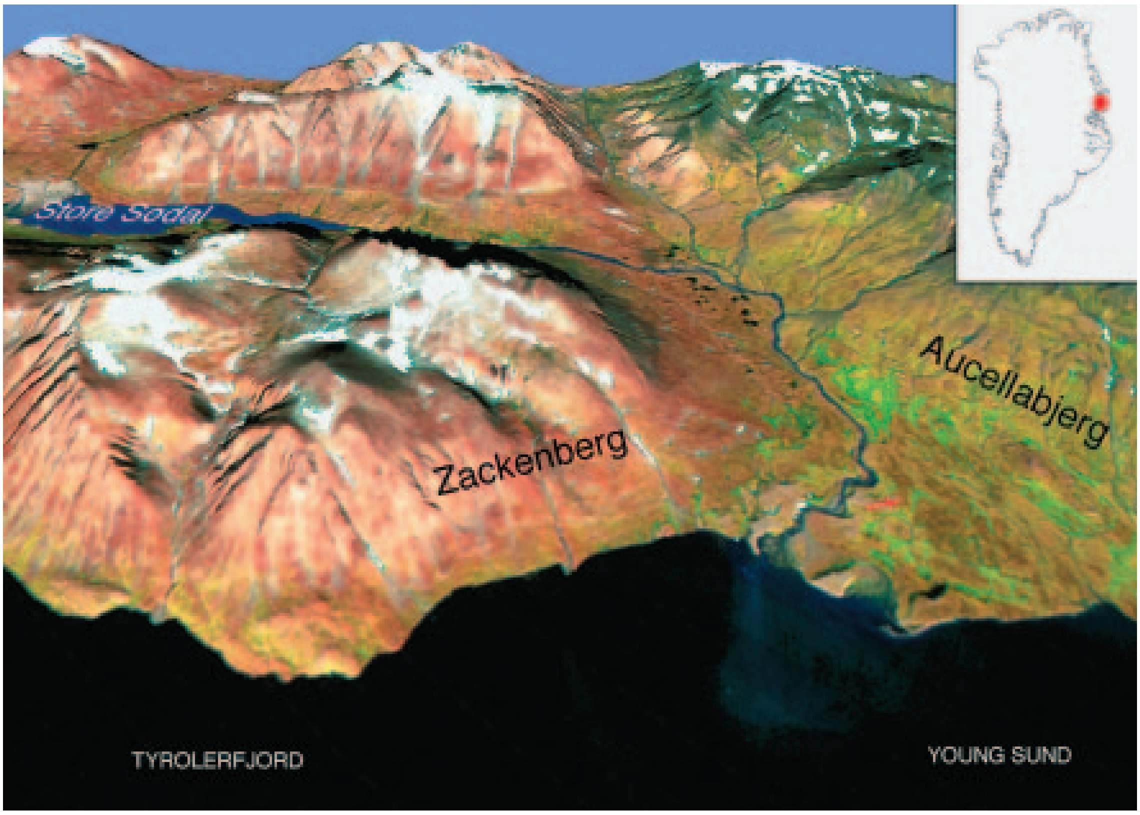
ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

2nd Annual Report 1996



Danish Polar Center

Ministry of Research & Information Technology

1997

Zackenberg Ecological Research Operations

2nd Annual Report, 1996

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Cover photo:
Zackenberg and a greater part of the study area as seen from the LANDSAT satellite orbiting c. 900 km above Earth. The imagery from space has been fitted into the Zackenberg digital 3-D terrain model and appears as a thematic layer useful in recording changes in vegetation and snow-cover. The 450 m / 140 m runways adjacent to the Zackenberg station have been added to provide a scale.
Computer manipulation: Mikkel Tamstorf

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Executive summary

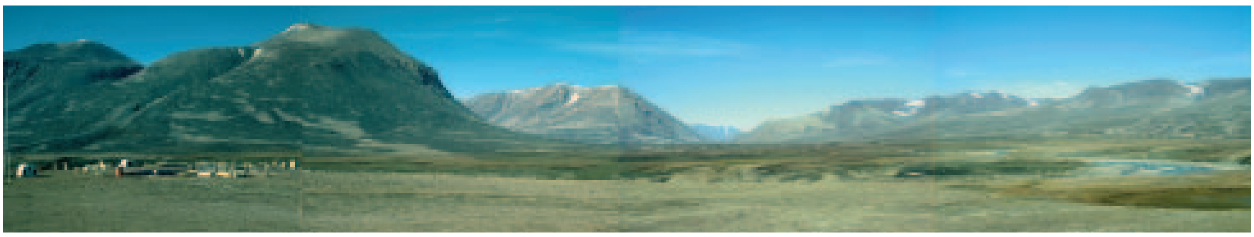
The Danish Polar Center launched the ZERO concept in 1991 but not until 1995 did the construction of the Zackenberg station start. In 1996 the main logistic efforts were the transportation from Denmark of 42 tons of building material, equipment and provisions as well as the erection of five permanent houses to host kitchen & mess, wet laboratory & showers/washing, dry laboratory & work space, Zackenberg Basic & work space, station office & communication & storage. Accommodation is allocated to a number of shelters adjacent to the houses. All logistic expenses in 1996 have been covered by a grant from the 'Commission for Scientific Research in Greenland'.

The 1996 field season was 100 days long with 1200 person-days logged at the Zackenberg station and an additional 300 person-days at the branch facility in Daneborg (25 km SSE of Zackenberg). This is a five-fold increase from 1995. Twentyeight scientists were in the field during the season. Two major multi-disciplinary projects as well as seven smaller ones represented the research part of ZERO in 1996. Furthermore, five staff members and four construction workers were responsible for operating the station and erecting the buildings. An additional five person were engaged in running the long-term ecosystem monitoring programme, Zackenberg Basic.

As Zackenberg Basic was initiated in July – August 1995 we now have the first 12 consequtive months of data on selected ecosystem parameters revealing the outline of the abiotic framework of the study area and the living conditions and constraints for the biotic elements that are monitored. Zackenberg Basic was funded in full by a grant from the 'Danish Fund for Environment and Disaster Releaf' (MIKA). In chapters 3 and 4 details and interpretations are given on the 1995-1996 data on abiotic parameters (GeoBasis) and biotic parameters (BioBasis), respectively. The fact that long-term ecosystem monitoring is an integrated part of ZERO's service offered to researchers makes Zackenberg a unique facility.

Research in relation to ecosystem dynamics and 'Global Change' is given priority at Zackenberg. In 1996, research focused on themes such as feedbacks and interactions among landscape processes, palaeo-ecological archives, nutrient turn-over in the coastal marine ecosystem, plant seed dynamics, lemming population dynamics, and muskox reproductive strategies. The 1996 research projects were funded through grants from 'Danish Research Councils' Polar Programme', Danish Natural Science Council, Alfred Wegener Institute for Polar and Marine Science, Germany, Max Planck Institute for Marine Microbiology, Germany, Institute of Biological Sciences, University of Aarhus. Results, interpretations and conclusions of the research projects are presented in chapter 5.

ZERO, composed of the three elements: research, monitoring and logistics, is executed within a conceptual and scientific framework approved by Danish and Greenlandic authorities. The Danish Polar Center is responsible for operating the station and the ecosystem monitoring, Zackenberg Basic. Before access is granted to any research activity within the Zackenberg study area, proposed project objectives and methods must be submitted to the Danish Polar Center. The procedures and all information pertinent to projects at Zackenberg are readily available from the Danish Polar Center electronic homepage at the Internet.



Zackenbergdalen in a 180 ° panoramic view 13 August 1996. To the left is the station with white shelters and building material distributed around the foundations for the five houses to be erected. Behind the station is Zackenberg proper with its 1,372 m summit. The river Zackenbergelven, visible to the right, is the main watercourse of the region and drains the entire 600 km² study area. Please confer the topographic map with locality names on p. 79 for further details on landscape features. *Photo: Danish Polar Center / Henning Thing*

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1. Introduction

In 1996 ZERO reached and passed two important milestones: 1) The five planned station buildings were erected and 2) the first multi-disciplinary ZERO research projects were launched in full scale.

The ZERO concept has received further attention by national and international funding agencies and research communities. The accomplishments in 1996 now provide a well-founded platform for finalising the station logistics and for an improved service to future High Arctic ecosystem research.

Zackenberg is located in the National Park of North and East Greenland. The ZERO concept, framework and logistics have been approved by the Greenland Home Rule and Greenland continues to play an essential part in providing improved opportunities for year-round ecosystem research and monitoring in the High Arctic.

Photo: Danish Polar Center / Henning Thing

1.1 The ZERO concept

ZERO has three main components: Research – Monitoring – Logistics. Each of them plays a synergistic rôle and the concept objective is the production of an effectively concerted action focused on disclosing the dynamics of an undisturbed High Arctic ecosystem.

'ZERO' is the acronym for 'Zackenberg Ecological Research Operations' as well as it is a reminder of the need to establish a zero line knowledge of the intrinsic plasticity and flexibility of ecosystem parameters in a High Arctic region that has hitherto received zero disturbance and manipulation by people and human activities.

Not until we know the natural dynamics of an *unchanged* 'zero ecosystem' can we engage in defining *change* in relation to anthropogenic effects with widespread consequences.

The thrust of ZERO research and monitoring is implemented as:

– basic quantitative documentation of ecosystem structure and processes,
– baseline studies of intrinsic short-term and long-term variations in ecosystem functions,
– retrospective analyses of organic and inorganic material to detect past ecosystem changes, and
– experimental studies enabling predictions of ecosystem responses to Global Change.

ZERO – 10

1. Zackenberg is the only High Arctic research station in Greenland.

2. Zackenberg is located in the most pristine ecosystem of the Northern Hemisphere.

3. Zackenberg secures – through planning, regulation and co-ordination, that the undisturbed study area will receive the least possible impact from human presence in relation to research and monitoring.

4. Zackenberg is the closest land-based neighbour to the Greenland Sea pivot of the 'Great Conveyour Belt of the Oceans' (the density driven sea current 'pump' with essential significance for global energy balance and climate trends). Hence, ecosystem changes caused by possible future switches in the 'pump' are likely to be detectible here first.

5. Zackenberg offers an easy access to research in natural paleo-ecology and paleo-climate 'archives'.

6. Zackenberg study area holds an exceptionally high biotic and geomorphic diversity.

7. Zackenberg is the only Arctic research station with long-term ecosystem monitoring (Zackenberg Basic) as an integrated part of its functions.

8. Zackenberg Basic monitors an entire catchment area (c. 600 km^2).

9. Zackenberg Basic display all spatial data as thematic elements in a digital 3-D terrain model of the entire monitoring area.

10. Zackenberg Basic data are published in a database, accessible on the Internet.

Definitions

ZERO

is the acronym for 'Zackenberg Ecological Research Operations'. ZERO includes all activities taking place in relation to Zackenberg (and its branch facility in Daneborg), i.e. planning, administration, logistics, research, monitoring, and publishing.

Zackenberg Station

is a sub-division of ZERO. The station (and its branch in Daneborg) provides the physical framework for research projects and for monitoring.

Zackenberg Basic

is a sub-division of ZERO. It is a long-term monitoring programme providing baseline data on selected ecosystem parameters in the study area. *BioBasis* handles all biotic parameters and *GeoBasis* handles all abiotic parameters.

Research Projects

are a sub-division of ZERO. The projects are individual scientific activitites, either uni- or multi-disciplinary. Research projects are funded independently and are accepted at Zackenberg with due consideration to the 'ZERO Framework' approved by the Danish Natural Science Council.

Science Advisory Group

The planning, structuring and implementation of the packaged service to High Arctic ecosystem science are provided by the Danish Polar Center in close cooperation with a 'Science Advisory Group' composed of Greenlandic and Danish key persons. In 1996 this group had the following members:

Morten Meldgaard
(Director, Danish Polar Center. Chairman)

Hauge Andersson
(Chief Logistician, Danish Polar Center)

J.P. Hart Hansen
(Chair, Commission for Scientific Research in Greenland)

Bjarne Holm Jakobsen
(Assoc. Professor, Inst. of Geography, Univ. of Copenhagen)

Ole Humlum
(GeoBasis Manager, Danish Polar Center)

Gunnar Martens
(High Commissioner for Greenland. Chair, the DPC Board)

Hans Meltofte
(BioBasis Manager, Danish Polar Center)

Bent Muus
(Professor, Zoological Museum, University of Copenhagen)

Klaus Nygaard
(Director, Greenland Institute of Natural Resources)

Hanne Petersen
(Director, Department of Arctic Environment, National Environmental Research Institute)

Henning Thing
(Programme Manager, Danish Polar Center)

Procedures

Any research project proposing activity under the ZERO auspecies is required to submit a completed 'Access Permit' form to the Danish Polar Center supplying all pertinent information on the planned project.

Due to physical and logistics constraints at the station as well as consideration for the impact on the core study area proposed research projects may be prioritised and subjected to temporal or spatial distribution, pending discussion with and agreement by the principal investigator(s) in question.

The procedure is described in details and all needed forms and background information are available at the World Wide Web homepage of the Danish Polar Center at http://www.dpc.dk/.

If any reader of this annual report wishes to obtain further insight into the research opportunities and working conditions at Zackenberg you are recommended to read the comprehensive 'ZERO Site Manual' on the WWW homepage.

1.2. Zackenberg study area

The entire catchment basin of the river Zackenbergelven has been designated the Zackenberg study area. It is located around 74°30'N and 21°00'W in the southern part of the National Park of North and East Greenland.

The study area totals c. 600 km^2, with a core area situated in the valley Zackenbergdalen at the lower reach of the river.

The topography features at Zackenberg are dominated by a major valley system comprising Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedal, surrounded by mountains rising to 1,450 m a.s.l. and bordered to the south by Tyrolerfjord and the sound Young Sund.

The study area is located in the zone of continuous permafrost with an active layer thickness varying from 20 cm to 80 cm, depending on material. June, July and August have positive mean air temperatures. At Zackenberg, the climate data recorded so far (*i.e.* August 1995 – August 1996) reveal that the warmest month is July with a mean air temperature of 5.2°C, while February is the coldest month with a mean of – 20.1°C. The comparative temperature data from Daneborg, 20 km SSE of Zackenberg, are 3.8°C and –17.6°C, respectively. The annual (1995-1996) amount of precipitation at Zackenberg is 223 mm water equivalent (Daneborg receives 214 mm water equivalent precipitation annually).(Danish Meteorological Institute; mean values 1961-1990).

A major geological flexure and thrust zone dissects Zackenbergdalen-Lindemansdalen along a N-S axis, separating Caledonian gneiss bedrock in the west (Zackenberg area) from Cretaceous sandstone capped by Tertiary basalts in the eastern part (Aucellabjerg area). This geological diversity is the source for a varied landscape, with both steep bedrock cliffs and slightly sloping sedimentary landscapes.

The current margin of the Greenland ice cap is situated c. 60 km west of Zackenberg, and only a few small, local glaciers exist within the study area. Relatively flat surfaces found on the top of Zackenberg and at adjacent mountain tops reveal, most probably, this part of the landscape to be relatively old, developed as etchplains during a warmer – and tropical – climate.

The youngest parts of the landscape, the glacial landscape, is found at the valley bottom, deglaciated 10,000 years ago. Different glacial landforms such as meltwater plains / sandurs and terminal moraine systems dominate in the study area.

Old coast lines are visible up to 50 to 70 m above the recent sea level. Furthermore, the study area hosts periglacial landforms such as ice-wedges, solifluction lobes, snow-patches and associated nivation niches.

One major lake, Store Sø in Store Sødal, and a large number of small lakes, ponds and tarns are present in the study area. In particular, Zackenbergdalen, with the core study area, holds a great variety of biotopes like ponds, fens, heaths, fellfield plateaus and grasslands.

Fig.1.2. Three of the newly erected station buildings as they appeared 21 August 1996. From left to right are house #2 (wet laboratory), house #4 (Zackenberg Basic & work space) and house #5 (communication, station office & storage). The remaining two houses (kitchen & mess and dry laboratory) are hidden behind #2 and #4, respectively. The orange box with the white dome is the Inmarsat-M telecommunication facility hosting the photo-voltaic power supply, battery pool and satellite antenna.

Photo: Danish Polar Center / Henning Thing

2. Logistics

During the 100 days of field season, 31 May - 6 September, a total of 37 researchers, construction workers, journalists and logistics personnel worked at Zackenberg. Additionally, 11 researchers and technicians worked at the branch facility in Daneborg during 17 June - 25 August (see section 9).

2.1. Transportation

The runway constructed in 1995 was partly snow covered at the time of arrival. Following manual dispersion of dust and gravel on top of the snow, it disappeared within a week, and the runway was again suited to service a total of 32 arrivals/departures, incl. the transportation of c. 8 tons of cargo, besides passengers (see also section 6.2). Due to hard winds, the secondary runway (perpendicular to the primary) was used twice for take-off.

The relatively high frequency of air service, one every third day, was partly due to central geographical position of Zackenberg and partly the high level of other activities in North and Northeast Greenland this year. In order to keep disturbances as low as possible, attempts will be made to reduce the number of arrivals/departures in the future.

During 10-11 August, M/S Kista Arctica was anchored off Zackenbergdalen, and in a total of about 120 sling operations 42 tons of cargo was brought in by a Hughes 500 helicopter.

For use by researchers and for transportation in Young Sund, a 15 foot inflatable boat was available at the old Zackenberg trapping station during late July and August.

Again this year, the passage of Zackenbergelven was by a small rubber dinghy that was be pulled along a steel wire.

No motorised vehicles were available for local transportation, besides a mini excavator for use on the station only.

2.2. Accommodation

To accommodate the increased number of researchers at Zackenberg, two additional 15 m^2 Weatherhaven shelters for housing and one larger (26 m^2) for combined kitchen and messroom were erected. Zackenberg inhabitants beyond the capacity of the five housing shelters were accommodated in tents. Other preliminary constructions were two sheds for toilets and a shower.

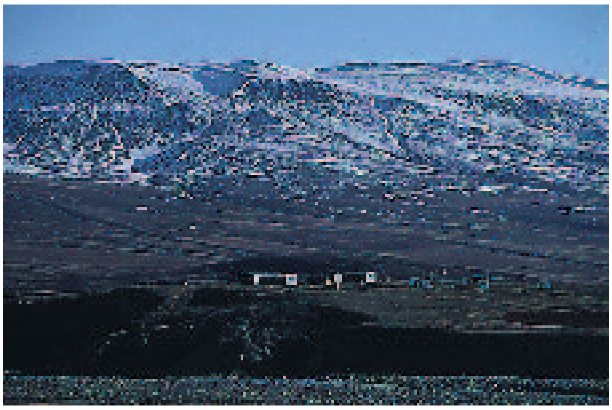
Filtrated river water was supplied to both kitchen and shower by 'on-demand' pumps from Zackenbergelven. These preliminary services improved daily life logistics at the station significantly. Based on the good experiences with the one shelter left to overwinter from September 1995, all six shelters were left erected for the winter 1996-1997.

2.3. Construction

By 10 August, all building material for five pre-fabricated houses arrived by the annual supply ship from Denmark and a construction team of four together with the logistics personnel started the construction of the permanent buildings. Roof-pitching of all five houses was celebrated only eight days later.

The kitchen/ messroom was finished first and was taken into service during the last few days of the 1996 season. Additionally, the two buildings holding the facilities for Zackenberg Basic, communications, office and work space as well as staff accommodation were also finished.

The two remaining houses (i.e. wet laboratory and showers as well as dry laboratory and work space) had the exterior finished, but lack essential parts of the interior. They will be finished by July 1997.



The Zackenberg station seen towards the east from the west bank of Zackenbergelven. Late August 1996.
Photo: Danish Polar Center / Hans Meltofte

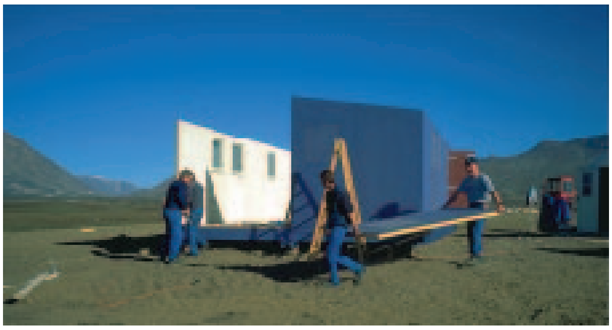
2.4. Telecommunication

To accommodate the increased communication needs Zackenberg now uses an Inmarsat-M satellite telephone year round. This facility also handles telefax, data transmission and e-mail. During off-season, the Inmarsat-M is linked to the climate station for a weekly 15-minutes transfer of data to Danish Polar Center .

For regional communication in Northeast Greenland Zackenberg operates a 100W HF radio. For local use, VHF radios are used.

Starting 10 August the Hughes 500 helicopter unloaded 120 slings of building materials at the construction sites.

Photo: Danish Polar Center / Henning Thing



The four construction workers from 'Venslev Cabins' at the chores of erecting the five buildings.

Photo: Mads C. Forchhammer

All Zackenbergians celebrating roof-pitching of the five houses. 18 August. *Photo: Danish Polar Center / Henning Thing*

The 'mini' excavator prooved indispensable in many situations from digging to fork-lifting.

Photo: Mads C. Forchhammer

Zackenberg station as it appeared 21 August. The shelters to the left were used for accommodation, labs and mess. In foreground is the temporary fuel cash.

Photo: Danish Polar Center / Henning Thing

Some shelters were turned into work spaces and preliminary labs for the researchers.

Photo: Hanne Hvidtfeldt Christiansen

Inside the mess shelter the cook conjured excellent meals despite sub-optimal facilities.

Photo: Danish Polar Center / Henning Thing

Temporary 'outhouses'. Shower to the left and toilets to the right. *Photo: Danish Polar Center / Henning Thing*

3. ZACKENBERG BASIC

The GeoBasis programme

The primary objective of the GeoBasis monitoring programme at Zackenberg is to establish baseline knowledge on the dynamics of fundamental physical parameters within the landscape. This is accomplished by various means; *e.g.* automatic data sampling, surveying, mapping and recurrent photography. This kind of information is a prerequisite for understanding the edaphic and climate factors controlling landscape processes, plant communities and terrestrial and limnic fauna.

GeoBasis was initiated during the summers of 1995 and 1996. A few additional monitoring activities will be launched during the summer of 1997. In the following, the results of GeoBasis are presented and the new monitoring initiated in 1996 described. The main permanent installations established in 1995 were described in the 1st Annual Report, 1995 (Meltofte & Thing 1996). The locations of the various installations and test sites are shown in Fig. 3.

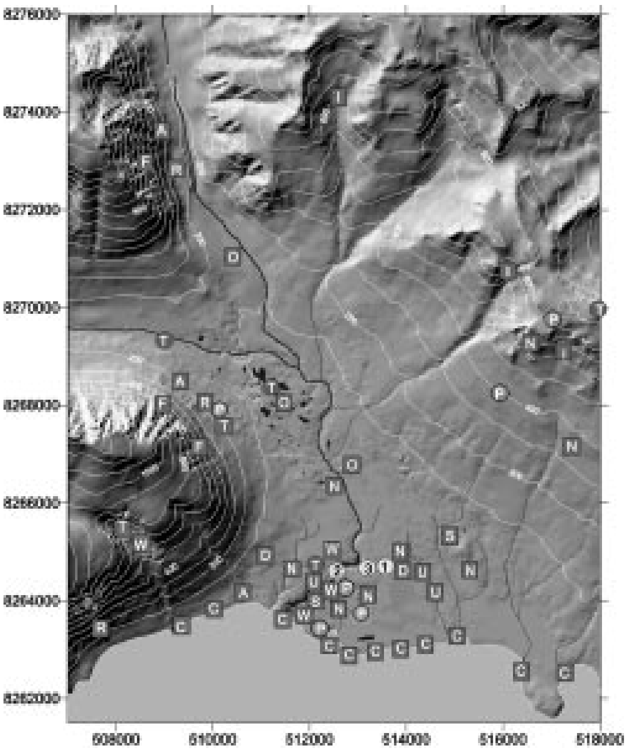


Fig. 3. Field sites and permanent installations for the GeoBasis monitoring programme. UTM - zone is 27. 1 = meteorological station. 2 = hydrometric station. 3 = temperature measurements in pond. P (in circle) = permafrost and active layer temperature profile. T (in circle) = air temperature at terrain surface. A = avalanche monitoring site. C = coastal monitoring site. D = debris island monitoring site. F = free rock face monitoring site. I = snow accumulation monitoring site. N = nivation monitoring site. O = windpolish monitoring site. R = rock glacier monitoring site. S = solifluction monitoring site. T (in square) = talus production monitoring site. U = fluvial monitoring site. W = ice-wedge monitoring site.

3.1. Meteorological station

The meteorological station (incl. two separate 7.5 m masts, Fig. 3.1) was constructed in August 1995, and has since then been operating almost without technical difficulties. The station and associated equipment are described in details in the 1st Annual Report, 1995.

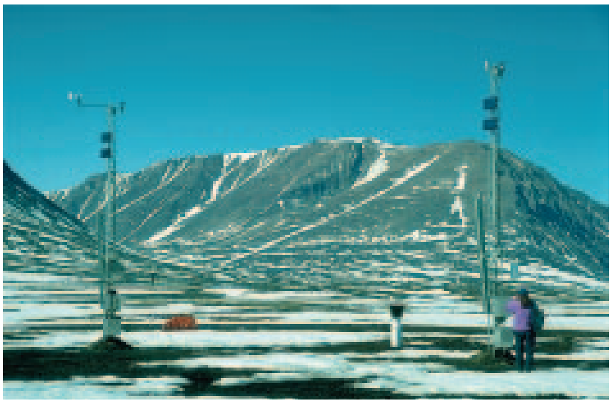


Fig. 3.1. The meteorological station at Zackenberg in mid June 1996. *Photo: Danish Polar Center / Ole Humlum*

Most meteorological parameters are recorded each hour. Wind sensors log, however, every 10 minutes. Data are obtained by means of a CR10 Campbell datalogger on each mast and subsequently stored on individual 1MB memory cards with a data storage capacity of about 21 months. Important annual mean values are presented in Table 3.1.

Table 3.1. Zackenberg meteorological key values 17 August 1995 - 9 August 1996.

Parameter	Mean	Maximum	Minimum
Air temperature (°C)	-9.8	16.3	-35.0
Relative humidity (%)	69	100	17
Wind velocity (m/s)	2.6	23.1	0
Air pressure (hPa)	1008	1039	955
SW in radiation (W/m²)	90	803	0
Net radiation (W/m²)	16	576	-86
Precipitation (mm w.e.)	total 223	-	-
Ground temperature (-2.5 cm)	-8.2	18.6	-21.7
Ground temperature (-10 cm)	-6.9	12.9	-19.4
Ground temperature (-40 cm)	-8.8	3.7	-16.8
Ground temperature (-80 cm)	-6.7	1.2	-12.2
Ground temperature (-130 cm)	-8.3	-2.4	-12.2

3.1.1. Air temperature

The mean annual air temperature measured 2 m above terrain during the first year of operation (*i.e.* mid August 1995 - mid August 1996) was -9.8°C (Fig. 3.1.1.1). The maximum temperature was +16.3°C (mid July 1996) and the minimum was -35.0°C (late December 1995). It is interesting that short, but distinct, meteorological events characterised by above-freezing temperatures occur throughout the winter 1995-96, probably due to short-lived foehn situations.

The period with frequent above-freezing day-light conditions in 1995 ended mid September and resumed in the second half of May 1996. Very high air temperatures (*i.e.* >10°C) were experienced during a week around mid July 1996 (Fig. 3.1.1.1). The coldest period was from early December 1995 to early January 1996.

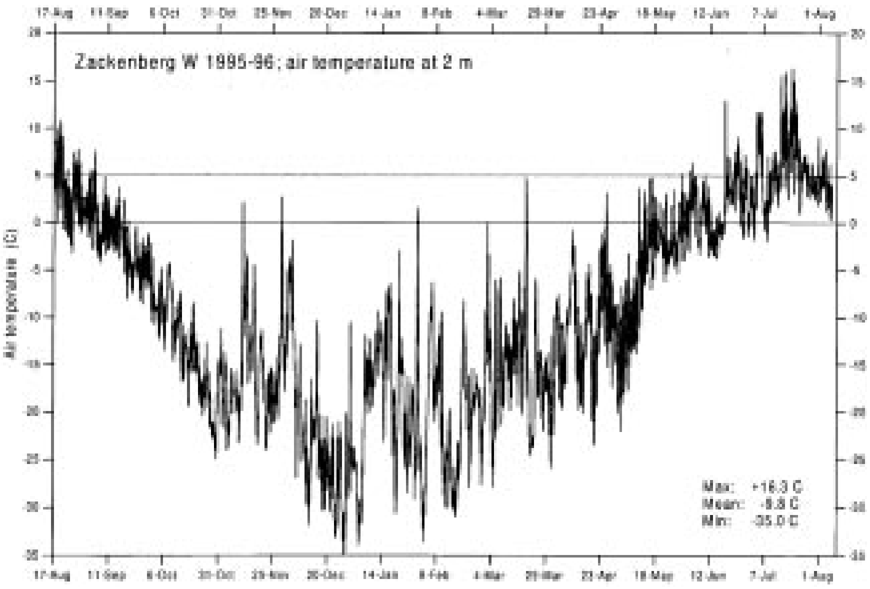


Fig. 3.1.1.1. Air temperature at Zackenberg, 1995-1996, 2 m above ground. Lower horizontal line indicates 0°C, upper horizontal line indicates 5°C.

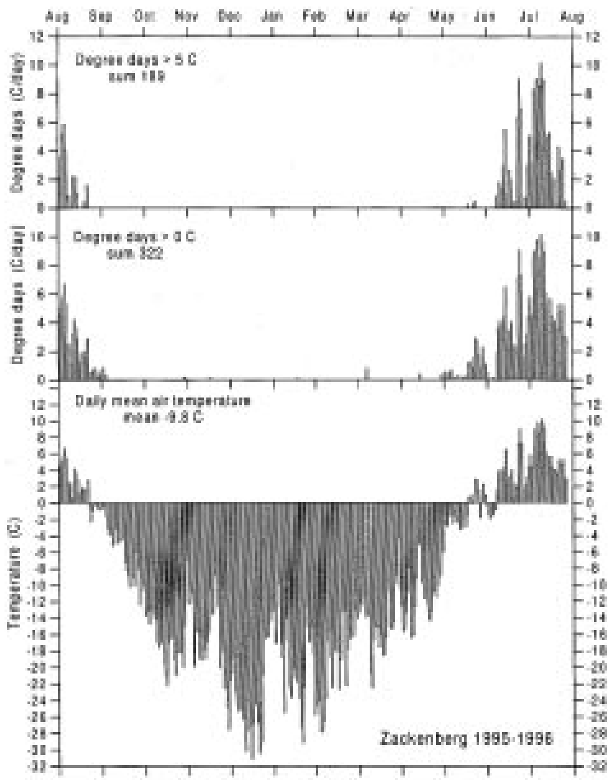


Fig. 3.1.1.2. Daily mean air temperatures at Zackenberg, 1995-1996, 2 m above ground. The upper two diagrams show 'degree days' above 5°C and 0°C, respectively.

Daily mean values for the 2 m air temperature are shown in Fig. 3.1.1.2. This diagram also shows daily mean temperatures above 0°C and 5°C. The cumulative heat accumulation units are 322 for temperatures above 0°C and 189 for temperatures above 5°C. These values are usually designated as Thawing Degree Days (TDD) and Growing Degree Days (GDD), respectively. TDD has turned out to be a useful parameter for correlation with snow melt, whereas GDD shows good correlation with plant growth.

3.1.2. Air humidity

Air humidity was high during summer and somewhat lower during winter (Fig. 3.1.2). Generally, lowest values are recorded from October 1995 to March 1996. However, the relative air humidity is difficult to measure with any degree of precision, and only the overall trends apparent from Fig. 3.1.2 should be considered.

3.1.3. Air pressure

The annual mean air pressure (Fig. 3.1.3) was 1008 hPa. Maximum and minimum values are given in Table 3.1. The air pressure was generally rather low (1000-1005 hPa) and stable during summer. In contrast, pressure was relatively high but fluctuating (990–1030 hPa) during winter.

3.1.4. Wind velocity

Wind velocity was logged each 10 minutes and is presented graphically in Fig. 3.1.4. The mean velocity was 2.6 m/s during the first year of operation. Wind force was significantly higher and more fluctuating during winter than during summer.

3.1.5. Wind direction

The wind direction, logged each 10 minutes, is shown in Fig. 3.1.5. From this, it is apparent that the dominant wind direction was northerly from mid September to mid May (*i.e.* winter). During the remainder of the year the dominant wind was south-easterly. The dominant, relatively strong, winter wind from the north is clearly reflected by the predominant orientation of snow drifts. During winter, the northerly winds are probably generated by Coriolis' force deflection of catabatic air masses flowing off the Greenland Ice Sheet, with recurrent enforcement by cyclones entering the Iceland region to the south. During spring and summer, the sun is permanently relatively high in the sky and large land areas rapidly loose their winter snow cover; the terrain heats up and a land bound breeze from the sea (Young Sund) is generated.

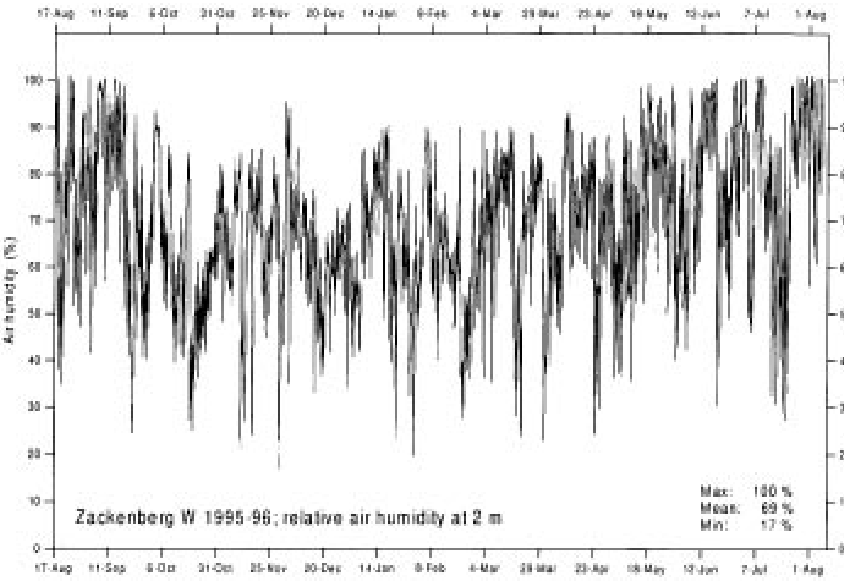


Fig. 3.1.2. Relative air humidity (%) at Zackenberg, 1995-1996.

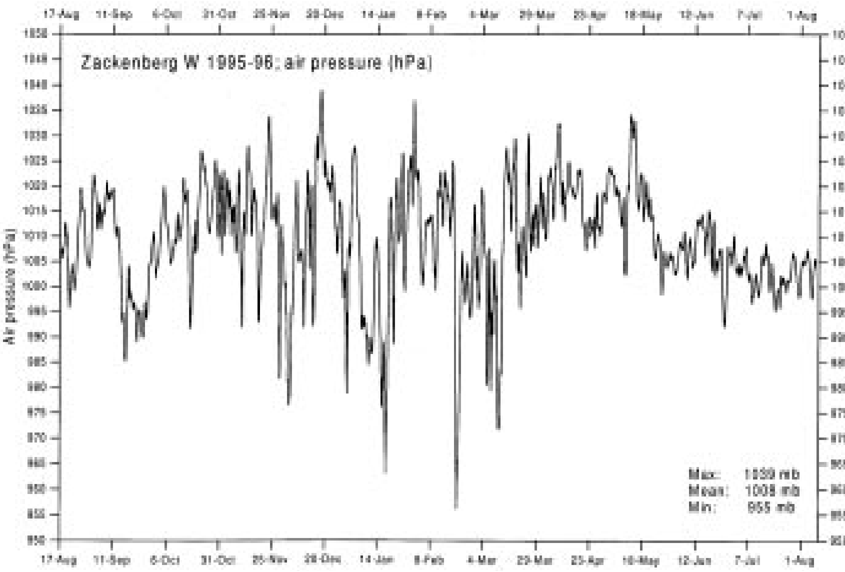


Fig. 3.1.3. Air pressure (hPa) at Zackenberg, 1995-1996.

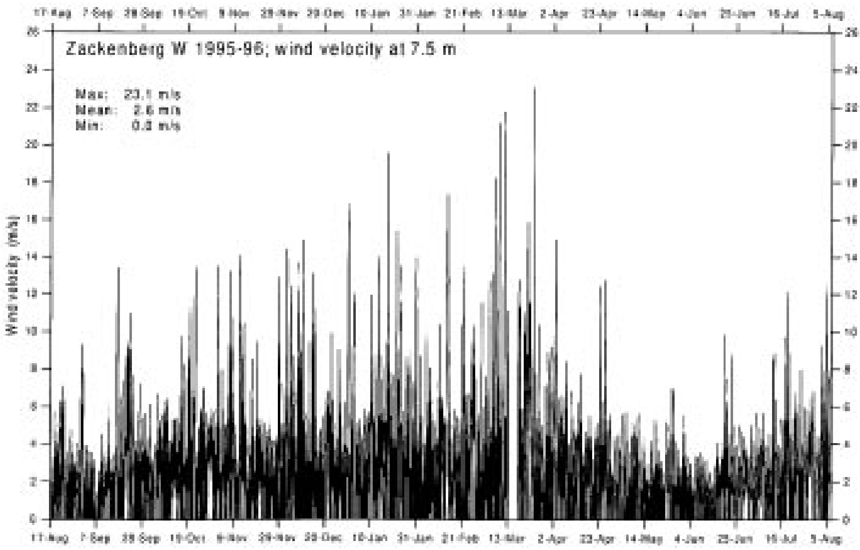


Fig. 3.1.4. Wind velocity (m/s), 1995-1996; scanning frequency: 10 minutes

3.1.6. Insolation

The distribution of incoming short wave (SW) radiation is illustrated in Fig. 3.1.6. The winter darkness from early November to early February is apparent. The positive insolation even during nights from early May to early August reflects the fact that the sun stays permanently above the horizon during this period. A typical daily maximum insolation of about 625 W/m^2 occurred around mid June 1996.

3.1.7. Net radiation

Distribution of the measured net radiation is presented in Fig. 3.1.7. The effect of the snow cover is obvious, especially when data are compared with insolation shown in Fig. 3.1.6. The net radiation drops markedly in the second half of September; probably due to the build-up of a snow cover. On the other hand, despite a very high insolation (Fig. 3.1.6), net radiation values stay rather low until mid June where snow cover disappears at the meteorological station site. The highest net radiation values (in excess of 550 W/m^2) occured shortly after the disappearance of the snow.

3.1.8. Albedo

Both incoming and reflected short wave radiation are recorded at the meteorological station and the daily mean albedo was subsequently calculated (Fig. 3.1.8). As pointed out in section 3.1.7, snow cover began to accumulate in the second half of September, increasing the daily mean albedo from a typical summer (1995) value of 12-13% to 60-70%. During autumn, the albedo undergoes significant variations, probably caused by recurrent snow falls and redistribution of the snow by strong winds (Fig. 3.1.4). The terrain surface albedo is not calculated when the sun stays below the horizon (early November – early February), but the value would probably be 80-90%, corresponding to the average value during February – April

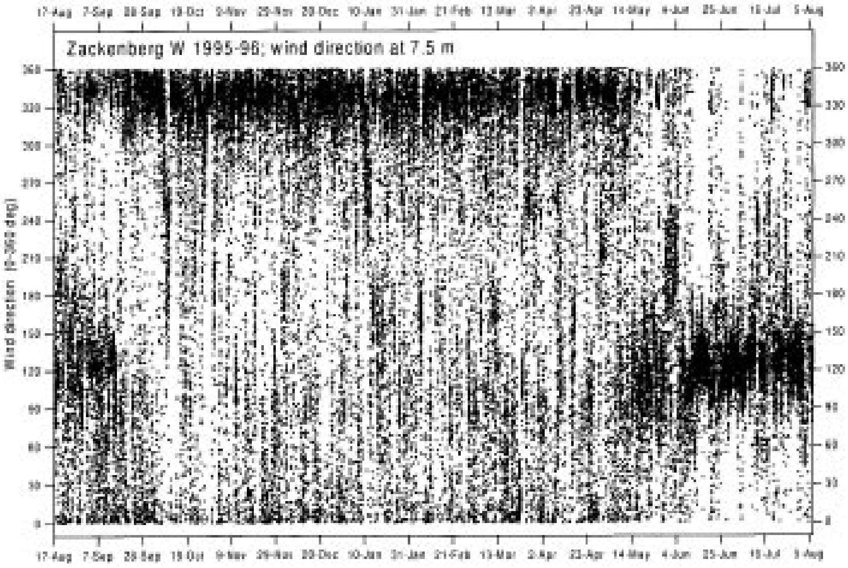


Fig. 3.1.5. Wind direction (0-360 deg.) at Zackenberg, 1995-1996; scanning frequency: 10 minutes

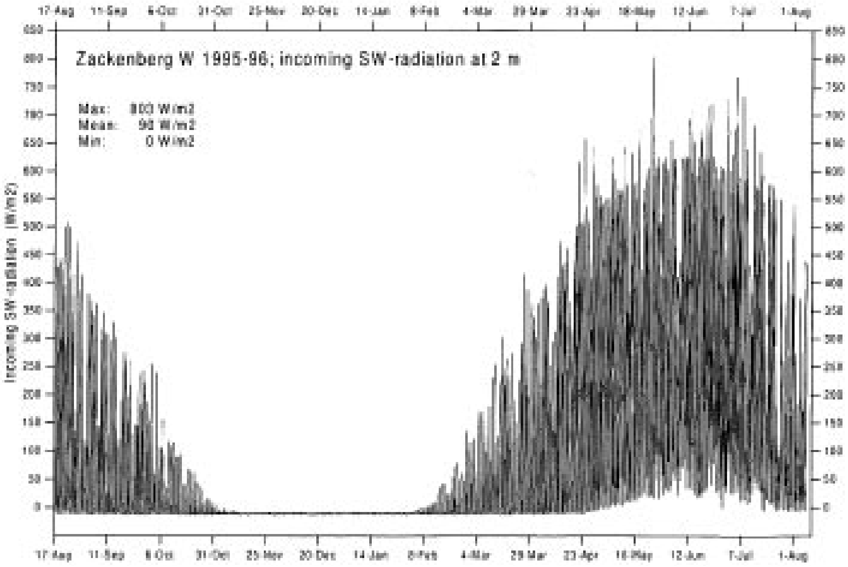


Fig. 3.1.6. Incoming short wave radiation (W/m²) at Zackenberg, 1995-1996.

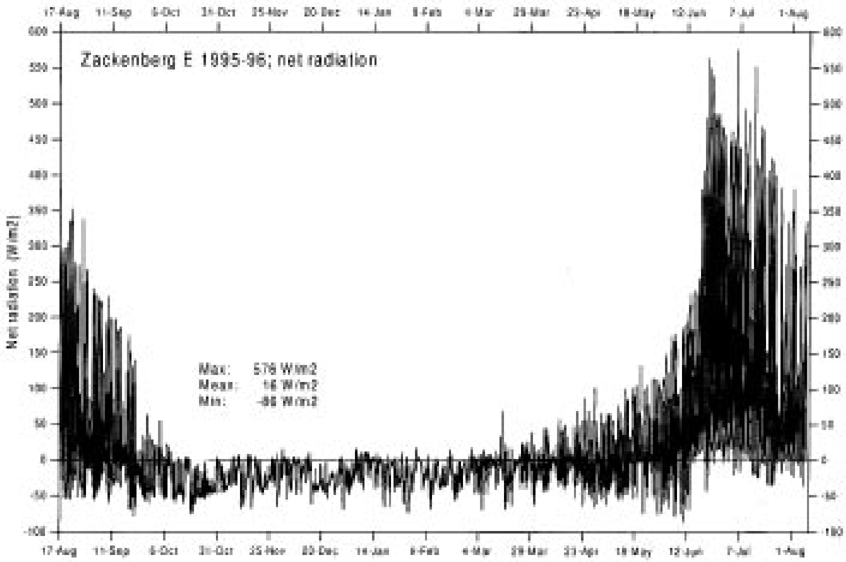


Fig. 3.1.7. Net radiation (W/m²) at Zackenberg, 1995-1996.

1996. From early May, the calculated albedo slowly decreased to 60-65% in early June. This decrease was most likely caused by metamorphosis of the snow as insolation increased (Fig. 3.1.6). The albedo decreased dramatically around mid June where the snow cover at the meteorological station site disappeared. The very low values (5-7%) following this event were due to the ground surface being covered by 2-5 cm water for a couple of days. Subsequently, the albedo recovered to a typical summer (1996) value of 12-13%.

3.1.9. Precipitation

The cumulative precipitation is displayed in Fig. 3.1.9. The total of 223 mm w.e. (*i.e.* water equivalents) is close to what would be expected (*i.e.* about 200 mm), considering published Daneborg values (data from Danish Meteorological Institute). The first significant precipitation event registered took place in mid September 1995 but the major part of the total precipitation fell (as snow) during six discrete meteorological events December-March (Fig. 3.1.9). The period April-July 1996 was very dry. Considering air temperatures (Figs. 3.1.1.1 and 3.1.1.2), almost all precipitation at Zackenberg (1995-1996) was in solid form.

3.1.10. Ground temperatures

Ground temperatures are logged by 10 sensors each hour at the meteorological station. Fig. 3.1.10 presents isotherms in a time-depth diagram. Shaded areas are below 0°C. Cross-hatched areas indicate the temperature interval from 0°C to -1°C, where most water-ice phase changes are expected to occur. From this diagram it appears that the maximum thickness of the active layer at this site is about 85 cm. Freezing of the ground in the autumn of 1995 took place around 20 September. Large temperature variations until early December indicate that the snow cover, in general, was thin. Thereafter, temperature variations were smaller, reflecting increased snow cover depth (compare with air temperatures in Fig. 3.1.1.1). Thawing in June 1996 was extremely rapid and concomitant with the visual observation of pools of melt water covering the ground surface around the meteorological station. The rapid thawing may partly represent an artefact, as some melt water may have entered the still frozen ground along the vertical thermistor string. Means to prevent this to occur in the future have been taken in August 1996.

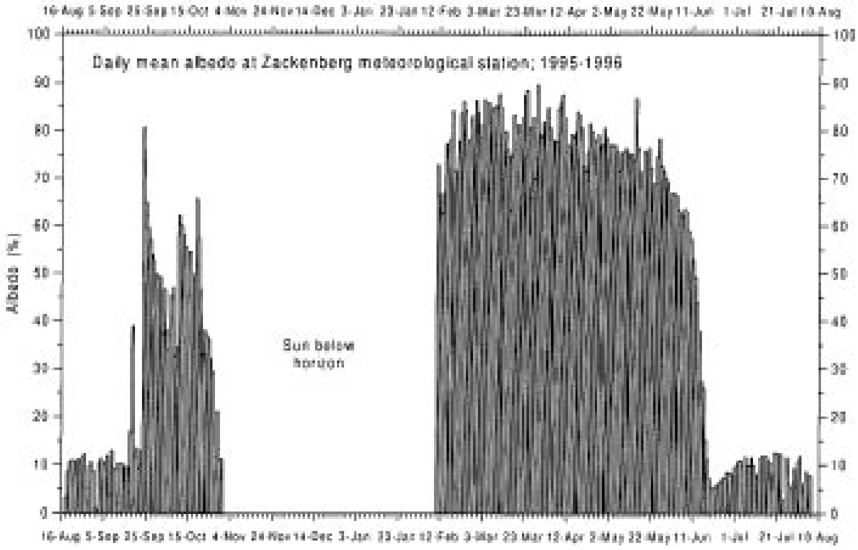


Fig. 3.1.8. Variation of calculated albedo (%) at Zackenberg, 1995-1996.

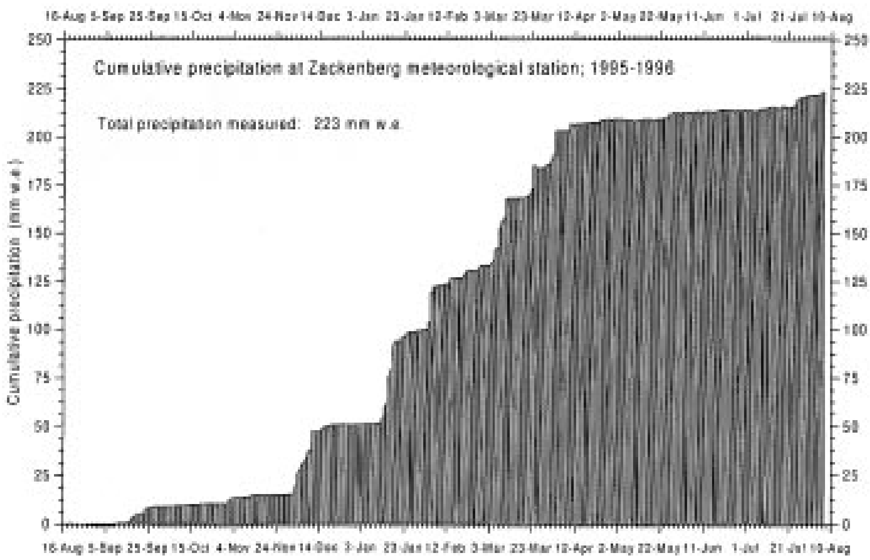


Fig. 3.1.9. Cumulative precipitation (mm w.e.) at Zackenberg, 1995-1996.

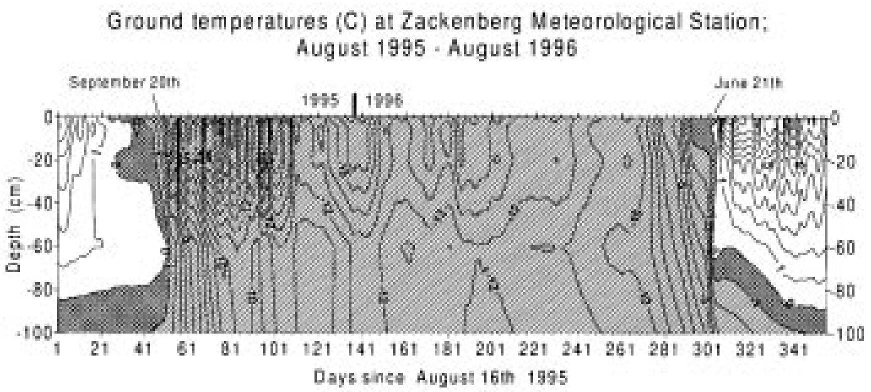


Fig. 3.1.10. Time-depth diagram of ground temperatures (°C) at Zackenberg, 1995-1996. Shaded areas indicate below-freezing temperatures.

3.2. TinyTalk dataloggers

Air, water, snow and ground temperatures are monitored at various locations within the study area. In 1995, a number of small-scale, waterproof and inexpensive TinyTalk dataloggers were placed at sites of special interest, such as ponds, lakes, rivers, snow patches and vertical soil profiles. All dataloggers were programmed to log the temperature five times a day and have operated flawlessly. During 1996, another type of small-scale dataloggers (TinyTag) with larger memory were installed at supplementary sites. These loggers are programmed to measure the temperature 12 times a day and they will log 600 days before the internal memory is filled.

3.2.1. Ground temperatures

Ground temperatures have been monitored at four separate vertical profiles by means of TinyTalk dataloggers. Two supplementary profiles were established in July 1996. In Fig. 3.2.1.1 the results from one of these profiles, P1, are presented. The temperature profile extends into the near-surface permafrost at an ice-wedge site, shortly south of the station. The active layer thickness at this site is 70 cm at which depth the upper surface of the 2.5 m wide ice-wedge is encountered. The lowermost thermistor is located at 155 cm depth, which is 85 cm into the solid ice-wedge. This ice-wedge is monitored at terrain surface with respect to its width (see below).

Ground temperatures were also measured at profile P3, located 400 m a.s.l. on the SW slope of Aucellabjerg (Fig. 3.2.1.2). In 1995 the sediment type at this site rendered it impossible to dig deeper than 70 cm. When this diagram is compared to the measurements at P2 (Fig. 3.2.1.1), a greater temperature variability at P3 is apparent. This is probably due to a thin snow cover at P3, compared to that of P2. Visual observations in early June 1996 showed the SW slope of Aucellabjerg to be partially free of snow, especially above 400 m a.s.l.

3.2.2. Zackenbergelven

One TinyTalk datalogger was installed in the river Zackenbergelven, close to the hydrometric station (see below), in order to monitor temperature at the river bottom. These measurements indicate time for the freeze-up and break-up events in the river which is the main water course draining the overall Zackenberg study area. The results are shown in Fig. 3.2.2.

In August and early September 1995, the water temperature fluctuated with a daily amplitude of 1-4°C. Around 20 September the river froze, and water was not present below the hydrometric station until around 20 June 1996. Visual observations in 1996, however, showed that lots of water was running in the central part of the river already by 1 June (see section 3.5). The dramatic temperature increase on 24 May probably indicates the release of latent heath from refreezing meltwater, percolating into the snow drift (from the snow surface above) at the hydrometric station. Alternatively, this event signals the first appearance of streaming melt water at the data logger. After 20 June 1996 daily temperature variations of 2-4 °C again dominate.

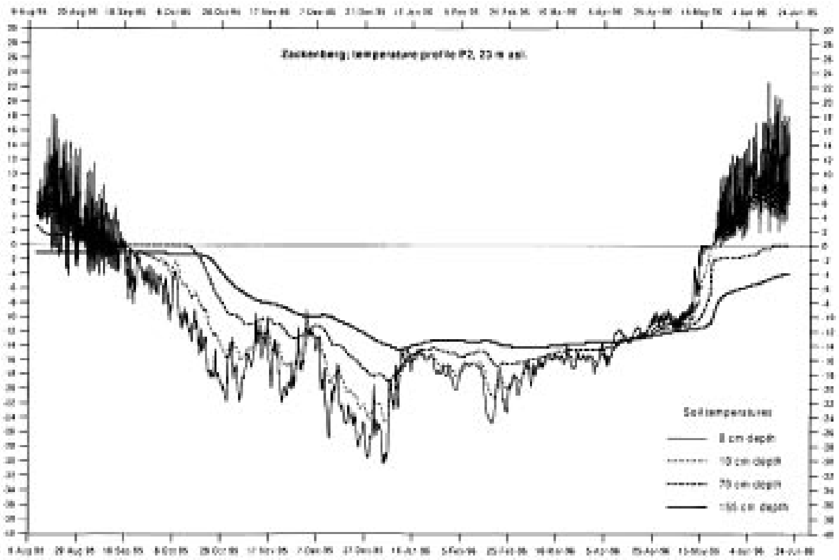


Fig. 3.2.1.1. Ground temperatures (°C) at Zackenberg, 1995-1996. The - 155 cm thermistor is inserted into an ice wedge extending upwards to 70 cm below the terrain surface.

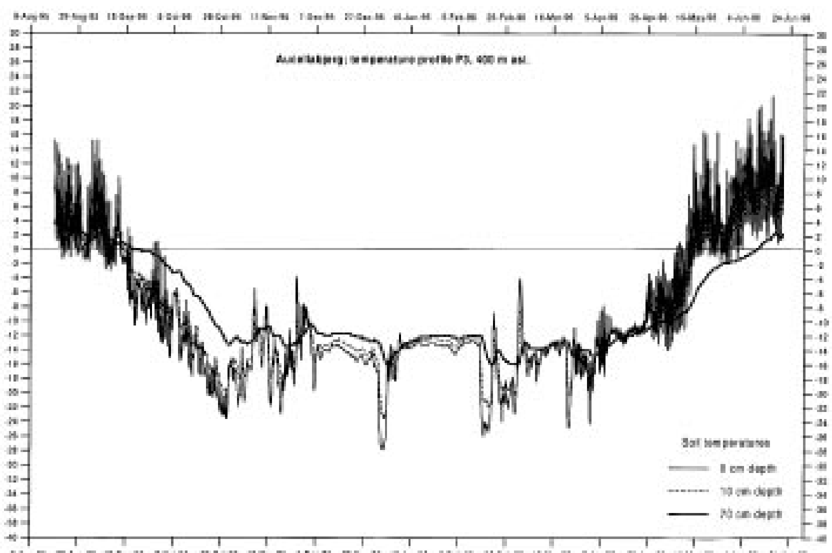


Fig. 3.2.1.2. Ground temperatures (°C) in soil profile at 400 m a.s.l. on the SW slope of Aucellabjerg. Rapid temperature fluctuations indicate the existence of a thin snow cover throughout the winter, 1995-1996.

3.2.3. Pond temperature

Water temperature was monitored in a small pond adjacent to the Zackenberg station. The measurements were obtained using a TinyTalk datalogger, scanning 5 times a day. The thermistor probe was installed 1 cm above the pond bottom. The results are given in Fig. 3.2.3.

The water at the pond bottom froze around 20 September 1995 and at the thermistor site it thawed around 2 June 1996.

Visual observations on 3 June showed the pond to be about 50% ice covered, while on 10 June only few remnants of ice still persisted.

Minimum temperatures (c. 24°C) were measured around the turn of the year 1995-1996. Temperatures rose significantly in late May 1996, from -12 °C to -2°C. This may be due to refreezing of percolating surface melt water, or it may be caused by solar light entering the clear ice and heating the dark pond bottom sediments beneath the ice cover.

Following thawing, the pond temperature rapidly increased to 4-6 °C. Maximum temperatures of 12-16 °C were recorded in late June 1996.

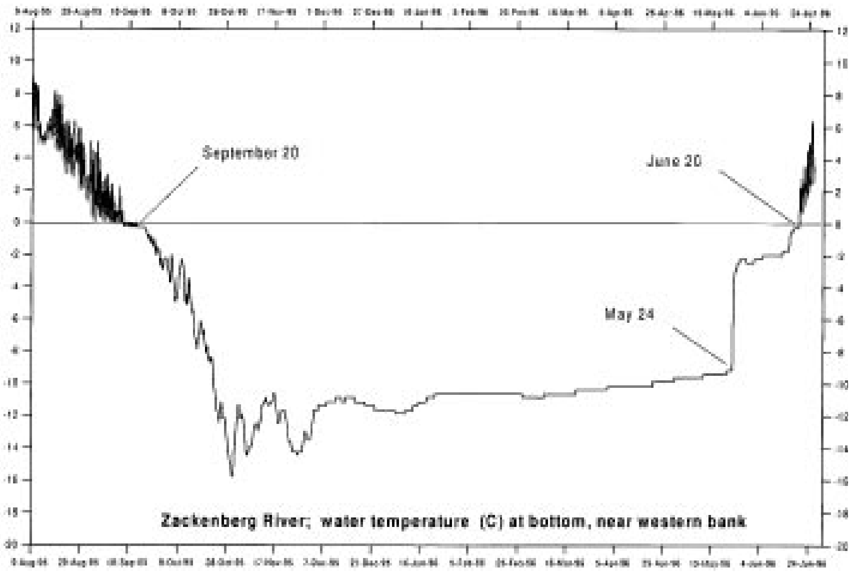


Fig. 3.2.2. Temperatures (°C) measured at the bottom of the river Zackenbergelven, 1995-1996. Autumn freeze-up and spring break-up of the river are clearly indicated.

Fig. 3.2.3. Temperatures (°C) measured 1 cm above the bottom in a pond at Zackenberg, 1995-1996. Autumn freeze-up and spring thaw of the pond are clearly indicated.

3.3. The hydrometric station

The hydrometric station (Fig. 3.3) at the river was described in details in 1st Annual Report, 1995. The station is equipped with a datalogger (Campbell 21X), a SM716 storage module and sensors for measuring air temperature and the vertical distance from a fixed position to the water surface below (SR Sonic Ranging sensor). By surveying, this distance is transformed into a corresponding water depth. Parameters are logged every15 minutes, and the station operated successfully throughout the winter 1995-96. The distance values logged during winter show the station to be buried beneath a thick snow drift from early March to late May. The first registration of a systematic daily distance variation, reflecting presence of a free water surface beneath the sonic sensor, appeared 15 June, when a hole was dug under the sensor.

Fig. 3.3. Zackenbergelven in mid June 1996. The hydrometric station is located just below the arrow at the western river bank.

Photo: Danish Polar Center / Hans Meltofte

3.3.1. Water depth

The calculated water depths and air temperatures at the hydrometric station are illustrated in Fig. 3.3.1.

Daily depth variations are detectable from c.15 June. At this time, water had been running in the central part of river for about three weeks.

The actual river break-up (*i.e.* spring flood) occured 21-22 June, when water depth abruptly increased to about 72 cm and the daily variation was partly obscured.

After the flood, water depth rapidly decreased to c. 40 cm, and the daily variation recurred.

Subsequently, water depth then slowly increased to a maximum of c. 60 cm (4 July), followed by a clearly decreasing trend.

The period with very high air temperatures following mid July generated a small increase in water depth.

A significant drop in water depth occured from 4 August to 7 August, following a period of cold weather, effectively signalling the reduced rate of snow melt and the onset of autumn.

By the end of August 1996, the water depth was again very low.

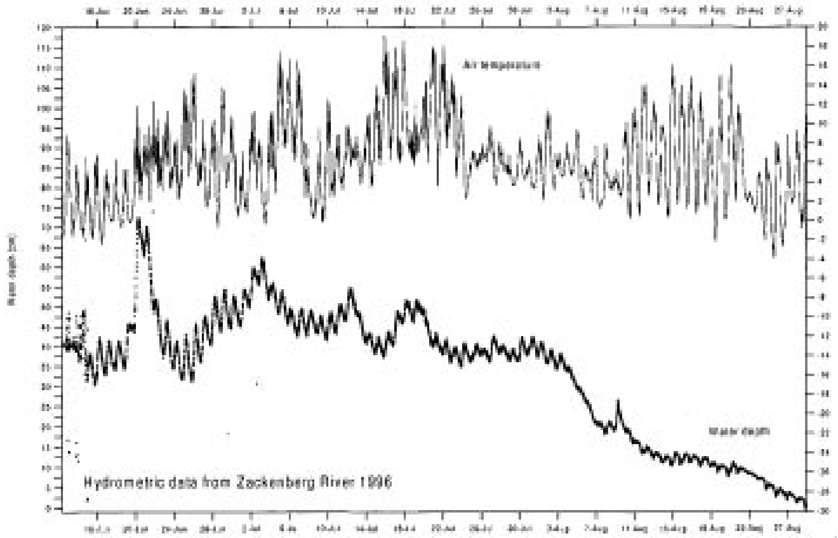


Fig. 3.3.1. Water depth (cm) and air temperatures (°C) at Zackenbergelven, June-August 1996.

3.3.2. Water discharge

Discharge measurements were performed manually in August 1995 (Hanne Hvidtfeldt Christiansen and Ole Humlum) and again in June-July 1996 (Bent Hasholt and Steen B. Pedersen). Data are plotted in a discharge – depth diagram (Fig. 3.3.2.1). This graph indicates the river bed to have been rather stable during the intervening period. A polynomial regression line is shown in Fig. 3.3.2.1. From this, the discharge may be calculated from the water depth data.

Fig. 3.3.2.2 discloses the calculated discharge variation in Zackenbergelven at the hydrometric station as well as the accumulated discharge (the broken line) during the entire summer season. The typical discharge in June and July 1996 was 20-25 m^3/s, with a spring flood peak value in excess of 50 m^3/s. Discharge dropped to c.10 m^3/s in early August and to less than 5 m^3/s by the end of the month. In 1996, c. 124,000,000 m^3 water was drained by the river, corresponding to the loss of c. 208 mm w.e. from the entire drainage area (almost 600 km^2). This value is comparable to precipitation measured August 1995 - August 1996 at the Zackenberg meteorological station (223 mm w.e.).

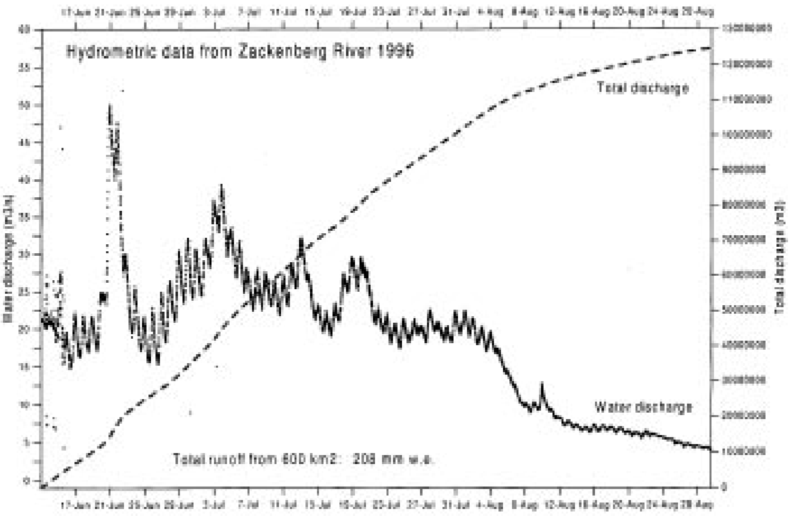


*Fig. 3.3.2.2. Variations (15 minutes intervals) in calculated discharge in Zackenbergelven, June-August 1996. The spring peak (*i.e.* the flood) on 20-21 June is seen clearly. The heavy broken line shows the calculated total discharge which corresponds to a mean value of 203 mm w.e. for the whole (600 km²) catchment area. The measured precipitation 1995-1996 at the Zackenberg station is 223 mm w.e. (Fig. 3.1.9).*

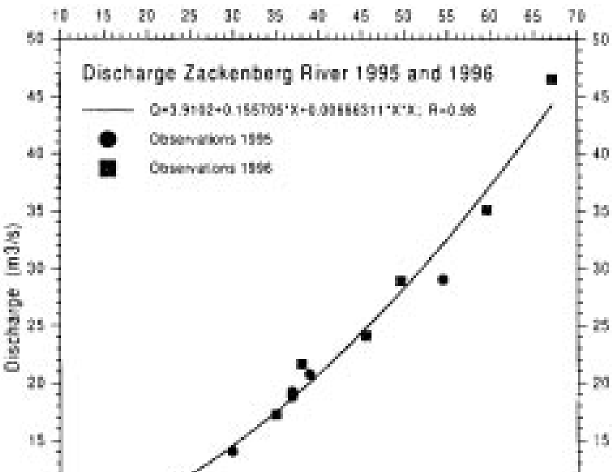


Fig. 3.3.2.1. Depth-discharge diagram of discharge measurements in Zackenbergelven, 1995 and 1996. Calculated polynomial regression curve is shown (R=0.98).

3.3.3. Suspended sediment

Water samples taken in Zackenbergelven from early June to early September 1996 have not yet been analysed. Analyses of August 1995 samples revealed that the river water carried suspended material in amounts ranging from 487 mg/l to 189 mg/l.

These preliminary results indicate that the overall load of suspended material transported from the 600 km² Zackenberg catchment area to the sea (*i.e.* Young Sund – Tyroler Fjord) probably is in excess of 60000 t annually.

3.3.4. Water chemistry, pH and conductivity

Conductivity and pH were determined in daily samples from the river. Most pH values range from 7 to 8, while typical conductivity values range between 15 and 30 mμS. The water samples are presently being analysed for their content of Na, K, Ca, Mg, Fe, Al, Mn, Cl^-, NO^-, SO_4^{2-} and alkalinity.

3.4. Landscape monitoring

3.4.1. Snow cover

Variations in the snow cover within Zackenbergdalen were monitored by means of recurrent photography during the summer of 1996 (see, *e.g*. Figs 3.4.1.1-3.4.1.2). An automated monitoring will be initiated in 1997 using a digital camera positioned on the eastern slope of the Zackenberg mountain. In 1996, snow distribution in the Zackenberg area during1986-1995 has been studied by means of Landsat TM and SPOT HRV satellite images (see section 5.1.2).

The amount of snow accumulated during the 1995-1996 winter was below what is considered normal for this area and what has been experienced during previous years (see section 5.1.2). In early June 1996, the bottom of Zackenbergdalen was still covered by 10-50 cm snow while large parts of the terrain at high altitudes (*i.e.* > 400 m a.s.l.) were without snow. This general distribution of snow is also indicated by various terrain surface temperature series obtained by dataloggers (see section 3.2.1). Positions of snow drifts indicate that snow was deposited mainly by NNW winds, the dominant wind direction in winter according to the meteorological station (see section 3.1.5). Substantial parts of the valley bottom snow cover melted during the second half of June. By the end of July, remnants of snow patches were, in general, smaller than average, judging from the small-scale geomorphology and vegetation zones associated with permanent and seasonal snow patches.

Fig. 3.4.1.1: The SW slope of Aucellabjerg as seen from the Zackenberg station on 19 June 1996.
Photo: Hanne Hvidtfeldt Christiansen

3.4.2. Active layer evolution

The gradual evolution of the active layer was monitored manually in June through August 1996 at two CALM sites (see section 5.1.12). One of these sites is situated on a almost level plain consisting of sandy deposits while the other covers both horizontal and sloping terrain segments. The two sites are subdivided into 10 m grids and cover 110 x 110 m^2 and 150 x 180 m^2, respectively. The maximum mean active layer thickness in 1996 was c. 60 cm at both sites.

3.4.3. Nivation

Nivation and associated geomorphic processes are monitored at several localities (Fig. 3) by means of recurrent photography (Fig. 3.4.3.1), surveying and TinyTalk dataloggers. Ground surface temperature data derived from five TinyTalks installed along a transect through a nivation hollow with a perennial snow patch are collected as described in Meltofte & Thing 1996 (section 4.2.6). Fig. 3.4.3.2 presents average temperatures from the first 11 months of measurements from the TinyTalk dataloggers. Only the backwall and the central sensors have been located under the permanent snow patch while the two sensors in the front and the one above the nivation hollow were not covered by snow for longer periods.

Fig. 3.4.1.2: The SW slope of the Aucellabjerg as seen from the Zackenberg station on 4 August 1996.
Photo: Hanne Hvidtfeldt Christiansen

Fig. 3.4.3.1: A monitored snow patch just west of the Zackenberg station; seen towards NE; 26 June 1996.
Photo: Hanne Hvidtfeldt Christiansen

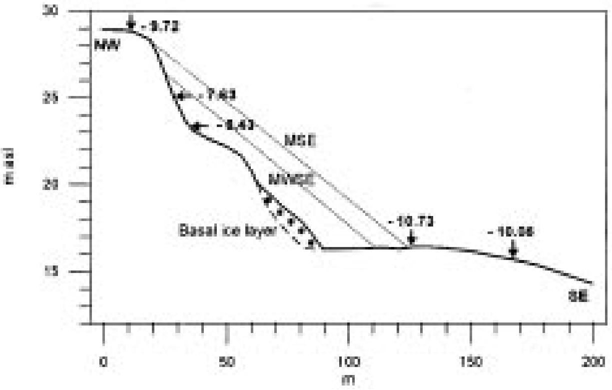


Fig. 3.4.3.2. Terrain profile through the nivation hollow shown in Fig. 3.4.3.1, as surveyed 1 August 1996. At this time, there was only a base of ice left from the snow patch. MSE = Maximum Snow patch Extension, MWSE = Minimum Winter Snow patch Extension. Arrows point out the location of the five TinyTalk temperature sensors. Average temperature values (°C) measured at terrain surface, from 27 August 1995 to 30 July 1996, based on five daily recordings, are shown at the arrows. The average temperature calculated for the sensor located c. 80 m from the lower front of the basal ice layer, in front of the snow patch, is based on data only from 27 August 1995 to 6 July 1996 when this sensor was removed. This causes a lower average temperature at this particular sensor than would have been found, had it been running as long as the other sensors. Notice the different scales used for the two axes.

A detailed study of the daily temperature variations reveals that a permanent snow cover was established c. 30 October and probably started to melt during late May. The sensor located at the backwall melted free on 12 July, while the sensor in the central part of the snow patch was just about to melt free on 30 July. Hence, the average period with snow present in the nivation hollow is 197 – 274 days. This range probably indicates a minimum value, as the summer snow melt was rapid in 1996, compared to the preceding summers. The monitored snow patch is perennial, as a base ice layer survived during the entire summer of 1996.

BTS (*i.e.* winter basis temperature of the snow cover) for the two sensors located below the snow patch were constantly c. – 10 to – 11°C from early December to late May for the backwall sensor, and persisted until early June for the central snow patch sensor. Prior to this period (*i.e.* from 30 October to early December 1995), when snow started to accumulate, the temperature fluctuated illustrating that the snow cover was still thin. This is depicted in Fig. 3.1.9 showing that c. 35 mm of the precipitation fell in the first days of December. This explains why the snow patch at that time became much thicker.

Knowledge of the winter temperature variation recorded by the five sensors and the morphology of the terrain surface profile allows for a general calculation of the maximum snow thickness in the snow patch of c. 4.7 m. The minimum winter thickness was about 1.1 m during the period with a permanent snow patch in the nivation hollow. As data from August 1996 are the only ones presently missing in a full year record, the base of the snow patch may be calculated to be less than 2-3°C warmer than the surrounding terrain surface.

3.4.4. Soil water chemistry

To characterise temporal variation of soil water chemistry of different soil water regimes, two locations were chosen. One location adjacent to the climate station is a relatively dry *Cassiope* heath where the snow cover disappears in early summer. The second location is a *Sphagnum* spp. / *Eriophorum spp*. dominated fen 200 m south of the runway. The fen area is located next to a snow patch yielding water to the area most of the summer.

As the active layer developed over the summer, ceramic suction probes were installed at 10 cm increments. The advantages of suction probes are their relatively simple installation and the negligible disturbance of the soil profile. Moreover, continuous sampling is possible at different depths within the same soil profile.

After implementation of the suction probes, they were connected to bottles at the soil surface. The suction probes should be sampled 3-5 times per season. Alkalinity, pH and conductivity of soil water samples were measured in the field, whereas Na, K, Ca, Mg, Fe, Mn, Al, Cl, NO_3^- and SO_4^{2-} will be analysed in the laboratory. Soil samples were collected at both

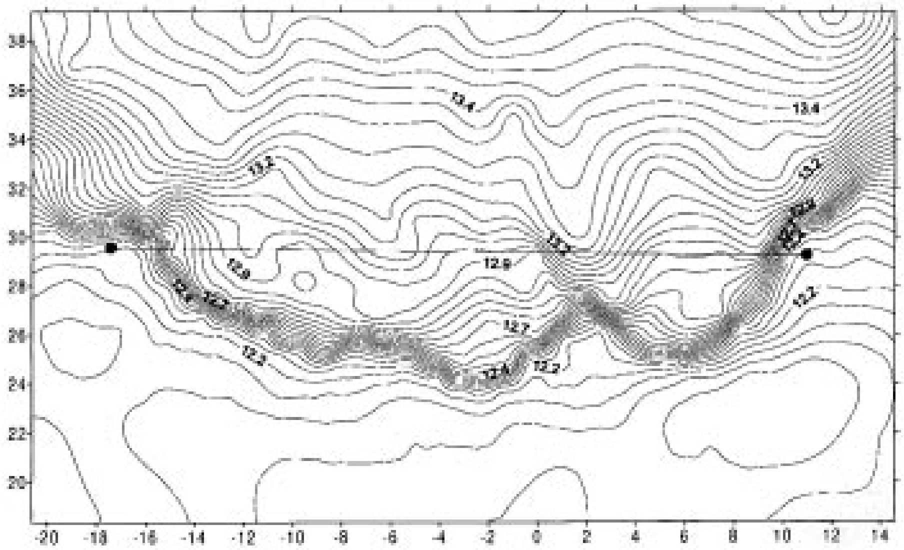


Fig. 3.4.5. Contour map of a monitored solifluction lobe SW of the Zackenberg station. Contour equidistance is 4 cm.

locations for further characterisation of the soil profile. The soil layering within the profiles was apparently influenced by cryoturbation.

The variation of pH and conductivity over time is limited whereas both pH and conductivity increase fairly consistently with depth. This spatial variation is probably due to several processes, including decomposition of organic matter, changes in the carbonate system and cation exchange processes. Based on the soil water chemistry and several soil characteristics, including the cation exchange capacity, it will be possible to describe the dynamics of such important components as carbon and nitrogen within the soil.

Fig.3.4.12.1. GeoBasis manager Ole Humlum at work on top of a rock glacier. Photo: Hanne Hvidtfeldt Christiansen

3.4.5. Solifluction

Solifluction rates are monitored by recurrent photography and recurrent surveying of profiles at two sites (Fig. 3). A map showing the surface topography of one of these solifluction lobes has been produced (Fig. 3.4.5). Surveys at the two sites show the mean soil flow rate to be c. 0.2 and 0.3 cm annually, respectively.

3.4.6. Ice wedges

The growth rate of ice wedge are monitored by recurrent photography and surveying at three sites in Zackenbergdalen (Fig. 3). Grids were established across individual ice wedges in 1995 to augment monitoring.

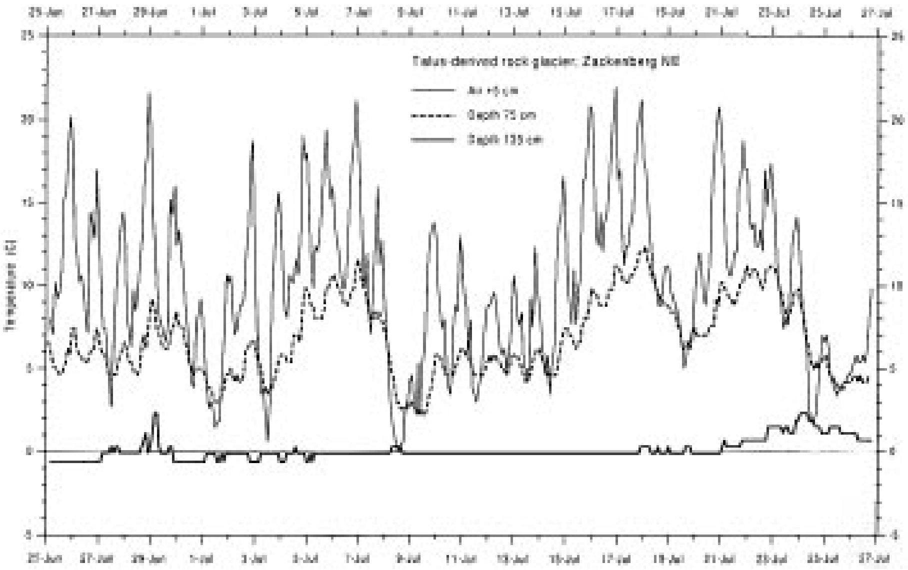


Fig. 3.4.12. Air temperatures (°C) within a monitored rock glacier NW of the Zackenberg station, June-July 1996. The temperatures are measured at the rock glacier surface and within pore spaces in the rock glacier body, respectively. The - 135 cm thermistor is located close to the permafrost core of the rock glacier.

3.4.7. Wind abrasion

Wind abrasion is measured by means of recurrent photography at two sites; one in the valley bottom, and another in 'Favoritdal' in the SE part of the Zackenberg mountain. These are test sites, established in 1995, and no detectable effect by wind abrasion is expected during the first years to come. The sites are, however, closely inspected and monitored by means of recurrent photography each year.

3.4.8. Debris islands

Debris islands are monitored at one site by means of recurrent photography each year (Fig. 3).

3.4.9. Free rock surfaces

Weathering of free rock surfaces is monitored by means of recurrent photography at three sites in Zackenbergdalen (Fig. 3).

3.4.10. Talus slopes

The accumulation of rock fragments is monitored by recurrent photography on three talus slopes (Fig. 3).

3.4.11. Avalanche tracks

The geomorphic activity on avalanche tracks is monitored at three sites by recurrent photography (Fig. 3). At one site, a more extensive study was carried out during July 1996. In order to elucidate the history of this avalanche boulder tongue, a lichenometric study was performed along with a rock fragment weathering study by means of measuring rebound values with a 'Smith Hammer' (see section 5.1.12).

3.4.12. Rock glaciers

Rock glaciers are monitored by means of recurrent photography at three sites (Fig. 3). At one of these sites, monitoring was supplemented by one vertical temperature profile of the active layer, using three TinyTag dataloggers, logging temperatures 12 times daily.

The surface layer consists of talus material with a typical grain size of 0.5-2 m (Fig.3.4.12.1). The preliminary measurements clearly show the isolating effect of this very coarse surface layer (Fig. 3.4.12.2). Beneath the surface layer solid ice with 2-3 cm large crystals was observed.

3.4.13. Coastal geomorphology

In 1996, the monitoring programme in the coastal zone was continued and extended to include measurements at 19 sites (Fig. 3.4.13.1). Photographs of characteristic coastal landforms from ten sites with known positions have been taken as a continuation of a photo monitoring programme initiated in 1992.

Two terrain profiles at a recurved spit near the old delta of Zackenbergelven were established in 1991 and re-surveyed in 1992, 1995 and 1996 (Fig. 3.4.13.2).

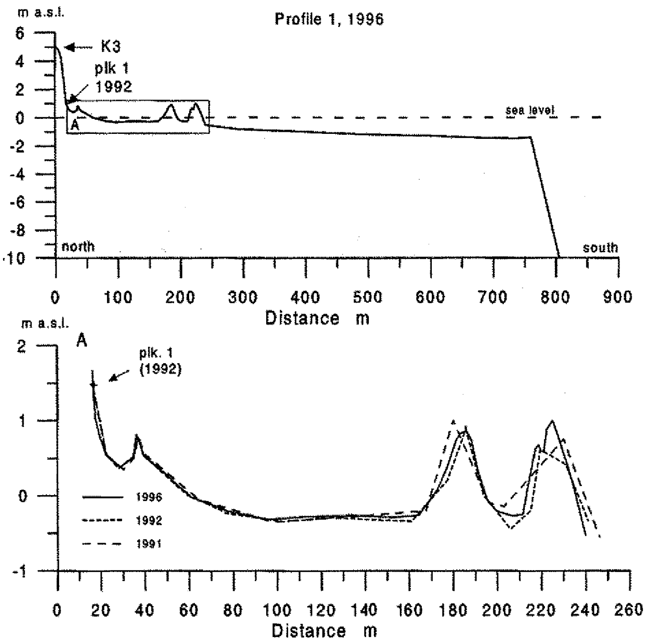


Fig. 3.4.13.2. Part I. Topographic profiles of the recurved spit at the old Zackenbergelven delta. No significant changes have occurred since 1991.

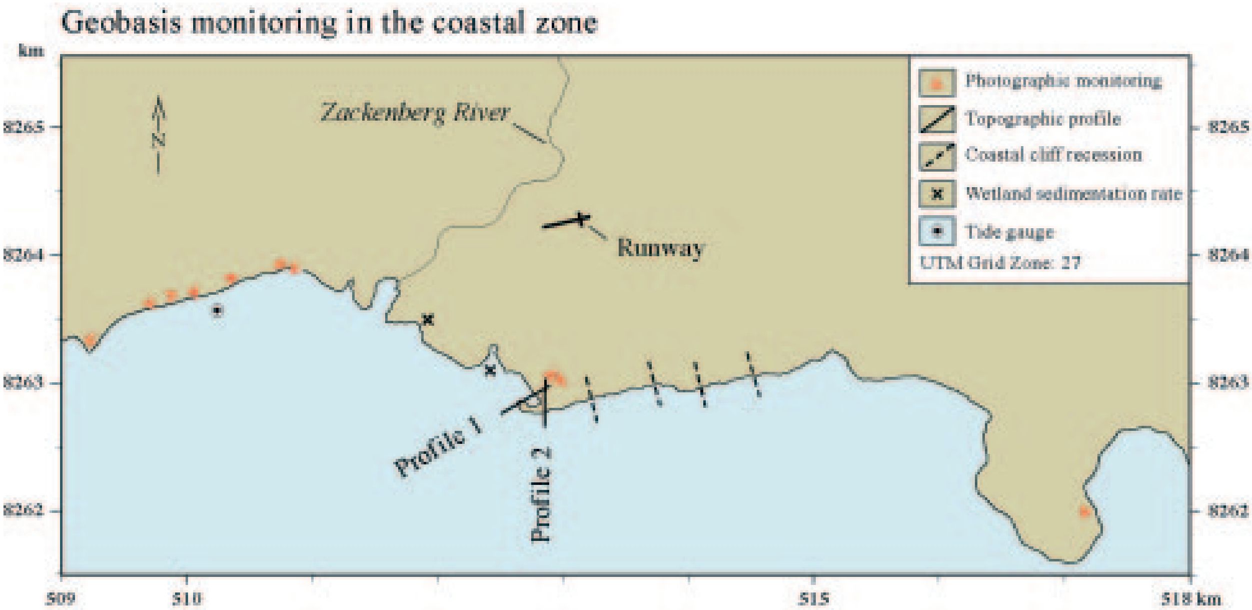


Fig. 3.4.13.1. The GeoBasis monitoring in the coastal zone at Zackenberg includes measurements of different parameters at 19 sites.

No significant changes of the shoreline position have occurred at the spit during 1991-1996. During the 1996 re-survey, the profiles were equipped with metal poles with known levels.

Four test sites for monitoring coastal recession were set up along the coastal cliff east of the old delta. At each site, a peg was situated at a known distance landwards from the cliff top. The coastal recession over time can be measured by repeating the measurements of distances between the pegs and the cliff top. Test fields for measurements of wetland sedimentation rates have been organised in the salt marshes of the old and the new delta, respectively.

Sedimentation rates are measured as the vertical accretion of sediment above a test surface established with sand of a known texture. The sites are marked with metal poles with known levels.

A tide gauge was installed near the old Zackenberg trapping station. The gauge measures the level of the sea at 5 minute intervals (Fig. 3.4.13.3).

The tidal record describes the tidal regime at Zackenberg, essential for establishing an altitudinal zero point for the Zackenberg area, as well as for construction of a tide prediction table and for direct measurements of sea level changes on an annual basis.

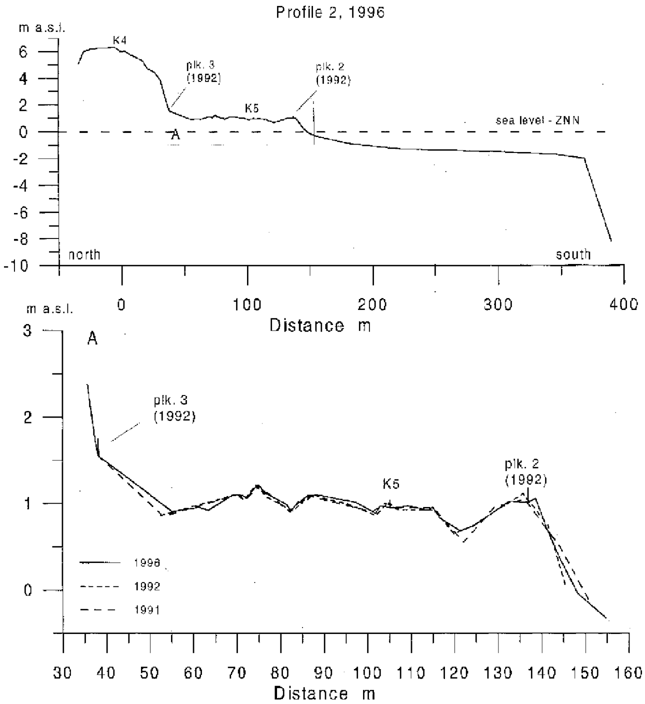


Fig. 3.4.13.2. Part II. Topographic profiles of the recurved spit at the old Zackenbergelven delta. No significant changes have occurred since 1991.

3.5. General observations on ice conditions

3.5.1. The fjord

At the start of the field season, the first days of June, the polynya off Young Sund covered the entire mouth of the fjord, and open water was present almost all around Sandøen. A narrow area of open water formed outside the outlet of Zackenbergelven during mid June, and in early July about 1 km^2 of open water was present here. Eventually, the ice on the entire fjord broke up during 12-13 July, which is comparable to 1995 (Meltofte & Thing 1996; section 4.2.18). Very little drift ice occurred off Zackenberg during the rest of the summer.

3.5.2. Lakes and streams

Zackenbergelven had apparently been running for at least a week before the station opened in early June and the ponds in the fens immediately north and south of the Zackenberg station were partly ice free. By 6 June the small streams on Aucellabjerg had started to run.

The ice on Lomsø started to break up on 24 June, on 4 July it was still about half covered, but all ice had disappeared by 10 July. Similarly, some of the lakes and ponds in Morænebakkerne were ice free on 26 June, while others were partly covered until 6 July.

Open water had formed in the western end of Store Sø by 21 June, and less than 10% ice remained on the lake on 16 July. This may even be earlier than in 1995 (cf. Meltofte & Thing 1996; section 4.2.18). New ice started to form on ponds by 1 September.

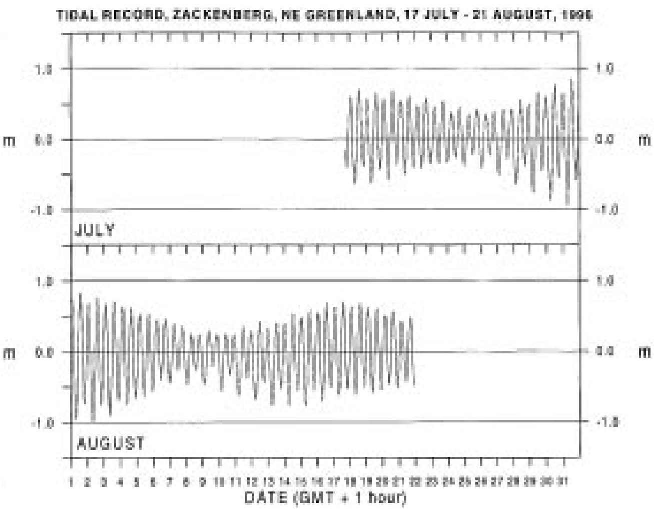


Fig. 3.4.13.3. Tidal record for the Zackenberg area, 17 July - 22 August 1996. Zackenberg have a semi-diurnal mixed tide with a spring tidal range of c. 1.8 m and a neap tidal range of c. 0.9 m.

Fig.3.4.13.4. Deltas and various coastal landforms at Zackenberg. The recurved spit in the background is c. 150 m long. Notice the wide intertidal flats at the mouth of Zackenbergelven. *Photo: Danish Polar Center / Henning Thing*

4. ZACKENBERG BASIC

The BioBasis programme

The elements of BioBasis have been selected to cover a wide range of trophic levels and ecosystem processes. The sampling methods are not described in detail in this report, but can be found in the 'Manual for BioBasis, the biological programme of Zackenberg Basic', available from the Danish Polar Center and on our homepage (http://www.dpc.dk).

4.1. Vegetation

In addition to the 18 ITEX study plots established in 1995, seven new plots were established in 1996, including three combined purple saxifrage *Saxifraga oppositifolia* and moss campion *Silene acaulis* plots as well as four cotton grass *Eriophorum* plots. The plots are all situated within 800 m from the climate station (Fig. 4.1). During late June and early July, TinyTalk dataloggers were installed in all plots (except for the *Eriophorum* plots), to record the microclimate temperature five times daily year round.

This summer, one more vascular plant species was added to the list for Zackenbergdalen, when large-flowered wintergreen *Pyrola grandiflora* was collected. This was species no. 150 recorded in the valley.

All manual data sampling at the ITEX plots was performed by Hans Meltofte.

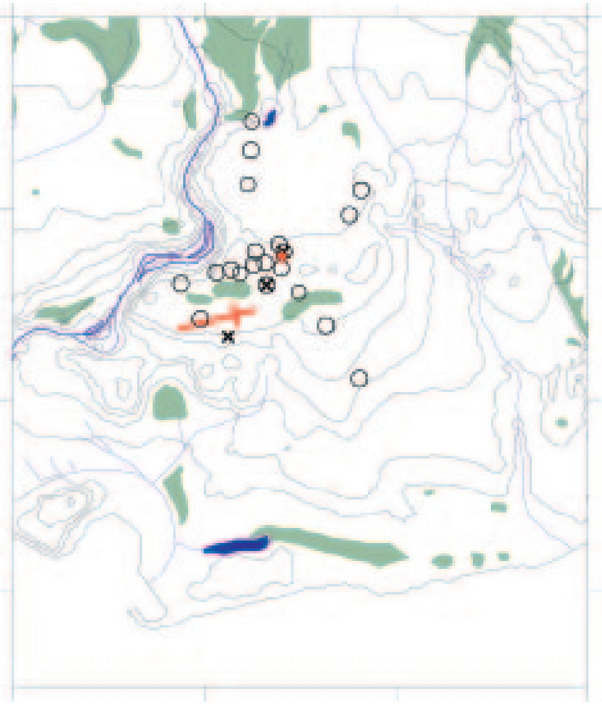


Fig. 4.1. Distribution of 25 ITEX study plots together with three 400 m² plant community study plots at Zackenberg (see section 4.1.4).

4.1.1. ITEX reproductive phenology

Following the start in 1995 of 18 ITEX study plots, it was possible to monitor the reproductive phenology during the entire 1996 season. This even included the three new purple saxifrage and moss champion plots, that were established already.

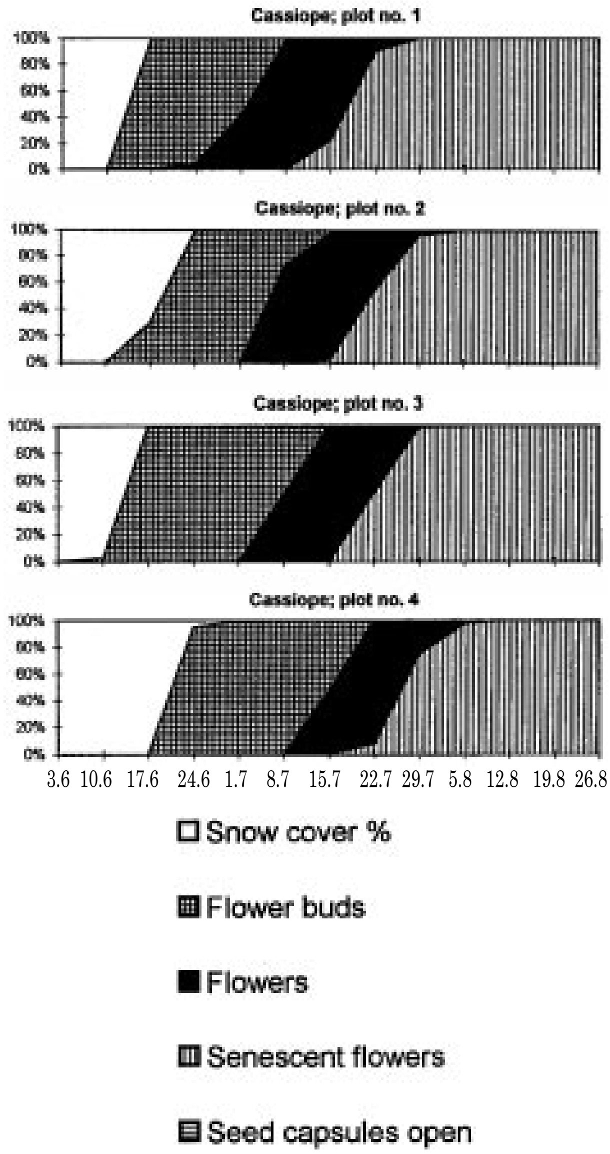
The ratio of flower buds, mature flowers, senescent flowers, seed stands *etc.* was checked at seven days intervals during 3 June - 26 August. This was done by counting a random sample of a minimum of 100 flowers *etc*. in each plot. At these checks also the percentage of snow cover in each plot was estimated. Regrettably, Arctic willow *Salix arctica* had to be left out of the phenology monitoring, as catkin buds could not be sexed and the different flowering stages were hard to define.

The results are presented in Fig. 4.1.1. The plots represent a wide range of snow melt regimes and this is clearly reflected in the reproductive phenology of the individual plots.

Table 4.1.2. Size, pH 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 in ITEX plots in 1995 and 1996. Seed stands of Arctic cotton-grass* Eriophorum scheuchzeri *is divided into fertile (*i.e. *pollinated) and infertile stands.*

Plot	Area (m²)	pH	# flowers etc. 1995 (date)	# flowers etc. 1996 (date)
Cassiope 1	2	6.1	1321 (23.7)	1386 (12.7)
Cassiope 2	3	5.8	–	1759 (18.7)
Cassiope 3	2	5.9	256 (22.7)	844 (18.7)
Cassiope 4	3	6.2	456 (27.7)	1789 (18.7)
Dryas 1	3	4.8	631 (28.7)	537 (02.7)
Dryas 2	60	5.7	554 (28.7)	1073 (25.7)
Dryas 3	2	6.1	603 (16.8)	622 (12.7)
Dryas 4	4	6.5	281 (27.7)	142 (14.7)
Dryas 5	3	6.8	335 (22.7)	258 (14.7)
Dryas 6	91	5.7	809 (27.7)	1408 (25.7)
Papaver 1	105	5.8	302 (23.7)	337 (18.7)
Papaver 2	150	6.1	614 (20.8)	545 (18.7)
Papaver 3	90	6.2	334 (27.7)	238 (18.7)
Papaver 4	91	5.7	166 (27.7)	169 (18.7)
Salix 1 [1]	60	5.7	–	807 ♂♂ (20.6)
			520 ♀♀ (26.7)	1066 ♀♀ (20.6)
Salix 2	300	5.7	–	790 ♂♂ (12.7)
			617 ♀♀ (14.8)	1376 ♀♀ (12.7)
Salix 3	36	6.1	239 ♂♂ (23.7)	479 ♂♂ (02.7)
			253 ♀♀ (23.7)	268 ♀♀ (02.7)
Salix 4	150	6.1	–	1314 ♂♂ (12.7)
			1073 ♀♀ (16.8)	1146 ♀♀ (12.7)
Saxifraga 1	3.5	7.2	–	566 (20.6)
Saxifraga 2	6	6.3	–	613 (20.6)
Saxifraga 3	10	7.7	–	529 (20.6)
Silene 1	3.5	7.2	–	167 (14.7)
Silene 2	6	6.3	–	493 (14.7)
Silene 3	10	7.7	–	348 (14.7)
Silene 4 [2]	1	5.2	466 (23.7)	270 (05.6)
Eriophorum 1	10		–	275/120 (03.8)
Eriophorum 2	10		–	266/137 (03.8)
Eriophorum 3	6		–	468/69 [3] (17.8)
Eriophorum 4	8		–	230/30 (17.8)

[1] grazed by muskoxen before count
[2] labled as *Silene* 1 in 1995 report
[3] plus 98 *Eriophorum triste*



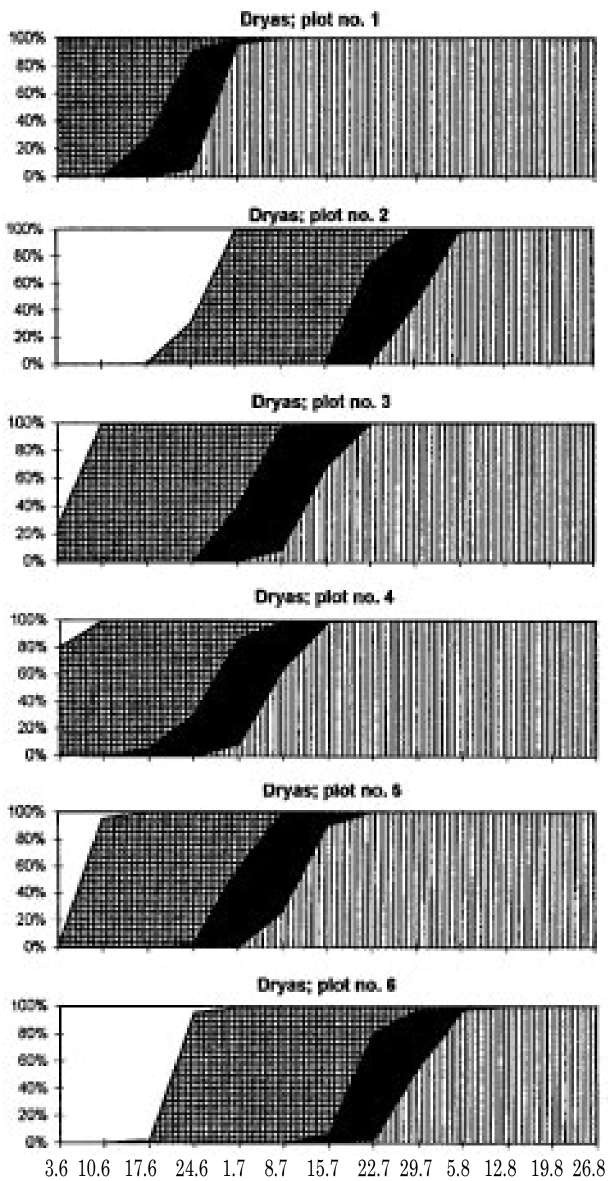


Fig. 4.1.1. Part I. Reproductive phenology of mountain avens Dryas integrifolia/octopetala, *white Arctic bell-heather* Cassiope tetragona, *Arctic poppy* Papaver radicatum, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *together with snow melt in ITEX plots in 1996*

4.1.2. ITEX quantitative flowering

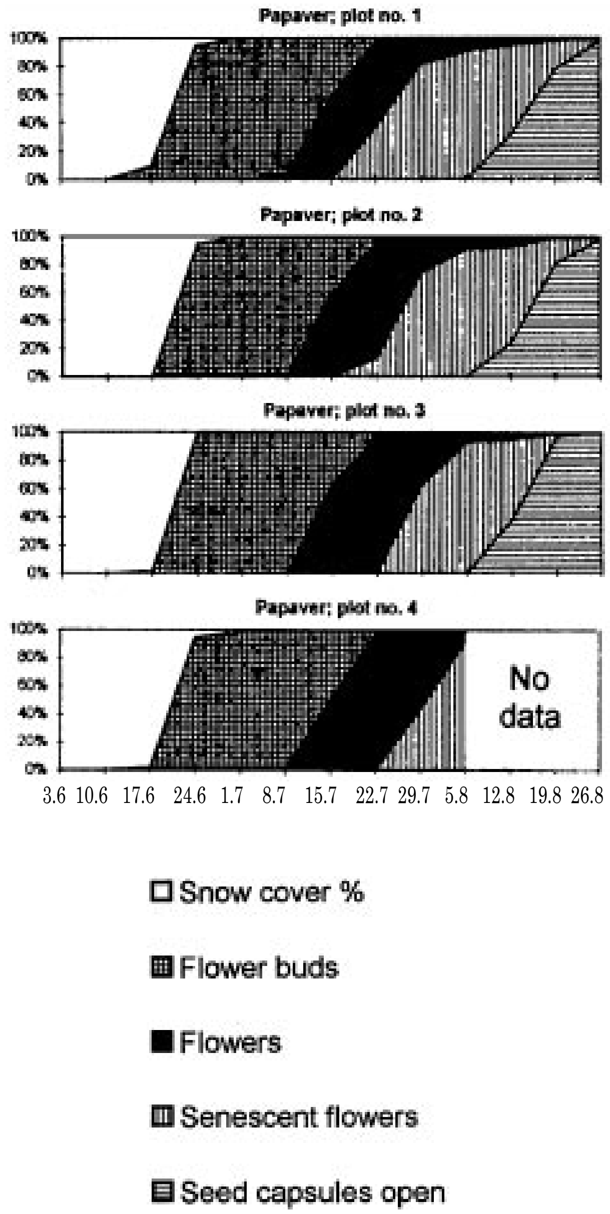
In addition to the plots initiated in 1995 and 1996 to monitor reproductive phenology in six selected vascular plant species (see section 4.1.1), four plots, monitoring the flowering of Arctic cotton-grass *Eriophorum scheuchzeri*, were established in 1996.

During the summer of 1996 flowering at several study plots showed interesting differences as compared to the previous year (Table 4.1.2). Mountain avens, at four relatively dry plots (*Dryas* 1, 3, 4 and 5) developed a lower number of flowers, while two 'wet' plots (*Dryas* 2 and 6) showed a significant increase. This also applies to female flowers in the wettest Arctic willow plots (*Salix* 1 and 2), and similarly in three 'wet' white Arctic bell-heather plots (*Cassiope* 2, 3 and 4).

The summer of 1995, when buds for 1996-flower of the dwarf shrubs (*i.e. Dryas, Salix, Cassiope*) were initiated, was a long and dry summer (see Meltofte & Thing 1996; section 4.2.18). This may have led to drought situations for 'dry' populations, while 'wet' populations may have benefited from the favourable summer conditions. However, the increase in number of male flowers in the 'dry' *Salix* 3 plot does not fit this explanation.

Among herbs, three out of four populations of Arctic poppy *Papaver radicatum* and the single repeated moss campion plot showed decreased flowering. In contrast to the shrubs, these forbs respond the same year to a long and warm summer with favourable growing conditions. Hence they may have exhausted their resources during 1995.

The relatively late dates that several of the plots were censused in 1995 are not considered to have any significant effect on the results.



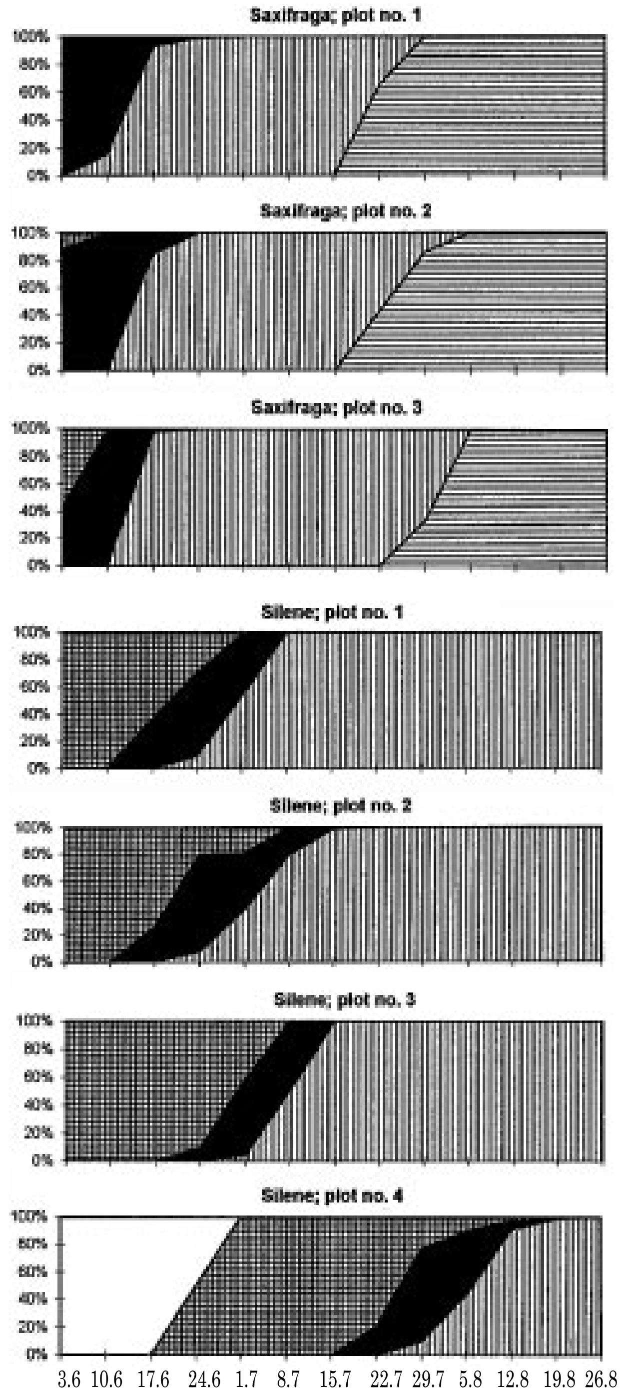


Fig. 4.1.1. Part II. Reproductive phenology of mountain avens Dryas integrifolia/octopetala, *white Arctic bell-heather* Cassiope tetragona, *Arctic poppy* Papaver radicatum, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis *together with snow melt in ITEX plots in 1996*

4.1.3. The ZERO-line

The ZERO line, recording vegetational transitions from sea level to the top of Aucellabjerg, 1040 m a.s.l., was initiated in 1992 and fully established and logged in 1994. It will be re-surveyed and re-logged every five years, the first check is scheduled for 1999.

4.1.4. 400 m² plant community study plots

The 400 m² plant community study plots (Fig. 4.1), surveyed and established in 1992, will be left unchecked until 1997 and thereafter checked at five years intervals.

4.1.5. Snow melt in 4.1.4 plots

Estimates of snow cover in three plant community study plots during the snow melt are presented in Table 4.1.5. A fourth plot was not sufficiently well marked to allow snow cover estimates.

4.1.6. Regional vegetation parameters

The monitoring of selected regional vegetation parameters awaits aerial false-colour photos of the study area and subsequent mapping and ground truthing of vegetation types in the field. An initial mapping effort is planned for 1997, based on existing satellite images and black/white aerial photos.

Table 4.1.5. Relative snow cover in three 400 m^2 vegetational study plots during the snow melt in June 1996.

Date	Plot 1	Plot 2	Plot 3
03.6	>90	30	100
10.6	75	25	100
17.6	15	3	80
24.6	0	0	0

4.1.7. Cryptogam study plots

The cryptogam study plots surveyed and logged in 1994 will be left unchecked until 1999, and thereafter re-checked every five years.

4.2. Arthropods

During the entire field season (3 June - 2 September), weekly samples of arthropods were taken by means of both transparent and yellow pitfall traps, yellow pan traps as well as window traps distributed on six locations within 800 m from the climate station (Fig. 4.2), *i.e.* in the same general area as the ITEX study plots (see section 4.1).

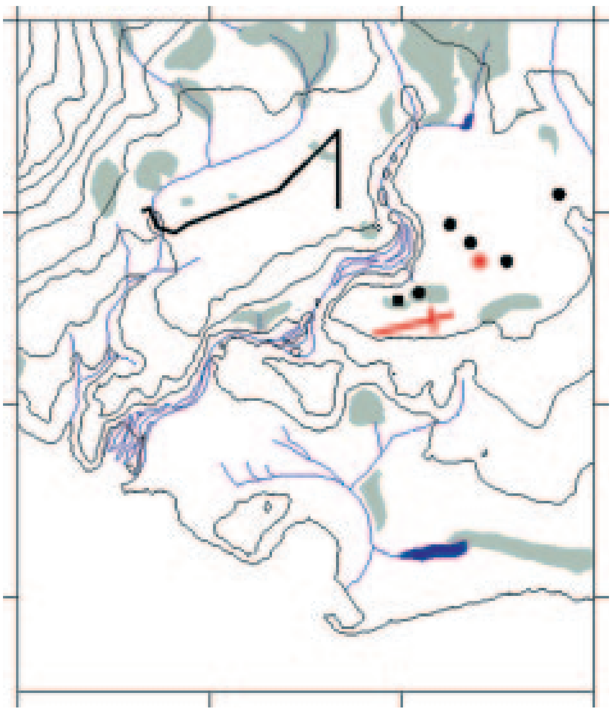


Fig. 4.2. Location of arthropod sampling plots and the line transect route at Zackenberg. ■ = window traps (Station 1). ● = pitfall traps (Stations 2-6). ✶ = meteorological station)

To reveal differences in trapping efficiency, four different types of traps were operated. Experiences gained in 1995 and 1996 will decide which types should be used in the continued monitoring. It was tested specifically, whether transparent pitfall traps could be combined with yellow pan traps to develop yellow 'panfall' traps catching surface living as well as pollinating arthropod species. The results were very promising, and in the future only yellow pitfall traps together with window traps will be used. Comparisons between the two types of pitfall traps are presented in section 5.6.

Furthermore, a 1,660 m line transect was walked once a week, and a number of arthropod parameters was studied in connection with the weekly check of the ITEX study plots (see section 4.1.1).

In total, c. 65,000 arthropods were collected this year. The samples were examined at the Zoological Museum, University of Copenhagen, by Mogens Lind Jørgensen, Aslak Jørgensen and Per Unger. All sampling in the field was performed by Hans Meltofte. The sorted samples are kept at the Zoological Museum, available for detailed examination in the future.

4.2.1. Yellow pitfall traps

On each of the arthropod stations 2-6 (see Fig. 4.2) four transparent and four yellow pitfall traps were positioned at random within squares of 5 x 5 m^2, respectively. On each of the stations 2-5, a yellow pan trap was also in use. Each trap contained water with a little formaldehyde, salt (NaCl) and detergent. A brief description of the habitat of each station is given in Table 4.2.1.1. On 24 June, a TinyTalk datalogger was installed on each plot, recording microclimate temperatures five times daily year round.

Table 4.2.1.1. Vegetation type at each of the arthropod trapping stations 2-6.

Station no.	Vegetation type
2	Marsh dominated by mosses
3	*Cassiope* heath
4	Mixed heath
5	Tufted *Dryas* heath
6	Snow bed with *Salix arctica*

As only yellow pitfall traps will be used at these sites in the future (see section 5.6), this chapter deals with results only from the yellow traps. Beginning in 1997, each station will include two sets of four yellow traps, so that the possibilities for statistical analysis of the results are improved.

Unlike the years to come, the traps were not in place at the start of the 1996 season. Therefore, setting up each trapping site not only had to wait for snow melt, but also for soil to thaw so deeply (>10 cm) that the traps could be dug down.

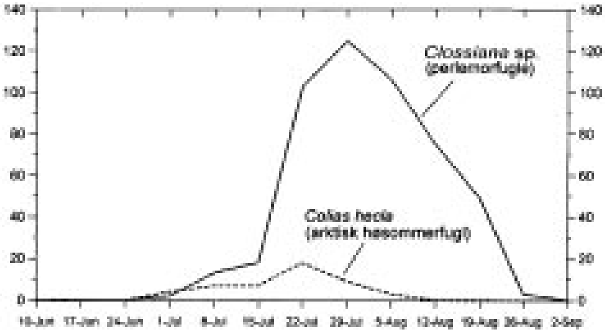


Fig. 4.2.1.1. Phenology of Clossiana spp. *and* Colias hecla *as shown by catches in 20 yellow pitfall traps distributed on five stations at Zackenberg, 1996. Values for each date represent catches from the previous week.*

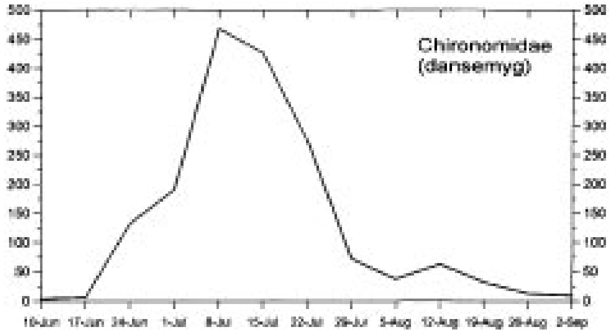


Fig. 4.2.1.2. Phenology of Chironomidae *as shown by catches in 20 yellow pitfall traps distributed on five stations at Zackenberg, 1996. Values for each date represent catches from the previous week.*

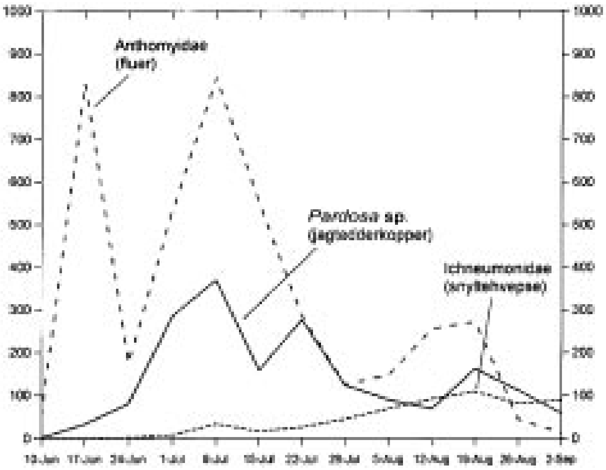


Fig. 4.2.1.3. Phenology of Anthomyidae, Pardosa spp. *and* Ichneumonidae *as shown by catches in 20 yellow pitfall traps distributed on five stations at Zackenberg, 1996. Values for each date represent catches from the previous week.*

The catches from all five stations are pooled in Table 4.2.1.2, and the phenology of selected taxa are presented in Figs 4.2.1.1-3. Note that all five stations were not in operation until the week of 1-8 July. Furthermore, on 10 and 17 June, varying numbers of traps were found to have been fully or partly out of function due to flooding for unknown periods. During the last two weeks of the field season, sampling was further biased by ice forming in the traps at night.

The most prominent phenological features are 1) the very early maximum numbers of some important taxa (midges *Chironomidae*, muscid & anthomyid flies, wolf spiders *Pardosa spp*.), whereas 2) ichneumon wasps and butterflies showed maxima late in the season. The pronounced peak of flies from the week of 10-17 June was due to one trap situated close to an old muskox carcass, however.

4.2.2. Window traps

Two window traps were placed on an islet in a pond immediately northeast of the Zackenberg station (station 1, Fig. 4.2). The windows, each 20 x 20 cm^2 wide, were placed perpendicular to each other in order to reduce the bias from varying wind directions. The traps rested on the ground and the catching basins below the windows were filled with water, added a little formaldehyde, salt (NaCl) and detergent. They were operated throughout the season (3 June - 2 September) and catches were sampled once a week.

Window traps catch flying insects that hit the windows and fall into the catching liquid in the basins below. Accordingly, the two traps are intended to monitor flight activity over the pond.

The results appear in Table 4.2.2. As expected, midges *Chironomidae* and muscid as well as anthomyid flies dominate the catch.

4.2.3. Insect line transect

The insect transect line west of Zackenbergelven (see Fig. 4.2) was walked once weekly during June, July and August, a total of 10 times (Fig.4.2.3. Table 4.2.3.1).

Two checks (one 8 - 15 July and again 29 July - 5 August) were missed due to adverse weather. All checks took place between 09.50 and 13.40 hrs (local time) and in fair weather (*i.e.* sun and light wind). The route is 1,660 m long and 10 m wide, and it runs through a variety of habitat types (Table 4.2.3.2).

During the two first checks most of the transect was snow covered, and it was followed on skis and snow-shoes, respectively. In the future, the line transect will not be checked when snow covered.

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

The six ITEX *Dryas* study plots were checked for predation by *Sympistis zetterstedtii* larvae at weekly intervals in connection with plant reproductive phenology checks (see section 4.1.1).

No larvae were observed, but the reproductive organs in a varying number of flowers were partly or wholly eaten at four sites (Table 4.2.4).

Table 4.2.1.2. Total numbers of arthropods caught in 20 yellow pitfall traps (ø10cm) distributed on five stations at Zackenberg, 1996. Values for each date represent catches from the previous week.

Date	**10.6**	**17.6**	**24.6**	**1.7**	**8.7**	**15.7**	**22.7**	**29.7**	**5.8**	**12.8**	**19.8**	**26.8**	**2.9**
No. of stations	**1**	**2**	**2**	**4**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
COLLEMBOLA	2	200	88	392	595	401	159	421	115	21	252	21	127
HEMIPTERA													
Heteroptera													
Nysius groenlandicus				8		1			1	1		8	1
Aphidoidea				1					2				
Coccoidea					13	17	20	30	2		20		
THYSANOPTERA			1										
LEPIDOPTERA													
Pieridae													
Colias hecla				4	7	7	18	9	3				
Nymphalidae													
Clossiana sp.				2	13	18	103	125	106	75	49	3	
Lycaenidae													
Plebeius glandon							1						
Noctuidae sp.					1	3	5	7	2	5	11	1	
Larvae sp.				2	2	4	10	6	6	5	11	1	
DIPTERA													
Nematocera													
Tipulidae						4	5	1					
Culicidae										1			
Chironomidae	3	6	132	191	468	426	276	72	37	63	32	13	9
Myceptophilidae		2		37	36	28	124	49	34	6	8		1
Larvae sp.			5	2	1	2	3	4		6		2	1
Brachycera													
Emipididae					1				1	3			
Cyclorrhapha													
Phoridae						2		5	34	7	6		1
Syrphidae			2	2	2	1	2	6	7	11	7		2
Larvae sp.			3	3						1			
Acalyptratae sp.										1			
Calyptratae													
Calliphoridae		9					4	2		3	3	1	
Muscidae (Anthomyiidae)	52	831	175	533	844	551	287	126	147	256	273	45	13
Scatophagidae								2		5	3	1	2
HYMENOPTERA													
Symphyta larvae sp.					1					1	1		
Apocrita													
Ichneumonidae			1	7	33	16	26	45	69	92	109	82	90
Braconidae				2	2	3	5	2			1	2	
Chalcidoidea				2			1		2	1	1		
Apidae (*Bombus* sp.)						1							
ACARI	1	10	515	315	374	220	200	696	646	40	502	542	493
ARANEA													
Juveniles sp.				5	22	1	7	16	23	38	126	6	9
Linyphiidae	34	61	93	97	264	64	60	27	25	28	56	80	102
Lycosidae													
Pardosa sp.		33	80	285	370	216	277	124	90	69	162	112	59
Egg sac				2	10	9	2	6	1	2		1	1
Thomisidae													
Xysticus sp.		3	4	16	11	7	8	11	3		5	4	1
TOTAL	**92**	**1155**	**1099**	**1908**	**3070**	**2002**	**1603**	**1792**	**1356**	**741**	**1638**	**925**	**912**

Table 4.2.3.1. Insects recorded during 10 line transects. ++++ denotes 50-100% snow cover, +++ 50-90%, ++10-50% and + 0-10% on different segments of the transect. Caliphoridae *were not separated from other flies on 6 June.*

Species etc.	**06.6**	**15.6**	**23.6**	**27.6**	**03.7**	**17.7**	**23.7**	**11.8**	**14.8**	**21.8**
Snow cover	++++	+++	++	+	+					
Clossiana spp.					1	19	32	14		
Colias hecla						1	6			
Plebeius glandon										
Sympistris zetterstedtii								5		
Other moths			1	1		10	5	6	2	1
Tipula arctica				1	1	6	2	1		
Caliphoridae	+									
Bombus polaris			1		1	3		2	1	

Fig.4.2.3. BioBasis manager Hans Meltofte engaged in the weekly check of the insect transect line west of Zackenbergelven.

Photo: Jens Böcher

Table 4.2.2. Total numbers of arthropods caught in two window traps on an islet in a pond adjacent to the Zackenberg station in 1996. Values for each date represent catches from the previous week.

Date	10.6	17.6	24.6	1.7	8.7	15.7	22.7	29.7	5.8	12.8	19.8	26.8	2.9
COLLEMBOLA		2		5	35			14	5		3	1	
HEMIPTERA													
Heteroptera													
Nysius groenlandicus					1		3						
Coccoidea	13											1	
THYSANOPTERA					1	2		1	1		3		
LEPIDOPTERA													
Pieridae													
Colias hecla							1						
Nymphalidae													
Clossiana sp.							1	1	1		2	1	
Noctuidae sp.							1	1					
Geometridae sp.						1		1	1				
DIPTERA													
Nematocera													
Culicidae				14		25	32	21	6				
Chironomidae	19	61	3240	1507	424	318	575	127	78	22	60	27	19
Cecidomyiidae				1									
Mycetophilidae				8	1	2	12	26	1	1	13		
Larvae sp.	13	35	8					2			2		
Brachycera													
Empididae					57	4	3		4	8	1		
Cyclorrhapha													
Syrphidae				1		1	1			1			
Calyptratae													
Calliphoridae			1		1								
Muscidae (Anthomyiidae)	4	11	22	181	294	294	255	78	55	56	68	30	7
Scatophagidae								1			6	1	3
HYMENOPTERA													
Apocrita													
Ichneumonidae						12	13	6	1	1	5	5	
Apidae (*Bombus* sp.)											4	1	
ACARI		1		2	120			62	43		68		3
ARANEA													
Linyphiidae etc.								2	4		1	1	
TOTAL	**49**	**110**	**3271**	**1719**	**934**	**659**	**897**	**343**	**200**	**89**	**236**	**68**	**32**

Table 4.2.3.2. Distribution of plant communities along the insect line transect.

Plant community	Proportion (%)
Dry wind abration surfaces	3.4
Dryas -dominated associations	11.1
Mixed heath vegetation	27.5
Cassiope -dominated heath	22.5
Grassland with *Cassiope*	5.2
Fairly humid grassland / less humid marsh	15.9
Humid marsh	14.4

Table 4.2.4. Peak number of larvae of Sympistis zetterstedtii *observed in* Dryas *flowers together with peak ratio of flowers damaged by larvae in six study plots, 1996. The latter ratio is given as percent flowers plus senescent flowers affected.*

Plot	# larvae observed	Percent flowers eaten (date)
Dryas 1	0	2 (17.6)
Dryas 2	0	0
Dryas 3	0	11 (01.7)
Dryas 4	0	17 (24.6)
Dryas 5	0	2 (08.7)
Dryas 6	0	0

4.2.5. Occurrence of woolly-bear caterpillars *Gynaephora groenlandica* in *Salix arctica* populations

No woolly-bear caterpillars were observed during the weekly checks of the four *Salix* study plots (see section 4.1.1). The only woolly-bear caterpillar found was an individual spinning a cocoon on 20 June.

4.2.6. Predation by larvae of an unidentified Lepidoptera on *Salix arctica* pods

In connection with the weekly reproductive phenology checks (see section 4.1.1) at the four ITEX study plots for *Salix* it became apparent that larvae of an unidentified butterfly species were predating the plant. Infested pods were recognised by seed hairs emerging from the lower part of the pod prior to the ordinary emergence of seed hairs from the top of the pod. Peak predation was recorded and presented in Table 4.2.6.

Table 4.2.6. Peak ratio of female Salix *stands infested by larvae of an unidentified Lepidoptera in four study plots, 1996. The ratio is given as percent infested stands of 'senescent' flowers.*

Plot	Percent stands infested (date)
Salix 1	+ (15.7)
Salix 2	3 (05.8)
Salix 3	9 (05.8)
Salix 4	0

4.2.7. General phenological observations

First observation dates of selected insect species are presented in Table 4.2.7. Mosquitoes (*Aedes nigripes*) started to be troublesome for people already on 20 June, and they continued to be so until mid August. They peaked in early July and decreased significantly in numbers from 23 July.

Especially during July, hundreds of muscid flies infested with fungi were found dying on features such as plot markers, runway markers, poles, houses and stones.

Species	Date
Clossiana sp.	10.6
Colias hecla	26.6
Plebeius glandon	04.7
Tipula arctica	12.6
Bombus polaris	06.6

Table 4.2.7. First observation dates of selected insect species.

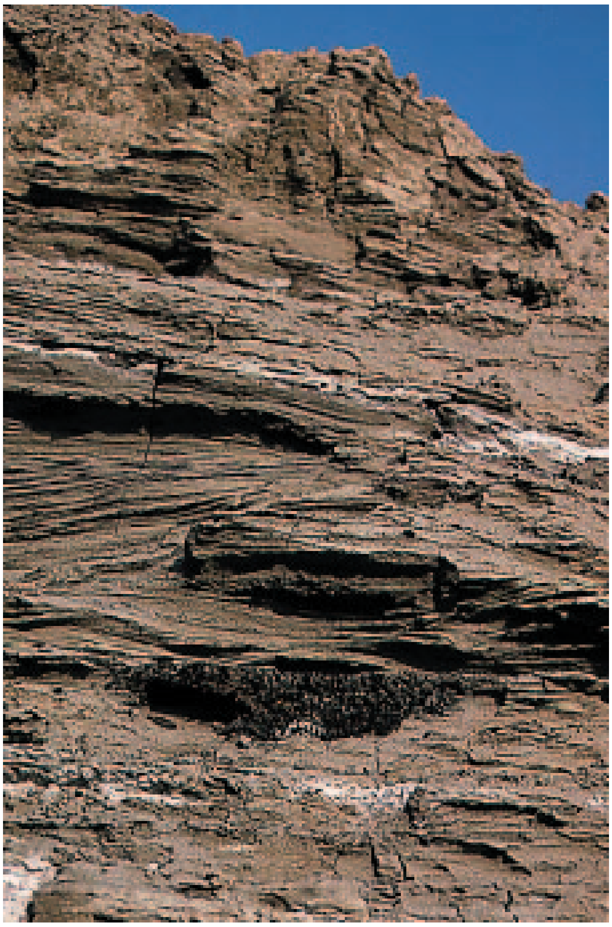


Fig.4.2.8. Layers of organic detritus originating from early Holocene, c. 7900 years ago, are visible and easily accessible in the natural sediment profile deposited by the Zackenberg river. Photo: Jens Böcher

4.2.8. Holocene arthropod samples

A number of samples have been collected from the Holocene sediment layers carrying organic detritus in the coastal cliff north of the mouth of Zackenbergelven (Fig.4.2.8). These layers have been dated to be c. 7900 years old (Ole Humlum, personal communication). The remains of terrestrial plants and arthropods in the sediments are presently being analysed. In addition to a number of widespread Arctic plant species (identified by Ole Bennike, GEUS), the material comprises a small number of orbatid mites, fly puparia and a single beetle species which are now being scrutinised. The presence of these insects in the core study area during the post-glacial period is indicative of a much warmer climate in early Holocene in Zackenberg.

4.3. Birds

Records of observed birds were kept by Hans Meltofte during the entire field season (3 June - 6 September). During June and July priority was given to the breeding populations in the bird census area in Zackenbergdalen, including searching for nests and young (see sections 4.3.1-2 & 4-5). In August, however, the main effort was directed towards censusing waders and other waterbirds in the two deltas of Zackenbergelven (section 4.3.3). Line transects through Store Sødal and adjacent valleys were checked once in July and again in August, in the latter month an additional transect between Daneborg and Zackenberg was covered (section 4.3.6). On this occasion, Sandøen south of Daneborg was also visited (section 4.3.7). These transects were walked by Thomas B. Berg, Henning Thing and Mads C. Forchhammer. Valuable supplementary records were provided by other persons at Zackenberg.

4.3.1. Breeding populations

The census area in Zackenbergdalen was covered extensively around mid June, when birds were concentrated on the rather limited areas of snow free ground. At that time, territory defence and egg-laying peaked (see section 4.3.2), and hence, the birds behaved conspicuously and were relatively easy to record. In the intensively covered 'small' census area west of Zackenbergelven, the census work continued during the rest of June and all of July, while in the extensive areas east of the river, only supplementary records were made during this period. A total of

54 census hours were allocated west of the river and 70 hours east of the river (Table 4.3.1.1). The census results are given in Table 4.3.1.2. However, as detailed maps were not available and census time was limited, the presented data are of a preliminary character. The accuracy varies from species to species,

Table 4.3.1.1. Number of trips and hours (trips – hours) allocated to bird censusing west and east of Zackenbergelven during June and July, respectively.

Month	West of river	East of river	Total
June	6 – 32	9 – 42	15 – 74
July	7 – 22	6 – 28	13 – 50
Total	13 – 54	15 – 70	28 – 128

Table 4.3.1.2. Estimated number of pairs/territories in the 19 km² census area in Zackenbergdalen 1996. Any site claiming or territorial pair or male is considered member of the local population.

Species	West of the river (5.0 km²)	East of the river (14.0 km²)	Total
Red-throated Diver *Gavia stellata*	0	1	1
King Eider *Somateria spectabilis*	0	2 – 3	2 – 3
Long-tailed Duck *Clangula hyemalis*	1 – 2	4 – 6	5 – 8
Rock Ptarmigan *Lagopus mutus*	1	3	4
Great Ringed Plover *Charadrius hiaticula*	11 – 12	39 – 44	50 – 56
Red Knot *Calidris canutus*	2 – 4	21 – 26	23 – 30
Sanderling *Calidris alba*	10 – 13	45 – 55	55 – 68
Dunlin *Calidris alpina*	19 – 26	38 – 45	57 – 71
Ruddy Turnstone *Arenaria interpres*	6 – 8	31 – 40	37 – 48
Red-necked Phalarope *Phalaropus lobatus*	0	0 – 1	0 – 1
Long-tailed Skua *Stercorarius longicaudus*	5 – 6	17 – 21	22 – 27
Snow Bunting *Plectrophenax nivalis*	>19 – 21	29 – 32	>48 – 53

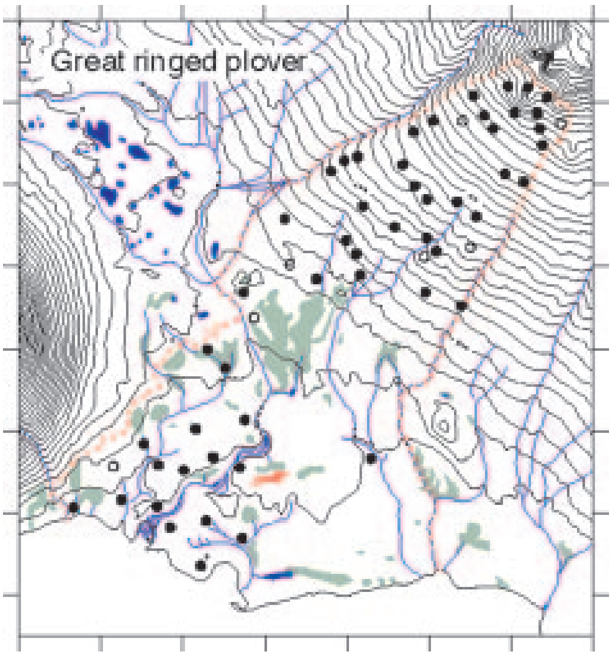


Fig. 4.3.1.1. Distribution of great ringed plover territories within the Zackenberg census area, 1996. Uncertain territories are marked with open symbols.

Species	West of the river (3.39 km²)	East of the river (15.41 km²)	Total
Red-throated Diver *Gavia stellata*	0	1	1
King Eider *Somateria spectabilis*	0	2-3	2-3
Long-tailed Duck *Clangula hyemalis*	1-2	4-6	5-8
Rock Ptarmigan *Lagopus mutus*	1	3	4
Great Ringed Plover *Charadrius hiaticula*	11-12	40-46	51-58
Red Knot *Calidris canutus*	2-4	21-26	23-30
Sanderling *Calidris alba*	10-13	45-55	55-68
Dunlin *Calidris alpina*	19-26	38-45	57-71
Ruddy Turnstone *Arenaria interpres*	6-8	31-40	37-48
Red-necked Phalarope *Phalaropus lobatus*	0	0-1	0-1
Long-tailed Skua *Stercorarius longicaudus*	5-6	17-21	22-27
Snow Bunting *Plectrophenax nivalis*	>19-21	29-32	>48-53

Fig. 4.3.1.2. Distribution of red knot territories within the Zackenberg census area, 1996. Uncertain territories are marked with open symbols.

probably with red knot as the most problematic. Snow bunting data are merely tentative. In the area west of the river, territories are based on a minimum of two records, while in the area east of the river only one total census was performed.

Distribution of each of the wader species as well as of long-tailed skua are presented in Figs 4.3.1.1-6. It appears that sanderlings were breeding on sparsely vegetated and early snow free ground in most of the area, red knots and ruddy turnstones predominantly bred on the well vegetated and relatively early snow free lower expanses of the mountain slopes, *i.e.* up to c. 200 m a.s.l.

Besides the modest numbers on the delta terraces, great ringed plovers were found – as the only species – in full density all the way up to the upper limit of the area. As expected, most dunlins bred in the lowland marshes.

4.3.2. Reproductive phenology in waders (shorebirds)

The peak of egg-laying was in mid June, with a number of possibly relays in late June (Table 4.3.2.1). This is in good accordance with general breeding conditions in Northeast Greenland (Meltofte 1985). Ruddy turnstones were surprisingly late, as this species normally is one of the earliest breeders.

For comparison, the 1995 data have been recalculated to first egg dates and medians (Table 4.3.2.2). These data are probably somewhat biased by our late arrival in the study area in 1995.

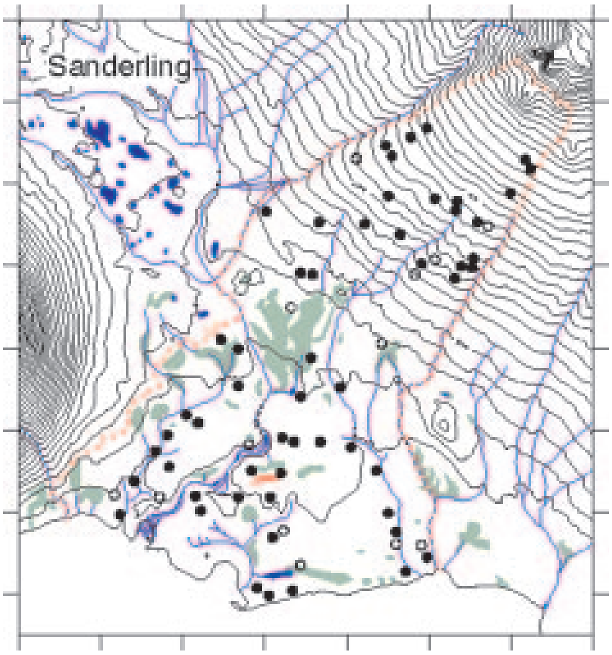


Fig. 4.3.1.3. Distribution of sanderling territories within the Zackenberg census area, 1996. Uncertain territories are marked with open symbols.

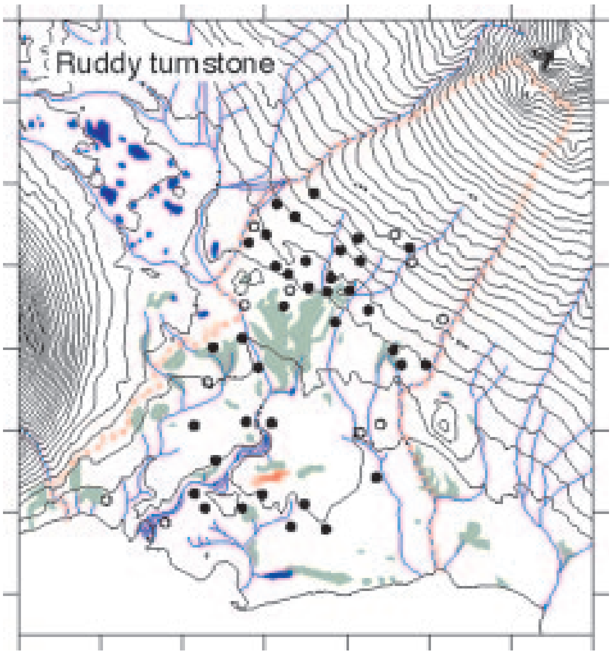


Fig. 4.3.1.5. Distribution of ruddy turnstone territories within the Zackenberg census area, 1996. Uncertain territories are marked with open symbols.

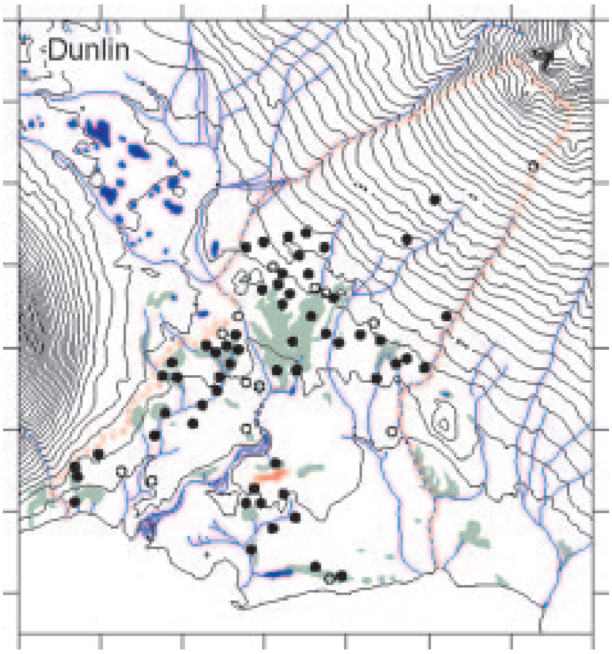


Fig. 4.3.1.4. Distribution of dunlin territories within the Zackenberg census area, 1996. Uncertain territories are marked with open symbols.

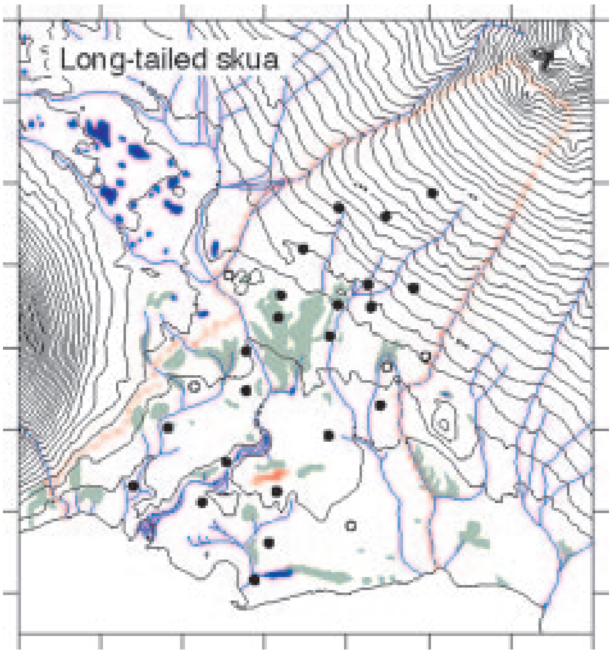


Fig. 4.3.1.6. Distribution of long-tailed skua territories within the Zackenberg census area, 1996. Uncertain territories are marked with open symbols.

4.3.3. Breeding success in waders

In an area like Zackenbergdalen, hatching success is not a good measure for breeding success since nests suffer increased fox predation after being visited by an observer. Consequently, most nests were not visited regularly to check hatching status.

Regional breeding success in waders was initiated in 1995, and continued in 1996, by counting juvenile waders at low tide in the old and the present deltas of Zackenbergelven every third day during August. Numbers of great ringed plovers, red knots, dunlins and ruddy turnstones were in the same order of magnitude as in 1995 (Table 4.3.3), while at least twice as many sanderlings were recorded this year. It is unknown to what extent this reflects regional breeding success in these species, but present data and observations of family groups in the valley indicate breeding success of waders in Zackenbergdalen to have been as good as in 1995.

Table 4.3.2.1. First egg dates for waders at Zackenberg 1996 as estimated from incomplete clutches, egg floating, hatching dates, weights of pulli and observations of newly fledged juveniles.

Species	Median date	Range	N
Great Ringed Plover *Charadrius hiaticula*	17 June	13-25 June	3
Red Knot *Calidris canutus*	11 June	9-12 June	2
Sanderling *Calidris alba*	16 June	8-28 June	8
Dunlin *Calidris alpina*	11 June	6-24 June	11
Ruddy Turnstone *Arenaria interpres*	19 June	8-28 June	14

Table 4.3.2.2. First egg dates for waders at Zackenberg 1995 as estimated from hatching dates, weights of pulli and observations of newly fledged juveniles.

Species	Median date	Range	N
Great Ringed Plover *Charadrius hiaticula*	20 June	–	1
Red Knot *Calidris canutus*	14 June	11-17 June	2
Sanderling *Calidris alba*	16 June	10-23 June	4
Dunlin *Calidris alpina*	18 June	13-29 June	7
Ruddy Turnstone *Arenaria interpres*	12 June	8-18 June	7

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 1-28 August 1995 and 1996. (For 1995 figures, see Meltofte & Thing 1996.) For scientific names, see Table 4.3.2.1.

Species	1995	1996
Great Ringed Plover	90	125
Red Knot	3	18
Sanderling	225 – 303	613
Dunlin	256 – 334	301
Ruddy Turnstone	58	80

4.3.4. Reproductive phenology and success in long-tailed skuas

Two nests, each with one egg, were found already on 12 June. Four more nests, each with two eggs, were located on 18, 18, 20 and 21 June, respectively; finally, one more nest with one egg was recorded on 27 June. All these nest were predated. On 27 July, the first and only *pullus* was found. It weighed 204 g and was accordingly estimated to be c. 15 days old (see de Korte 1986). With an incubation period of 23-25 days (Cramp & Simmons 1983), the egg would have been laid around 18 June.

In total, nests or young of eight pairs were found and most of the remaining 14-19 pairs probably attempted to breed as well. Most probably, however, no young fledged neither in the census area, nor in the remaining parts of Zackenbergdalen in 1996 (see also section 3.3.8). Apparently, the lemming population was moderate in numbers in the summer of 1996 (see section 4.4.1), while Arctic foxes occupied four of the five known dens in the valley – two of them even holding pups (see section 4.4.3).

4.3.5. Breeding barnacle geese

The first pair with a brood of two goslings were seen on the coast west of the old Zackenberg trapping station on 3 July. During the following two days a total of four broods of 1, 2, 4 and 5 goslings, respectively, showed up at Lomsø.

Already by 7 July, they were reduced to 1, 2, 2 and 4, respectively, but maintained their size during the remainder of their stay at Lomsø. On 19 and 23 July they were scared to the fjord by human traffic near Lomsø, and on 10 August they left for good when the helicopter sling operation with building material started to pass over Lomsø (see section 6.2).

In the upper part of the Zackenbergdalen, 2-3 pairs with goslings were observed on the east side of the river on 23 July. On 27 July two pairs with 4 and 5 goslings, respectively, were likewise encountered here. The broods included the same number of goslings when they started to roam the valley as juveniles in mid August, but by 25 August, one juvenile was missing from the smaller brood. Hence, a total of 6-7 pairs of barnacle geese brought their goslings to Zackenbergdalen. This is comparable to the seven pairs found in 1995. The location of nest sites is still unknown.

4.3.6. Line transects

Three line transects through the adjacent valleys and along the coast between Daneborg and Zackenberg were walked in July and August (Table 4.3.6; see also section 4.4.4). Pink-footed and barnacle geese dominated together with waders in July. Compared to Zackenbergdalen, only few long-tailed skuas were found in the adjacent valleys.

4.3.7. Sandøen

The sanctuary of Sandøen south of Daneborg was visited on 13 August. Several hundred pairs of Arctic tern were breeding on the island together with at least 20 pairs of Sabine's gull. *Pulli* of both species were seen. The visit was too late to record breeding of common eider, but several broods were seen around the island. These could, however, also originate from the large colony in Daneborg.

Table 4.3.6. Birds recorded (adults – young) during three line transect surveys 1: through Lindemansdalen, Slettedal and Store Sødal, 2: between Daneborg and Zackenberg, and 3: through Store Sødal, in July and August 1996.

Species	1: 12 – 15 July	2: 14 August	3: 16 – 19 August
Red-throated Diver	3 – 0		2 – 2
Pink-footed Goose	122	131	94
Barnacle Goose	186	110	72
Anser sp.			257
King Eider	2		
Somateria sp.		81	
Long-tailed Duck	5		
Gyr falcon			1
Rock Ptarmigan	1 – 6		1 – 4
Great Ringed Plover	49 – 3		25
Sanderling	13 – 0		3
Dunlin	44 – 2		2
Ruddy Turnstone	14		0 – 1
Long-tailed Skua	3 – 0		
Glaucous Gull	4 – 0		8 – 0
Arctic Tern	5		
Northern Wheatear			1 – 5
Common Raven	2		5
Arctic Redpoll			3
Snow Bunting	111		98

4.3.8. Other observations

This section presents bird records in the study area other than those presented in sections 4.3.1-7. When nothing else is stated, observations refer to the census area in Zackenbergdalen (see Figs 4.3.1.1-6).

Red-throated diver *Gavia stellata*

The pair breeding in the census area was seen copulating on a hummock in the big pond north of the runway on 4 June. From 19 June, one bird was sitting on a nest on a hummock in the big pond south of the runway, but already on 22 June the nest was abandoned, perhaps as a result of disturbance. On 2 July the pair was building on the nest in Lomsø also used in 1991 and 1995, but not until 24 July continuos incubation started. By 21 August, Lomsø was abandoned, and tracks in the mud in the shallow water showed that it had probably been predated by a fox. One bird was incubating on a nest on the shore of a pond immediately north of the census area west of Zackenbergelven on 7 July. By 23 July the nest was predated. A pair was seen in the lakes in Morænebakkerne in July, and one pair had a large pulli on a lake west of the river from Lindemansdalen on 31 August. Up to seven individuals were seen in Lomsø and off the deltas in July and August. Hence, the total population in Zackenbergdalen probably numbered four pairs.

Northern fulmar *Fulmarus glacialis*

One and four fulmars were seen over Young Sund on 25 and 29 July, respectively.

Pink-footed goose *Anser brachyrhynchus*

Up to six pairs and a single individual were seen in the census area before the moult migration started, but no indications of breeding were found. A flock of 20 individuals arrived from the south on 14 June. Up to 31 were seen 19-20 June, and on 21 June, a total of 397 migrated north over the valley. On each of 28 June and 3 July 29 migrated north, and flocks of up to 30 were seen in the area. The last flying bird was seen on 12 July. 40 flightless geese were seen in the deltas of the census area, but these moulting sites, which held 300 birds in 1995, were soon given up due to disturbance. Only the moulting area around the peninsula to the Southeast was occupied by 246 birds (counted on 21 July), which is the same as in 1995 (Meltofte & Thing 1996; section 4.3.3.7). Possibly as a result of disturbance, these birds dispersed west along the coast during late July. On 26 July, the first birds (10) were flying again, and by 9 August 250-300 birds were seen flying. The last flightless geese (12) were seen on 10 August. During late August, when new flocks had arrived from the north, up to 455 pink-footed geese were feeding in Rylekærene and around Gåsesø. This is about half the numbers recorded in 1995. South migrating flocks were seen on 29 August (90) and 4 September (11).

Barnacle goose *Branta leucopsis*

Besides a few flocks of up to 12 individuals, 2-4 nonbreeding pairs were seen during most of June. During July, 3-4 non-breeding pairs moulted at Lomsø together with the family-groups present there (see section 3.3.5). Only one barnacle goose moulted together with the pink-footed geese at the peninsula to the Southeast, as opposite to at least 100 in 1995. 85 individuals moulted at the lakes in Morænebakkerne, which is very much the same as last year. The first flying birds (<10) were seen on 24 July. From mid August until our departure, flocks up to 80 occurred in Rylekærene and at Gåsesø.

Common eider *Somateria mollissima*

Between 13 June and 7 July, up to six males and 12 females were seen in open water areas off Zackenbergdalen. The first two broods probably originating from the colony at Daneborg were seen on 17 July, and from then on, up to at least 10 families were found off the deltas with a maximum of 45 individuals recorded in August. This is somewhat less than in 1995.

King eider *Somateria spectabilis*

Between 12 June and 4 July, most often three pairs together with a female were found on ponds and on open water areas off the deltas. Females were seen a few times later in July, and on 22 July the remains of a predated nest was found at Gåsesø, east of the census area. Other breeding attempts may have occurred, but no further indications of breeding was encountered.

Long-tailed duck *Clangula hyemalis*

Long-tailed ducks were already present on ponds around the Zackenberg station at our arrival in early June. The maximum record was 10 pairs on 8 June.

From 14 June they started also to utilise open water areas off the deltas. An incubating female was encountered at the northern border of the census area west of Zackenbergelven on 25 June, and down from a predated nest was found in the same area on 30 June. No ducklings were seen. The last pair was seen on 14 July, and on the same day the first post-breeding flock of six females were present on Lomsø. Already on the next day, the flock numbered 20 males and females. Groups of males and females were seen on ponds and along the coast during the rest of July, while in August only flocks of 6-7 moulting males were found on the fjord off the old trapping station. This is only half the number moulting here in 1995.

Gyr falcon *Falco rusticolus*

On five occasions between 15 and 27 August one adult gyr falcon was seen in Zackenbergdalen.

Rock ptarmigan *Lagopus mutus*

Pairs and displaying males were recorded four times during June. Broods of 11 and c. 10 small pulli were encountered west of Zackenbergelven on 5 and 7 July, respectively. On 21 July a brood of six large pulli were seen east of the runway, and on 29 July a brood of at least six small pulli were found near Ulvehøj, east of the census area. Pairs without young were seen twice in July, while no ptarmigan were encountered in August. On 1 September, groups of 5, 12 and 4 were found west of Zackenbergelven and on the slopes of the Zackenberg mountain.

Great ringed plover *Charadrius hiaticula*

Pre-breeding groups of up to six individuals were feeding in the fen north of the runway during the first few days after our arrival on 3 June. During the waterbird counts in the deltas, up to 21 adults and 45 juveniles were recorded on 13 August, and on 29 August 54 juveniles were found in the same area. The first juveniles (3) were seen on 1 August and the last adults (2) on 22 August. During most of August, single individuals and small groups were feeding at ponds and on the tundra.

European golden plover *Pluvialis apricaria*

One pair was encountered in the census area on 16 June, one was seen in lower Store Sødal on 29 June, and one individual passed over Zackenbergdalen on 22 August.

Red knot *Calidris canutus*

Intensive song flight display occurred from the day of our arrival. Feeding groups of up to 7-11 individuals were seen from 21 June until 16 July. The first juveniles (2) were encountered on 29 July, and the last adults were seen on 13 August, when eight adults and 14 juveniles were counted in the deltas.

Sanderling *Calidris alba*

A few post-breeding groups of up to 14 individuals were recorded on the tundra during 7-19 July. During the counts in the deltas, up to 27 adults were recorded (on 7 August), and the last adults (2) were seen on 22 August. The first juveniles (11) were recorded in the deltas on 29 July, and peak numbers were 115 and 113 on 13 and 16 August, respectively, and 137 on 29 August. Still on 1 and 3 September, 102 and 95 juv., respectively, were recorded. This is significantly more than in 1995 (see section 3.3.3).

Dunlin *Calidris alpina*

The number of adult post-breeders feeding in the deltas peaked with 100 on 27 July, when also the first juveniles (2) were recorded here. The last adults (3) were recorded in the deltas on 13 August, when also the number of juveniles peaked with 65. Still, on 1 September, 44 juveniles were counted in the deltas.

Ruddy turnstone *Arenaria interpres*

Up to c. 10 pre-breeders were feeding in the fen just north of the runway during the first few days after our arrival on 3 June. No more than 2-3 post-breeding adults were recorded in the deltas during late July and the first half of August, and on 27 August the last adult was seen in Daneborg. The first independent juveniles were eight in the deltas on 29 July, and on 13 August a peak record of 40 was counted. 25 juveniles were feeding among the tethered huskies in Daneborg during a visit on 27-28 August.

Fig.4.3.8. Adult sanderling on the nest site with two newly hatched pulli.
Photo: Danish Polar Center / Hans Meltofte

Red-necked phalarope *Phalaropus lobatus*

A single female was recorded six times between 5 and 16 June. On 17 August, two juveniles were feeding on a pond in the census area.

Long-tailed skua *Stercorarius longicaudus*

Long-tailed skuas were recorded in the census area already on 1 June. On 7 July, an immature was seen. During the second half of July up to 15 were displaying together. Numbers decreased during the first half of August, and the last individual was seen in the census area on 12 August. However, on 15 August a pair was mobbing a gyr falcon on the south slope of the Zackenberg mountain. No juveniles were recorded.

Glaucous gull *Larus hyperboreus*

Between one and five individuals were seen almost daily along Zackenbergelven and the coast during June and July. A few immatures were seen in late June and early July. During the waterbird counts in the deltas between late July and early September, up to 15 adults were recorded. A juvenile appeared on 3 September. On 28 August, at least 10 nest sites could be counted on the steep northern bluff of Basaltø.

Arctic tern *Sterna paradisaea*

Two Arctic terns were feeding in the old delta on 29 July.

Pied wagtail *Motacilla alba*

A pied wagtail was present at the Zackenberg station on 7 and 12 June. Two juveniles stayed with the tethered huskies in Daneborg during our visit 27-28 August. This indication of breeding is the northernmost made so far in East Greenland.

Northern weathear *Oenanthe oenanthe*

An alarm calling female and a do. pair were recorded in two different places high on the slopes of Aucellabjerg on 16 and 22 July, respectively. Adults and juveniles were recorded in the lowland on eight occasions between 8 August and 1 September.

Common raven *Corvus corax*

Between one and four ravens were recorded regularly in Zackenbergdalen during the entire season. No clear evidence of breeding was found. 15 were present at the tethered huskies in Daneborg during our visit 27-28 August.

Arctic redpoll *Carduelis hornemanni*

Pairs and single individuals regularly flew over Zackenbergdalen until 14 June. Later, single individuals were recorded only on 4 and 5 July.

Snow bunting *Plectrophenax nivalis*

The first family flocks were recorded in the lowland on 27 July, and on 21 August the first post-breeding flocks of 60 were seen.

4.4. Mammals

Observations of mammals were made by Thomas B. Berg 19 June - 6 September and additionally by Hans Meltofte 3 June - 6 September and by Mads C. Forchhammer 4 August - 6 September. The 250 ha census area for collared lemming *Dicrostonyx groenlandicus* was censused for winter nests and active summer burrows. Muskoxen *Ovibos moschatus* were counted daily from a fixed, elevated point at the station, and the total number of muskoxen within 39.1 km^2 of Zackenbergdalen was censused once a week. Thirteen muskox carcasses from the winter of 1995-1996 were recorded in the valley. Arctic fox *Alopex lagopus* occupied both of the two known dens in the valley and during the field season three additional dens were located within Zackenbergdalen. To position and log two future line transects to be covered twice annually, three transects were walked this summer, one from Daneborg to Zackenberg and two in the adjacent inland valleys. All observations of mammals other than muskoxen are included in section 4.4.5.

4.4.1. Winter nests and summer burrows of collared lemming

Following the disappearance of the snow cover, the designated 2.5 km^2 lemming census area was searched by transects at 15-20 m intervals. As in 1995, winter nests were referred to either of the two age categories, I: nests built in the winter of 1995-1996 or II: nests older than I. For each nest the following parameters were recorded: UTM co-ordinates, nest diameter (5 cm intervals), pellet index (<500, 500-2000, 2000-4000, >4000), signs of predation by Arctic fox or ermine, and presence of moulted lemming fur.

In addition to the winter nest survey, active summer burrows were systematically recorded along the transects. They were identified as holes with fresh soil digging or with well worn pathways in the surrounding vegetation. There are two kinds of summer burrows: those used for breeding and those used for retreat only. The latter is just a short tunnel, often less than 75 cm long, while those used for breeding have more than one entrance and a well built nest of grass, leaves and moss just as the winter nests.

In all, 424 winter nests were examined; 161 (*i.e.* 64/km^2) were from the previous winter and 263 were of older age (Table 4.4.1). It is too early to interpret the trend in the lemming population at Zackenberg. A similar study on Traill Ø, 220 km south of Zackenberg, has been going on since 1988. The snow cover there is 3-4 times thicker than at Zackenberg, and the area (10 km^2) has a much higher carrying capacity for lemmings.

Lemming index (winter nest/km^2) ranged from 369 (1989/1990) to 10 (1991/1992) (Sittler 1995). The range of the lemming index at Zackenberg may turn out to be much lower, mostly due to the lesser amount of snow. Despite the short distance between the two sites, the lemming populations at Traill Ø and Zackenberg seem to have been out of phase in 1996 with an index of 20/km^2 at Traill and 69/km^2 at Zackenberg. Aa additional 80 active summer burrows were found.

The efficiency in detecting the fresh winter nests is estimated as 90%, whereas the efficiency with respect to age category II is judged to be around 65%; the latter calculated as the 263 old nests found in

1996 (missed in 1995) divided by the 830 old nests found in 1995, indicating an efficiency of less than 65%. During the forthcoming field seasons the study area will be cleaned for old nests. The efficiency of detecting active summer burrows is estimated to be around 75%.

Table 4.4.1. Number of examined winter nests.

Year	Category I	Category II
1995	279*	830
1996	161	263

*) includes nests from the winters of 1993-1994 and 1994-1995

The nesting habitat differs between winter and summer. Winter nests were primarily located on slopes and in tufted vegetation (Fig. 4.4.1). In contrast, summer burrows were found in drier and flat habitats such as windswept terrain or on the upper part of slopes in *Dryas* heath.

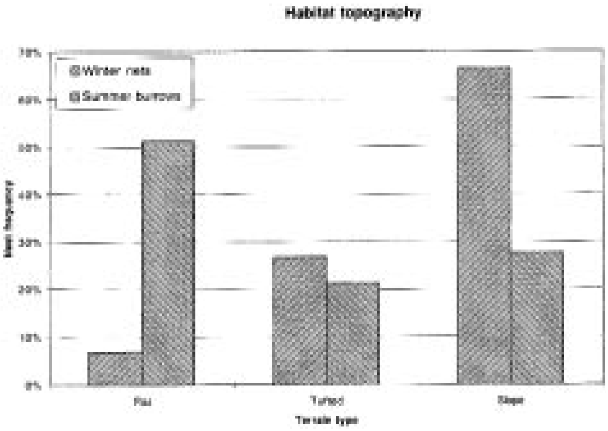


Fig. 4.4.1. The relative frequency of terrain types used by lemmings for winter nests and summer burrows within the 2.5 km² study area at Zackenberg.

Of the 161 fresh winter nests found, only one had been predated by ermine (*i.e.* scats and fur were present) whereas 12 had been predated by Arcticfox (*i.e.* scats present) (see Table 5.7.1).

4.4.2. Muskox population biology

In 1996, muskox monitoring was fully established and implemented as an integrated part of BioBasis. Monitoring muskoxen has two main objectives: 1) to obtain data on how muskoxen interact with the local ecosystem, and 2) to obtain long-term data on how muskoxen respond to changes in their biotic and abiotic environment.

More specifically, muskox monitoring focuses on spatial and temporal aspects of local population structure and dynamics and distributional characteristics in combination with reproduction and age- and sex-specific survival.

The monitoring is divided into four parts: 1) weekly census of all muskox groups within a 39.1 km² census area in Zackenbergdalen (Fig. 4.4.2), including information on herd size and structure, 2) daily total counts of groups (number and size) from a fixed, elevated point at the station, 3) transect census of muskoxen covering areas adjacent to the census area twice per season (see section 4.4.4), and 4) registration of all new muskox carcasses in Zackenbergdalen.

4.4.2.1. Muskox population dynamics and structure

The field season at Zackenberg extended over three seasons of the annual muskox life cycle: post-calving (1-30 June), summer (1 July - 14 August) and rut (15 August - 15 September). During these periods, the total number of muskoxen in the census area varied considerably (Fig. 4.4.2.1.1). From late June to mid July the local population averaged 13-14 individuals. However, from 22 July through August, the number of muskoxen within the census area increased rapidly to a peak of 166 on 1 September (Fig. 4.4.2.1.1). Although significantly underestimating the total number of muskoxen within the census area (by a mean of 35%), this seasonal trend was also apparent from the data obtained by the daily fixed-point counts (Fig. 4.4.2.1.1; ANCOVA, means: $F_{(1,60)} = 10.13$, $p < 0.005$; slopes: $F_{(1,60)} = 0.61$, $p > 0.25$).

The daily occurrence of muskoxen outside the area, primarily towards SE, was likewise recorded by the fixed-point counts (Fig. 4.4.2.1.1). These numbers underestimate the actual number of muskoxen present even more than within the census area. Nevertheless, the trend observed is indicative of the annual migration patterns. As seen from Fig. 4.4.2.1.1,

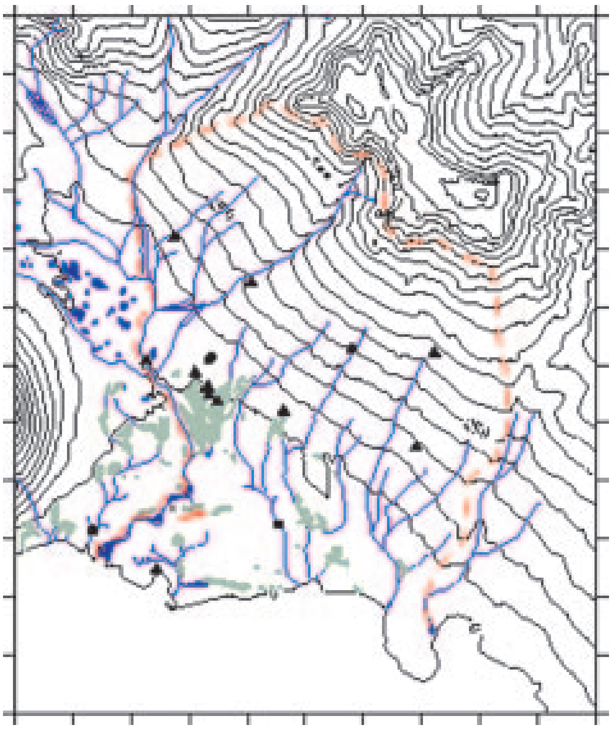


Fig. 4.4.2. Location of muskox census area and localities mentioned in the text, as well as muskox carcasses (▲) and Arctic fox dens (■). Fixed-point muskox counts were carried out daily from a building roof (marked with •) recording all visible muskoxen in a 360° scan.

numbers outside the census area also increased through late summer and rut, although less significantly. This suggests that the increase in Zackenbergdalen and the coastal region between Zackenberg and Daneborg is a result of muskoxen immigrating from surrounding areas. Similar high densities of muskoxen in Zackenbergdalen have been reported during the winter period (Boertmann & Forchhammer 1992). Results presented below are all based on data from total censuses within the census area in Zackenbergdalen (Fig. 4.4.2).

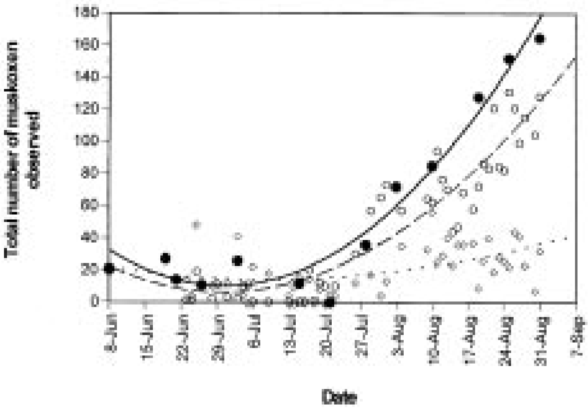


Fig. 4.4.2.1.1. Numbers of muskoxen counted within the census area (•: total census; °: fixed-point count) and outside the census area (◊: fixed-point count) in Zackenbergdalen, 1996. Lines are polynomial regression lines for the three data sets (solid: within census area - total censusing; dashed: within census area - fixed-point count; dotted: outside census area - fixed-point count). Throughout the field season, all counts were made from the same point (see Fig. 4.4.2).

The temporal dynamics in population numbers within the census area can be analysed further by considering how the specific age- and sex-classes relate to the total number of muskoxen. The causal mechanism behind distribution of individuals varies greatly outside and during the mating season (see section 4.4.2.2). During the post-calving and summer seasons, all age and sex classes showed highly significant, positive correlation with the total number (Multiple regression: $R^2 = 0.99$, $p < 0.001$), indicating that all age and sex classes used Zackenbergdalen equally during this particular period.

Quite a different picture emerges when we look at the temporal dynamics during the rutting season. The high rate of increase in muskox immigrating to Zackenbergdalen from the beginning of August was primarily related to a high influx of adult females, yearlings and calves (Multiple regression: $b' = 0.85$) as compared to subadult ($b' = 0.12$) and adult ($b' = 0.23$) males (Fig. 4.4.2.1.2). In early rut, males followed the influx of females but dropped again in numbers during the peak rut (Fig. 4.4.2.1.2), primarily as a result of intra-sexual competition for access to females (Forchhammer 1995, 1996; Forchhammer & Berg *in prep.*). The number of subadult males remained constantly low throughout the rutting season ($r = -0.06$; $p > 0.75$).

As expected from the high percentage of calves in 1995 (29%; Berg 1996), the overall structure of the local muskox population in 1996 was dominated by this cohort (*i.e.* 22.8% yearlings; Fig. 4.4.2.1.3). Taken over seasons, the overall effective sex ratio (adult females / adult males and females) within the census area averaged 0.59±0.25 (±SD). The highly female biased sex ratio of 3-year individuals (Fig. 4.4.2.1.3) is probably related to the difficulty in separating 2- and 3-year females in the field. However, the presence of 3-year males within the census area was relatively low, especially during the rutting season. As

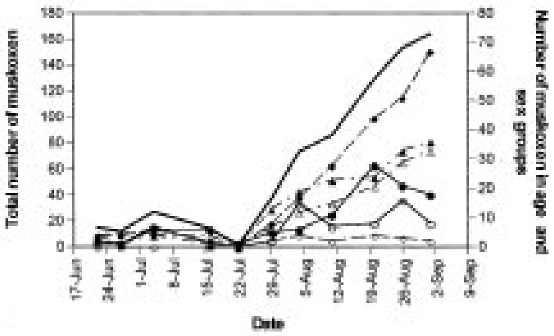


Fig. 4.4.2.1.2. Numbers of adult males (4+ yrs: •), subadult males (2-3 yrs: °), adult females (3+ yrs: ◆), subadult females (2 yrs: ◊), yearlings (▲) and calves (Δ). Numbers obtained by total censusing of muskoxen within Zackenbergdalen, 1996 (see Fig. 4.4.2). Total number of muskoxen is given by the bold, solid line.

expected from the high influx of females (Fig. 4.4.2.1.2) and the increased male-male competition (Forchhammer & Berg *in prep.*) during the rut, the average sex ratio increased from 0.48±0.30 during the pre-rutting seasons to 0.73±0.06 in the rut. Due to the large variation in sex ratio during pre-rut, the increase was not statistically significant (two sample *t* test: $t_9 = 1.81$, $p > 0.1$).

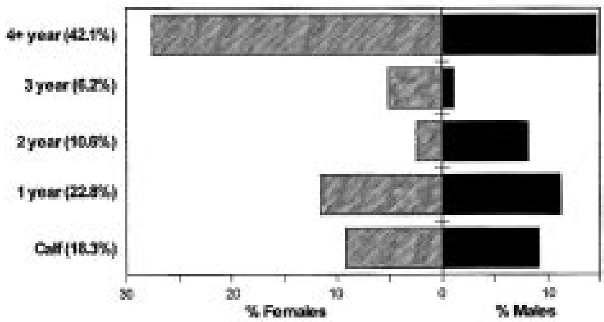


Fig. 4.4.2.1.3. Population structure of the local muskox population in Zackenbergdalen, 1996, divided into percent females and males for five cohorts. Individuals aged 4 or more years were pooled into the same age group (4+). Percentages were taken of all observations from total censuses covering all seasons. Sex of calves could not be determined in the field and the sex ratio was assumed to be 1:1.

4.4.2.2. Distribution and social environment of muskoxen

In order to evaluate, on a larger geographical scale, the relative use of Zackenbergdalen throughout summer and rut, the adjacent valley, Store Sødal, and the coastal region between Daneborg and Zackenberg were censused by means of transect routes (see section 4.4.4). During mid July, before the high influx of muskoxen to Zackenbergdalen, muskox densities in Zackenbergdalen and surrounding areas were similar (Table 4.4.2.2). However, as the density of muskoxen in Zackenbergdalen increased, the density in Store Sødal decreased during mid August (Table 4.4.2.2), indicating a migration of individuals to Zackenbergdalen from Store Sødal in this particular period (see also section 4.4.2.1).

Table 4.4.2.2. Seasonal changes in muskox densities (#/km²) in Store Sødal (91.8 km²), the census area (Zackenbergdalen: 39.1 km²) and the coastal region between Daneborg and the Zackenberg census area (37.4 km²). The Daneborg-Zackenberg area was not censused in mid July. Density values for Zackenbergdalen are calculated on the basis of total censusing in the census area during the given time periods.

Period	Store Sødal	Zackenbergdalen	Daneborg-Zackenberg
12-15 July	0.37	0.35	–
16-19 August	0.13	3.30	0.48

Within the census area in Zackenbergdalen, a seasonal change in altitudinal habitat use was observed. Habitats up to 100 m a.s.l. were used intensively throughout June (33%) to August (67%) (Fig. 4.4.2.2.1). Habitats between 100 and 300 m were primarily used in July (7-21%) and August (5-8%). As the season progressed, the use of habitats above 300 m a.s.l. decreased from 14-28% to 5-14% (Fig. 4.4.2.2.1). This seasonal distribution of muskoxen within the census area reflected the relative availability of habitats as documented by the seasonal pattern of thawing of snow (see section 3.4.1).

Even though the seasonal patterns of altitudinal habitat use (Fig. 4.4.2.2.1) within the census area were similar for all age and sex classes, individuals did segregate spatially within these habitats, especially adult bulls, cows and subadult bulls. During the pre-rutting seasons, low proportions of coincidence in habitat use were observed between adult bulls, cows and subadult bulls (0.2; Fig. 4.4.2.2.2). Coinciding habitat use increased at the beginning of rut (0.8-1.0). As rut progressed, coincidence of adult bulls and cows remained relatively high (0.6), whereas associations between cows and subadult bulls as well as between adult and subadult bulls decreased considerably (0.3; Fig. 4.4.2.2.2) as would be expected from the increased male-male competition (Forchhammer & Berg *in prep.*). This seasonal pattern of coinciding habitat use, illustrates the importance of female distribution and male-male competition on the general distributional patterns of muskoxen during the rut.

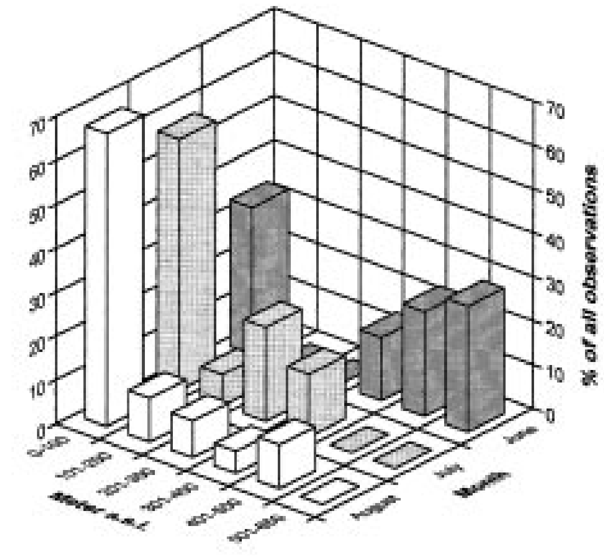


Fig. 4.4.2.2.1. Seasonal variation in the altitudinal distribution of muskox herds in the census area, 1996. Sample sizes (number of herds) for June: 21; July: 14; and August: 60.

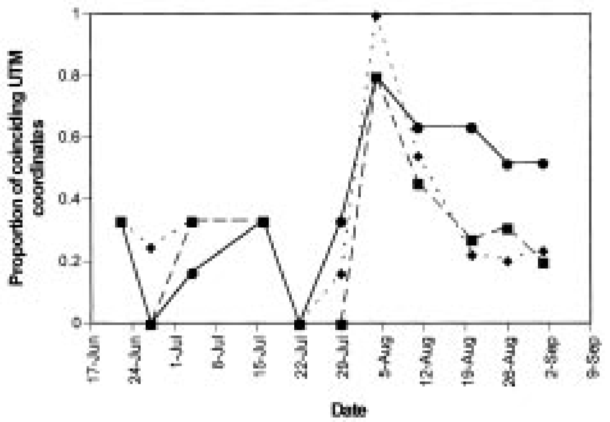


Fig. 4.4.2.2.2. Seasonal variation in the proportion of coinciding UTM co-ordinates between adult bulls and cows (•), adult and subadult bulls (n), and adult cows and subadult bulls (u).

The social environment of the individual muskox relates to intra- as well as inter-herd interactions with other individuals (Forchhammer 1996). The evolutionary implications of variation in the social environment of muskoxen on the reproductive strategies will be presented in detail elsewhere (Forchhammer & Berg *in prep*). Here, focus is put on the description of the general seasonal variations in the social environment, *i.e.* herd size and herd structure. Herd size increased significantly from 4.3±1.6 in pre-rutting seasons to 8.0±3.7 in rut (two sample t test: $t_{11} = 2.51$, $p < 0.05$). Similarly, the presence of mixed herds (herds including both males and females) within the census area increased significantly from 43.1%± 27.1% in pre-rut to 82.7%±11.2% in rut ($t_9 = 3.05$, $p <$ 0.02). The structure of mixed herds varied over seasons. Although fluctuating, the number of cows increased significantly through seasons ($r = 0.70$, $p <$ 0.05) from 2-3 to 3-4 cows per herd (Fig. 4.4.2.2.3). During the pre-rutting seasons, the number of adult and subadult bulls in mixed herds averaged 0.9±1.0 and 1.3±1.1, respectively. In rut, an average of one adult bull (0.9±0.2) was observed per herd, whereas only one subadult bull (0.5±0.2) was observed in every second mixed herd (Fig. 4.4.2.2.3). The average number of calves and yearlings per herd was similar to those of cows during pre-rut, *i.e.* one calf and yearling per cow. However, during rut, the number of both calves and yearlings decreased to one calf and yearling per two cows.

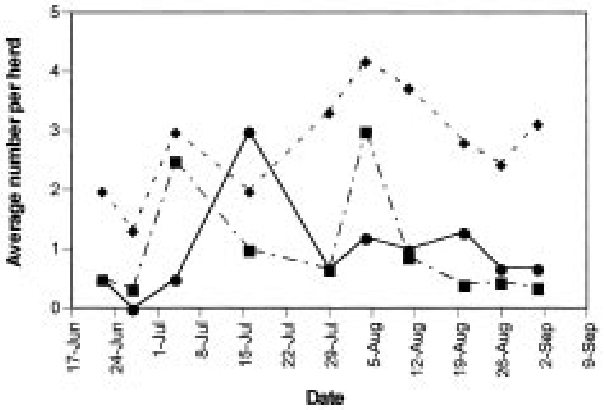


*Fig. 4.4.2.2.3. Seasonal variation in the structure of mixed herds including the average number of adult bulls (•), adult cows (u), and subadult bulls (*n*) in Zackenbergdalen, 1996.*

4.4.2.3. Survival and reproduction of muskoxen

The survival of muskoxen is significantly influenced by the density-independent influence of extreme, adverse winter weather conditions (Vibe 1967; Forchhammer & Boertmann 1993). In the local muskox population in Zackenbergdalen, age- and sex-specific survival and mortality rates were obtained by two procedures: 1) cohort analysis based on total census and 2) analysis of carcasses.

Due to limited access to ageing of individuals in the field, cohort analysis could be made only until an age of 3 years. Additionally, the cohort analysis was constrained by census procedures. Since the censused muskox population in Zackenbergdalen is part of a larger population also inhabiting the remaining parts of Wollaston Forland and Payer Land, migration is expected to have a major effect on the observed number of age and sex classes in Zackenbergdalen, especially during the rutting season where there is a considerable influx of individuals (Fig. 4.4.2.1.1). This problem is illustrated by comparing the presence of the 1994- and 1995-cohorts in Zackenbergdalen in 1996. The 1995-cohort decreased to 22% in 1996, indicating an overall survival probability of 0.79 during the first year of life. In contrast, the 1994-cohort increased from 8% in 1995 to 11% in 1996 (Fig. 4.4.2.1.3), clearly demonstrating the effect of immigration to Zackenbergdalen.

Alternatively, survivorship of muskoxen can be calculated by analysing the occurrence of carcasses. Even though this procedure mixes cohorts, the analysis does provide an indication of survival rates *before* and *after* the establishment of ZERO as the registration of new carcasses continues as part of BioBasis. During the 1996 field season, a total of 66 carcasses were located in Zackenbergdalen. Of these, 50 (29 males and 21 females) were determined to have died from natural causes (*i.e.* malnutrition, disease, injury, or predation). Based on this sex-specific survivorship, curves were constructed (Fig. 4.4.2.3) following the procedure by Thing (1985). The mortality rate of males increased as they reached their prime breeding age, whereas the mortality rate of females increased more steadily throughout their age of breeding (Fig. 4.4.2.3). The general survivorship pattern corresponds to that calculated for the Jameson Land muskox population, except for the higher probability of survival of young muskoxen (1-3 years) in Zackenbergdalen (Thing 1985).

Calf production in 1996 was considerably lower (18.3%; Fig. 4.4.2.1.3) as compared to 1995 (29%; Berg 1996) and closer to the average annual production of calves as previously reported in East Greenland (Thing *et al*. 1987; Bay & Boertmann 1988; Sittler 1988). The overall calf/cow ratio was 0.65±0.51 and somewhat higher than previously reported from Jameson Land (Thing *et al*. 1987).

Although not statistically significant, the calf/cow ratio decreased from 0.74±0.64 in pre-rut seasons to 0.49±0.04 in rut, indicating an influx of barren (or currently calf-less) cows to Zackenbergdalen during this period. This pattern is confirmed in Fig. 4.4.2.1.2, where the slope for immigrating females is steeper than that of calves in this particular period.

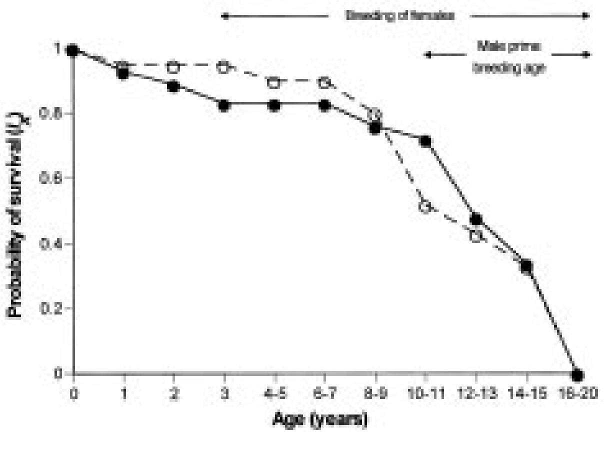


Fig. 4.4.2.3. Survivorship curves of males (•) and females (°) based on carcasses found in Zackenbergdalen until 1996. Age of carcasses was estimated following Smith (1976). Molars were collected to determine the accurate ontogenetic age based on analysis of cementum layers. Range of ages of breeding indicated by arrows for males and females as documented by Thing et al. *(1987) and Forchhammer & Berg (*in prep.*).*

4.4.2.4. Fresh muskox carcasses from the 1995-1996 winter

Within the Zackenberg valley a total of 13 fresh muskox carcasses were found, all located between 2 m a.s.l. and 400 m a.s.l. (Table 4.4.2.4). Older carcasses have been recorded at 800 m a.s.l. Due to presence of bone marrow in all carcasses none of the animals appeared to have died from starvation.

Table 4.4.2.4. Fresh muskox carcasses found in 1996 within the 39,1 km² census area. Age is estimated by horn development and tooth wear. Exact age will be determined by analysis of dental cementum layers. See Fig. 4.2.2 for spacial distribution. M = male; F = female; bone marrow is analysed by cross sectioning the femur.

ID #	Sex	Estim. age	Year of death	Bone marrow
96.001	M	10-12 yrs	95/96	present
96.002	F	10-12 yrs	95/96	present
96.003	F	1 yr	95/96	present
96.004	M	1 yr	95/96	present
96.005	M	2 yrs	95/96	present
96.006	M	3 yrs	95/96	present
96.007	F	10-12 yrs	95/96	present
96.008	F	10-12 yrs	95/96	present
96.009	F	16+ yrs	95/96	present
96.010	F	13-15 yrs	95/96	present
96.011	M	1-2 yrs	95/96	present
96.012	F	8-9 yrs	95/96	present
96.013	F	10-12 yrs	95/96	present

Fig.4.4.2.4. Carcass #95-012 of an old muskox bull as it appeared in August 1996. *Photo: Mads C. Forchhammer*

4.4.3. Arctic fox dens

Probably as a result of the abundance of muskox carcasses during the past winter, the fox pairs at dens #1 and #3 each produced a litter (Fig. 4.4.2 and Table 4.4.3); both litters were mixed blue/white). Of the five Arctic fox dens located in Zackenbergdalen den #1 and den #3 were visited regularly throughout the season, the other three on an irregular basis.

Table 4.4.3. Data on five Arctic fox dens in Zackenbergdalen.

Den #	# entrances	# active entrances	Litter (minimum)
1	50	37	3 white +3 blue
2	50	5	0
3	22	9	2 white +1 blue
4	30	0	0
5	11	4	0

Den #1 hosted a minimum of six pups. One of them had apparently died prior to the first observation in June. The remaining pups (*i.e.* three white and two blue colour phase) were seen playing outside the den with a fresh piece of fur from a blue phase pup on 3 July. Apparently, all the blue phase pups died, as only one was seen on 14 July and none after 12 August. All the white phase pups were observed throughout the field season. Only one adult fox (white phase) was observed at this den, probably the female.

At den #3, the female was also a white phase individual. A minimum of three pups were seen (two white and one blue). Last observation of the foxes from den #3 was on 1 September, when the female was accompanied by the two white phase pups. At that date, all pups from the 1996-litter most likely would have accompanied the female on her hunt, hence implying that the blue phase pup had died earlier in the season. Bones from juvenile foxes were found outside both dens.

The colour phase dichromatism is controlled by recessive genetic inheritance (Johansson 1960), the blue phase dominating the white. Accordingly, the mix of blue and white phase pups in the two litters reveals that the male(s) was a heterozygotic blue phase fox carrying white genes.

Den #4 was situated 68 m from den #3 and was thus within the homerange of the pups from #3. No entrances showed fresh digging indicating that it was in use only as a playground for the pups.

Dens #2 and #5 showed clear signs of being active because of fresh excavations; den #2 further had scattered fresh bones and feathers from at least one goose. There were no signs of litters at these two dens. Den #2 was occupied by a white phase fox according to fur remains found at the entrances. In addition to the two adult females at dens #1 and #3, 2-3 adult foxes (*i.e.* one blue, one white and probably one more white phase fox), recognised individually by their progressing moult, were seen regularly in the valley.

4.4.4. Line transects

The transect through the adjacent valleys (*i.e.* Lindemansdalen, Slettedal, upper and lower Store Sødal) was covered 12-15 July by Thomas Berg and Bo Elberling hiking the route (Fig. 4.4.4). Observations of mammals are presented in Table 4.4.4.1.

In total, 42 muskoxen, two lemmings and fresh tracks of at least two wolves and several foxes were recorded. An additional transect route from Daneborg to Zackenberg was covered by Berg and Henning Thing on 14 August. Mammal observations are presented in Table 4.4.4.2. Following the experiences gained during the first line transect through the adjacent valleys on 12-15 July, future transecting of Lindemansdalen and Slettedalen was discontinued due to the infrequent occurrence of mammal and bird habitat. The resulting transect route through lower and upper Store Sødal was covered by Berg and Mads Forchhammer 16-19 August. Observations of mammals are given in Table 4.4.4.3.

A new parameter was added to muskox observations during the latter transect: registration of piles of faeces from the past winter (separate, hard, black pellets) and the recent spring/summer (grouped, adhesive, soft, black pellets), respectively. This provides an index for muskox use of the area during the past seasons. Older piles of faeces from previous years have an easily recognisable gray surface.

For bird observations, see section 4.3.6.

Table 4.4.4.1. Mammal observations on a 75 km line transect 12-15 July from the Zackenberg station along the east side of Zackenbergelven, northward through Lindemansdalen, southward through Slettedalen, westward along the north side of upper Store Sødal to the head of the valley and back along the south side of the valley all the way to the Zackenberg station. Ad. = adult, M = male, F = female, subad. = ≤ two years. For scientific names, see section 4.4.5.

Section	Muskox	Lemming	Arctic Fox	Arctic Wolf
Lindemansdalen		3 winter nests		
		2 tracks		1+2 tracks
Slettedal			tracks	
	1 ad. M			
	2 ad. F			
	1 subad. M			
	2 subad. F			
	1 calf			
Upper Store Sødal		1 winter nest	barking heard	
	3 ad. M	1 summer burrow	tracks	
	7 ad. F			
	7 unspec. ad.			
	3 subad. M			
	3 subad. F			
	7 unspec. subad.			
	3 calves			
Lower Store Sødal	1 ad. F			
	1 calf			

Table 4.4.4.2. Mammal observations on a 25 km line transect from Daneborg to Zackenberg on 14 August. Ad. = adult, M = male.

Section	Muskox	Lemming	Arctic Fox	Arctic Wolf
Daneborg- Zackenberg	1 ad. M			
	17 unspec. ad	–	tracks	track

Fig.4.4.4. The Daneborg – Zackenberg (DZ) and Store Sødal (S) transects with positions of scanning sites.
Reproduced with permission from the National Survey & Cadastre.

Section	Muskox	Lemming	Arctic fox	Arctic hare
Lower Store Sødal, north side	2 ad. F 17 unspec. ad. 2 subad. M 2 subad. F 4 calves	1 winter nest 1 summer burrow		
Upper Store Sødal	3 ad. M 4 ad. F 2 subad. M 3 subad. F 1 calf	2 winter nests		2 adults
Lower Store Sødal, south side	5 summer faeces 11 winter faeces		tracks	

Table 4.4.4.3. Mammal observations on a 60 km line transect through Store Sødal on 16-19 August. Ad. = adult, M = male, F = female, subad.= ≤ two years.

4.4.5. Other observations

Collared lemming *Dicrostonyx groenlandicus*

Observations of live lemmings included two individuals at the station; three lemmings were encountered within 3 km from the station and one at 600 m a.s.l. on the south slope of Aucellabjerg.

Arctic wolf *Canis lupus*

Since 13 fresh muskox carcasses were found and none of them had died from starvation (see section 4.4.2.4), more than one wolf had probably been present at Zackenberg during the winter of 1995-1996. In all, four sets of tracks were found, two of which were from two individuals running along each other.

Arctic fox *Alopex lagopus*

A minimum of four adult foxes were seen within the study area: two white females with at least six and three pups, respectively (see section 4.4.3), as well as two adults (*i.e.* one white and one blue phase) of unknown sex.

Only one blue phase adult was recorded and the colour mix in the two litters required the genetic input from at least one blue phase male. Thus, the blue phase adult was probably a male.

The station was visited regularly by at least two adult white phase foxes, one adult blue phase was seen only once. Lemmings in several winter nests and summer burrows were predated by foxes.

Adjacent to various fox den sites there were fresh left-overs from goose, rock ptarmigan, fox pup and muskox calf. Single observations of white phase foxes were made at the west and east ends of Store Sø, at Favoritdal and at Ulvehøj.

Arctic hare *Lepus arcticus*

At least three individuals were observed on the east facing slope of Zackenberg mountain between 100 m and 1200 m a.s.l. Additionally, two adults hares were seen at the west end of Store Sødal.

Ermine *Mustela erminea*

A total of two individuals were recorded. One observation was made at the station in the first part of June. Further, one adult was seen in a boulder scree on the Zackenberg mountain at 900 m a.s.l. One lemming winter nest from the 1995-1996 winter was predated and taken over by ermine(s) (see section 5.7.1).

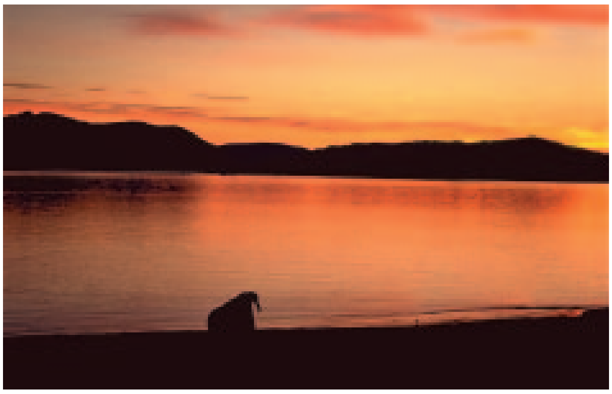


Fig.4.4.5. Silhouetted against the glowing nighttime waterscape of Young Sund an adult female walrus rests on the beach of Sandøen. 13 August 1996.

Photo: Danish Polar Center / Henning Thing

Walrus *Odobenus rosmarus*

The wildlife island sanctuary, Sandøen, was visited on 13 August. Four adult males were found sleeping on the sand beach at the south end of the island and one lone adult female was resting on the west beach. Walrus observations off Daneborg made by the research team headed by Søren Rysgaard, most often were of small feeding groups of 2-3 individuals during early morning and late afternoon. The maximum count on Sandøen was 20 walruses. One observation was made at Lerbugten (Clavering island), where one individual was seen. According to Rysgaard, the Young Sound bottom fauna was highly productive down to water depth of 50 m.

Seals *Phocidae*

Following the daily fixed-point counts of muskoxen between 19.00 hrs and 22.00 hrs, the abundance of seals on the sea ice in Young Sund was recorded during 22 June to 7 July with a maximum count of 21 seals on 29 June (average: 8; range: 1-21). After 7 July the fjord ice surface became unsuitable for seals and it broke up around 10 July.

5. Research projects

5.1. The Arctic landscape: Interactions and feedbacks among physical and biological processes. A biological and geo-environmental Arctic system research project 1995-1997

Sven Jonasson

The research, funded by the Danish National Science Research Council, aims at increasing the understanding of processes in the physical and biological systems of the Arctic, and how the processes are coupled through interactions in space and time within and between the four main 'spheres' of the system: the geo-, hydro-, bio- and atmosphere. The contexts of this multidisciplinary research effort was presented in the 1st Annual ZERO Report 1995.

The work is based on an interdisciplinary co-operation between researchers within bio- and geosciences and it addresses the issues of [1)] how Arctic systems operate at different spatial and temporal scales, and [2)] how past and present conditions and future predicted man-induced or natural environmental changes may affect the systems. The questions are answered by a combination of observational and experimental approaches.

Co-operation between the geo- and biosciences is particularly important for successful research in the Arctic because, from a biological point of view, environmental constraints exert a proportionally great control, relative to strictly biological regulations, on the biota in these climatically harsh, low energy systems.

The ecosystems in polar regions tend to be highly specialised and biological communities are typically stressed and sensitive to relatively small disturbances and changes, human or natural, because they operate under environmental conditions close to the physiological limits for several processes. From a geoscience point of view, the Arctic biota acts as a key link and buffers processes in the system. The biota is the main regulator of carbon fluxes between the terrestrial environment and the atmosphere and influences the energy exchange, the bio-geochemical and hydrological cycles, thereby controlling fluxes of sediments and the geomorphology.

In practise, the research is pursued through a main co-ordinated research effort concentrated to specific interactions, particularly energy and gas exchange, between biota, soil, atmosphere and hydrosphere at the landscape level. This research is supplemented by more specific biological and physical geographical studies at larger and smaller temporal and spatial scales. The main co-operation focuses on issues addressing how processes and feedbacks in the Arctic could influence global climate.

Efforts are concentrated on two issues of particular relevance: [1)] Arctic climate–landscape interactions and the role of the Arctic as amplifier of global warming, and [2)] the role of the Arctic as source or sink for atmospheric carbon. In addition, we collect information on how abiotic and biotic 'archives' can be used to understand past processes in the Arctic – ranging over time scales from decades to millennia – in an attempt to improve predictions of future changes in the systems.

Net carbon fluxes (carbon dioxide and methane) between soil/vegetation and atmosphere are measured on a landscape scale as well as in detail on a plot scale within different vegetation communities. The gas fluxes are related to large scale landscape and vegetation patterns through analyses of vegetation features, snow melt pattern, hydrology *etc.* using remote sensing techniques. On the smaller scale, trace gas fluxes and carbon sequestration are related to the heterogeneity of soils and vegetation through

Fig.5.1. Researcher Claus Nordstrøm has secured a top-down view of the Arctic landscape of Zackenbergdalen. Notice research station and runway visible between the foreground rocks. *Photo: Danish Polar Center / Henning Thing*

detailed analyses of physical, chemical and biological processes of relevance within m^2 areas distributed over the main plant communities. The study of past processes are pursued through analyses of sediments deposited in lakes and fjords, past and present changes of the coastline, and through analyses of the periglacial landscape. The work carried out in the summer of 1996 within the different items is summarised on the following pages.

5.1.1. Atmospheric fluxes of greenhouse gasses

Claus Nordstrøm

The anticipated global temperature rise caused by the increased greenhouse effect is expected to have greatest impact in the High Arctic region. The Arctic tundra ecosystems cover about 10% of the Earth's land surface area, but contain 14% of the total global terrestrial carbon reserves. Of the 14% a greater part is stored in the permafrost. In order to increase the understanding of how tundra ecosystems might respond to warming and how possible large-scale feedback mechanisms will work in a longer time perspective, it is essential to first appreciate the fundamental processes controlling gas exchange. The objective of the present study is to analyse the physical and biological processes which control the gas exchange between atmosphere and land surface in the High Arctic on a hourly, diurnal and seasonal basis.

The project focuses on atmospheric fluxes of the most important greenhouse gasses *i.e.* water vapour H_2O, carbon dioxide CO_2, and methane CH_4. The research in 1996 concentrated on water vapour and carbon dioxide, while the main effort, from May to September 1997, will include investigations on turbulent methane fluxes as well.

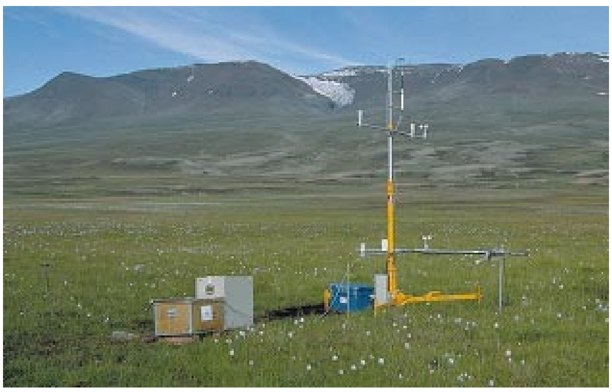


Fig. 5.1.1.1. Micro-meteorological tower with eddy correlation equipment. Aucellabjerg in background. August 1996.

Photo: Danish Polar Center / Henning Thing

This research is made in close co-operation with the plant eco-physiologists Sven Jonasson, Torben Røjle Christensen and Anders Michelsen who study gas exchange and the associated processes on plot scale using chamber measurements (see section 5.1.4). At a landscape scale, measurements of turbulent area-integrated fluxes by the eddy correlation technique and measurements of other micro-meteorological parameters, are carried out by Henrik Søgaard, Thomas Friborg Jacobsen and Claus Nordstrøm. Further up-scaling to regional fluxes and the link to remote sensing are primarily performed by Birger Ulf Hansen (se section 5.1.3).

The measurements started just after snow melt in June and continued until the end of the growing season in late August. High frequency (*i.e.* 21 times per second) measurements of water vapour and carbon dioxide concentrations along with wind speed in three dimensions and speed of sound were sampled from a mast at 3.5 m above ground level (see Fig. 5.1.1.1). Water vapour and carbon dioxide concentrations were recorded by a LI-COR 6262 infra-red gas analyser. High frequency wind speed in three dimensions and speed of sound were measured by a GILL 3-axis sonic anemometer. With data from these parameters, the eddy correlation fluxes of water vapour, carbon dioxide, sensible heat and momentum will be calculated. At present, only preliminary eddy correlation fluxes have been computed.

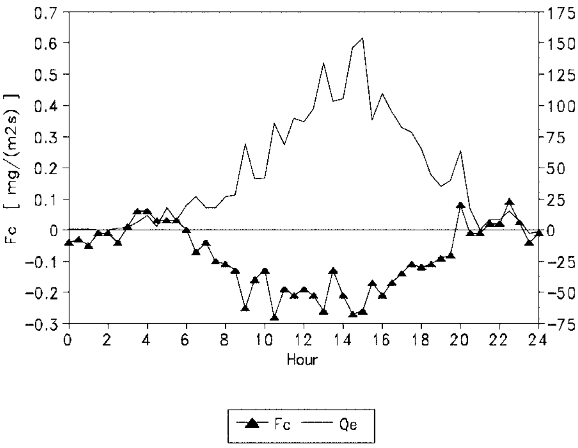


Fig. 5.1.1.2. Preliminary carbon dioxide (Fc) and water vapour (Qe) fluxes from Rylekærene 12 August 1996. Carbon dioxide daytime photosynthesis-generated fluxes far exceed night-time respiratory fluxes indicating that Rylekærene at this date was acting as a sink of carbon dioxide. The accumulated evapotranspiration amounts to 1.6 mm. Maximum temperatures were measured to values around 10°C.

Fig. 5.1.1.2 displays data of carbon dioxide and water vapour fluxes on 12 August reflecting a presumably typical situation for a fair weather day in the second half of the growing season. Additional to the eddy correlation data, standard meteorological parameters of air and soil temperature, ground heat flux, wind speed, humidity and different radiation data were logged during the entire period.

The mast and the instrumental set-up were situated in Rylekærene, an extensive fen (approximately 600 x 1000 m^2) in the middle of the flat valley bottom. This location was chosen to meet the requirements for unbiased flux measurements of the wetland gas exchange) The wind was primarily from the SSE-ESE during the field period (see section 3.1.5).

South-eastwards from the mast site and for more than 600 m to the border of a dry *Cassiope* / *Dryas* heat, a flat surface extends dominated by very wet *Eriophorum scheuchzeri* / *Carex atrofusca* meadow tundra – with a ground water level at or just beneath the surface – and of patches of moderately wet *Salix arctica* / moss tundra.

5.1.2. Snow and vegetation mapping by use of Landsat TM and SPOT HRV images

Mikkel Tamstorf

Eleven satellite images were used to map snow and vegetation patterns in a 100 km^2 area located around Zackenbergdalen (UTM co-ordinates: NW corner: 509010 easting / 8270990 northing; SE corner: 519250 easting / 8260750 northing; zone 27). The satellite images, extracted from the years 1986 to 1995, span from 6 June to 28 August and cover almost the entire ablation period. A digital terrain model (DTM) covering the region was employed in order to correct for terrain induced differences.

Analysis of the snow patterns showed great variation in the amount and coverage of snow at Zackenberg. Winters with large amounts of snow were followed by a growing season with less flourishing vegetation. In spite of large variations in snow fall and progress of snow melt, the distribution patterns during the investigated years showed a comparable spatial snow distribution during the annual snow melt.

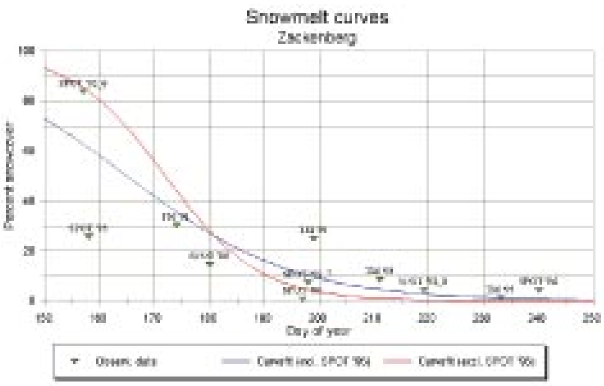


Fig. 5.1.2.1. Snow melt curves for the area around Zackenbergdalen based on eleven satellite images 1986-1995.

Snow-cover maps were produced by classification of the satellite images and then used to estimate snow melt patterns over the entire ablation period. A non-linear relationship between time of year and percent snow-cover was established, and fitted to the observed snow-cover maps. The fitted curves are shown in Fig. 5.1.2.1.

A normalised difference vegetation index (NDVI) was used to analyse the vegetation cover in the area. Three smaller areas and the ZERO-line (see section 4.1.3) were used to compare dates in order to show differences and changes during the growing season. NDVI maps for ten dates during the growing season have been produced. In Fig. 5.1.2.2 the changes of maximum NDVI values during the growing season are illustrated along with the overall trend for the area. The area used for this fig. is a fenin the lower part of Zackenbergdalen (UTM co-ordinates: NW corner: 512900 easting / 826400 northing; SE corner: 513100 easting / 8263800 northing) and the locally flat landscape, impedes water run off, resulting in a lush, moist fen vegetation cover. During analysis of vegetation patterns the earlier produced snow maps were used to relate the availability of moisture to the amount and type of vegetation cover. Classification procedures were performed on all images including the DTM and brought about one thematic map for each satellite image. Four vegetated and four non-vegetated classes were mapped in the classification procedure. The four vegetation classes were:

heath dominated by *Cassiope* sp.

dry heath dominated by *Dryas* sp.

dry, lush vegetation.

moist-wet, lush fen vegetation.

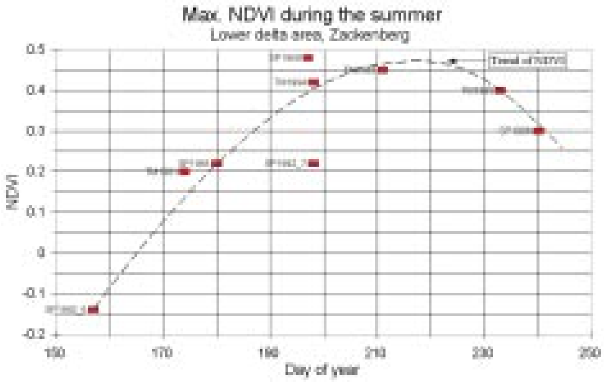


Fig. 5.1.2.2. Seasonal distribution of maximum NDVI values from the south part of Zackenbergdalen 1986-1995. The dashed line indicates the overall trend.

The classification results were combined with snow maps and overlays showing the fjord and major rivers, yielding eleven classification maps of the area. On the basis of these maps a general map of the land cover classes in the Zackenberg area was produced (Fig. 5.1.2.3).

Surface moisture and spectral measurements of the Landsat TM band 4 and 5 formed the background for surface moisture maps for the area. There was a good correlation with observed values acquired during the field season in the summer of 1996. The surface moisture maps in combination with NDVI were found to give a more detailed basis for analysis of the fen vegetation than the NDVI alone.

The produced maps were compared with vegetation surveys (Fredskild 1992; Fredskild & Bay 1993) and were found to be very reliable. The overall distribution of the vegetation classes in relation to three altitude intervals are presented in Fig. 5.1.2.4.

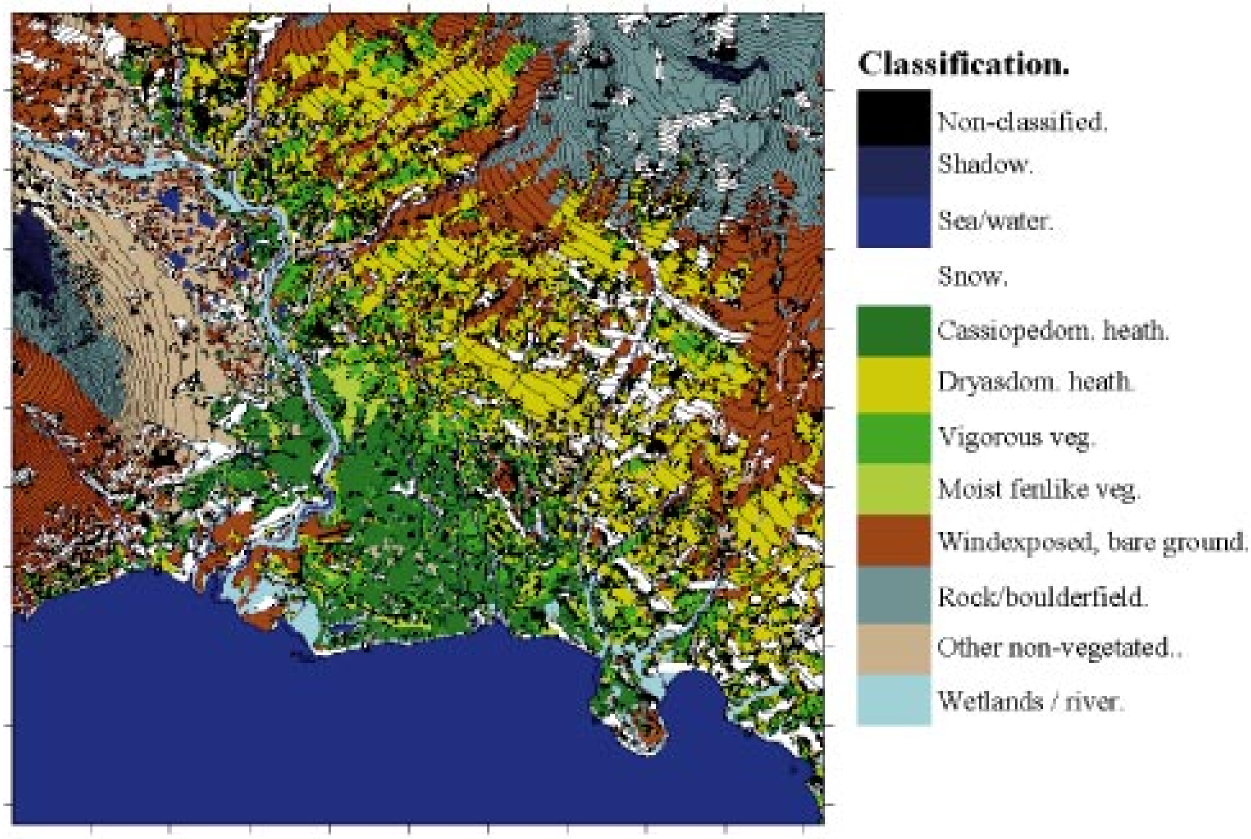


Fig. 5.1.2.3. Land cover classes produced from classification on Landsat TM and SPOT images 1986-1995.

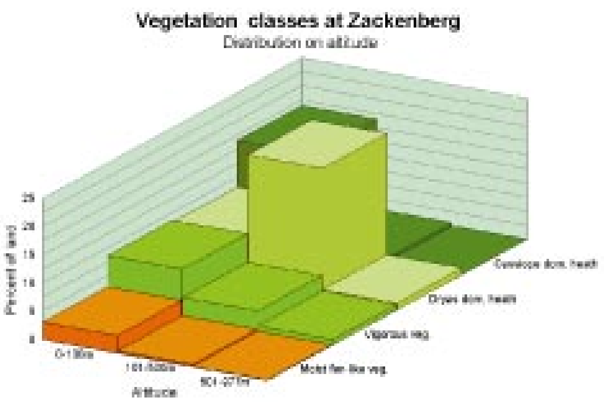


Fig. 5.1.2.4. Altitudinal distribution of vegetation classes.

5.1.3. Field measurement of spectral signatures and other surface parameters

Birger Ulf Hansen

Ground level spectral radiance data were collected using a Ger Mini Iris 2100 with a single field of view and a spectral resolution of 10 nm in the 300 - 1000 nm region and 24 nm in the 1000 - 2500 nm region. The radiometer had a 15° instantaneous field of view (IFOV) yielding a circle of c. 0.05 m diameter when sampling vertically from a mount at c. 0.3 metres above ground. Prior to each target measurement the spectral radiance of a $BaSO_4$ reference panel was measured. All measurements were collected under cloud free conditions and with solar zenith angle ranging from 63° to 50°.

Immediately following each reflectance measurement, a colour photography covering both the reference and the target areas were taken. After the field season the percent vegetation cover weas calculated using a photo projector to enlarge the colour picture over a grid. Subsequently, measurements of net radiation, soil heat flux, surface temperature and TDR measurements of surface moisture were carried out at each surface plot, while measurements of air temperature, humidity and wind speed were taken simultaneously.

Typical reflectance curves show a very low reflectance in the visible area (VIS = 400 - 700 nm) (Fig. 5.1.3.1) for the non-vegetated areas due to dark colours as well as for the vegetated areas due to strong absorption by the photosynthetic pigments. The white seed hairs of *Eriophorum*, the white flowers and reddish leaves of *Cassiope* and *Vaccinium* have a high reflectance in the visible spectrum. In the near infrared spectrum (NIR = 700 - 1300 nm) reflectance increased significantly as biomass and percent plant cover increased, while in the mid infra-red area (MIR = 1300 - 2500 nm) reflectance decreased as biomass and percent plant cover increased. All non-vegetated surfaces showed a significant decrease in reflectance throughout the entire spectrum due to increases in soil moisture. The measurements were carried out along a transect in Rylekærene (Fig. 5.1.3.2), in a grid south of the runway as well as along the ZERO-line, all covering representative cover types.

The understanding of natural systems at large spatial scales has increased the interest in deriving ecological variables, but collecting such data through field surveys is time consuming and expensive in Arctic areas. Remotely sensed reflectance data from satellite images provide an alternative means.

Mapping of vegetation-related parameters have benefitted significantly by the development of vegetation or greenness indices such as the normalised difference vegetation index NDVI (NDVI = (NIR-VIS)/(NIR+VIS)) and wetness-related parameters such as the infra-red index IR (IR = (NIR-MIR)/(NIR+MIR)).

The ratio enhances vegetation in the satellite image and reduces variations caused by changes in irradiance which varies as a function of solar elevation. Results from the 1992 field season (Jacobsen & Hansen 1996) showed that NDVI correlated strongly with percent vegetation cover, with dry and wet biomass as well as with the soil heat flux/net radiation (G/Rn) ratio.

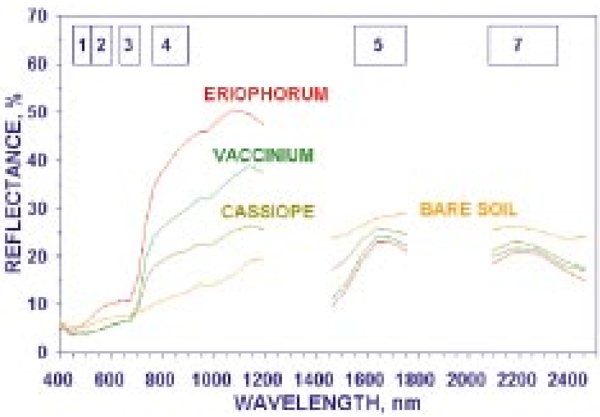


Fig. 5.1.3.1. Reflectance spectra of different surfaces based on ground measurements at Zackenberg, 1996. Wavelengths of Landsat TM bands are given at the top of the graph.

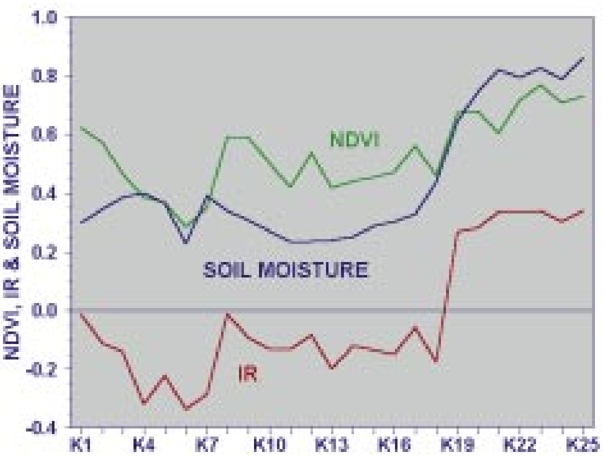


Fig. 5.1.3.2. Normalised Difference Vegetation Index (NDVI), Infra-red Index (IR) and soil moisture along a 140 m transect in Rylekærene. The left of the transect is dominated by dry grassland with a drainage channel, the middle is dominated by a dry Cassiope *heath, while the right is a moist fen with* Eriophorum.

Preliminary results from 1996 show a strong correlation between IR, surface temperature and surface moisture, essential parameters in the modelling of fluxes of CO_2 and CH_4. This indicates that multi-temporal analysis of satellite-based vegetation indices, such as NDVI and IR, may prove to be a very useful tool in monitoring regional and seasonal variation of CO_2 and CH_4 exchanges in large High Arctic areas. The planned extensive field campaign in 1997 will be used to implement and validate the satellite-based parameters in the models of both gas and energy fluxes.

5.1.4. Gas exchange and plant – microbe interactions in different habitats of Zackenbergdalen

Sven Jonasson, Torben R. Christensen & Anders Michelsen

5.1.4.1. Gas exchange and nutrient pools in a drained fen

A naturally drained fen, Tørvekæret, provided a possibility to study how drainage may affect the trace gas emission and soil, plant and microbial nutrient pools in a natural environment. The fen has been drained following a thermokarst erosion, and is currently covered by one or a few moss species and a single graminoid.

In order to elucidate whether primary production and microbial activity are limited by water and/or nutrient availability, we added nitrogen and/or phosphorus to 30 permanent plots, each 1 m^2. Soil extractable and microbial nutrient (phosphorus and nitrogen) pools were measured, the latter using the fumigation-extraction technique. The extracts are currently under analysis.

The CO_2 flux was measured in dark chambers one, two and four days after nutrient addition. As there were no significant responses of the total respiration to nutrient additions we conclude that the microbial activity is not affected by the soil nutrient content, but by other factors such as substrate availability (or quality) or soil moisture. These hypotheses will be further tested in 1997.

5.1.4.2. Plant-microbe competition in dry tundra

A similar experiment was initiated near the research station, in a dry *Kobresia-Dryas-Salix arctica* heath. In order to investigate if plants in a dry High Arctic tundra are nutrient limited, and to determine the importance of periodic plant-microbial competition possible in such an area, 48 permanent plots (0.5 m x 0.5 m) were either fertilised with nitrogen and/or phosphorus, or left unperturbed. Water treatment of

24 of the plots will begin in 1997 (Jonasson and Michelsen 1996). The extent and species composition of the current vegetation cover in each plot was documented in August 1996 by photography. Plant performance and soil microbial characteristics will be analysed in the years to come.

5.1.4.3. Mycorrhiza and plant ^{15}N

Recent observations from sub-Arctic Sweden have revealed that plants with different types of mycorrhizal fungi associated with their roots differ in their ^{15}N natural abundance (Jonasson and Michelsen 1996). We assume this fact to be caused mainly by differential use of various forms of soil nitrogen, having different ^{15}N sources. Hence, dwarf shrubs with ericoid or ecto-mycorrhizal fungi differ widely in ^{15}N content from that of graminoids; dwarf shrubs probably access organic nitrogen, a hitherto neglected form of soil N in relation to plant nutrition.

In order to test if this pattern is dominating in tundra ecosystems, we sampled plant, root and fungal material in various Arctic ecosystems, including material from heaths in Zackenbergdalen. The material collected in 1996 (top and sub-soil, soil extracts, 13 plant species, and roots) supplements a preliminary collection performed in 1995 (eight plant species). The material is currently analysed for ^{15}N natural abundance, and soil extracts are analysed for inorganic and microbial nutrient (N and P) pools. The result of a preliminary analysis is shown in Fig. 5.1.4.3).

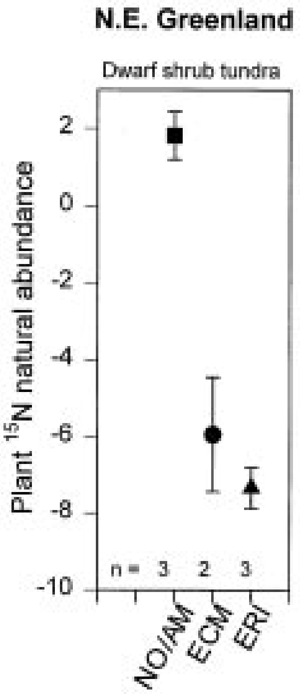


Fig. 5.1.4.3. ^{15}N natural abundance in eight Arctic plant species: 3 with arbuscular or non-mycorrhizal fungi (NO/AM), two with ecto-mycorrhizal fungi (ECM) and three with ericoid mycorrhizal fungi (ERI). Preliminary data; from Michelsen et al. *(*in prep.*).*

5.1.4.4. Gas exchange at the landscape level

Transect measurements of soil respiration and methane emissions were conducted in 1996 in continuation of measurements started in 1995. Some preliminary measurements of N_2O fluxes were also carried out in Rylekærene. The spatial variation in gas fluxes along transects are evaluated in relation to the remote sensing parameters measured by Birger Ulf Hansen (see section 5.1.3). The measurements also provide background information for the site selections forthe intensive study in 1997.

Emissions of CH_4 followed a pattern correlating with a soil moisture index which may be derived from remote sensing images. In addition, soil respiration in the study area showed a marked maximum at a narrow soil moisture range corresponding to findings in the literature. Together, this may provide the opportunity for modelling CO_2 and CH_4 fluxes based on data derived from remote sensing images.

Ground truth data on the physical parameters in combination with gas flux data from different sites are currently being investigated and will be used to test and validate this linkage and develop the model further before applying it at a larger scale in 1997.

Fig.5.1.4.4. Sven Jonasson, Anders Michelsen and Torben R. Christensen engaged in measuring soil respiration and methane emissions. August 1996.

Photo: Danish Polar Center / Henning Thing

5.1.5. Studies on soils

Jakob Simonsen & Bjarne H. Jakobsen

During the summer of 1996, the geography of soils in Zackenbergdalen was studied along topographical sequences and different types of patterned grounds. Soil distribution was described in the field, and samples collected for analysis to describe the soil – plant interaction and the variability of leaching and nutrient characteristics. Both small-scale and meso-scale system variations were studied.

Individual, patterned ground landscape elements, *e.g.* hummocks and frost boils, showed a strong influence on soil mosaic. Soil instability and variations in micro-topography and drainage conditions strongly influenced soil development, *e.g.* the amount and form of humus and the general nutrient status. Due to the soil – plant interaction, the small-scale variation in biodiversity of different heath sites closely follows the present soil mosaic.

At the meso-scale landscape level, the soil – plant interaction, in sequences associated with wind-swept areas and snow-patches, is controlled mainly by the duration of snow coverage and soil hydrology, *i.e.* varying active layer thickness and drainage conditions (Figs 5.1.5.1 and 5.1.5.2).

Fig. 5.1.5.1. Level landscape in Zackenbergdalen showing a strong control of micro-topography on vegetation and soil development.

Photo: Bjarne Holm Jakobsen

Fig. 5.1.5.2. Strong zonation of vegetation and soils along a snow-patch sequence.

Photo: Bjarne Holm Jakobsen

The occurrence of fossil Podzol-like soil characteristics in Zackenbergdalen was known from reconnaissance work in 1991. These fossil features indicate distinct climatic changes during the Holocene period.

At level and relatively well drained sites, the occurrence of distinct soil horizons (Fig. 5.1.5.3), showing an eluvial zone (horizons 2A and 2E and an illuvial zone (horizon 2Bhs), implies biological soil conditions determined by climatic and vegetation conditions presently found in humid, Low Arctic Greenland. Hence, the Zackenberg area must have had moist Low Arctic or even sub-Arctic conditions during the climatic optimum in early Holocene.

The climatic change to colder and drier conditions has imposed a secondary soil development, such as [1)] accumulation of basic ions, including sodium (Na^+), in the soil, [2)] cryoturbation of soil horizons and [3)] young aeolian sediments covering soils (horizon 1A).

During the 1996 field season, the polygenetic soils were described and sampled. Along active coastal cliffs (Fig. 5.1.5.4) and river banks it was possible to study the variability of both the early Holocene Podzol formation and the later development of secondary soil characteristics in relation to parent material and geomorphological factors. In addition, samples were collected of humic substances to determine the ^{14}C age of different humus fractions involved in the different stages of soil development during the Holocene.

Fig. 5.1.5.3. In the presently cold and dry High Arctic climate and buried by younger wind deposits, relict early holocene Podzols are found at level well drained sites.

Fig. 5.1.5.4. The polygenetic soil development caused by the changing climatic conditions during the Holocene are exposed along coastal cliffs and riverbanks.

Photos: Bjarne Holm Jakobsen

5.1.6. Water chemistry during snow melt and soil thawing in a permafrost area

Bo Elberling & Bjarne Holm Jakobsen

The influence of global climate on water and carbon cycles in Arctic regions has been predicted to have a pronounced effect on *e.g.* the exchange of greenhouse gases (CO_2 and CH_4). Short- and long-term effects of climate changes on Arctic soil water have not been studied to the same degree, although the soil – atmosphere exchange of greenhouse gases is controlled predominantly by biological (*i.e.* net primary production *etc.*) as well as geochemical processes within the soil (*i.e.* the carbonate system, pH, ions exchange processes *etc.*).

The present study aims at evaluating the geochemical processes controlling the pore water chemistry of the active layer within a High Arctic fen area. The preliminary work in the 1996 summer included installation of 30 suction probes in a transect from a snowdrift and 20 m downhill, parallel to the water flow. The thickness of the active layer within the transect increased consistently from 0 cm next to the snowdrift to 70 cm as a result of the steady retreat of the snowdrift. The transect is shown on Fig. 5.1.6.

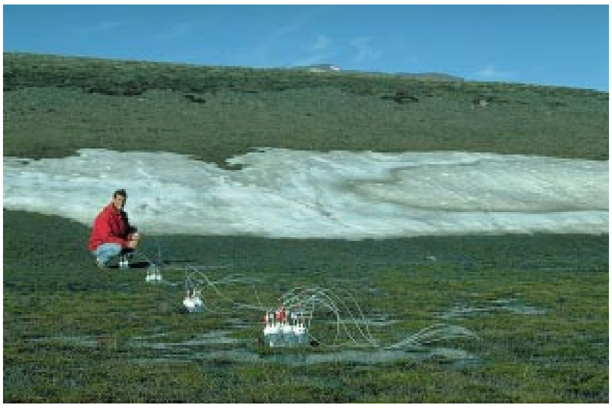


Fig. 5.1.6. Pore water sampling of the transect next to the snow-patch. *Photo: Heidi Elberling*

All suction probes within the transect were sampled twice (10 and 26 July) and one profile was sampled six times between 24 June and 27 July. During this period there where no precipitation and thus, the only source of water was the meltwater from the snowdrift and the frozen part of the soil.

Alkalinity, pH and conductivity of the soil water samples were measured in the field, whereas Na, K, Ca, Mg, Fe, Mn, Al, Cl, NO_3 and SO_4 are being analysed in the laboratory. Along with water sampling, the thickness of the active layer was measured and the soil temperature was monitored in the profiles. Moreover, soil samples were collected for analysis of carbon and nutrient content, metals and cation exchange capacity.

As the laboratory analyses of water and soil samples are not yet (*i.e.* December 1996) completed, the following discussion is based entirely on field measurements of alkalinity, pH and conductivity. The melt water from the snow-drift had a very low conductivity (<6 µS/cm) with pH values ranging from 5.5 to 6.1. In contrast, the conductivity of the soil water varied from 20 - 30 µS/cm near the soil surface to more than 250 µS/cm at the bottom of the active layer. The pH varied from 6.0 to 6.8 near the soil surface to almost neutral condition (*i.e.* pH = 7) at the bottom of the active layer. In all profiles, a consistent increase in pH, conductivity and alkalinity was observed with depth, whereas only small temporal changes were observed. This calls for further attention to processes buffering the supply of H^+ releasing ions to the soil water.

The exchange of cations on the solids is probably the primary process responsible for the geochemical trends observed in the profiles. The exchange of ions is related to the exchange capacity of primarily clay minerals, organic matter and oxides/hydroxides and is a well documented process controlling pH between 5.5 and 7 in many environments. In practice, it may be difficult to discern between exchange processes and other reactions with solids such as precipitation and dissolution. These processes may therefore also influence water chemistry at the Zackenberg site. Geochemical modelling of water chemistry will render it possible to differentiate between different processes affecting soil water chemistry and to describe the dynamics of important components such as carbon and nitrogen within the soil.

5.1.7. Monitoring unfrozen water content and soil water variability

Peter van der Keur

Permafrost terrain is characterised by a seasonally active surface layer, that thaws each summer, underlain by perennially frozen ground. This research project focuses on the active layer dynamics in relation to the hydrological conditions

It is well known that thickness of the active layer depends on several factors, such as soil properties and initial water content. Monitoring unfrozen water content at different vertical levels during winter and summer is thus expected to elucidate soil water dynamics in relation to active layer depth.

Time Domain Reflectometry (TDR) is a well established method for measuring unfrozen water content. It is based on the high difference in di-electric properties of ice and (unfrozen) water. A Tektronix 1502B TDR system was installed to measure unfrozen water content within the active layer (0-60 cm) six times daily during winter and summer by horizontally inserted 20 cm long TDR probes in a soil profile near the automatic meteorological station at Zackenberg, located on a remnant of a melt water plain covered by a homogeneous *Cassiope* vegetation. Temperature was measured every two hours at the same depths by Campbell P107 thermistor probes. All data were collected by a Campbell CR10 datalogger. The relationship between unfrozen water content and temperature is expected to be used in subsequent modelling of hydrologic and thermal processes within the active layer.

Spatial and temporal variability of soil water content during summer was measured by a mobile TDR device (TRASE5060XI, Soil Moisture Equipment Corp). For this purpose an already established grid was used, few meters from the automatic meteorological station. Soil moisture content was measured for every 10 meters in a 100 m by 100 m grid using 15 cm, 30 cm and 45 cm probes, inserted vertically, over several days. At a larger scale and across different soil types, soil moisture variation was studied by a hand held TDR device (TRIME-system, IMKO Micromodultechnik GmbH) along a transect ranging from 400 m a.s.l. at Aucellabjerg towards the automatic meteorological station.

Fig.5.1.7.1. Researchers Peter van der Keur (left), Claus Nordstrøm (sitting) and electronics technician Bent Sørensen in the midst of servicing and calibrating equipment at the meteorological station adjacent to the soil water study site.

Photo: Danish Polar Center / Henning Thing

5.1.8. Hydrology and sediment transport

Bent Hasholt

The Zackenberg water catchment basin is complex. Varying hydrological regimes and sediment transport conditions are therefore to be expected within the basin. The easternmost part is characterised by rather low sedimentary mountains, while the western part consists mainly of older crystalline rocks reaching elevations of 1,000-1,400 m a.s.l. This causes regional differences in both transport of solutes and sediments. The landscape is dominated by large valleys, the north-south oriented Lindemansdalen and the east-west oriented Store Sødal leading to another north-south valley system receiving water and sediment from glaciers in the high westernmost part of the basin.

The objectives of this research project were to identify important hydrological processes and to describe the local hydrological regimes. Furthermore, a more detailed study of the transport of solutes and sediments at the outlet was carried out together with a reconnaissance of source areas for different transport components. This study was supplementary to the GeoBasis monitoring programme and proposes, at a later stage, to explain temporal and spatial variations.

Field work consisted of manual data sampling at the main hydrological station (see section 3.3), as well as automatic recording of transmissivity (of suspended sediment) and conductivity (of dissolved solids). Lindemansdalen and Store Sødal were surveyed 28-30 June. Measurements of soil moisture and evaporation are treated separately (see sections 5.1.7 and 5.1.9). At our arrival on 19 June, snow melt was at its highest. The run-off in the river was dominated by melt water from the lower part of the basin, and an annual peak discharge of 50 m^3/s was recorded (see section 3.3.2). However, not all melt water ran off. Due to the permafrost, many small ponds occur in the terrain. These tend to delay the run-off, and, depending on weather conditions, a substantial amount of water can evaporate (see section 5.1.9). The lifetime of these ponds, important for freshwater algae and animal life, depends on the rate of evaporation and the development of the active layer capable of sub-surface draining of the pond.

Between 19 June and 10 July, a number of small ponds disappeared, the snow-cover around the Zackenberg station was reduced from c. 60% to c. 10%, and there was a clear recession in the river. The recession was interrupted by minor peaks (see section 3.3.2). As there was no precipitation, these peaks indicate delayed contributions from higher areas and glaciers in the basin. The heterogeniety of the hydrological regime could however also be explained partly by the orientation of the valleys. In sloping areas ponding was small and the run-off ended quite abruptly when all snow in the area had melted away.

Fig.5.1.8.1. Measuring water discharge at the outlet of Store Sø into Zackenbergelven. 29 June 1996.

Photo: Bent Hasholt

This was partly the case on southfacing slopes in the eastern part of the basin. In Store Sødal there was a marked difference between the simultaneous run-off from the north and the south side of the valley, respectively. At the end of June, the sun had melted most of the snow on the north side, the surface was quite dry, and only a few small streams carried water, mainly from remaining snow-drifts or higher areas in the adjacent mountains.

The south side of the valley was soaked with water. Hence, Store Sø and Zackenbergelven in the valley bottom received a very asymmetric lateral input of both water and sediment. This indicate that a hydrological model of the area must be able to deal with areas where the contribution to the watercourse is very dependent on incoming radiation and the aspect of the terrain.

The sediment transport peaked together with the discharge. The maximum concentration was 671 mg/l. During a ten day period 26 June - 5 July, there was a significant diurnal variation in the sediment concentration. The average morning concentration was 92 mg/l and the evening concentration was 317 mg/l. The conductivity varied from 18 to 38 µS/cm. However, large differences were found in both sediment concentration and conductivity within the basin.

The run-off from the sedimentary east part of the basin was characterised by high concentrations of sediment (up to 1277 mg/l) and high conductivity (up to 85 µS/cm). Exemptions were water leading from local ponds and fens in the low-lying area. The confluence of the river from Lindemansdalen and the river from Store Sødal is situated at the divide of the two dominating rock types. The river from Lindemansdalen is clearly dominated by muddy water (982 mg/l) from the sedimentary rocks, while the river from Store Sødal is dominated by rather clear water (23 mg/l) from the crystalline rocks.

As this river also carries a glacial component, there is a slightly milky appearance of the water. Input to Store Sø in Store Sødal was 157 mg/l from a glacial tributary. The water running to Store Sødal had low conductivity values (7-12 µS/cm), while the water from Lindemansdalen showed higher values (36-84 µS/cm). There was no significant difference in water pH from the two areas (7.8 - 8.1). The sediment concentration was low in the river in Store Sødal (12-23 mg/l).

The major contribution originates from glacial rivers from the westernmost part of the basin. Part of the sediment from these rivers will however be deposited on the large delta flat at the western end of Store Sø or in the lake itself. Windblown sand and silt depositions are found around the delta flat, in particular at the south side. Several minor watercourses erode in these depositions and create local deltas at their outlet into the lake.

An overview of the complicated hydrological and sediment transport conditions clearly demonstrates that the variation through time is significant. It is therefore important that identified patterns are confirmed by field work later in the run-off season before modelling and computation of water and sediment balances are be created.

5.1.9. Evaporation from snow and the free water surface of a shallow pond

Steen B. Pedersen

The project objective is to determine the magnitude of evaporation from a free water surface and from surfaces with snow-cover. The observation period was from 20 June to 10 July, *i.e.* in the late part of the break-up.

The evaporation from the snow surface was monitored from a south-facing snow-drift, just south of the Zackenberg station. Evaporation from a free water surface, was monitored in a small, shallow pond, a few hundred meters south of the station.

The snow-drift as well as the pond were of a temporary character as the snow-drift disappeared completely a few days before the monitoring was terminated, and the pond, fed partly by the melt water from the snow-drift, dried up in part during the observation period. Climatic parameters, important for evaluating the free water surface evaporation, were monitored.

The evaporation was logged directly using a simple water lysimeter placed in the middle of the pond, with equal water level inside and outside of the lysimeter. Every day the water level in the lysimeter was measured and the magnitude of evaporation was determined as the difference in water level from the previous day.

Further, water level in the pond was recorded daily. However, pond water influx and outflux render it impossible to calculate evaporation, by measuring water level in the pond, unless the fluxes can be quantified.

Parameters essential for determining evaporation from the pond, using the Penman equation, were measured at 10 s intervals and a 15 minutes average was stored in a Campbell CR10 logger. The evaporation of snow was recorded by a small snow lysimeter.

The daily evaporation from the pond, as measured by the water lysimeter, ranged between 3 mm and 6 mm. Results from the calculation of evaporation, by using water level in the pond or the Penman equation, are not yet available.

The water level change in the pond was about twice than that in the lysimeter indicating that the outflow from the pond was larger than the inflow. However, the pond and the lysimeter revealed comparable variations in water level as well as fairly equal reactions to changing weather conditions.

The evaporation from the snow shows some unexpectedly high values, particularly at the end of the observation period (*i.e.* just before 10 July). These values were probably caused by melting snow inside the lysimeter which consequently showed evaporation from a water surface. Realistic values would be in the order of 0.5 - 1 mm per day.

Relating the evaporation from these and other types of quantified surfaces to climatic parameters will make it possible to estimate the magnitude of evaporation in larger areas.

5.1.10. Lake corings

Bjarne Holm Jakobsen & Bent Fredskild

The sediments of two lakes in the dead ice landscape just west of Zackenbergelven were cored in order to trace Holocene changes in vegetation, wind and water transported soil particles, climate, *etc.*

The first coring, c. 80 m a.s.l., revealed that the gyttja sediments were surprisingly thick. Below 3 m of water no less than 405 cm of gyttja, in the lowermost part with some clay, were overlying a 3 cm moss layer resting upon stones.

When extruding the cores, the following became clear: the thick gyttja layer was caused by so-called 'sediment slumping' (*i.e.* some sediment, originally deposited at lower water depth closer to the edge of the lake, for unknown reasons had slumped one or more times towards the deeper parts of the lake).

Fig. 5.1.11.2.1. At spring high tide (left photo) the water level at Zackenberg is above the level of the cliff foot along the cliff coast east of the old delta. In this situation, even small waves can erode the cliff. The photo to the right shows the same cliff section at low tide.
Photos: Niels Nielsen

In the second lake, c. 95 m a.s.l., the core was 1.5 m long which is the normal thickness of a High Arctic lake sediment covering all or most of Holocene.

In the deepest part of the core the sediment held much sand-clay, upwards turning into a watery, jelly-like gyttja with varying but mostly small amounts of clay. The deeper 2/3 of the core has been analysed for pollen contents. The immigration of *Salix arctica* and, shortly after, of *Betula nana* has been recorded but not yet ^{14}C-dated.

5.1.11. Coastal geomorphology and fjord sedimentology

Niels Nielsen & Morten Rasch

In addition to the GeoBasis coastal monitoring (section 3.4.13) efforts concentrated on reconnoitering for future studies of Holocene relative sea level changes, recent landscape dynamics in the coastal zone, and sedimentology of Young Sund - Tyrolerfjord.

5.1.11.1. Holocene relative sea level changes

The Holocene marine has been determined as the lowest occurrence of boulders on three localities (Revet in Rudis Bugt, Zackenberg, and Blæsedalen east of Daneborg) along the natural E-W transect of Young Sund and Tyrolerfjord. Localities along the transect were visited to look for potential areas for more thorough studies. At five localities marine fossils were sampled and later submitted to the AMS facility at the University of Aarhus for ^{14}C dating. The forthcoming radiocarbon dating results will be combined with previous ^{14}C dates from the region to construct a preliminary Holocene relative sea level curve.The coastal morpho-stratigraphy was logged on topographic profiles from two localities (Blæsedalen and Dolomitdalen on the SW shore of Young Sund) providing data on possible minor transgressions during the overall Holocene emergence. Based on preliminary results, it appears that an Early-Middle Holocene emergence was succeeded by submergence in Late Holocene.

5.1.11.2. Landscape dynamics in the coastal zone

Several test sites were set up in the coastal zone near Zackenberg as benchmarks for shore dynamics (Fig. 3.4.13.1). Two topographic profiles at the recurved spit in the old delta area were established in 1991 and re-surveyed in 1992, 1995 and 1996. The profiles indicate that the shoreline position at this site is stable (Fig. 3.4.13.2). During the 1996 field season the topographic profiles were supplemented with four test sites along the cliff coast east of the old delta and two test sites on the wetlands west of the old delta and east of the present delta, respectively.

Cliff recession is measured as the distance between the top of the cliff and a peg situated c. 100 m landwards the cliff. The sedimentation rate of the wetlands is measured as the vertical accretion on top of a test surface established with sand of a known texture.

Further, a number of photographs of coastal landforms have been taken from well-established positions. Repetitions of the photographs will allow a future qualitative description of landscape changes in the coastal zone.

At present, tide appears to be the major dynamic agent in the coastal zone. Generally, impact from waves in this part of Young Sund is very limited due to limited fetch distances. However, during extreme high tides even small wind generated waves will erode the coastal cliffs (Fig. 5.1.11.2.1).

Attempts will be made to substantiate this hypothesis. In this respect, the GeoBasis data series on tide and wind contain valuable information.

5.1.11.3. Sedimentology in Young Sund and Tyrolerfjord

Surveying the bottom topography of a smaller part of Young Sund and Tyrolerfjord (Fig. 5.1.11.3.1) was carried out from a Zodiac using a 200 kHz echo sounder for depth measurements and a portable GPS for positioning (Fig. 5.1.11.3.2).

Fig. 5.1.11.3.2. Mapping of the fjord bottom topography was carried out from a Zodiac using a 200 kHz echo sounder and a portable GPS. Photo: Morten Rasch

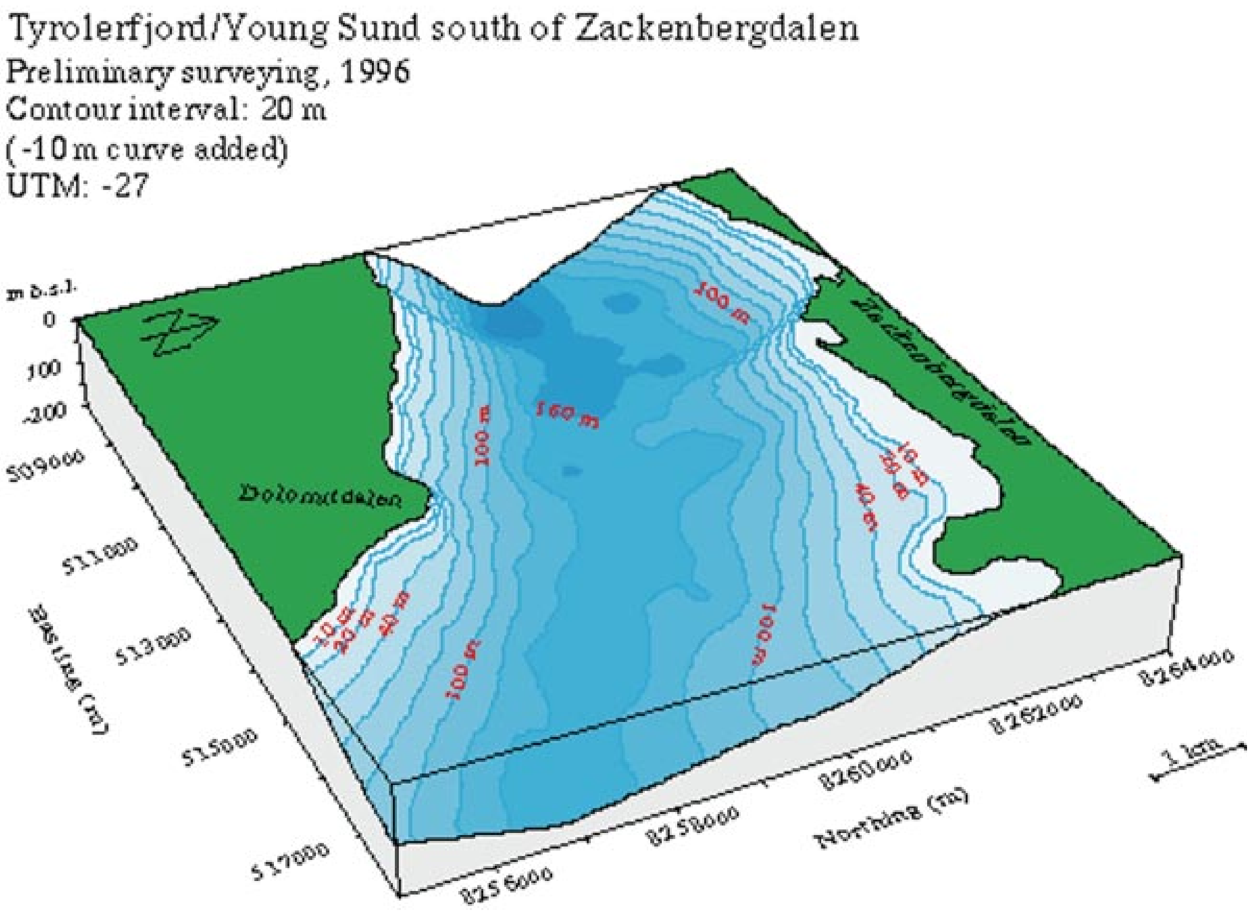


Fig. 5.1.11.3.1. The bottom topography of western Young Sund and eastern Tyrolerfjord. Note the decrease of water depth and fjord width at the transition between Young Sund and Tyrolerfjord.

The bottom topography map is an important tool in planning future investigations concerning Holocene sedimentation in the fjord. Bottom samples of fjord sediment taken in the new and the old deltas of Zackenbergelven will help to clarify present sediment characteristics.

It is our plan in the future to collect more data concerning the Holocene sedimentary environment in the fjord. Future field studies will include acoustic seismic, CTD-castings, measurements of present sedimentation rates and coring of fjord bottom sediments with drop cores and/or piston cores. The purpose of the investigation is to reveal temporal changes in sub-aerial landscape denudation rates and to compare these changes with the Holocene climate changes in the region.

5.1.12. Periglacial and glacial geomorphological research

Hanne Hvidtfeldt Christiansen

Detailed investigations of nivation forms, processes and sediments have been carried out as part of the study on the effect of nivation on periglacial landscape development in the High Arctic. Several sediment samples for textural investigations and for ^{14}C AMS dating were collected from nivation basins and are being analysed.

In mid June, the quick onset of thawing of the still rather continuous winter snow-cover resulted in nival flooding of large parts of Zackenbergdalen with watercourses being more than brimming and streams flooding the otherwise dry landscape (see Fig. 5.1.12.1). This situation and the resulting sedimentological consequences have been studied in detail (Christiansen *in prep.*).

Fig. 5.1.12.1. Nival flooding of Kærelv in a small valley in the southern part of Zackenbergdalen. During summer, Kærelv normally is a 1-2 m wide small stream, running in a well-developed channel. However, when snow melt starts in mid to late June, large amounts of water drain through the valley for a short period. The channel is then full and the surrounding valley bottom is flooded. *Photo: Ole Humlum*

Two active layer monitoring grids called ZERO-CALM-1 and -2 have been set up in the central part of Zackenbergdalen and re-measured several times during the summer season. They represent the first CALM grids established in Greenland.

CALM (Circumpolar Active Layer Monitoring Program) is an informal activity under the auspices of ITEX (International Tundra Experiment) and IPA (International Permafrost Association) aiming at collecting long-term data on the active layer. Hence, the name of the active layer monitoring sites is ZEROCALM, and the annual measurement of maximum thickness in late August in both fields from now on will be part of the GeoBasis programme.

ZEROCALM-1 is situated shortly north of the meteorological station on an almost horizontal marine abraded melt water plain, consisting mainly of sandy sediments. This grid is 100 m x 100 m, with 121 measuring points. The ZEROCALM-2 grid is 120 m x 150 m with 208 measuring points, and covers a seasonal snow-patch with a southern aspect. This area is dominated by both sandy and silt-clay sediments. In each of the two grids the grid size is 10 m x 10 m. The maximum active layer thickness was 60 cm in ZEROCALM-1 and 61 cm in ZEROCALM-2 on 16 August.

During the 1996 field season both sites were remeasured weekly from mid June to early August, and on 16 August in order to describe the development of the active layer in further details (Fig. 5.1.12.2). There is a difference in timing of the early development of the active layer while later both thaw rate and active layer thickness follow each other. This fact highlights the control that local conditions, such as

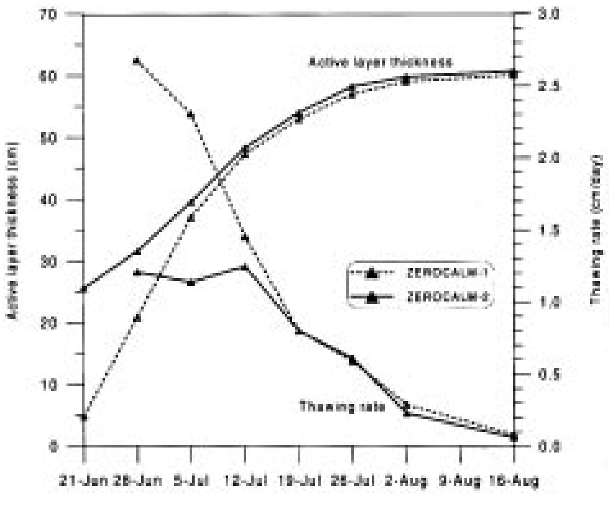


Fig. 5.1.12.2. Active layer development in the ZEROCALM-1 and -2 grids. The triangles illustrate when measurements of all grid points took place. In late June ZEROCALM-1 was nearly totally covered by snow and had only few grid points with any active layer, while in the ZEROCALM-2 grid snow existed only in the snowpatch which is why the early active layer establishment had already taken place. In general, the development of the two grids was equal in the later part of the summer.

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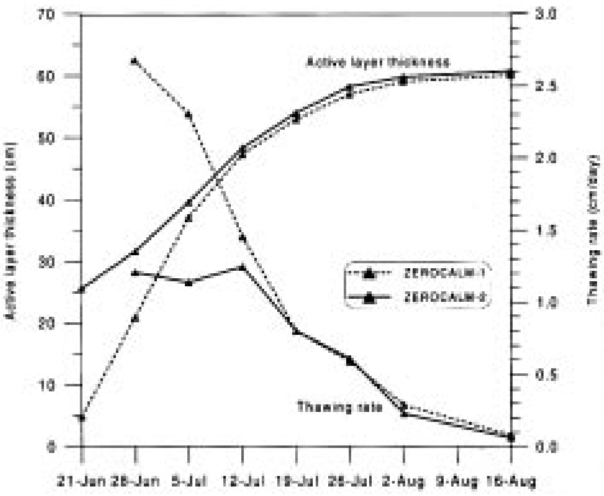

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snow-cover and duration, landform and texture, exert on the initiation of the active layer development, while later in mid and late summer, active layer thickness is primarily determined by the overall supply of energy.

Within the ZEROCALM-2 grid a small-scale snow modification experiment was initiated in 1996 .

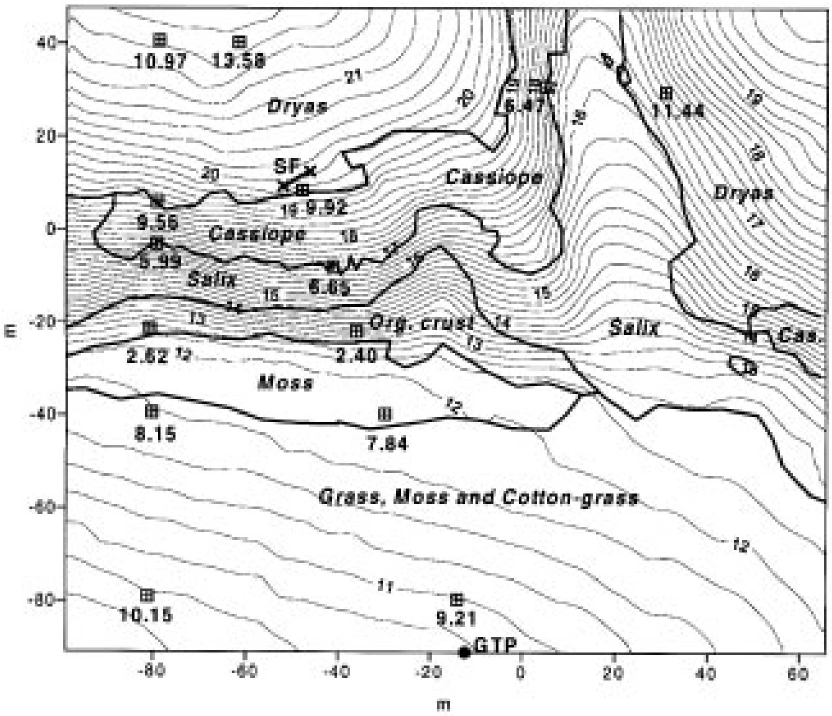

Fig. 5.1.12.3. The ZEROCALM-2 grid area with vegetation zones. North is towards the top. The squares with crosses inside show the location of the 14 TinyTag temperature dataloggers measuring at terrain surface. Average temperature values from the loggers from the period 24 June to 30 July are shown close to the measuring points. The location and extension of the snow fence (SF) is marked c. 2.5 m upwind/northwards of the upper Cassiope *vegetation zone. The point, marked GTP, shows the* ***G****eoBasis* ***t****emperature* ***p****rofile with continuous measurements in the active layer and in the upper permafrost.*

A snow fence, 0.6 m high x 5.5 m long, was installed about 2.5 m from the upper limit of the *Cassiope* vegetation zone in an upwind (*i.e.* northwards) direction (see Fig. 5.1.12.3) on 24 July, when the active layer was 70 cm thick at the fence location. The snow fence will lead to an increase in the thickness of snow in the seasonal snow-patch that normally accumulates in the area. It will then be possible to study the effect on active layer development and thickness, as well as surface temperature and the location of the very distinct vegetation zones which until now have been in balance with the recent amount of snow accumulated in the seasonal snow-patch.

Fourteen small TinyTag temperature sensors with individual dataloggers were installed at distinct vegetation limits primarily along two profiles at the terrain surface, one inside the area that will have a longer snow-cover caused by the snow fence as well as one outside (see Fig. 5.1.12.3). With this configuration it will be possible, in the future, to measure the effect of a longer period of snow-cover in some parts of the grid. Seven of the TinyTag dataloggers were installed at the bottom of the snow-patch, as the installation was done in mid June. Data are recorded 5 times daily by all the loggers.

Calculated average temperatures from 24 June to 30 July, generally show a decrease towards the location of the snow-patch (Fig. 5.1.12.3), where the last snow melted away on 22 July. Likewise, the asymmetrical distribution of vegetation zones in the small N-S oriented valley, clearly appears in the temperature difference of nearly 5°C between the east and west facing sides.

These significant differences in temperature within the grid are caused primarily by the distribution and extension of snow in the area. In the future it is intended to follow the location of the vegetation zones closely and register how they react to changes in thickness of snow-cover and duration, as registered by the TinyTags.

In the future it will be interesting to see how the snow fence will affect the active layer development, as it will be possible to use ZEROCALM-1 as a kind of control grid for the manipulated ZEROCALM-2 grid.

In the ZEROCALM-2 grid, measurements of soil moisture and micro-meteorological parameters such as surface temperature and temperature of the air and wind speed at 2 m were carried out as spot measurements for each grid point under different meteorological conditions. This was done to locate and describe micro-meteorological changes in the grids. Likewise, a profile of geochemical measurements of the active layer water has been measured twice during the summer below the snow-patch in the ZEROCALM-2 grid to describe the geochemistry of the developing active layer (see section 5.1.6). A permanent soil water measurement station was established in the moss zone below the summer snow-patch extension (see section 3.4.4).

Schmidt hammer measurements of the surface hardness and the compressive strength of bedrock and boulders are closely related to the degree of weathering and thus to surface age. Such measurements were carried out in profiles from the valley bottom to the top of both Zackenberg (Fig. 5.1.12.4) and Aucellabjerg, in order to detect and map periglacial trimlines and to be able to reconstruct the thickness of former glaciers covering Zackenbergdalen.

Sediment samples have been collected from selected landforms for luminescence dating, as part of a more detailed reconstruction of the glacial geomorphological development in key areas. These samples were taken at the upper marine limit and from deglaciation landforms where Store Sødal ends in upper Zackenbergdalen, and from Morænedal, west of the Zackenberg mountain.

Fig. 5.1.12.4. Schmidt hammer measurements were performed on boulders in a profile all the way from the bottom to the top of Zackenberg. At this level the investigator is still looking happy, despite the fact that the job lasted more than two days, including a transport-saving lift with a helicopter most of the way to the top on the second day. *Photo: Ole Humlum*

5.2. Nutrient dynamics in North-east Greenland waters and sediments

Søren Rysgaard, Peter Berg, Peter B. Christensen, Tage Dalsgaard, Henrik Fossing, Ronnie N. Glud, Ola Holby, Thomas Jensen, Lars Lund-Hansen, Niels P. Revsbech, Nils Risgaard-Petersen & Bo Thamdrup

A prerequisite for being able to understand long-term control of the higher organism biomass in Arctic marine environments is an understanding of nutrient availability and recycling in Arctic coastal waters, and its impact on primary and secondary production.

The objective of this project is to elucidate the cycles of energy, carbon and nitrogen in Arctic waters, as current knowledge of these aspects are negligible. The project focuses on the recycling of nutrients in the water column as well as nutrient regeneration and removal within the sea bottom of these coastal waters (Fig. 5.2).

The magnitude of the primary production of phytoplankton, and thereby the basic food source for higher animals, is controlled by several physical and chemical parameters. For example, light availability for phytoplankton is determined by the intensity of incoming light, the thickness of ice-cover and the stability of the water column. Furthermore, phytoplankton growth is controlled by the availability of nutrients. An important nutrient source for primary producers is provided by bacterial degradation of dead organic matter.

Part of this mineralisation takes place in the water column, but dead phytoplankton together with zooplankton exuvia and faecal pellets constitute a large fraction of organic particles precipitating from the water column. In general, much of the primary production in shelf areas (*i.e.* 0 - 200 m water depth) is deposited on the bottom, and this project has allocated special efforts to obtain detailed information about the sedimentary regeneration pathways.

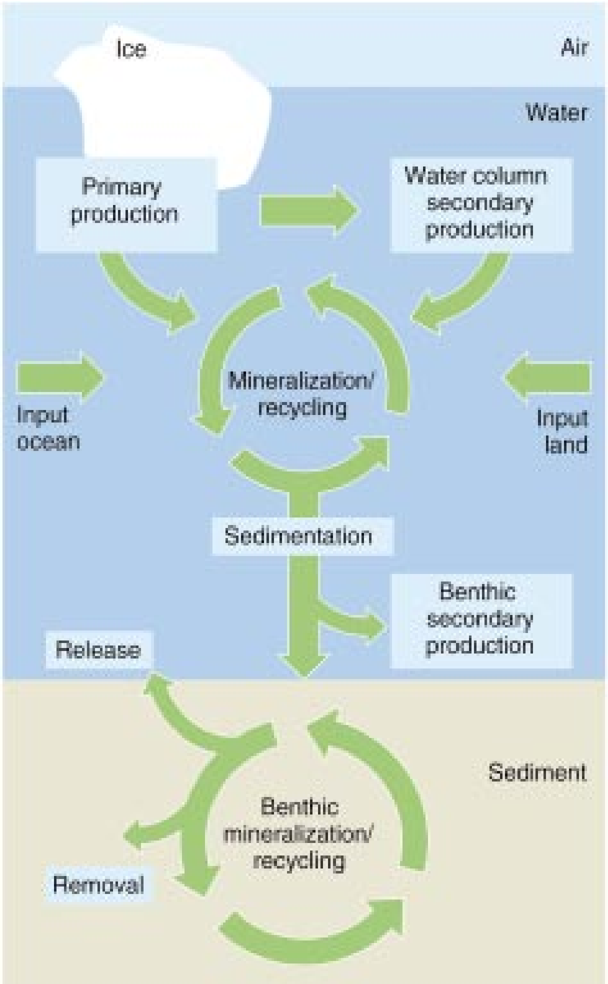

Fig. 5.2. The nutrient cycle in Young Sund. Primary production in the water column is stimulated when ice breaks during the summer thaw. This increased production provides an increased food source for zooplankton and benthic animals thereby enhancing their growth rates. Likewise, sedimenting dead phyto-plankton cells stimulate microbial mineralization at the sea floor. Here, the sedimenting organic material is de-graded through various bacterial processes leading to both a permanent removal of nutrients in the sediment and a release of nutrients to the water column.

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Søren Rysgaard, Peter Berg, Peter B. Christensen, Tage Dalsgaard, Henrik Fossing, Ronnie N. Glud, Ola Holby, Thomas Jensen, Lars Lund-Hansen, Niels P. Revsbech, Nils Risgaard-Petersen & Bo Thamdrup

A prerequisite for being able to understand long-term control of the higher organism biomass in Arctic marine environments is an understanding of nutrient availability and recycling in Arctic coastal waters, and its impact on primary and secondary production.

The objective of this project is to elucidate the cycles of energy, carbon and nitrogen in Arctic waters, as current knowledge of these aspects are negligible. The project focuses on the recycling of nutrients in the water column as well as nutrient regeneration and removal within the sea bottom of these coastal waters (Fig. 5.2).

The magnitude of the primary production of phytoplankton, and thereby the basic food source for higher animals, is controlled by several physical and chemical parameters. For example, light availability for phytoplankton is determined by the intensity of incoming light, the thickness of ice-cover and the stability of the water column. Furthermore, phytoplankton growth is controlled by the availability of nutrients. An important nutrient source for primary producers is provided by bacterial degradation of dead organic matter.

Part of this mineralisation takes place in the water column, but dead phytoplankton together with zooplankton exuvia and faecal pellets constitute a large fraction of organic particles precipitating from the water column. In general, much of the primary production in shelf areas (*i.e.* 0 - 200 m water depth) is deposited on the bottom, and this project has allocated special efforts to obtain detailed information about the sedimentary regeneration pathways.

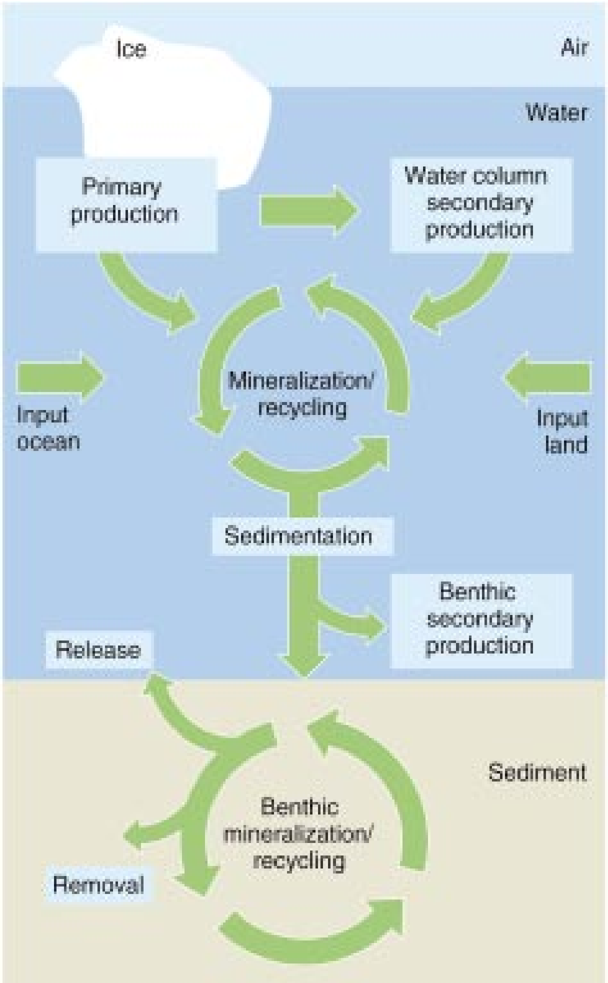

Fig. 5.2. The nutrient cycle in Young Sund. Primary production in the water column is stimulated when ice breaks during the summer thaw. This increased production provides an increased food source for zooplankton and benthic animals thereby enhancing their growth rates. Likewise, sedimenting dead phyto-plankton cells stimulate microbial mineralization at the sea floor. Here, the sedimenting organic material is de-graded through various bacterial processes leading to both a permanent removal of nutrients in the sediment and a release of nutrients to the water column.

At the sediment surface, mineralisation of organic material is aerobic, (*i.e.* with O_2, oxygen), through the activity of benthic micro-organisms and animals. These organisms constitute an oxygen consuming detritus food chain through which organic compounds are degraded to CO_2, NH_4^+ and PO_4^{3-} (carbon dioxide, ammonium and phosphate, respectively). Thus, in shelf areas, the oxic zone is reduced to a thin surface layer, below which further mineralisation takes place anaerobically (*i.e.* without O_2). Sedimenting organic material may be transported to deeper anoxic sediment layers through the activity of benthic animals or buried by deposition of fresh sediment.

Further degradation of organic material releases organic molecules which serve as substrate for micro-organisms that carry out denitrification, sulfate reduction and methane production. Through these processes, organic molecules are likewise metabolised to CO_2, NH_4^+ and PO_4^{3-} in the anoxic sediment layer. In addition, anaerobic degradation results in the formation of N_2, Mn^{2+}, Fe^{2+}, H_2S and CH_4 (dinitrogen, manganous and ferrous ions, sulphide and methane). These accumulate in the pore water and may subsequently diffuse upwards to the oxic surface layer and, except for N_2, undergo oxidation. Furthermore, NH_4^+ may be oxidised to NO_3^- in the oxic zones by nitrifying bacteria.

The nitrogen gasses N_2O (nitrous oxide) and NO (nitric oxide) are also produced as intermediates through denitrification or nitrification and although they are typically minor products, they are of interest as possible sources of atmospheric nitrogen gases.

As a result of all the benthic mineralisation processes, the products from both aerobic and anaerobic degradation may be released to the overlying water and be re-assimilated by primary producers, thereby completing the nutrient cycle.

5.2.1. Sampling stations

The marine study area was located in the east part of Young Sund approximately 25 km SSE of Zackenberg (Fig. 5.2.1). A station at 36 m water depth (Station A; 74°18.58N and 20°14.74W) was selected for intensive sampling of both water column and sea bottom during the summer period (19 June - 25 August). Furthermore, biological and bio-geochemical processes were investigated at different water depths in a transect from the former Daneborg Weather Station (74°18.51N and 20°13.71W) to Clavering Ø (74°18.38N and 20°28.36W).

To cover as many different sediment types as possible, measurements were performed at depths of 20 m, 36 m, 60 m, 85 m and 163 m. Finally, a brief survey was conducted by boat from the east part of Young Sund near Sandodden to Basalt Ø, Zackenberg Bugt, Rudi Bugt and to the west end of Tyrolerfjord to gain information on water depth, sediment texture and benthic fauna and infauna.

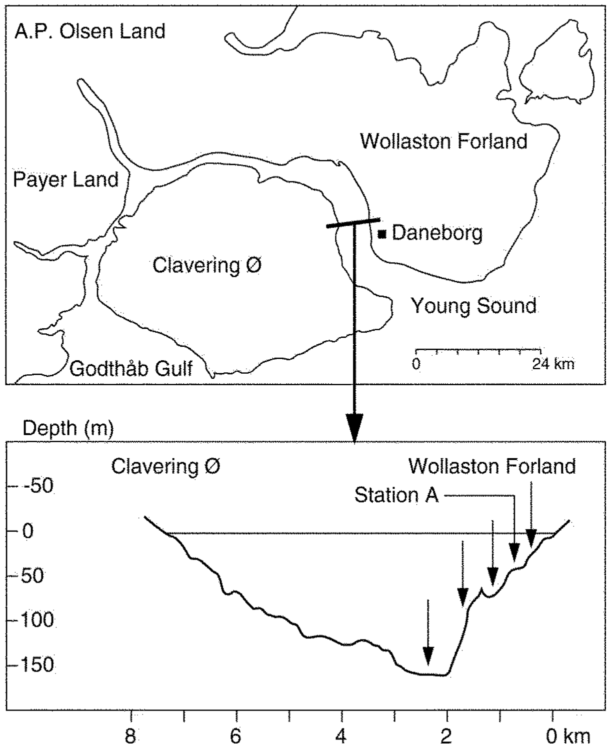

Fig. 5.2.1. The marine study area with the depth transect investigated and sampling stations marked with arrows. On Station A, measurements were performed regularly throughout the summer period.

5.2.2. Water column

In the early summer, when the study began, Young Sund was covered by two meters of ice. A seal hole was selected for sampling through the ice and later, when the ice broke and finally disappeared, a boat was used (Fig. 5.2.2.1-3).

Physical measurements of ice thickness, light, air and water temperature, salinity, tidal amplitude, along with chemical parameters such as water column concentrations of nitrate (NO_3^-), ammonium (NH_4^+), urea, phosphate (PO_4^{3-}), silicium (Si), dissolved organic nitrogen (DON), oxygen (O_2), total inorganic carbon (TCO_2) and nitrous oxide (N_2O), were obtained regularly during the study period. Water column samples were collected for later determination of phyto- and zooplankton composition together with measurements of chlorophyll. Primary production in the water column was measured in the field using ^{14}C methodology.

To determine the origin, quality and amount of material in the water column we collected water samples and recorded the suspended matter (*i.e.* concentration and isotopic labelling of nitrogen and carbon). The flux of suspended material to the seafloor was investigated using sediment traps suspended at several depths in the water column. The isotopic composition of organic carbon ($d^{13}C$) and nitrogen ($d^{15}N$) in off-shore marine sediments is very similar to that of the local planktonic communities and land plants generally have significantly lower d-values. Hence, measurements of the d-values in phytoplankton, suspended material and sediment at Station A, outside Young Sund and in Zackenbergelven, were taken to evaluate the relative importance of the marine and terrestrial contribution. These data have not yet been analysed and we are therefore unable to present a final conclusion concerning the composition of the depositing organic matter.

Fig. 5.2.2.1. Station A, the seasonal sampling station during June. A seal hole was selected for sampling through the two meter thick ice. *Photo: Søren Rysgaard*

Fig. 5.2.2.2. En route to Station A in the middle of July. Ice was breaking up. At several locations the ice-cover was less than 10 cm. *Photo: Søren Rysgaard*

5.2.3. Sea floor

In order to investigate the permanent accumulation of carbon and nitrogen in the sediment, undisturbed sediment cores were sampled from different depths and locations in Young Sund, to measure the vertical concentration of these components as well as the vertical distribution of radio-isotopes of lead and caesium (^{210}Pb and ^{137}Cs). ^{210}Pb is formed chemically in the atmosphere where it is adsorbed to aerosol particles and transported via the air-water interface to the sediment. Because ^{210}Pb decays ($t_{1/2}$ = 22.3 yr), the age of the sediment can be derived from the vertical decrease in the ^{210}Pb signal.

Furthermore, the vertical distribution of ^{137}Cs in the sediment can be correlated to discrete anthropogenic discharges from the nuclear fuel reprocessing plant Sellafield in UK and from fall-out from atmospheric nuclear tests providing additional information for dating. These dating procedures also yield information about the burrowing activity of benthic animals because bioturbation will tend to homogenise the distribution of ^{210}Pb and ^{137}Cs in the surface sediment. Data have not yet been analysed, but data from the same area obtained in 1994 suggest that benthic animals affect the upper 4 cm due to bioturbation and that the sea floor grows by 0.12 cm annually. In 1996, intact sediment cores were also collected from the deepest part of our transect (*i.e. 163* m) to be analysed for accumulation. It is assumed that accumulation at this depth is higher, due to the hydrographic conditions.

The number and species of benthic animals were determined on each sampling occasion in sediment collected by Van Veen and dredge equipment. All animals (≥0.5 mm) were preserved in buffered formaldehyde for later determination. Furthermore, a visual

Fig. 5.2.2.3. Sampling from boat on Station A in early August when Young Sund was free of ice. *Photo: Søren Rysgaard*

impression of the sea bottom, the benthic animals colonising the sediment surface and their community structure was obtained with an underwater video camera (Fig. 5.2.3). Production of benthic animals will be calculated from the density, growth rate and size specific weight of the predominant species during the study period.

Fig. 5.2.3. Underwater photo of the sea floor of Station A at the end of August. *Photo: Peter B. Christensen*

The most precise estimates are obtained on molluscs which dominate the biomass of Arctic coastal water; as their growth rate is easily estimated from their growth rings. As for the taxonomic groups, including molluscs, growth rate can be determined by separating the individual cohorts using length-frequency distribution histograms. The temporal changes in density are determined by quantitative sampling. Length-weight relationships will be determined for all important species present and used to estimate their biomass. Analysis of these samples have begun but no conclusions can be drawn yet. However, the sediment at Station A was inhabited by dense populations of bivalves, tube-dwelling polychaetes and bristle stars.

5.2.4. Sediment-water exchange rates

To investigate the degradation of organic material reaching the sea floor and to measure the resultant release of nutrients to the water column, intact sediment cores, together with bottom water from the locality, were sampled regularly and brought back to the laboratory at the Daneborg Weather Station. For determination of benthic fluxes, a number of these cores were incubated under *in situ* conditions, *e.g.* field temperature, nutrient, oxygen and flow conditions in specially designed incubators. In short, the sediment cores were placed in the incubator containing constantly aerated bottom water, and the water overlying the sediment core was kept in circulation by a magnetic stir-bar. Incubation was initiated by closing the cores with a gastight lid and water samples were collected at regular time intervals for measurements of the production or consumption of nitrate, nitrite, ammonium, urea, phosphate, silicium, dissolved organic nitrogen, oxygen, total inorganic carbon and nitrous oxide (Fig. 5.2.4). Production of these components will result in release from the sediment to the overlying water and consumption will result in transport from the water column to the sediment.

Fig. 5.2.4. Sampling from sediment cores during incubation at the end of June. In June, when ice and snow covered Young Sund, the sediment cores were submerged in bottom water from the locality and the incubator cooled with snow to maintain correct in situ *temperature. Later, ice was collected from icebergs and brought to the laboratory for temperature control.*
Photo: Egon Frandsen

5.2.5. Porewater

As mentioned in the introduction, microbial mineralisation within the sediment results in consumption of oxygen in the sediment. Therefore, on several occasions, the penetration of oxygen into the sediment was measured using microelectrodes (Fig. 5.2.5.1-2). Furthermore, bacterial mineralisation of organic material on and within the sediment results in the production and consumption of various components

Fig. 5.2.5.1. Measurement of the oxygen concentration profile within the sediment. The measurements were performed in the laboratory of the Daneborg Weather Station.
Photo: Søren Rysgaard

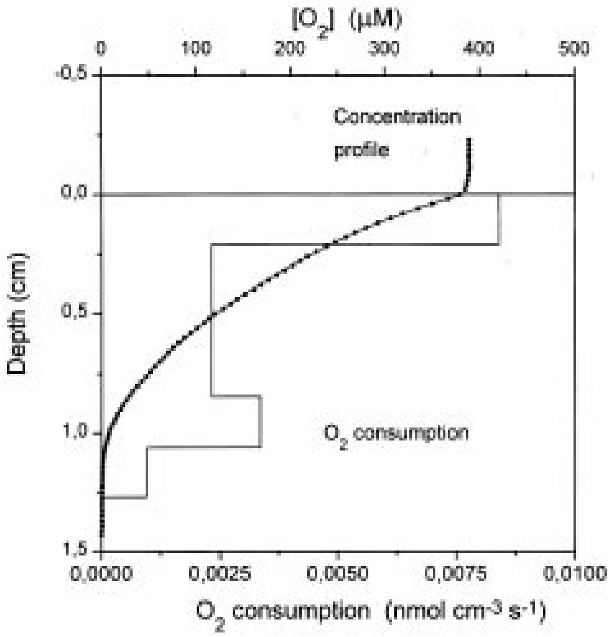

Fig. 5.2.5.2. An example of the oxygen concentration profile from Station A in late July. The concentration of oxygen was close to atmospheric saturation above the sediment surface and penetrated approximately 1 cm into the sediment. The high oxygen consumption found close to the sediment surface was caused by high microbial mineralization associated with fresh organic material reaching the sediment after a phytoplankton bloom. The peak of oxygen consumption at 1 cm depth was caused by reduced substances diffusing upwards from deeper sediment layers.

in the sediment porewater. Therefore, intact sediment cores were collected and sectioned for analysis of porewater concentration profiles of NH_4^+, NO_3^-, TCO_2, urea, DON, PO_4^{3-}, SO_4^{2-}, HS^-, Fe^{2+}, Fe^{3+}, and Mn^{2+}; and for extraction of manganese and iron oxides as well as iron sulphides from the solid phase. In addition, measurements of porosity, density and content of drop-stones (>1 cm) in sediments of various locations were obtained.

5.2.6. Sediment microbial activity

Measurements of nitrogen removal through bacterial nitrification and denitrification were obtained using ^{15}N isotope techniques. In short, sediment cores are incubated with $^{15}NO_3^-$ (^{15}N labelled nitrate) in the overlying water. Water samples collected at regular time intervals and analysed for their content of ^{15}N labelled N_2 can be used to calculate the bacterial denitrification activity. The denitrification activity reflects the capacity of the sediment to remove nitrogen from the environment. Measurements of the dilution of added $^{15}NO_3^-$ with internally produced $^{14}NO_3^-$ during incubation, together with denitrification measurements give the nitrification activity. Nitrifying bacteria oxidise ammonium, produced by degradation of organic material, to nitrate thereby making nitrogen available for denitrifying bacteria.

Fig. 5.2.6. Anoxic extraction of porewater in Glove box.
Photo: Søren Rysgaard

Sulfate reduction rates within the sediment were measured several times during the study period using radiolabelled sulfate, $^{35}SO_4^{2-}$. Trace amounts of the compound are injected into intact sediment cores, and the accumulation of reduced ^{35}S compounds determined. With this technique, rates can be determined in short (24 h) incubations. Similar, rapid techniques are not available for the measurement of manganese and iron reduction rates. The roles of these pathways in carbon mineralisation were therefore determined by anoxic incubation at bottom water temperature of sediment sectioned into depth intervals. This was done in the middle of the sampling period at both Station A and at a station at 80 m depth. Total mineralisation rates were determined from the accumulation of dissolved inorganic carbon and ammonium, and the contributions of the different electron acceptors were deduced from changes in oxidised and reduced manganese and iron pools and from sulfate reduction rate determinations. Due to the sensitivity of reduced iron and sulphur stages to oxygen, all handling of the samples had to take place in an anoxic glove bag (Fig. 5.2.6). In addition to these incubations, aimed at quantifying actual field rates, an experiment was conducted to further examine the adaptation of the anaerobic bacterial population to permanently low temperatures and, consequently, the effect of temperature on carbon mineralisation. To this end, portions of homogenised sediment were amended with varying amounts of fresh organic matter in the form of freeze-dried phytoplankton, and rates and pathways of carbon mineralisation as well as the bacterial population size were monitored during anoxic incubation at 0, 10 and 20°C.

The experiment will provide new information on 1) the response of the Arctic benthic bacterial community to pulses of organic matter such as the settlement of a phytoplankton bloom, 2) the decay constants of such organic matter at low temperature, and 3) the temperature characteristics of the bacterial population.

Fig. 5.2.7. Transportation of the lander, ELINOR, to Station A during late July when the ice was breaking. A block of ice was used to float the lander across open water to safe ice from where it was carried to the sampling station. *Photo: Bo Thamdrup*

5.2.7. Benthic landers

In addition to our measurements of the biogeochemical processes and fluxes in the laboratory, several investigations on different sediment types were performed in the field using benthic landers. Two landers were used, the PROFILUR and the benthic flux chamber ELINOR. In principle, the landers are lowered to the sea floor and carries out measurements in the field. Stepwise (*i.e* 25-100 µm steps), the PROFILUR measures the vertical profile of various parameters, *e.g.* O_2 concentration, pH and temperature from the bottom water through the sediment-water interface and into the sediment. The ELINOR lander was used to measure sediment-water nutrient and gas exchange rates together with bacterial nitrification and denitrification in the field. This lander inserts a square respiration chamber into the sediment and by closing its lid a section of the sediment is enclosed together with its overlying water.

During the incubation, the water-phase is stirred and the O_2 concentration in the overlying water is continuously measured by microelectrodes. An internal computer controls the sampling of water at different time intervals and at the end of incubation, a scoop is closed beneath the chamber thereby catching the sediment before the lander is collected.

Following recovery, water samples are frozen for later analysis, the sediment core sieved for benthic animals, and data recorded by the microelectrodes are transferred to a PC (Fig. 5.2.7).

5.2.8. Data analysis

We are currently working on the analyses of all samples and data collected during the field campaign and hope that we can complete most before 1997. Therefore, a thorough description of data obtained in this 1996 field campaign must wait until data are ready.

However, most of the data analysed so far show a rapid increase in biological activity following the ice break-up. An increase in the primary production activity was observed in connection with the ice-breaking period causing sedimentation to increase and thereby stimulating the bacterial activity in the sediment.

As an example, the oxygen consumption of the sediment increased 3-4 times within few days after the phytoplankton bloom. Further details concerning this project will be published in international journals in the near future.

5.2.9. Acknowledgements

Several people and institutions have been helpful to this project. The Danish Research Councils (grant no 9501025) are acknowledged for financial support together with the National Environmental Research Institute, Silkeborg, Denmark, the Max Planck Society, Munich, Germany, and the University of Aarhus, Denmark.

We thank the Sirius Patrol for their hospitality and outstanding help with transportation and storing of equipment, weather reports, supplies, extra generator *etc*. Egon Frandsen is thanked for skilful technical assistance in the field and Kitte Gerlich, Marlene Jessen and Anna Haxen for their work in the laboratory.

The Danish Polar Center is acknowledged for help with logistics. Miss Miyuki Komatsu is thanked for excellent diversion and for keeping everyone warm during periods of cold weather.

5.3. Seed dynamics of Arctic plants

Heidi Elberling

Only few studies have focused on plant population processes in the Arctic and consequently, the existing theories relating to plant population biology have been developed primarily on the basis of studies in the temperate region. Knowledge of plant population processes in severe physical environments may turn out to be crucial in order to predict the effects of the increased resource utilisation and the potential global warming on the Arctic ecosystems.

The open habitats of the High Arctic, where most plants reproduce only sexually, are particularly sensitive and one can therefore expect the first and foremost effect of a global warming to be observed here. Several aspects of seed dynamics in the High Arctic have been examined, but a general understanding has not yet been established. Some studies have demonstrated an increased seed production when High Arctic plants are subjected to an increase in temperature and this has implications for predictions of vegetation development following a global temperature increase. However, until the seed dynamics of High Arctic plants have been elucidated, it will be difficult to evaluate the effects of for instance global warming on the High Arctic habitats.

During the 1996 summer, a field experiment was initiated on a 50 m x 50 m abrasion plateau due south of the Zackenberg station. Within the experimental site, 90 plots of 0.5 m x 0.5 m were distributed randomly. The project is a detailed study of the seed flow (*i.e.* 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*. The seed dynamics parameters will be measured several times in order to evaluate the temporal variation.

Seed production was estimated by recording the number of fruits produced per individual in the 90 plots. Fruits were collected outside the plots in order to evaluate the number of seeds per fruit. In 1997, all fruits produced within the plots will be collected.

Seed dispersal was estimated by placing 30 traps of 0.20 m x 0.22 m randomly within the study area. The traps were emptied shortly before the end of the season, and will be emptied again at the beginning of the season and just before plant seed set in 1997.

The *seed bank* was sampled randomly within the study area at both 0-2 and 2-4 cm depths. The samples were collected before seed dispersal and at the end of the season, and more samples will be collected in 1997, at the beginning of the season and before seed dispersal. The seed bank samples are at the moment being germinated in a greenhouse in Denmark. Mature seeds were collected from the plant species within the study area. These seeds will constitute a reference collection for seeds and seedlings in the seed dispersal samples as well as the seed bank.

Seedling establishment was studied by recording the spatial distribution of all individuals within each plot at the beginning and then again at the end of the season. Very few seedlings appeared during the summer. The location of all individuals within the plots will be mapped again at the beginning and the end of the season of 1997.

Fig. 5.3. The 90 plots within the field site were assigned six different treatments (i.e control, moisture, nutrients, disturbance, temperature, and a combination). Seed production was estimated within the plots, seed dispersal was evaluated using seed traps placed between the plots, seed bank samples were taken between the plots and seedling establishment was recorded within the plots.

Photo: Bo Elberling

To assess the influence of moisture, nutrients, disturbance and increased temperatures on seed dynamics, the 90 plots were given six different treatments which were randomly assigned to plots (15 replicates of each treatment). [1)] Control (*i.e.* no treatment). [2)] Moisture (*i.e.* each plot was given 2 l water every four days). [3)] Nutrients (*i.e.* each plot was given 12 g N, 5 g P, and 14 g K at the beginning of the season). [4)] Disturbance (*i.e.* approximately 50% of each plot was disturbed by breaking and turning the top soil). [5)] Temperature (*i.e.* ITEX corners increased the average temperature approximately 2°). [6)] A combination of treatments [2)], [3)], [4)] and [5)].

On the basis of the field results, a seed dynamics model of the study species will be constructed in order to simulate long-term effects on reproduction of for instance global warming.

5.4. Pollination community ecology

Heidi Elberling

Most literature on pollination biology focuses on single plant species and their associated fauna of flower visitors. Thus, despite the fundamental fact that coevolution between plants and their pollinators is a diffuse process taking place at the community level, research in pollination ecology on a community level is scarce. Existing community studies of pollination mutualisms have typically occured in species-rich temperate and sub-tropical communities, where the degree of specialisation presumably is higher than in more species-poor communities.

In order to extrapolate knowledge across latitudes, more studies of communities with few species and non-specialised interactions are necessary. A few sub-Arctic - alpine studies have been made with the explicit purpose of investigating community interactions between plants and their pollinators, however, the present project is the first High Arctic study.

Insects are important for the pollination of many Arctic plants and in fact up to 2/3 of the Arctic flora may have facultative insect pollination. In order to register the plant-pollinator interactions in Zackenberg, a study plot of approximately 750 m x 750 m was chosen for pollination observations.

The plot was located south of the Zackenberg station and included several types of plant communities, *i.e.* fellfields, *Dryas* heaths, *Cassiope* heaths, dry *Dryas-Kobresia* communities, and old riverbed / snowpatch communities.

Fig. 5.4.1. A visit to Arnica angustifolia *by* Clossiana polaris. *Butterflies are generally thought to be specialised pollinators in contrast to flies, which are considered unspecialised pollinators.*

Photo: Bo Elberling

Observations of flower-visiting insects were made by regular census walks throughout the flowering season. If flower-visiting insects were observed to forage for nectar or pollen, they were regarded as potential pollinators. Insects classified as pollinators were caught and preserved for later identification, and the visited plant species was recorded.

Approximately 500 pollinator visits were observed on 30 different species of flowering plants. Some of the most visited species were *Cerastium arcticum*, *Dryas octopetala*, *Papaver radicatum*, *Polygonum viviparum, Potentilla rubricaulis*, *Saxifraga caespitosa*, *Saxifraga nivalis*, *Saxifraga oppositifolia*, *Silene acaulis* and *Stellaria longipes*. Pollinators primarily belong to Diptera, Lepidoptera and Hymenoptera.

Fig. 5.4.2. Flies visit flowers for both food (i.e. nectar and pollen) and heating. Dryas octopetala*, the flowers of which are very attractive to insects, increases temperature within the parabolic-shaped flowers above the ambient by concentrating the solar radiation.*

Photo: Bo Elberling

When the insects have been identified, a plant-pollinator interaction matrix will reveal the trophic and reproductive interactions between the plants and insects. Connectance, *C*, which is the fraction of realised interactions in a community, will be calculated as a measure of interaction that can be used for comparisons between communities.

The connectance of plant-pollinator systems is defined as $C=I/(m \times n)$, where I is the total number of interactions between species, m is the number of animal species and n is the number of plant species. Comparisons with studies from other latitudes will allow discussions whether interactions are more specialised or generalised in the Arctic than at lower latitudes.

Observations of interactions throughout the flowering season will make it possible to consider both phenological displacement and morphological mismatches between plants and insects when calculating connectance of the system.

5.5. Vegetation analyses

Bent Fredskild

In addition to the 103 vegetation analyses made in 1992 east of Zackenbergelven, 63 of which were located along the ZERO-line, a further 33 analyses were made in 1996, mainly in the lowland west of the river and in the old delta of Zackenbergelven. The analyses (elucidating the plant species composition, distribution and coverage at a given site) were concentrated on *Phippsia algida-Luzula confusa* snowbeds, *Salix herbacea* snowbeds, *Empetrum hermaphroditum* heaths, and, in the old delta, on species-rich communities on moist ground, dominated by *Saxifraga hirculus* and *S. platysepala*, and on salt marshes. The results are presented in Fredskild & Bay 1993 and in Fredskild 1996.

Fig.5.5. Arctic Jacob's Ladder, Polemonium boreale*, displays its beautiful blue flowers along the coastline and on basaltic soils in the study area.*

Photo: Danish Polar Center / Henning Thing

5.6. Comparison of three different types of arthropod traps

Jens Böcher & Hans Meltofte

During the first monitoring season (*i.e.* the summer of 1995) pit fall trapping was performed using transparent, colourless plastic jars combined with yellow pan traps, attracting flying insects (see Böcher *in* Meltofte & Thing 1996).

In order to simplify the procedures it was decided to use yellow plastic jars of about the same size as the transparent jars (diameter of 10 cm and 9 cm, respectively). This should combine the pitfall qualities with those of the yellow pan traps.

During the 1996 season, both types of pitfalls were operated in combination with yellow pan traps in order to compare their efficiency.

5.6.1. Comparing yellow to transparent pitfall traps

On each of the five pitfall trapping stations, four transparent and four yellow traps were operated. Each trap was placed at random within a square of 5 m x 5 m (see further in section 4.2.1). The catches of selected taxa appear from Figs 5.6.1.1-3 where the catch of ground-dwelling Lycosid spiders (*Pardosa* spp.), flies, *Muscidae + Anthomyidae*, and butterflies *Clossiana* spp., respectively, are compared. Apparently, there is no significant difference in the catch of wolf spiders, whereas the difference in caught butterflies is conspicuous. Furthermore, there is an order of magnitude in difference between the catch of flies by means of the two methods. The total catch of mites (Acari) from all traps during the season is almost twice as large from yellow traps as from colourless traps (4554 versus 2863 individuals).

The comparison between the two types of pitfall traps clearly demonstrates that yellow traps are superior to colourless ones as regards attraction of arthropods and at least equal in efficiency as regards pitfall qualities.

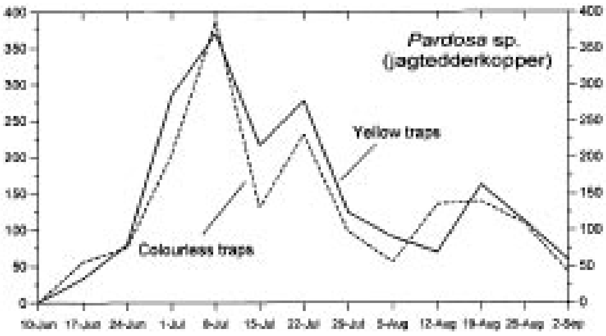

Fig. 5.6.1.1. Comparison of catches of wolf spiders Pardosa *spp. during the 1996 season in 20 yellow and 20 colourless pitfall traps, respectively.*

5.6.2. Comparing yellow pitfall traps to yellow pan traps

The catching efficiency of yellow pitfall traps was compared to that of yellow pan traps by operating one pan trap randomly placed within each of the trapping stations 2-5 (see section 4.2.1). From the results presented in Table 5.6.1 it is evident that pan traps are highly superior in catching midges, *Chironomidae*, and also much more efficient than pitfalls regarding muscid plus anthomyid flies (note that the total catching area of the pitfall traps was only about 60% of that of the pan traps – 1040 cm^2 versus 1760 cm^2 of horizontal yellow area).

When chironomid midges are excluded (Table 5.6.1, lower part) it appears that pitfall traps are relatively more efficient in catching butterflies, Lepidoptera, fungus gnats, *Mycetophilidae*, and ichneumon wasps, whereas possibly less so as regards hover flies, *Syrphidae*.

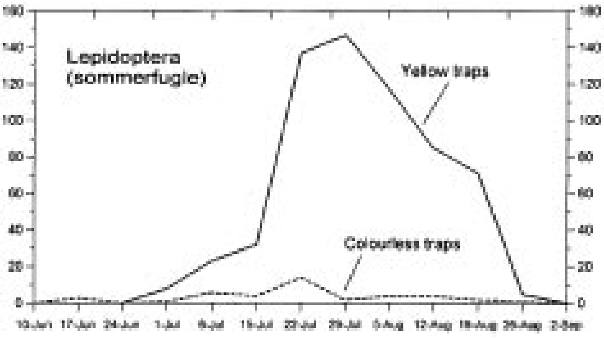

Fig. 5.6.1.2. Comparison of catches of butterflies, Lepidoptera, during the 1996 season in 20 yellow and 20 colourless pitfall traps, respectively.

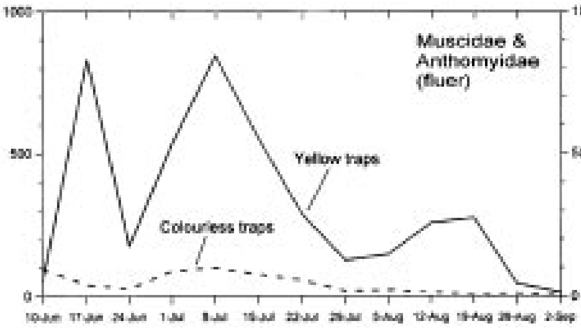

Fig. 5.6.1.3. Comparison of catches of flies, Muscidae + Anthomyidae*, during the 1996 season in 20 yellow and 20 colourless pitfall traps, respectively.*

Hence, yellow pan traps are much more efficient than yellow pitfall traps in catching midges and muscid and anthomyid flies, whereas they are less efficient regarding a number of other insect groups. However, window traps primarily catch these two groups (section 4.2.2) and represent therefore a valuable supplementing means of collecting for the monitoring programme at Zackenberg. For faunistic purposes it is possible that collections by means of pan traps are important. However, decisions concerning this issue must await the identification to the species level of the Zackenberg arthropod material.

Table 5.6.1. Comparison of total number of insects from selected groups caught by four yellow pan traps (20 x 26 cm) and 16 yellow pitfall traps (ø10cm) during 1996.

	Yellow pitfalls		Yellow pan traps	
	#	%	#	%
Lepidoptera	412	6.47	132	0.56
Chironomidae	1486	23.35	14696	61.49
Mycetophilidae	234	3.68	80	0.33
Syrphidae	33	0.52	82	0.34
Muscidae + Anthomyidae	3794	59.61	8690	36.36
Ichneumonidae	406	6.38	218	0.91
Total	6365		23898	

	Yellow pitfalls		Yellow pan traps	
	#	%	#	%
Lepidoptera	412	8.50	132	1.43
Mycetophilidae	234	4.83	80	0.87
Syrphidae	42	0.74	82	0.89
Muscidae + Anthomyidae	3794	78.29	8690	94.44
Ichneumonidae	406	8.38	218	2.37
Total	4888		9202	

5.7. Collared Lemming Project - Zackenberg

Thomas Bjørneboe Berg

The project continued data sampling on collared lemming *Dicrostonyx groenlandicus* initiated in 1995 on habitat selection, feeding biology, population dynamics and morphology.

5.7.1. Population dynamics and habitat use

The location of all 1995-96 winter nests (161) and summer burrows (80) were related to the UTM grid and mapped (Fig. 5.7.1.1). The nests were checked for [1)] signs of breeding, [2)] predation by ermine *Mustella erminea* and Arctic fox *Alopex lagopus*, [3)] lemming pellets within the nest (*i.e.* indicating that the nest had been abandonned as living quarters and hereafter only used for pellet dropping), and [4)] presence of white and grey fur. Grey fur reveals that the nest was built before November (Degerbøl & Møhl-Hansen 1943; TBB pers. obs.) while white fur indicates that the nest has been in use during May. Data are presented in Table 5.7.1.

Long-tailed skuas *Stercorarius longicaudus* attempted to breed both in 1995 and in 1996 (section 3.3.4 in this volume; Meltofte & Thing 1996, section 4.3.3.4) indicating that the lemming population in the Zackenberg study area was not at a low. Several other facts suggest that the lemming population in the study area was in fact increasing during the 1996 field season:

Predation by Arctic fox during winter showed the same index as the winters of 1993-1995 combined. Live lemmings were seen more frequently that in 1995. Twentytwo nests in 1996 showed sign of breeding against 16 in 1993-1995 combined. Nest sites were used more intensively than in the period 1993-1995 according to the 36 abandoned nests (*i.e. used* as pellet site) in 1996 against 15 in 1993-1995.

The vegetation around nests and burrows was described by plant species coverage within a radius of 10 m from the nest. The frequency distribution of plant species around nest and burrows is presented in Fig. 5.7.1.2.

All pellets around winter nests from the previous winter were collected by means of a battery-powered vacuum cleaner. Analyses are still in progress and will provide data on plant species, pellet production, C:N ratio, and protein contents with reference to the specific nest number and vegetation around the sample site.

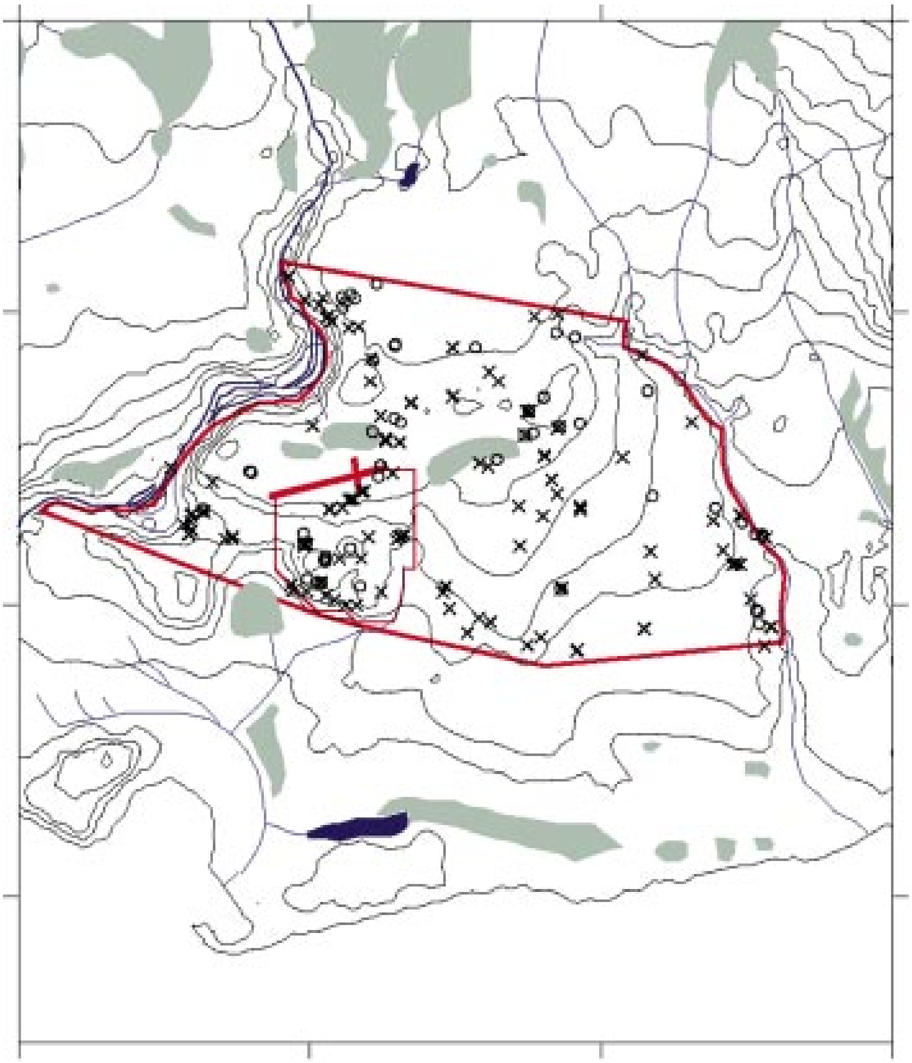

Fig. 5.7.1.1. The 2.5 km2 lemming monitoring area and the 0.5 km2 capture–recapture area south of the runways. Winter nests (✕) from the winter of 1995/1996 and active summer burrows (❍) recorded in 1996. Scale: 1 km between marks on axes.

Lemmings are active year round and have a high demand for food. During winter, the feeding area used by lemmings is probably smaller than during summer. Therefore, a more intensive use of a smaller home range leads to pellets accumulating within the nesting area. The number of lemming pellets around winter nests was estimated and is indicative of the variation in consumption from year to year. The total number of pellets produced per nest has not yet been calculated, but the frequency of the different

Fig. 5.7.1.4. Collared lemmings prefer to build their winter nests in graminoid dominated habitats on the shoulders of low lying areas.

Photo: Mads C. Forchhammer

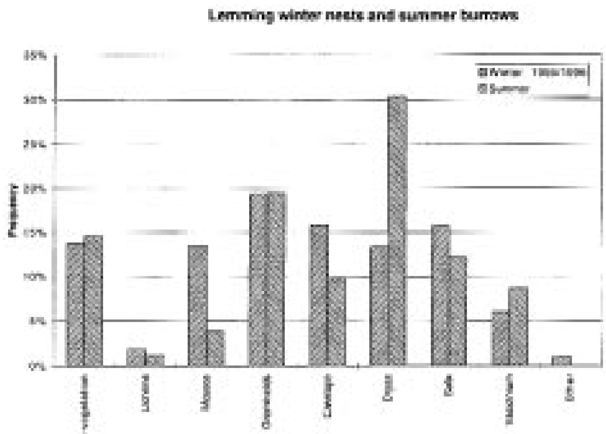

Fig. 5.7.1.2. The average frequency of plant species around winter nests and summer burrows within the 2.5 km² study area. The frequency of the different plant species were estimated by 5 % intervals within a radius of 10 meter around the nest or burrow. Sample size: winter nests = 161, summer burrows = 80.

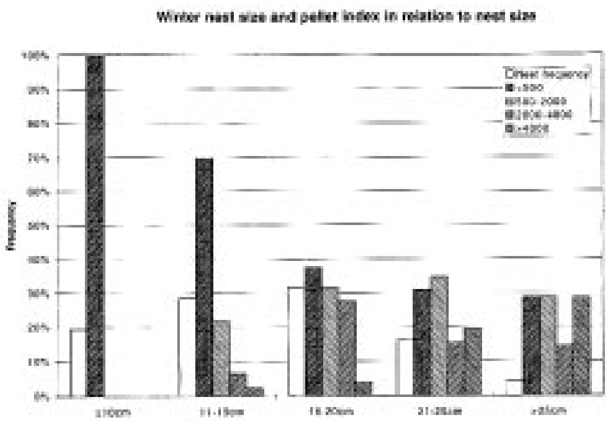

Fig. 5.7.1.3. Pellet index as estimated amounts of pellets around winter nests within the 2.5 km² study area.

pellet indexes is shown in Fig. 5.7.1.3. By the end of August, leaves from *Salix* and *Dryas* as well as flower stems of *Bistorta vivipara* were collected for later analysis of C and N contents. It is expected that the C and N contents of the pellets will differ from year to year and among nest sites in accordance with the digestibility and nutritive value of food plants.

Thirty sites (22 from 1995 and eight from 1996), where snowy owls *Nyctea scandiaca* and long-tailed skuas have regurgitated their casts, were checked within the 2,5 km² lemming monitoring area, resulting in only few skua casts from the eight new sites. Bone remains from lemmings (*i.e.* mainly skull, mandible and leg bone fragments [front: humerus, ulna, radius; hind: femur, tibia]) will be analysed for asymmetry according to methods used by Bendix (*in* Meltofte & Thing 1996).

5.7.2. Population demography

Within the 2.5 km² study area, 0.5 km² has been selected for live trapping twice per season, *i.e.* beginning of July and end of August. The study area is heterogeneous with respect to vegetation and topography, including slopes with late thawing snow beds, sparsely vegetated wind blown areas, together with wet, mesic and dry tundra. A test trapping was made in mid August giving only one trapped lemming in 4000 trap hours: a subadult male weighing 36 g, with still not fully developed testes. In 1997 100 traps will be placed within a 20 m x 20 m grid as well as at active summer burrows. Traps will be open 12 hours a day and moved every 24 trap hours covering the 0.5 km² in 12 days. Trapped animals will be tagged (use of microchips is planned), sexed and aged and their reproductive state determined.

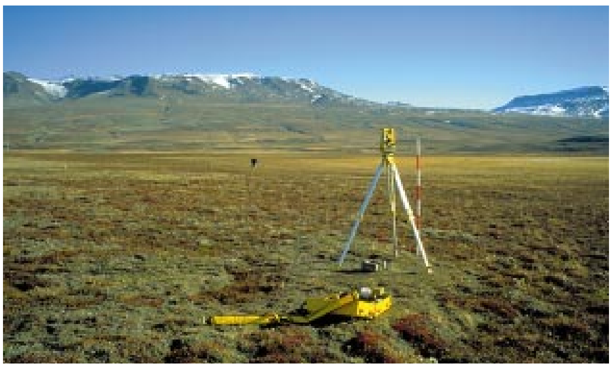

Fig.5.7.2. All new winter nests were given exact UTM co-ordinates by means of triangulating with an electronic teodolite. *Photo: Aurora / Thomas B. Berg*

Table 5.7.1. Winter nests within the 2.5 km² study area examined in 1996.

Winter	# nests	Predated by		Nests with		Signs of	Nests with
		Ermine	Arctic Fox	grey fur	white fur	breeding	pellets
1993/1994+1994/1995	279	5	11	20	14	16	15
1995/1996	161	1	12	23	1	22	36

5.8. Male reproductive strategies in muskoxen: a between population analysis

Mads C. Forchhammer

Previously, the muskox mating system has been viewed as traditional harem defence polygyny as documented in muskox populations in Canada and Alaska (Forchhammer 1996). However, recently it was documented that muskox bulls in West Greenland roved between cow-groups following an optimal strategy maximising their number of matings per unit of time (Forchhammer 1996). Additionally, it has been hypothesised that this staying-roving dichotomy observed between populations is related to a phenotypic response in male reproductive strategy dictated by social and environmental conditions. In particular, female-biased sex-ratio and high density would favour a roving strategy, whereas the opposite would favour a staying (*i.e.* harem defence) strategy (Forchhammer 1996).

To test the influence of social and environmental factors on male reproductive strategies across populations a study on reproductive decision making of muskox bulls were carried out in Zackenbergdalen, covering the two peak weeks of muskox mating season. A total of 23 focal bulls divided into four age-groups was sampled following the procedure described by Forchhammer (1996).

Preliminary results show that the muskox bulls roved between cow-groups similar to what they do in West Greenland. The high density of muskoxen and the female-biased sex ratio observed in Zackenbergdalen are comparable to those in West Greenland (Forchhammer 1996). Several observations were made of bulls leaving cow-groups immediately after successful mating without being displaced from the cow-group. Additionally, the age-specific investment in reproductive activities by bulls apparently deviated from the pattern observed in the West Greenland population (Forchhammer & Berg *in prep.*).

Fig.5.8. A small muskox group with a dominating adult bull. An adult cow is lying to the right.

Photo: Mads C. Forchhammer

5.9. Long-term modelling of muskox population dynamics: the effect of social and environmental factors

Mads C. Forchhammer

In contrast to small herbivores with short generation times (*e.g.* heteropteran insects, microtine rodents), the effect of environmental changes of large-size species with long generation cycles (*e.g.* caribou, muskox) are difficult to study under purely experimental conditions. An alternative approach using data from different populations in natural habitats involves developing models that 1) link environmental variation with physiology and life history traits of individuals, 2) integrate these patterns across individuals resulting in predictions about population level response to environmental variation, and 3) incorporate intra- and interspecific interactions and other feedback dynamics into the model.

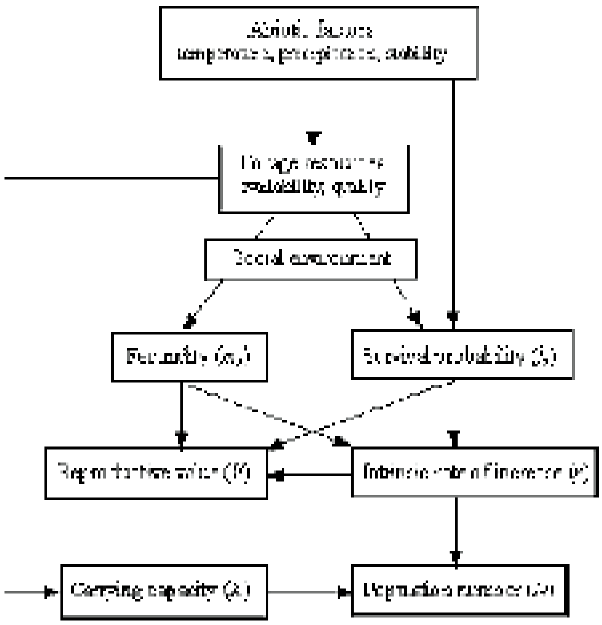

Fig. 5.9. Sequential flow scheme showing the interactions from the influence of abiotic factors through forage resources and social environment to the population level response.

Based on empirical data collected from the BioBasis monitoring of muskoxen (see section 4.4.2) and data obtained from other muskox populations (see Forchhammer 1996 for review), this study aims to model the effect of social and environmental conditions on the population dynamics of muskoxen. This is accomplished by simulating the effect of changes as a sequential process from the level of resource characteristics to population level response (Fig. 5.9). The simulation procedure is carried out by applying age-classified matrix models. Results and predictions will be published in detail elsewhere.

5.10. Sex specific variation in fluctuating asymmetry in muskoxen

Mads C. Forchhammer

The forces of natural and sexual selection act on the phenotype which in turn is the result of interactions between genotype and environment. Developmental stability, *i.e.* the ability of a genotype to control homeostasis in the development of a phenotype, is a simple measure of the efficiency by which a genotype is translated into a well-functional phenotype.

Disrupture of developmental homeostasis in phenotypes are recognised by deviations in bilaterally symmetrical traits, *i.e.* fluctuating asymmetry (FA). In a large range of organisms, FA has been found to correlate with a number of fitness related parameters, *i.e.* the lower FA the more fit a phenotype. In ungulates, the degree of FA in horns have proven to be a reliable one-dimensional fitness parameter describing phenotypic quality.

In muskoxen, both bulls and cows have well-developed horns and both sexes use these in intra- and interspecific interactions. This study analyses the variations of fluctuating asymmetry in the horn characteristics of muskox bulls and cows. In particular, the study focuses on [1] sex specific variation in FA, [2] the between population variations in FA related to environmental variation, and [3] the individual relationship between FA and fitness.

The first part of the study was carried out at Zackenberg and focused on whether selected muskox horn characteristics demonstrate directional asymmetry, antisymmetry or fluctuating asymmetry. Results from Zackenberg will be compared with data from other populations and published elsewhere.

Table 5.10. Summary of morphological horn characteristics of adult (8+ years) muskox bulls and cows. Horn length was measured from basis to tip following horn curvature, horn width was measured in a straight line from basis to horn tip, and basis height was measured from top to bottom of basis following basis curvature. Character size is the mean of right and left side. Absolute asymmetry is the unsigned right-minus-left side and relative asymmetry is the absolute symmetry divided by character size. Values (mean ±SD) are in cm except relative asymmetry which is dimensionless.

	Horn length	Horn width	Basis height
Males, sample size	25	25	30
Character size	57.5 3.6	36.7 3.4	25.3 2.5
Signed right-minus-left side	-1.0 3.4	-1.0 3.8	0.3 0.9
Absolute asymmetry	3.1 1.7	3.2 2.2	0.8 0.6
Relative asymmetry	0.05 0.03	0.09 0.06	0.03 0.02
Females, sample size	16	14	20
Character size	38.5 2.1	24.9 2.0	10.5 0.9
Signed right-minus-left side	0.3 2.6	-0.8 1.6	-0.1 0.4
Absolute asymmetry	1.7 1.9	1.3 1.2	0.3 0.2
Relative asymmetry	0.04 0.05	0.05 0.05	0.03 0.02

Three horn characteristics were recorded from muskox skulls located in Zackenbergdalen. Male horn length, horn width and basis height were significantly larger than those of females (Table 5.10; two sample t tests, $p < 0.001$). Since either absolute or relative asymmetry differed significantly from zero (one-sample t tests, $p > 0.10$), the three morphological characters demonstrated fluctuating asymmetry in both males and females (Table 5.10). Absolute asymmetry in horn length, horn width and basis height were significantly larger in males than in females (Mann-Whitney U tests, $p < 0.01$), whereas relative asymmetry only differed significantly between sexes in horn width (Table 5.10; $p < 0.05$). In both males and females only absolute asymmetry in basis height was found to differ significantly from absolute asymmetries in horn length and horn width, rspectively (Table 5.10; Bonferroni adjusted Mann-Whitney U tests, $p < 0.01$). No significant differences were found in relative asymmetries among characters in either sex (Table 5.10).

The data suggest that both natural and sexual selection act on the development of muskox horns. Muskox bulls use horns as a defence mechanism against predators as well as in agonistic intrasexual interactions. Since muskox cows select their mates (Forchhammer 1996), sexual selection is probably also involved in developing bull horn characteristics. In contrast, horn characteristics of muskox cows are probably a result of mainly natural selection through defence against predators and intraspecific competition for access to food. Additional planned field work will test these hypotheses as well as document the individual relationship between the dregree of FA and individual fitness.

5.11. Magnetometer recordings at Zackenberg

Vera Schlindwein

From 29 June to 24 July the Danish Polar Center operated a magnetometer at Zackenberg for the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany. The reference recordings at Zackenberg form part of an aeromagnetic mapping programme of Northeast Greenland (AEROMAG).

An aeromagnetic anomaly map reflects contrasting magnetic properties of crustal rocks and therefore can provide information on geological structures even in inaccessible areas. The total intensity of the magnetic field is recorded during survey flights. In order to determine the remanent and induced magnetic field in the Earth's crust, the internal and external components of the Earth's magnetic field have to be removed from the raw data. While the internal part is easily corrected, the external field needs to be recorded by a reference station at a fixed location.

This external field basically results from the interaction of the solar wind with the Earth's magnetic field. It varies quickly in time and space and, especially in polar regions close to the auroral belt, the amplitude of these temporal variations can be larger than the amplitude of the spatial anomalies produced by crustal rocks.

AEROMAG96 surveyed the area between 73°15'N and 78°15'N (Fig. 5.11.1) and closed the remaining data gap of earlier AEROMAG campaigns. Since Constable Pynt and Station Nord, as bases of operation, lie well outside the survey area, a proton precession magnetometer was installed at Zackenberg as reference station, continuously recording the temporal variations. Operation involved daily data dumps and checks of power supply from the solar panels. A second magnetometer at Constable Pynt was used to identify magnetically favourable survey times.

Apart from a few quiet days, most days during the survey showed disturbances of the order of 100 nT. Variations were generally smaller during day time.

Fig. 5.11.2 shows a typical 24 h plot of the temporal variations at Zackenberg compared with Constable Pynt. Both magnetograms are clearly related: disturbances occur simultaneously or with phase shifts; the frequency content in a given time window is similar. However, the shape of the curves may differ significantly, illustrating the spatial variability of the external field. This clearly demonstrates the necessity to install a reference station within the survey area.

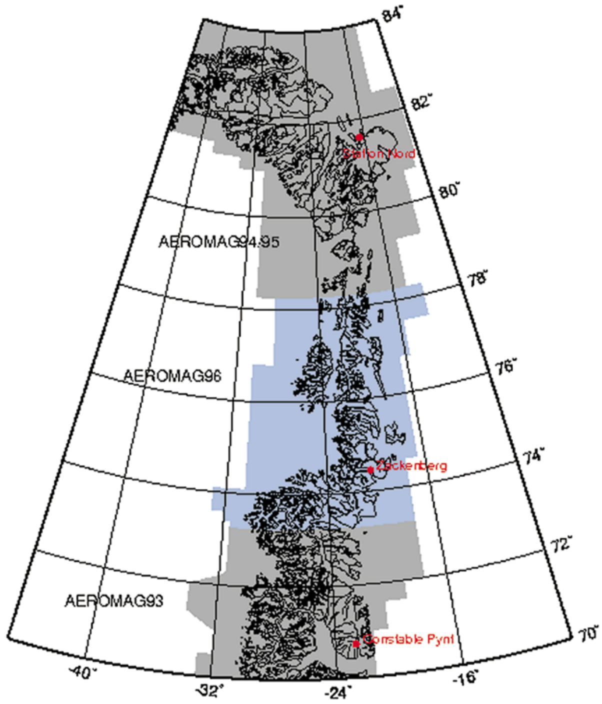

Fig. 5.11.1. Aeromagnetic survey areas and bases of operation in Northeast Greenland.

The long wavelength component (T > 30 min) of the Zackenberg data was used to correct the airborne survey data. The remaining misfit at flight line intersections due to imperfect removal of temporal variations was critically assessed. A sufficient accuracy for the compilation of a large scale aeromagnetic anomaly map could be achieved.

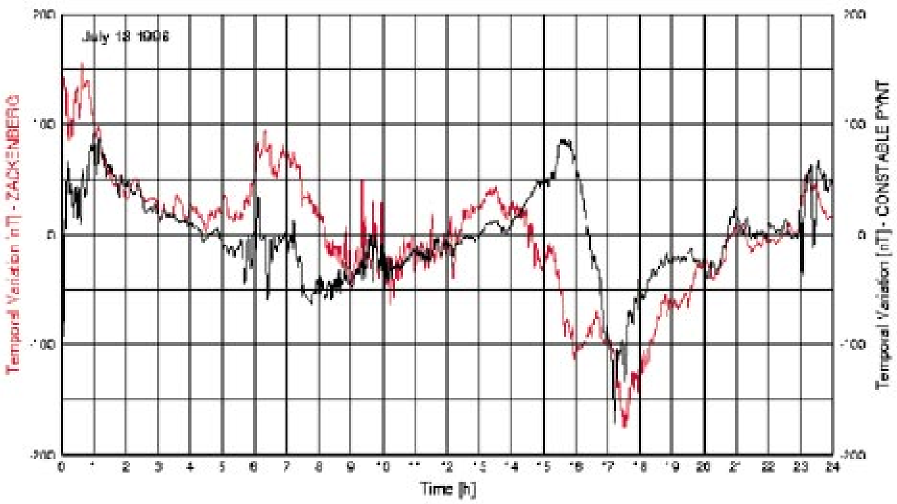

Fig. 5.11.2. Temporal variation of the Earth' magnetic field at Zackenberg compared to Constable Pynt.

6. Disturbance

Hans Meltofte

To enable future analysis of human impact on the study area at Zackenberg, records of different kinds of disturbance are presented. Details on regulations of traffic *etc.* are found in 'ZERO Site Manual. Guidelines for activities under Zackenberg Ecological Research Operations' available from the Danish Polar Center web home page at http://www.dpc.dk .

6.1. Surface activities in the study area

Table 6.1.1 presents the number of 'person-days' allocated to the different research zones in the Zackenberg study area (Fig. 6.1). A 'person-day' is one visit by one person in the zone. Only persons active in the field are included, *i.e.* personnel working on the station and its immediate surroundings are excluded. Zone 1b is a 'minimum impact' study area, while zone 1c is a protection zone for moulting pink-footed geese between 20 June and 10 August. Similar data for 1995 are presented in Table 6.1.2.

Table 6.1.1. 'Person-days' allocated to the research zones in the Zackenberg study area 1 June - 6 September 1996.

Research zone	June	July	August	September	Total
1	120	320	210	20	670
1b	8	12	22	8	50
1c (20.6-10.8)	0	5	3	–	8
2	9	8	8	0	25

Table 6.1.2. 'Person-days' allocated to the research zones in the Zackenberg study area 13 July - 30 August 1995.

Research zone	June	July	August	September	Total
1	–	60	170	–	230
1b	–	18	20	–	38
1c (20.6-10.8)	–	8	2	–	10
2	–	6	0	–	6

The most obvious effect of human presence in the study area was the reduction from 550 (1995) to 250 (1996) moulting pink-footed geese along the coast off Zackenbergdalen (see section 3.3.8). Actually, only the birds moulting off the 'minimum impact' study area (1b) remained.

Furthermore, barnacle goose families (*i.e.* flightless adults with goslings) had their feeding areas significantly reduced as compared to conditions prior to 1995 (see also Meltofte & Thing 1996).

Finally, it can not be excluded that human traffic in the area was responsible for the breeding failure of one or two pairs of red-throated divers in 1996 (see section 3.3.8).

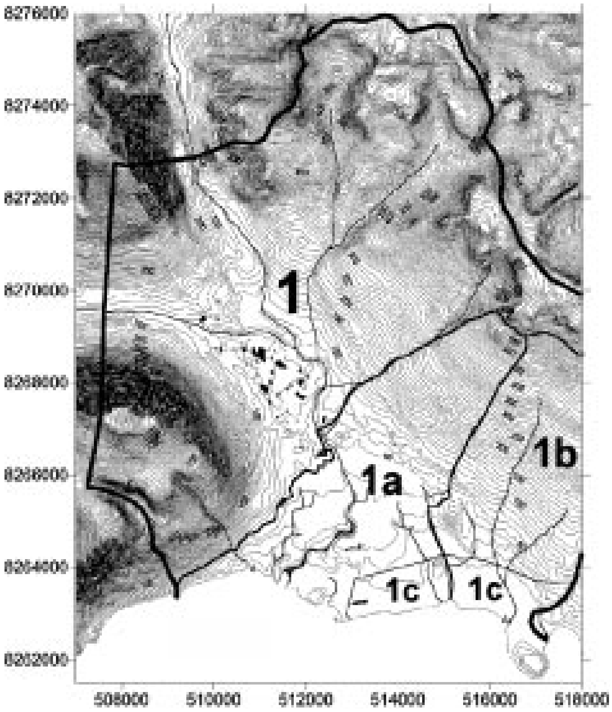

Fig.6.1. Research zone 1: Zackenberg core study area. Regulations and characteristics of the zone and its divisions are detailed on page 80 of this report.

6.2. Aircraft activities in the study area

The monthly numbers of aircraft flights over the study area at Zackenberg are presented in Table 6.2.1. One landing and take-off together with the approach and departure at low level are considered two flights. In August, 120 of the helicopter flights were sling-load roundtrips between the ship (anchored c. 1 km off the coast south of Lomsø) and the station. Similarly, flights in 1995 are presented in Table 6.2.2.

Table 6.2.1. Numbers of flights with fixed-wing aircraft and helicopter over the study area in Zackenbergdalen 1 June - 6 September 1996.

Type of aircraft	June	July	August	September	Total
Fixed-wing	26	21	15	4	66
Helicopter	2	7	126	0	135

Table 6.2.2. Numbers of flights with fixed-wing aircraft and helicopter over the study area in Zackenbergdalen 13 July - 30 August 1995.

Type of aircraft	June	July	August	September	Total
Fixed-wing	–	6	33	–	39
Helicopter	–	0	10	–	10

One clear effect of the flights was that four barnacle goose families left Lomsø because of the helicopter disturbance, and they were not seen again (see section 3.3.5). Furthermore, the flight activities may have contributed to the significant decline in numbers of moulting pink-footed geese along the coast off Zackenbergdalen (see sections 3.3.8 and 6.1).

Fig.6.2. A Hughes 500 helicopter transported 42 t of cargo from the ship to Zackenberg station in 120 sling-load flights at low level above the south part of Zackenberg-dalen. *Photo: Danish Polar Center / Henning Thing*

6.3. Discharges

During the 1996 field season untreated waste water from the kitchen, shower, sinks, and laundry machines were let into Zackenbergelven. The total amount equaled 1200 'person-days'. Combustible waste - excluding most plastic - was burnt on site. All other waste, incl. 'solid' toilet sewage, was flown out of the area or kept for later treatment. Entrails from a few hundred Arctic char were disposed of in the fjord off the old trapping station (see section 6.5).

Small amounts (< 0.005 l) of formaldehyde were lost in arthropod study plot no. 2, when traps were flooded (see section 4.2.1).

In 1995, untreated waste water and sewage from 320 'person-days' was let into Zackenbergelven. All combustible waste was burnt on site, while all other waste was flown out of the area. Entrails from a few hundred Arctic char were disposed of on the beach off the old trapping station, as has been done for many decades.

6.4. Manipulative research projects

In Elberling's seed dynamics study plot south of the Zackenberg station (UTM 512623 easting, 8264264 northing, zone 27) a total of c. 180 g N, 75 g P and 210 g K was added on 1 July (see section 5.3).

At the study plot, by Jonasson *et al.*, in Tørvekæret (UTM 513343 easting, 8265440 northing) a total of 15 g N and 3.75 g P was added in August. In a similar study plot just south of the station (UTM 512625 easting, 8264159 northing) a total of 22.5 g N and 4.86 g P was added, also in August (for both plots, see section 5.1.4.1).

An east-west running snow fence, 60 cm high and 5.5 m long, was erected southeast of the station (UTM 513059 easting, 8264062 northing) (see section 5.1.12).

6.5. Sampling of organisms

Except for the arthropod samples (see sections 4.2 and 5.4) no collection of organisms was undertaken. For local consumption at Daneborg and Zackenberg, a few hundred Arctic char *Salvelinus alpinus* were caught along the coast off the old trapping station. A similar harvest (*i.e.* 300-400) has been taken in late summer for several decades.

7. Economic investment in ZERO 1996

The three elements of ZERO, Research – Monitoring – Logistics, of course need a steady input of funding to secure optimal performance. Although the station as such will not become fully fledged until the summer of 1997, funding interests have already led to quite impressive grants in support of the station and its activities.

During the years 1991 - 1995 a total of 15,088,000 DKK were allocated to ZERO, distributed with 7,887,000 DKK to research, 2,820,000 DKK to monitoring and 4,381,000 DKK to logistics. In 1996, additional 9,866,000 DKK have been granted to activities within the ZERO framework. Specifically, 5,375,000 DKK were donated to research projects, 1,650,000 DKK supported monitoring, and 2,841,000 DKK covered logistics. Thus, by the end of 1996 the overall ZERO 'investment' has totalled 24,954,000 DKK.

Fig.7.1. Visiting the stone cairn at the summit of Zackenberg mountain. Tradition requires every visitor to add one more stone to the cairn.
Photo: Danish Polar Center / Henning Thing

8. Publications

8.1. Scientific papers

Hansen, E.S. 1996: Vertical Distribution of Lichens on the Mountain, Aucellabjerg, Northeastern Greenland. - Arctic and Alpine Research 28: 111-117.

Hasholt, B. 1996: Sediment transport in Greenland. - Erosion and Sediment Yield: Global and Regional Perspectives. IAHS Publ. no. 236: 105-114.

Rasch, M., Christiansen, H.H., Hansen, B.U., Hasholt, B., Humlum, O., Jakobsen, B.H. & Nielsen, N. 1996: Greenland landscape elements as indicators of rapid environmental change. Pp. 69-92 in Berger, A.R. & Iams, W.J. (eds.): Geoindicators. Assessing rapid environmental change in earth systems. - A.A. Balkema, Rotterdam/Brookfield.

Rysgaard, S., Finster, K. & Dahlgaard, H. 1996: Primary production, nutrient dynacics and mineralization in a northern Greenland fjord during the summer thaw. - Polar Biol. 16: 497-506.

8.2. Reports

Fredskild, B. (ed.) 1996: Grønlands Botaniske Undersøgelse 1995-1996. Rapport. - Botanisk Museum, 21 pp.

Meltofte, H. & Thing, H. (eds.) 1996: Zackenberg Ecological Research Operations. 1st Annual Report, 1995. - Danish Polar Center. Ministry of Research & Technology, 64 pp.

8.3. General information

Anon. 1996: Kiisami suliarilerpaat. Nu gør de noget ved det. Ny forskningsstation skal være basis for langsigtet økoforskning. - Atuagagdliutit/Grønlandsposten no. 30: 4.

Andreassen, J. 1996: En god gang gas. - Berlingske Tidende, 21 January 1996.

Andreassen, J. 1996: Forskere måler naturens kædereaktion. - Berlingske Tidende, 24 September 1996.

Christensen, T.R. 1996: Sumpgas, tundra og klima. - Naturens Verden 1996: 57-63.

Christiansen, H.H. 1996: News from Members. Denmark. - Frozen Ground 19: 5.

Groes-Petersen, H. 1996: Jagten på år nul. - Dagbladet Politiken, 4 August 1996.

Hansen, E.S. 1996: Zackenbergs laver. - Naturens Verden 1996: 15-19.

Kjærgaard, J.J. 1996: Fornemmelse for snedriver. - Berlingske Tidende, 17 December 1996.

Thing, H. 1996: Zackenberg år 1: Tag over hovedet. Zackenergip ukiua 1: Oqqiffissaqalerpoq. - Forskning i Grønland/tusaat 3/96: 4-9.

Thing, H. 1996: ZERO News # 6, April 1996. ZERO News #7, October 1996.

8.4. Supplementary list of publications

Born, E.W., Wiig, Ø. & Neve, P.B. 1995: Observations of Muskoxen (Ovibos moschatus) in Central East Greenland. - Z. Säugetierkunde 60: 373-379.

Dawes, P.R., Elander, M. & Ericson, M. 1986: The Wolf (Canis lupus) in Greenland: A Historical Review and Present Status. - Arctic 39: 119-132.

Forchhammer, M. & Boertmann, D. 1993: The muskoxen Ovibos moschatus in north and northeast Greenland: population trends and the influence of abiotic parameters on population dynamics. - Ecography 16: 299-308.

Hansen, E.S. 1982: Lichens from Central East Greenland. - Meddr Grønland, Biosci. 9. 33 pp.

9. Personnel

9.1. Research & Monitoring

9.1.1. Zackenberg

Thomas B. Berg, M.Sc., Danish Polar Center (BioBasic and lemming ecology, 19 June - 6 September)

Torben Røjle Christensen, Ph.D, Botanical Institute, University of Copenhagen (trace gas exchange, 4-12 August)

Hanne H. Christiansen, Ph.D., Institute of Geography, University of Copenhagen (periglacial geomorphology, 19 June - 2 August)

Bo Elberling, M.Sc., Institute of Geology, University of Aarhus (water chemistry and plant ecology, 19 June - 4 August)

Heidi Elberling, ca,d.scient., Ph.D. student, Department of Ecology and Genetics, Institute of Biological Sciences, University of Aarhus (plant ecology, 19 June - 12 August)

Mads C. Forchhammer, Ph.D., Department of Ecology and Genetics, University of Aarhus (muskox research, 4 August - 6 September)

Bent Fredskild, Ph.D., Botanical Museum, University of Copenhagen (lake corings, 15 July - 2 August)

Birger Ulf Hansen, Ph.D., Institute of Geography, University of Copenhagen (remote sensing, 15 July - 2 August)

Bent Hasholt, Ph.D., Institute of Geography, University of Copenhagen (water and sediment transport, 19 June - 10 July)

Ole Humlum, Ph.D., Danish Polar Center (GeoBasic, 19 June - 2 August)

Bjarne Holm Jakobsen, Ph.D., Institute of Geography, University of Copenhagen (lake corings, 15 July - 2 August)

Sven Jonasson, Professor, Ph.D., Botanical Institute, University of Copenhagen (trace gas exchange, 4-12 August)

Peter van der Keur, Ph.D. student, Institute of Geography, University of Copenhagen (water chemistry, 10-23 August)

Hans Meltofte, D.Sc., Danish Polar Center (station manager and BioBasic, 3 June - 6 September)

Anders Michelsen, Ph.D., Botanical Institute, University of Copenhagen (trace gas exchange and plant ecology, 4-12 August)

Niels Nielsen, Ph.D., Institute of Geography, University of Copenhagen (coastal geomorphology, 15 July - 2 August)

Claus Nordstrøm, Ph.D. student, Institute of Geography, University of Copenhagen (trace gas exchange, 19 June - 23 August)

Steen B. Pedersen, graduate student, Institute of Geography, University of Copenhagen (water and sediment transport, 19 June - 10 July)

Morten Rasch, Ph.D., Institute of Geography, University of Copenhagen (coastal geomorphology, 15 July - 2 August)

Jacob Simonsen, graduate student, Institute of Geography, University of Copenhagen (soil chemistry, 15 July - 10 August)

9.1.2. Daneborg

Peter B. Christensen, Ph.D., National Environmental Research Institute, Denmark (marine biology, 6-25 August)

Tage Dalsgaard, Ph.D, National Environmental Research Institute, Denmark (marine biology, 9-31 July)

Henrik Fossing, Ph.D., Max Planck Institute for Marine Microbiology (marine biology, 15-31 July)

Egon Frandsen, technician, National Environmental Research Institute, Denmark (marine biology 17 June - 10 July)

Ola Holby, Ph.D., Max Planck Institute for Marine Microbiology (marine biology, 9 July - 3 August)

Ronni N. Glud, Ph.D., Max Planck Institute for Marine Microbiology (marine biology, 9 July - 3 August)

Lars Lund-Hansen, Ph.D, Institute of Geology, University of Aarhus (marine oceanography, 17 June - 10 July)

Niels P. Revsbech, D.Sc., Institute of Biological Sciences, University of Aarhus (marine biology, 9-25 August)

Nils Risgaard-Petersen, Ph.D, Institute of Biological Sciences, University of Aarhus (marine biology, 18 June - 4 August)

Søren Rysgaard, Ph.D., National Environmental Research Institute, Denmark (marine biology, 18 June - 25 August)

Bo Thamdrup, Ph.D., Max Planck Institute for Marine Microbiology (marine biology, 10 July - 3 August)

9.2. Logistics and construction, Zackenberg

Aksel Andersen, Venslev Cabins (construction, 10 August - 6 September)

Hauge Andersson, Danish Polar Center (logistician, 22 August - 6 September)

Tine Gad, Danish Polar Center (station assistant, 2-29 July)

Steen B. Jensen, Danish Polar Center (station assistant, 1 June - 2 July)

Kjeld Johnsen, Venslev Cabins (construction, 10 August - 6 September)

Bo Knudsen, Venslev Cabins (construction, 10 August - 6 September)

Henrik Lassen, Danish Polar Center (logistician, 1 June - 27 August)

Kresten Mathiasen, Danish Polar Center (station assistant, 4 August - 6 September)

Inger Meltofte, Danish Polar Center (cook, 3 June - 6 September)

Martin Pedersen, Venslev Cabins (construction, 10 August - 6 September)

Bent Sørensen, Asiaq (electronics technician, 4-12 August)

9.3. Other, Zackenberg

Dennis Carter (in transit, 7-20 June)

Ulf Marquard-Petersen (in transit, 9-16 June)

Henrik Groes Petersen, Dagbladet Politiken (journalist, 2-15 July)

Henning Thing, Ph.D., Danish Polar Center (supervision of ZERO, 10-23 August)

Steen Yssing, Danish Broadcasting Corporation (journalist, 11-19 August)

Peter Watt, Danish Broadcasting Corporation (photographer, 11-19 August)

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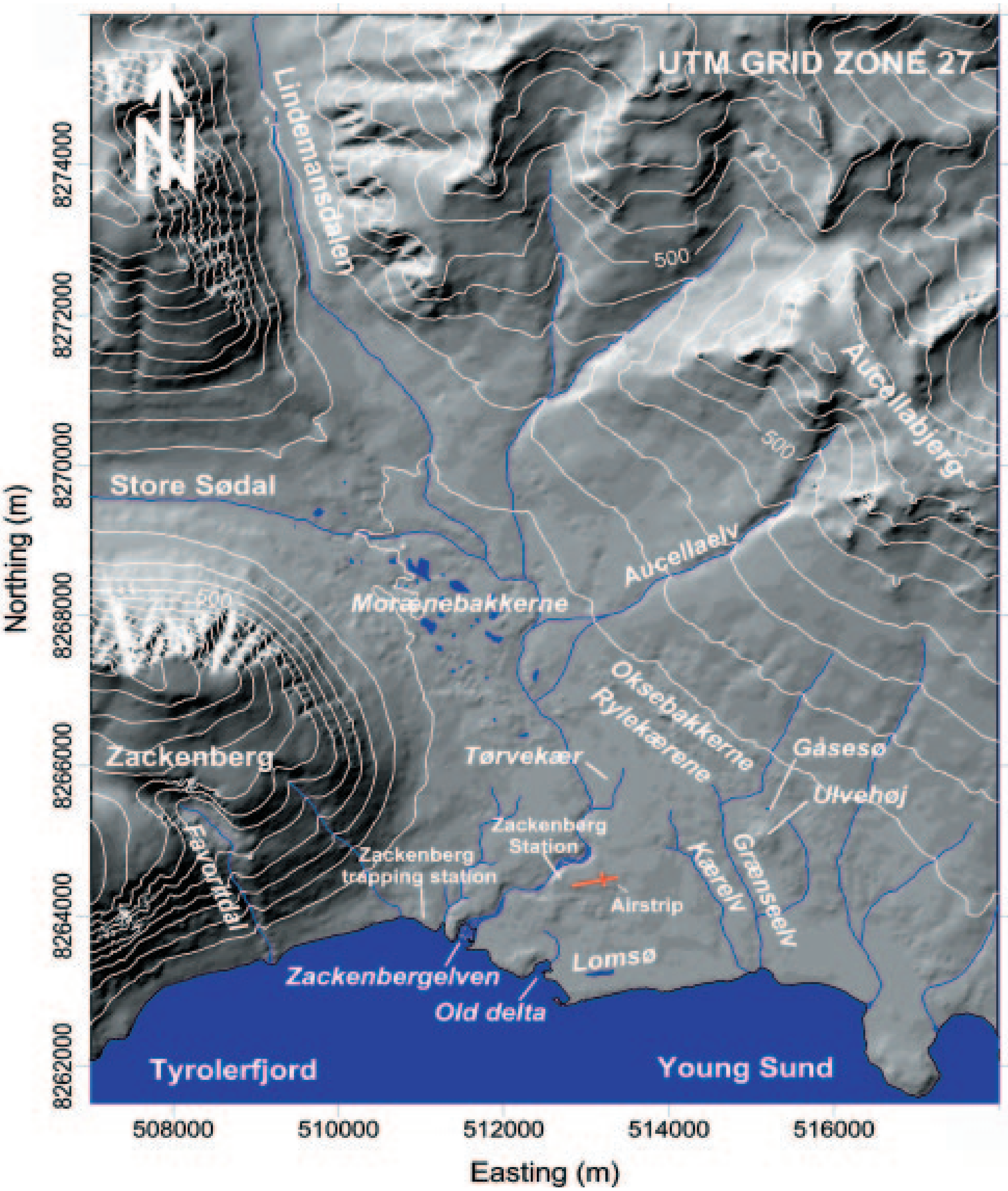
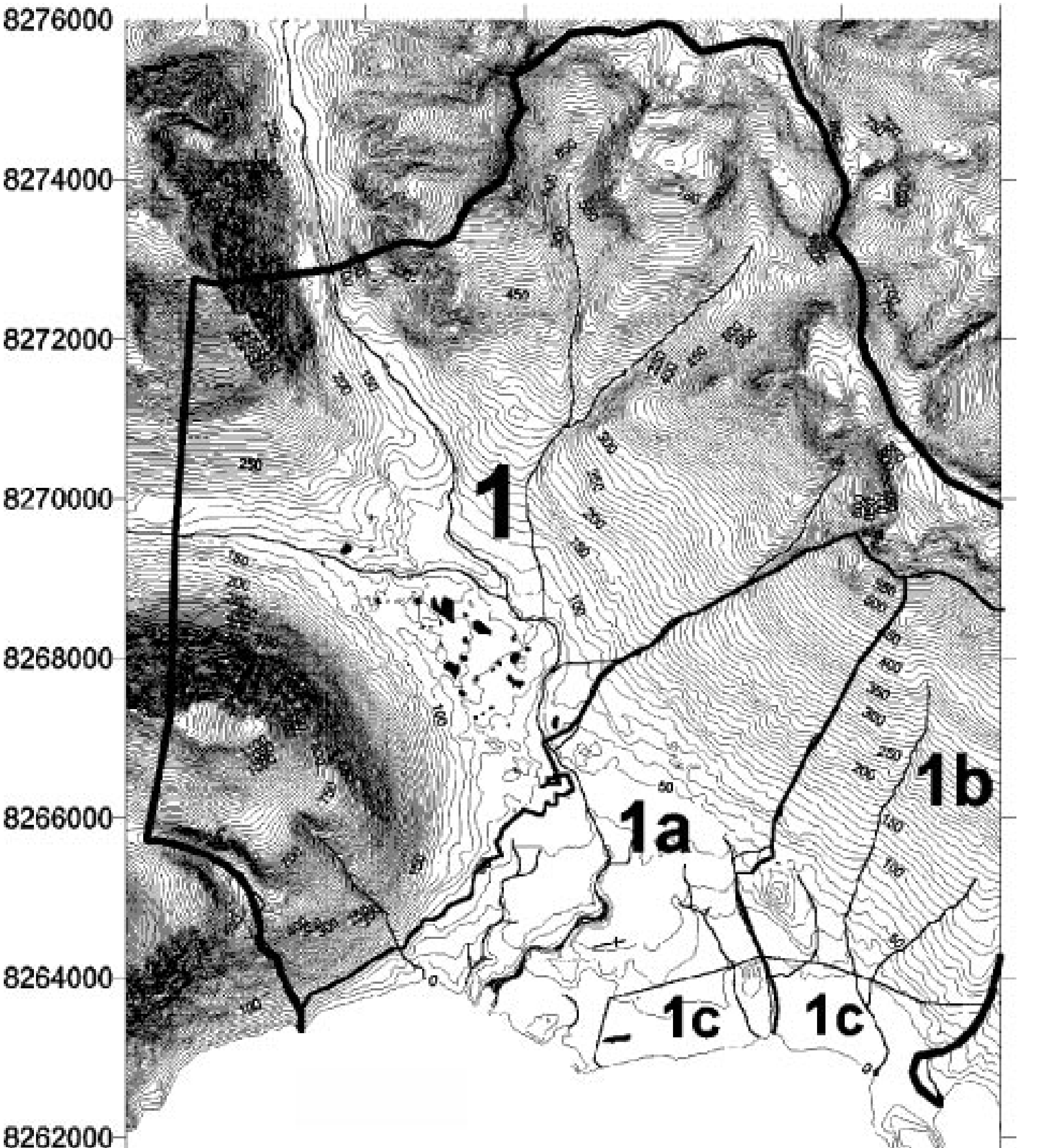
A ZERO researcher heading into the future to discover more details on the dynamics of the High Arctic ecosystem.

Photo: Aurora / Thomas B. Berg



APPENDIX 1

The core of Zackenberg study area with locality names mentioned in this annual report. All unofficial place names are given in italic.



APPENDIX 2

***Research Zone 1** and its divisions. The core of Zackenberg study area is partitioned as follows:*

***Zone 1a** is the core area for monitoring and research projects. In this zone a number of transportation corridors (e.g. pathways or boardwalks marked with green-topped nylon sticks) are staked out to concentrate general surface traffic to the least fragile habitats.*
***Zone 1b** is set aside as a 'minimum impact' study area. This implies that only a minimum of activities will be permitted here and that research can take place only following approval.* Ad hoc *access by individuals may be granted by the station manager.*
***Zone 1c** is a waterfowl protection area. Several hundreds of geese moult in the lowlands adjacent to the coastline. During the 50 days moulting season the geese are extremely sensitive to disturbance. In order not to scare off the geese permanently and thereby altering significantly the grazing regime of the coastal meadows, access to zone 1c is prohibited between 20 June and 10 August. Proposed research in zone 1c requiring access during the critical period must be approved before the field season.*