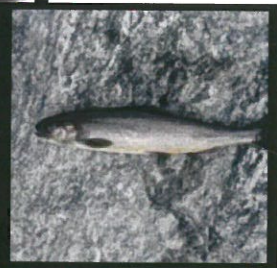


# Arctic Biology Field Course Qeqertarsuaq 2004



University of Copenhagen

**Title:** Arctic Biology Field Course Qeqertarsuaq 2004

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## Preface

The Arctic Field Course 2004 was organized by the Biological Institute, University of Copenhagen and carried out between 12 July and 5 August at the Arctic Station, Qeqertarsuaq, Disko, West Greenland.

Among many qualified applicants, twelve students from the University of Copenhagen, who had all successfully participated in the courses Arctic Biology and Polar Biology, were chosen to carry out their proposed field projects.

The students worked in four teams with quite different subjects including colony attendance of Black Guillemots, freshwater Arctic charr responses to climate changes, plant-insect interactions and feeding biology of a seed bug. The teams were supervised by Marianne Philipp (population biology), Kirsten Christoffersen (freshwater ecology) and Mads C. Forchhammer (population biology), who are all members of the permanent staff of the Biological Institute at the University of Copenhagen. In addition, three other groups of students were associated with the course through ongoing research projects. These were a comparative study of Alpine-Arctic plant communities (supervised by M. Philipp), a limnological survey of lakes and ponds in the area (supervised by K. Christoffersen) and a population study of the endemic White-fronted Goose and the invasive Canada Goose (supervised by David Boertmann (National Environmental Research Institute) and Jens Nyeland Kristiansen (Greenland nature Institute)). This report presents the results from all these projects.

During the four weeks of studying, we were situated in West Greenland and conducted many activities, which were sometimes challenging but still must be regarded as successful. A written and illustrated account of our trials and tribulations can be found in the diary, which is situated in the last part of the report.

For a comprehensive introduction to the Arctic Station, please consult the homepage <http://www.nat.ku.dk/as/>. For further information about the Arctic Field Course 2004, please visit the homepage [http://www.fbl.ku.dk/kchristoffersen/arktisk\\_kursus/arktisk\\_feltkursus.htm](http://www.fbl.ku.dk/kchristoffersen/arktisk_kursus/arktisk_feltkursus.htm).

## Acknowledgements

We wish to acknowledge the staff at the Arctic Station; Rasmus Ejrnæs and Kjeld Mølgård as well as Frederik Grønvold and his crew at Porsild. They have been very helpful and shared their profound knowledge about the Arctic environment and local matters. Gitte Henriksen from the Arctic Station Secretariat in Copenhagen assisted in logistic aspects and Jens Laursen from the Municipality Office in Qeqertarsuaq offered time to introduce us to the environmental problems in an Arctic society. We are also thankful for the support and assistance from the logistic managers at Kangerlussuaq International Support Center.

A special thanks go to our kind and helpful supervisors Kirsten Christoffersen, Mads C. Forchhammer and Marianne Phillip for excellent guidance and for creating a good atmosphere during the course. Also thanks to David Boertmann and Sten Asbirk (Danish Forest and Nature Agency) who inspired and co-supervised the Black Guillemot project.

We wish to extend our sincere thanks to the Faculty of Science for covering travel expenses, lodging and local transportation for twelve students. Substantial support was given by the Oticon foundation, His Royal Highness Prince Frederik's Foundation (the Goose project), Ing. Svend G. Fiedler and Vife's grant, Carlsberg memorial grant for Brewer J. C. Jacobsen, the Nuna Foundation and WWF Denmark – Biodiversity grant (the comparative plant community study). Thanks to the Arctic Station Board for financing the print of the report.

The Citizens from the local community kindly invited us to their homes to share "Kaffemik" and to let us see their skills in craftwork. We are indeed thankful for the overwhelming hospitality and kindness of the people, not only in Qeqertarsuaq, but also in all other places we visited during our stay.

On behalf of all the participants

Anne-Mette Hoeg Andersen, Thomas Rohde Jørgensen & Katrine Rahe

Copenhagen, March 2005

## Participants in Arctic Biology Field course 2004



1: Mads C. Forchhammer; 2: Signe Sveegaard; 3: Rasmus K. Larsen; 4: Thomas B. Klinggaard; 5: Pablo Tejero ; 6: Jesus Villellas ; 7 : Kirsten Christoffersen; 8: Thomas R. Jørgensen; 9: Christina Løjtnant; 10: Marianne Philipp; 11: Louise H. Krøjgaard; 12: Aida Cuni; 13: Linnea H. Fosdal; 14: Anne-Mette H. Andersen; 15: Kathrine Rahe; 16: Majken Sønderholm; 17: Maria Moltesen; 18: Jonas Thormar; 19: David M. Kristensen; 20: Mikkel B. Randløv; 21: Rune Bille Hansen.

## Spatial and Temporal dynamics of Black Guillemots *Cephus grylle* in West Greenland: Censusing colony attendance<sup>1</sup>

Anne-Mette Høeg Andersen, Katrine Rahe & Signe Sveegaard

Colony attendance of Black Guillemots (*Cephus grylle*) was studied at a colony on Skarvø in West Greenland. Observations were conducted in the post hatching period by scan sampling birds in the colony every 30 minutes. The rhythm of colony attendance varied diurnally, peaking in the early morning and late evening. The latter is the time of day with least variation between observations days. We divided the area at and around the colony in five sections and found large variations in both attendance and dynamics within and between them. Several factors affect these variations, the most important being time of day. Julian date and wind also had an effect. Results showed that the optimal census time in the post-hatching period is during the evening peak from 2000-2330. We do not recommend the use of correction factors at other hours. Due to the locality of the colony, undisturbed counts are to be recommended in preference to disturbed counts from a boat. Considerations about census time and weather conditions in combination with intensive preliminary studies are crucial factors affecting the accuracy of counts.

**Keywords:** Black guillemots, *Cephus grylle*, colony attendance, optimal census time, spatial and temporal dynamics, West Greenland.

### Introduction

Populations of seabirds are vulnerable to human influences such as hunting, collecting of eggs, fishing, boat disturbance and coastal pollution (Asbirk, 1979b; Cairns, 1980; Ewins, 1985; Barret *et al.*, 1987; Ronconi & St. Clair, 2002). Seabirds are centrally involved in complex interactions in marine food webs (Harris & Birkhead, 1985) and so; fluctuations in prey distribution and abundance evoke several behavioural and biological responses by the birds. Seabirds can thereby indicate changes in marine prey stocks (Montevicchi, 1993).

Recently, populations of seabirds in Greenland have received a lot of attention because of the documented decline in bird population numbers (Hansen, 2001), and because of the progressing search for oil in the sea next to the Greenlandic west coast, which may affect colonies in the area (Mosbech & Boertmann, 1995). Black Guillemots (*Cephus grylle*) are especially vulnerable to human influences, because they are essentially resident (Ewins, 1985) and prefer coastal areas (Tucker & Heath, 1994).<sup>1</sup> The Home Rule of

Greenland has passed a law<sup>2</sup> that prohibits approaching of Black Guillemot breeding colonies within 200 metres.

Developing reliable census methods is a high priority for the conservation of bird species. Accurately censusing of Black Guillemots is extremely difficult (Diamond, 1996). Thus, visual counts are more useful as indices of year-to-year population changes than as indicators of true colony size (Cairns, 1979). However, intensive studies of variation in colony attendance of adult birds from each colony are necessary, because colonies show different attendance patterns (Ewins, 1985). The census method for Black Guillemots, recommended by most authors, is to count birds displaying in pairs on the sea, early in calm mornings pre-breeding (Diamond, 1996). Depending on the position and logistics of the colony, undisturbed counts from a hide are recommended (Cairns, 1979; Petersen, 1981) as well as disturbed counts made from a boat or from land (Ewins, 1985; Hildén, 1994).

Counting populations of auks is particularly critical, because of the inaccessibility of the nests,

<sup>1</sup> This publication is based on an article to be submitted to Wildlife Biology.

<sup>2</sup> Hjemmestyrets bekendtgørelse nr. 1 af 21. januar 2004, § 8.



which are often concealed in crevices in talus that might be many meters deep (Cairns, 1979; Petersen, 1981).

When monitoring populations of colonial sea birds in Greenland the method frequently used consists in counting the birds visible at the surface of the colony area (Boertmann pers. comm., 2003). This is mainly because of the practical difficulties associated with counting the accurate number of breeding pairs or detecting the nest sites directly but also because time and manpower of survey teams often are limited. Several studies of colony attendance (i.e. number of birds visible at and around the colony) in various species of sea birds have shown, that great variation often occur in the relationship between the number of birds visible at the surface of the colony area and the actual number of breeding birds in the colony (e.g. Cairns, 1979; Slater, 1980; Petersen, 1981; Ewins, 1985; Jones, 1992; Hildén, 1994; Murphy & Schauer, 1994; Diamond, 1996). For each colony, the number of birds attending the colony area is likely to fluctuate greatly both seasonally and diurnally or in response to different weather conditions or food availability. When monitoring populations of Black Guillemots, the accuracy of counts is further complicated, because the birds often breed sparsely and young non-breeders, which are not easily distinguished from adults, often mingle freely with the breeders (Petersen, 1981).

Several studies focusing on colony attendance of Black Guillemot in Europe and North America have been published including oceanic coasts of Finland (Suomalainen, 1939; Koskimies, 1949; Hildén, 1994), Shetland (Slater & Slater, 1972; Ewins, 1985), Denmark (Asbirk, 1979a), Canada (Cairns, 1979) and Iceland (Petersen, 1981) but no such studies have ever focused on colonies in Greenland.

This study was carried out on a colony of Black Guillemots (*Cephus grylle arcticus*)<sup>3</sup> in Killiit (Fortunebay) in western Greenland. Researchers from NERI (National Environmental Research Institute) in Denmark conducted a previous count of the colony at 0800 local time on 25 July 2001, estimating 190 birds (Boertmann pers. comm., 2003). NERI designated the colony code number 69097 (Boertmann *et al.*, 1996). The count was

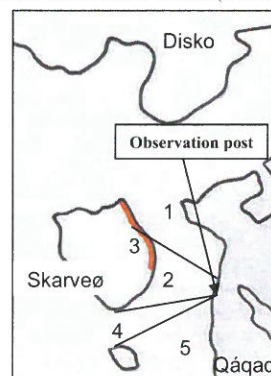
made from a boat passing by the colony disturbing the birds and scanning the ones visible at the sea in front of the nesting area. This count was not corrected for daily or seasonal variation in colony attendance.

The aim of this study was to examine colony attendance of Black Guillemots at the nesting area and factors influencing their attendance pattern in order to work out a reliable method for censusing the colony.

## Study Area and Methods

### Study area

The colony is located on an island, called Skarveø (Appendix 1, Fig. 2a), (69°15'N, 53°46'W) in Killiit (Fortunebay) northwest of Qeqertarsuaq (Godhavn) on Disko Island, West Greenland. The colony is about 200 m. wide and situated on a steep cliff. The lower parts are primarily made of rocks, which are very suitable for Black Guillemot nests. The upper part of the island is grass slope. We observed birds flying to their nests in both the rocky and grass part of the island, but the conditions of the island make it difficult to differentiate one nest from another (Appendix 1, Fig. 2b). The colony on Skarveø is facing southeast and presents good conditions for the Black Guillemot: Predators are limited to a few Greater Black-backed Gulls (*Larus marinus*)



**Figure 1** Sketch map of the colony and surrounding areas. The five areas around the colony (1-5) and the observation post are marked. Red marks the colony. (Drawing: S. Sveegaard).

and some Iceland Gulls (*Larus glaucoideus*). The Black Guillemots were only harassed by the presence of seagulls on very few occasions. There are other colonies nearby and shallow water between the islands just in front of the colony, which indicate that food availability is high.

We observed Great Cormorant (*Phalacrocorax carbo*), Common Eider (*Somateria mollissima*) and Northern Fulmar (*Fulmarus glacialis*) around the colony as well.

### Data collection

Our study was conducted between 22 July and 3 August. This is the post hatching period, in which the birds are nestling their young. We chose to observe the colony from a nearby island, Qaqaaq, approximately 150 meters from the colony. The birds were not disturbed by our presence. Due to the midnight sun it was possible to make observations throughout the night.

We divided the area on and around the colony into five smaller areas (Fig. 1). This was done to get a better distinction between the birds in the colony on land (area 3), in the immediate vicinity of it on the water (area 1-2) and the birds further away (area 4-5). All birds visible within an area were counted including the ones flying.

We censused the birds by scan sampling with a 30-minute interval conducted by two observers using binoculars (8x35). We counted the birds beginning in area 1 at exactly the same time and continued through all five areas. Each scan took from 2-5 minutes. Altogether we conducted 240 counts (for details see Appendix 1, Table 2), equally divided across the day (48 counts from 0000 to 2330), i.e. five counts for each time of censusing.

Every second hour we shifted observer, so that one observer continued to count but this time with another second observer. All in all we were three observers, who each counted for four hours, followed by a two-hour break, throughout each period of observation.

To minimize between-observer differences we conducted preliminary studies in Denmark (Sejro) on 30 May and 31 May. This was done to familiarize observers with the methods of counting and the behaviour of the Black Guillemots. After arrival in Qeqertarsuaq we conducted further preliminary counts of the colony on 20 July. Statistical testing of between-observer reliability shows no significant difference ( $F_{2,138}=0.017$ ,  $P=0.984$ ).

We measured the wind force and direction. From 22-24 July we measured every fourth hour and from 26 July and forward every second hour. Following each scan we noted whether or not sun was shining directly on the colony and whether or not we observed birds carrying fish in their beak.

Ewins (1985) found no effect of tide on colony attendance. Thus, we did not include tide in our study. Measurements of temperature were not included.

From 27 July the level of flight (0, 1, 2) at the colony was determined. The observations were made to give an indication of when the birds are most active and hence, more difficult to count. Each observer made an estimate in connection with each scan: (0) few birds flying, (1) some flight, but the birds are still easily counted and (2) many birds flying, making them difficult to count.

We compared undisturbed counts with disturbed counts by counting the Black Guillemots every five minutes after a boat had disturbed the colony. The disturbance flushed the birds away from the colony and we continued counting until the number of birds was back to the original size.

On one occasion (24 July at 1230) we took digital photos in connection with a scan to see if this method of counting gave similar results to the counts made by the observers.

## Results

### Daily attendance

The number of Black Guillemots attending the colony varies significantly during the day (ANOVA:  $F_{47,192}=4.864$ ,  $P=0.000$ ). Peak attendance occurs in the morning at 0730 with an average of 235 birds visible at the colony (see Fig. 2). A slightly smaller evening peak occurs at 2130 with 217 birds attending. Minimum counts are at 1530 when the number of visible birds has dropped to a fourth of peak attendance.

**Table 1.** Variation in hourly counts of Black Guillemots grouped in four-hour blocks. SD = Standard Deviation. CV = Coefficient of Variation = SD/mean

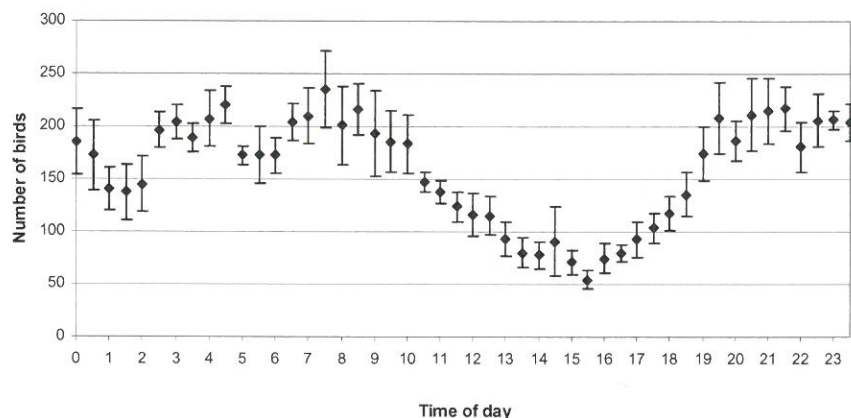
Time	Mean	SD	CV
0000 - 0330	171.30	26.74	0.16
0400 - 0730	199.28	23.95	0.12
0800 - 1130	173.54	32.99	0.19
1200 - 1530	87.46	21.16	0.24
1600 - 1930	123.25	47.17	0.38
2000 - 2330	203.41	13.04	0.06

<sup>3</sup> For a general description of taxonomy and biology of the Black Guillemot see Appendix 1.



In order to find the time of day best suited for

( $F_{47,192}=3.018$ ,  $P=0.000$ ), area 2 ( $F_{47,192}=1.681$ ,



**Figure 2.** Numbers of Black Guillemots attending the colony. Vertical bars show  $\pm 1$  standard errors calculated across five censusing days (range: 29-322 birds).

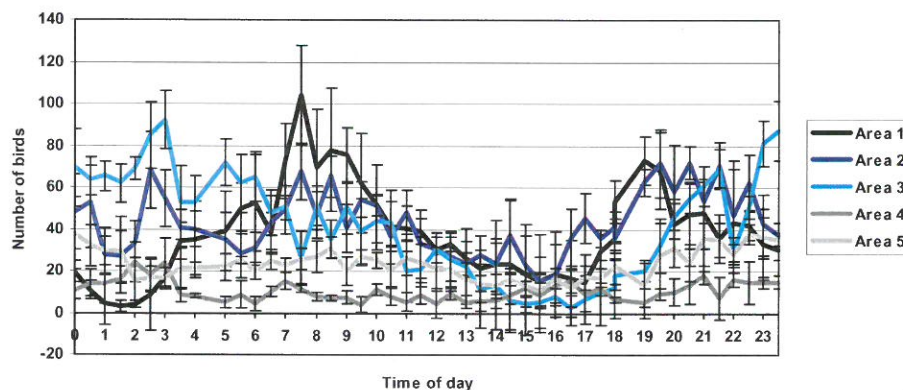
censusing the Black Guillemot, i.e. many birds visible and little variation between days, we grouped all counts into blocks of four hours. We calculated mean, standard deviation (SD) and coefficient of variation (CV) for each block (see Table 1). The results show that the period with highest mean number and least variation is in the late evening between 2000 and 2330 or, secondly, in the early morning from 0400 to 0730.

#### Area distribution

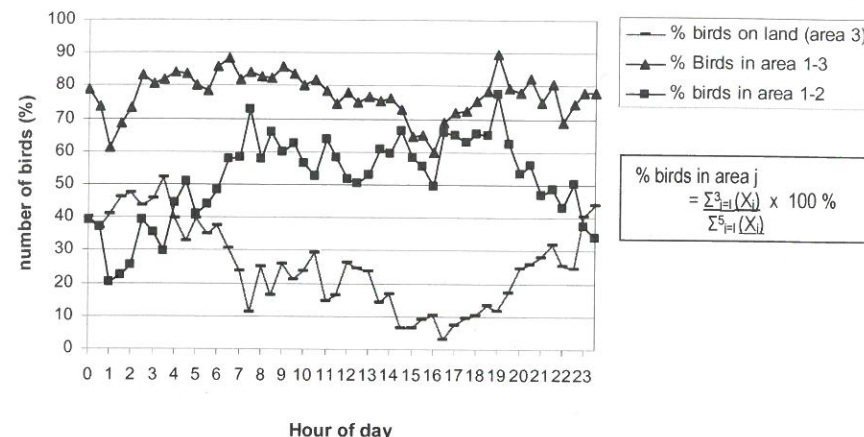
Daily distribution of birds in the five areas can be seen in Fig. 3. The number of visible birds varies significantly during the day in area 1

( $P=0.008$ ) and area 3 ( $F_{47,192}=9.669$ ,  $P=0.000$ ). In Area 4 ( $F_{47,192}=1.050$ ,  $P=0.398$ ) and 5 ( $F_{47,192}=1.060$ ,  $P=0.383$ ) it does not. The number of birds in each of the five areas is significantly different from each other ( $F_{4,1194}=73.950$ ,  $P=0.000$ ).

CV was calculated for each area. Area 1 (Mean=22.12, CV=0.59) and 3 (Mean=25.29, CV=0.61) have the highest mean number of birds, whereas area 4 (Mean=4.84, CV=0.46) and 5 (Mean=7.33, CV=0.31) have the lowest mean number. Since area 4 and 5 are situated furthest away from the colony our results show that the Black Guillemots mainly stay closer to the



**Figure 3** Daily distribution of birds in area 1-5. Each value represents an average of the five censuses at the time of day. Vertical bars show standard errors between the five censusing days



**Figure 4** Numbers of Black Guillemots attending the colony converted into percentages. 100 % represents the total number of birds in all five areas.  $j$ =average number of birds in an area.

colony. Area 2 (Mean=15.06, CV=0.35) and area 5 have the lowest variations and area 1 and 3 the highest, which indicates that the numbers of birds in area 2 and 5 remains fairly stable at all times.

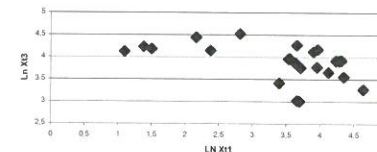
To obtain a clearer picture of how the Black Guillemots are distributed in the areas at the colony (area 1-3) and further away (area 4-5) we converted the counts into percentage of total number of visible birds (see Fig. 4). The results show that at any hour of day at least 60 percent of the visible birds will be located in area 1-3. If we exclude a few counts around 0100 and 1600 this proportion of birds in area 1-3 will raise to at least 70 percent. Fig. 4 also shows that percentage birds on land (area 3) are inverse proportional to percentage birds in area 1 and 2, i.e. if many birds are located on land, few will be on the water in area 1 and 2 and vice versa. We examined the correlation on original data at different times in the three areas and found threshold dependence between area 1 and 3 from 0030-1200. I.e. when number of birds on respectively land or water reaches a certain threshold it declines steeply, see Fig. 5.

Autoregressive analyses of counts in area 1, 2 and 3, respectively, showed a clear temporal correlation between each count and the previous count. Calculated correlation factors for area 1, 2 and 3 (see Fig. 6) all show a clear positive

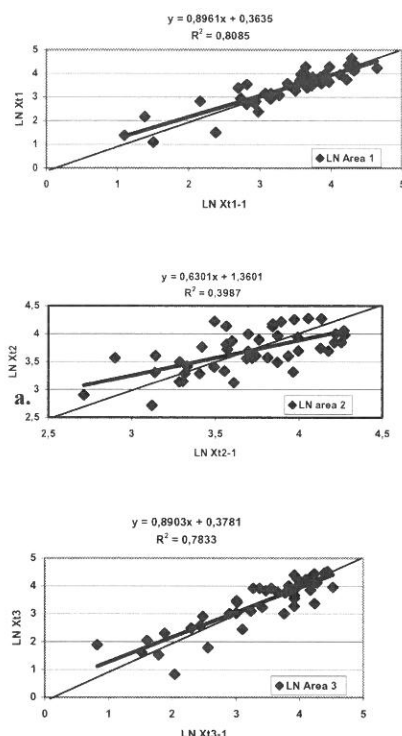
correlation (area 1,  $r=0.899$ , area 2,  $r=0.631$  and area 3,  $r=0.885$ ). Areas 1 and 3 have an especially high level of correlation, which indicates, that counts in these areas are particular dependent on the previous counts. The slope of the regression line estimated from data of area 2 ( $\alpha=0.630\pm0.117$ ) was compared to  $\alpha=1.00$ , which demonstrated that the slope was significantly smaller than one, i.e. the temporal dynamics of birds in area 2 displayed negative density dependence. Thus, when many birds are present in this area, the high number will have a suppressive effect on the number of birds observed in the following count. This is not the case in area 1 ( $0.8961\pm0.066$ ) and in area 3 ( $0.8903\pm0.071$ ). Hence, there is no density dependence in these two areas.

#### Behaviour

Level of flight was estimated after each count



**Figure 5** Correlation between birds in area 3 (on land) and in area 1 from 0030-1200 shows threshold dependence. Data are logarithmically transformed.



**Figure 6** Autoregressive analysis of area 1(a), area 2(b) and area 3 (c). The regression line shows the correlation between one count ( $X_t$ ) and the previous count ( $X_{t-1}$ ). Data are logarithmically transformed.

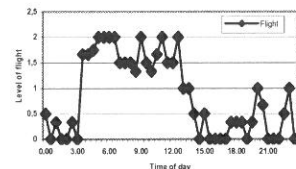
and results are presented in Fig. 7. It can be seen that the birds showed the highest level of flight between 0300 and 1300 and the lowest at 0000-0300 and 1500-2000.

We observed birds carrying fish in their beak throughout our period of observation from 22 July to 3 August.

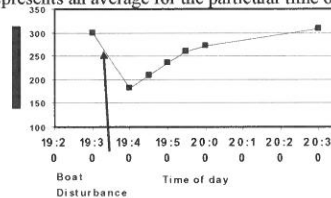
#### Methods for censusing

Following a boat disturbance a large proportion of the birds would take off and only slowly return. Counts made before and after a boat disturbance on 23 July at 1935 are shown in Fig. 8 and show that number of birds immediately decline by almost fifty percent. After this the birds slowly return and after one hour at 2030 the attendance is back to its original size. Thus censusing the birds at this colony by disturbed counts will produce a lower number than by non-disturbed counts.

Digital photo count compared with observer count was remarkably similar, see Table 2.



**Figure 7** Diurnal level of flight (0, 1, 2). Each value represents an average for the particular time of censusing.



**Figure 8** Numbers of Black Guillemots attending the colony following a boat disturbance on 23 July at 1935.

**Table 2** Comparison of digital photo count and observer count.

Digital photo count	Observer count (n=2)
111	109.5

#### Multiple regression analysis

Since data (Fig. 2) are non-linear we have divided the day in two: morning (0000-1530) and evening (1600-2330) and conducted General Linear Model (GLM) analysis stepwise. Results are shown in Table 3.

From the Whole colony (area 1-5) and area 2-5,

individually, it can be seen that Time of day is the overall most important factor. In the morning the coefficients are negative, i.e. the later in the afternoon, the fewer birds will be visible. In the evening the coefficients are positive, i.e. the later in the evening, the more birds will be visible.

In the Whole colony and in areas 1, 3 and 4

**Table 3** Results of GLM. Significant coefficients and total  $R^2$  are highlighted. Dependant variable = number of birds, independent variables: day (Julian date), Time of day (0.5 hours), wind direction (SE, S, N, NW). Categorical: 1=SE, 2=S, 3=N, 4=NW, wind speed

Area	Variables	Morning (0000-1530)		Evening (1600-2330)	
		Coefficient $\pm$ S.E.	$R^2$	Coefficient $\pm$ S.E.	$R^2$
<b>Whole colony</b>	<b>Total <math>R^2</math></b>		<b>0.36</b>		<b>0.51</b>
<b>(1-5)</b>	<b>Day</b>	<b><math>6.80 \pm 1.52</math></b>	0.09	$3.75 \pm 2.23$	
	<b>Time of day</b>	<b><math>-6.69 \pm 1.26</math></b>	0.22	<b><math>22.53 \pm 2.76</math></b>	0.45
	<b>Wind direction</b>	<b><math>-15.13 \pm 2.54</math></b>	0.03	$-10.34 \pm 7.47$	
	<b>Wind speed</b>	$-3.778 \pm 2.54$	0.02	$-0.57 \pm 3.76$	
	<b>Sun</b>	$14.61 \pm 12.55$		<b><math>43.79 \pm 21.44</math></b>	0.04
<b>1</b>	<b>Total <math>R^2</math></b>		<b>0.21</b>		<b>0.05</b>
	<b>Day</b>	<b><math>5.35 \pm 0.95</math></b>	0.14	$0.62 \pm 1.38$	
	<b>Time of day</b>	$0.69 \pm 0.78$		$2.93 \pm 1.71$	
	<b>Wind direction</b>	<b><math>-9.02 \pm 2.88</math></b>	0.04	$-5.89 \pm 4.63$	
	<b>Wind speed</b>	$-0.50 \pm 1.58$		$1.59 \pm 2.33$	
	<b>Sun</b>	$9.89 \pm 7.83$	0.03	$22.76 \pm 13.30$	
<b>2</b>	<b>Total <math>R^2</math></b>		<b>0.10</b>		<b>0.09</b>
	<b>Day</b>	$0.53 \pm 0.73$		$0.87 \pm 1.20$	
	<b>Time of day</b>	$-0.62 \pm 0.61$	0.01	<b><math>3.44 \pm 1.49</math></b>	0.07
	<b>Wind direction</b>	$-2.41 \pm 2.23$		$-0.39 \pm 4.04$	
	<b>Wind speed</b>	<b><math>-3.65 \pm 1.22</math></b>	0.08	$0.36 \pm 2.03$	
	<b>Sun</b>	$-0.95 \pm 6.05$		$8.55 \pm 11.59$	
<b>3</b>	<b>Total <math>R^2</math></b>		<b>0.61</b>		<b>0.69</b>
	<b>Day</b>	<b><math>2.51 \pm 0.56</math></b>	0.06	<b><math>3.36 \pm 0.86</math></b>	0.07
	<b>Time of day</b>	<b><math>-4.70 \pm 0.46</math></b>	0.55	<b><math>11.50 \pm 1.06</math></b>	0.61
	<b>Wind direction</b>	$1.08 \pm 0.70$		$-0.63 \pm 2.88$	
	<b>Wind speed</b>	$0.29 \pm 0.94$		$0.81 \pm 1.45$	
	<b>Sun</b>	$-1.23 \pm 4.63$		$3.73 \pm 8.26$	
<b>4</b>	<b>Total <math>R^2</math></b>		<b>0.16</b>		<b>0.10</b>
	<b>Day</b>	<b><math>-1.07 \pm 0.28</math></b>	0.05	$-0.67 \pm 0.53$	
	<b>Time of day</b>	<b><math>-0.80 \pm 0.23</math></b>	0.08	$0.90 \pm 0.65$	
	<b>Wind direction</b>	<b><math>-1.93 \pm 0.87</math></b>	0.02	$-0.09 \pm 1.77$	
	<b>Wind speed</b>	$-0.22 \pm 0.48$		$-0.45 \pm 0.89$	
	<b>Sun</b>	$1.87 \pm 2.35$		$3.64 \pm 5.07$	
<b>5</b>	<b>Total <math>R^2</math></b>		<b>0.09</b>		<b>0.38</b>
	<b>Day</b>	$-0.47 \pm 0.42$		$-0.43 \pm 0.63$	
	<b>Time of day</b>	<b><math>-1.29 \pm 0.35</math></b>	0.05	<b><math>3.77 \pm 0.78</math></b>	0.22
	<b>Wind direction</b>	$-2.09 \pm 1.29$		$-3.55 \pm 2.11$	0.03



individually Day is significant in the morning and the coefficients are positive. This means that more birds were visible at the end of our observation period than in the beginning.

Wind direction is significant in area 1, area 4 and the Whole colony in the morning. The coefficients are negative, which means that when the wind direction is north/northwest, there are fewer birds than when the direction is south/southeast.

Wind speed is significant in area 2 in the morning and area 5 in the evening. The coefficients are negative meaning that fewer birds can be seen in strong wind.

Sun on the colony has no effect in the five areas individually. It is, however, significant in the Whole colony in the evening and the coefficient is positive, i.e. more birds are visible, when sun is shining directly on the colony.

## Discussion

Our study shows that the most reliable method of censusing this particular colony of Black Guillemots is to carry out scan samplings of undisturbed birds residing at the colony or in the immediate vicinity of it. Observations should be conducted between 2000 and 2330. We found that time and weather influence the attendance pattern of the birds.

Since accurate censusing of cliff nesting Black Guillemots is essentially impossible in the field, yearly fluctuations in colony attendance can be useful indicators of trends in populations as well as ecological changes in the bird's environment (Calvert and Robertson, 2002). However, colony attendance cannot be used as a measurement for the accurate number of breeding pairs, since knowledge about the breeding success of the birds or the ratio of non-breeders staying in the area is insufficient. Hence, the use of an accurate method for censusing is essential.

We found a clear diurnal variation in number of visible birds at the colony at Skarvø (see Fig 2). This confirms the importance of conducting counts at the time of day with maximum attendance.

Strong morning attendance at Black Guillemot colonies has been reported on several locations, e.g. Canada (Cairns, 1979), Denmark (Asbirk, 1979a), Shetland (Ewins, 1985) and Finland (Hildén, 1994). This was also the case at our

colony. However, along with the morning peak we also found a clear evening peak. This pattern is similar to the one found in the post hatching period by Ewins (1985). Though separated, colony attendance remains high through the night (Fig. 2). This is concordant with Petersen (1981), who found that birds at higher latitudes have a merged morning and evening peak. A possible explanation could be that the midnight sun enables the birds to conduct active behaviour starting at earlier hours. Asbirk (1979a) found that Black Guillemots at Nordre Rønner in Denmark spend the night away from the colony out at sea in the post-hatching period. The birds at Skarvø, however, stayed in the colony on land and in the surrounding areas (Fig. 3).

Since the lowest variation between days and maximum attendance occurs in the evening at 2000-2330 censusing should be conducted at this hour, when surveying in the post-hatching period (Table 1). Alternatively, censusing the colony in the morning at 0400-0730 provides almost as favourable conditions in the aspect of attendance and variation.

Several authors recommend using correction factors when conducting counts outside of the peak attendance periods (e.g. Cairns, 1979; Hildén, 1994). However, due to the huge variation between days in the time periods with few birds, the use of correction factors would give an inaccurate estimate of our observed maximum attendance. Hence, we do not recommend using correction factors.

Large variations occur within the five areas (Fig. 3). Previous studies have often chosen to ignore birds not within the immediate vicinity of the colony, since these birds may not belong to the colony or may not be active breeders (Ewins, 1985; Hildén, 1994). Our results show that the majority of birds always reside on the water near the colony (area 1 and 2) and on land (area 3), while the number of birds in the areas further away (area 4 and 5) is fairly stable. In our recommended censusing periods more than seventy percent of the birds are located in area 1-3 (see Fig. 4). Thus, excluding the birds further away from the colony will not affect the counts greatly, and can be necessary when conducting counts from a boat, which may prevent a clear view of areas further away from the colony.

We found a threshold dependence between area 3 (land) and area 1 (water) in the morning period (see Fig. 5), i.e. the dynamic of attendance

between the two areas is reverse and it is dependent on the number of birds staying in them. The morning is also the time of day when number of birds reaches maximum in the two areas: Area 1 peaks at 0800 with 140 birds and area 3 peaks at 0300 with 92 birds (Fig. 3), yet numbers fluctuate greatly within the period. Simultaneously, this is the time of day with the highest level of flight (Fig. 7). These fluctuations in bird numbers in the two areas combined with the observed increased level of flying make it extremely difficult to conduct counts during the morning peak.

Overall the dynamics within the five areas show different patterns. Time of peak attendance in each area differs across the day and so does the factors influencing this. Autoregressive analysis (see Fig. 6) shows that area 2 differs from areas 1 and 3 in being limited by density dependence. Thus, when the number of birds staying in the area reaches a certain threshold the number negatively affects whether or not a bird chooses to reside there. A possible explanation could be that area 2 is located right in front of the colony and, hence, the most attractive area for the birds. Area 2 is, however, a relatively narrow area (see Fig. 1), thus providing little space for the birds to reside in. Another explanation could be that perhaps the area offers good biological conditions for the Black Guillemots, e.g. high food availability or shelter from wind. The reason for the density dependence remains unclear but it is important to notice that the dynamics observed within the different areas varies according to different parameters.

Multiple regression analysis (Table 3) shows that several abiotic factors may influence the number of birds attending a colony e.g. weather, time of day and day in the season. The latter is of great importance in the post hatching period. Late in the breeding season there is a greater chance of observing more birds around the colony than earlier in the season. These birds are believed to be either non-breeders or birds passing by from other colonies (Petersen, 1981). At Skarvø the number of Black Guillemots attending the colony increased in time during our census period, but only in the morning. If these birds indeed are from other colonies, counts in the morning will be strongly influenced by their presence, and thus results will show overestimated values. Therefore, censusing in the evening is to be recommended.

Our results (Table 3) show that some aspects of weather, i.e. wind direction in the morning, wind

speed and sun in the evening, also have a slight influence on the attendance pattern of birds. This is concordant with the study of Black Guillemots in Shetland that found factors such as temperature and wind speed to have a significant influence on colony attendance (Ewins, 1985).

Due to the considerable variation in attendance within short periods of time, several counts should be conducted when censusing a colony of Black Guillemots. Furthermore, it is of great importance to conduct preliminary observations of the colony to obtain a clear perspective as to where the birds are located before making the first count. Our results in Table 2 indicate that it is possible to make counts using digital photos. Additional investigations will be necessary before taking this method into use.

Several authors (e.g. Ewins, 1985; Hildén, 1994) recommend using disturbed counts. In our study at Skarvø we found undisturbed counts to be preferable (see Fig. 8). This might be the case because of the relatively narrow water area between the colony and nearby islands, which makes it difficult for the birds to land on the water, when a boat is residing in the immediate vicinity of the colony. Furthermore disturbing the birds makes it difficult to get an overview of the birds when many of them are flying.

Several factors should be considered, when censusing a colony of birds. Especially light conditions, weather and behaviour of birds may influence counts. When light is sparse, counting during time periods with many birds on land should be avoided since visibility of the birds is decreased. In our study, many birds stayed at land from 2300 to 0400 and it was occasionally difficult to distinguish each individual bird. During sunset counting is extremely difficult because of reflections from the sea. Similarly, when the sun is located just behind the colony, the sunlight blinds the observers. When sea is rough, counting the birds residing on the water is problematic because of ripples. Knowledge about the distribution of birds in the areas around the colony is therefore valuable before making the choice of censusing period.

Finally, the behaviour of the birds may influence counting, especially when the activity level is high. The high intensity of flying to and from the colony in the morning period (fig. 7) makes censusing extremely difficult due to the risk of counting some of the birds more than once.

## Conclusion

We found large temporal and spatial variation in the diurnal rhythm of Black Guillemots on Skarveø. Colony attendance is influenced by several factors, such as hour of day, day in season and weather. The time period with maximum attendance and least variation between days is the optimal censusing time. Hence, when censusing colonies similar to that on Skarveø in the post hatching period, we recommend: Several counts of the birds in an undisturbed environment, conducted in calm weather, preferably in the evening between 2000 and 2330.

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## Appendix 1

### General description of the Black Guillemot, *Cephus grylle*

#### Taxonomy

The Black Guillemot belongs to the family alcidæ. Their area of distribution stretches along the coastline of the Northern Atlantic Sea. The Black Guillemot is divided into seven subspecies, three of which are found in Greenland: *Arcticus* in the Southwest of Greenland, *ultimus* in the Northwest of Greenland and *mandtii* in East Greenland (Asbirk, 1979b). Subspecies are classified by differences in distinct features, such as length of beak and colouration on speculum (Asbirk, 1979c). To determine which of the West Greenlandic subspecies our studied colony belongs to, we measured the length of the beak from the base and forward and the black on the outermost primary from the tip of the feather and down to the beginning of the white part (Fig. 1) on a dead adult bird found at the colony. We compared our measurements with similar measurements conducted on three specimens of *arcticus* and three *ultimus* (Table 1). The six specimens belong to the Zoological Museum of Copenhagen. Our comparison showed that the bird found on Skarveø has similar proportions to the three *arcticus* specimens. Thus, we conclude that the birds residing on Skarveø belongs to the subspecies *arcticus*.



Figure 1 A measurement of primaries from a bird at Skarveø. The red line shows how to measure the black part of a primary. Photo: K. Rahe.

#### Biology

The adult Black Guillemot is recognisable with its white speculum on the wing, which can be seen from quite a distance. The young birds, up to the second year are more speckled in colour; these young birds are rarely seen at the colony. The birds normally start shedding to winter coat in August (Asbirk, 1979b). Nevertheless we saw one bird in the winter coat, which some birds keep all year round. In our study we found it very difficult to separate the young birds from the adults, when seen from a distance.

The pre-breeding period of the Black Guillemots generally begins in April followed by egg laying late May and June. Hatching starts from late June to July (Asbirk, 1979a & Ewins, 1985). But arctic birds are dependent on the melting of the ice coverage around their colony and probably have a much shorter pre-breeding period, which starts later in the season (Hildén, 1994). The Black Guillemot prefers to live in monogamous pairs and keep the same partner in several seasons. The birds lay two eggs, but the young birds, in their first breeding season, normally lay one. Contrary to other auks Black Guillemots feed in inshore waters, down to 10 metres depth. Their choice of food consists in smaller fishes, e.g. Sand Eel (*Ammodytes*) or Butter Fish (*Pholis gunnellus*) (Asbirk, 1979b).

Table 1 Comparison of beak and feather measurements of the two subspecies of Black Guillemots *arcticus* and *ultimus* living in West Greenland. The bird at Skarveø was found the 24 July, the bird had been dead for a longer period of time. *Arcticus* was caught in Skarvefjeld (\*Julianehåb), near Godhavn, by Asbirk the 8 July 1973. *Ultimus* was caught in Upernavik the 5 June (females) and 18 July (male) 1936.

	Length of beak (cm)	Black on outermost primary (cm)
Bird at Skarveø	3.3	5.25
<i>Arcticus</i> ♂	3.2	5.5
<i>Arcticus</i> ♂	3.3	5.0
<i>Arcticus</i> * ♂	2.85	5.18
Average	3.12	5.22
<i>Ultimus</i> ♀	2.65	4.0
<i>Ultimus</i> ♀	2.7	4.5
<i>Ultimus</i> ♂	2.9	4.55
Average	2.75	4.35

We believe that the fishes caught at Skarveø primarily were Capelins (*Mallotus villosus*). The birds nest in loose colonies and prefer nesting grounds in boulder areas or talus slopes, but some also nest in cliffs (Petersen, 1981).

The Greenlandic Black Guillemots spend the winter either on offshore waters or by the coastline at the South-western Greenland from Paamiut (62° N) to Sisimiut (67° N). There is no ice in these areas due to the West Greenland Current, which is a mix of a cold upper current and a warm lower current (Merkel *et al.*, 2002).

The Black Guillemot is a species of European concern; it is in category 2 of SPECS (Species of European Conservation Concern), i.e. a species with a global population concentrated (> 50%) in Europe and with an unfavourable conservation status in Europe. In all of Europe there is estimated a population size between 120.000 and 280.000 pairs, which includes the Greenlandic population of an estimated 25.000 - 100.000 pairs (Tucker & Heath, 1994). In Greenland the Black Guillemot is the most common and widespread auk (Boertmann *et al.*, 1996).

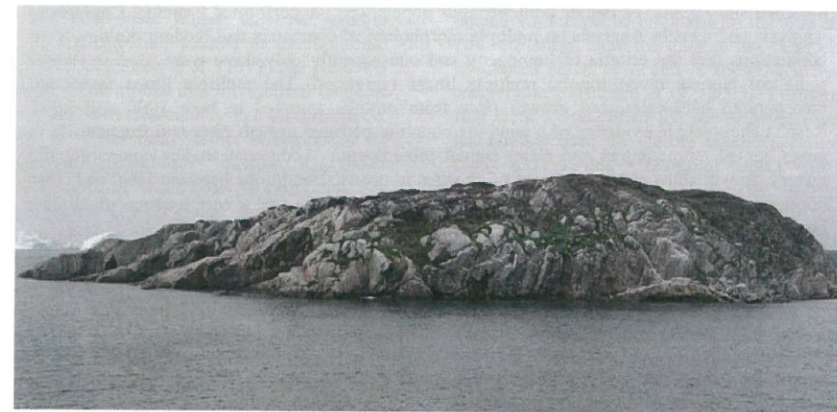


Fig. 2a. Colony at Skarveø as seen from the observation post. Photo: K. Rahe.

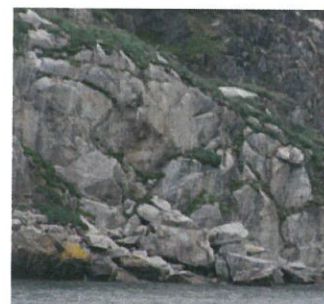


Fig. 2b. Close-up photo of colony showing potential nesting holes underneath the rocks. Photo: K. Rahe

Day	Time period
22 July	1100 - 2330 (26)
23 July	0000 - 0030 (2), 0600 - 2330 (36)
24 July	0000 - 0530 (12), 1000 - 1400 (9)
26 July	2100 - 2330 (6)
27 July	0000 - 0830 (18), 1430 - 2330 (19)
28 July	0000 - 0230 (6), 0900 - 2030 (24)
29 July	0100 - 0930 (18)
1 August	1730 - 2200 (10)
2 August	0300 - 1700 (29), 2230 - 2330 (3)
3 August	0000 - 1030 (22)

Table 2. Table of observations periods in local Greenlandic time. Number of counts is shown in parentheses, in all 240 counts.

# Growth rates from Arctic charr (*Salvelinus alpinus*, L) show complex interactions with weather parameters and climate change

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The circumpolar Arctic charr (*Salvelinus alpinus*) is in the present study used as a bioindicator for the climate changes observed in the Arctic region during the last decade. The Arctic charr is often the only fish species in Arctic limnic ecosystems, and demonstrates remarkable morphological plasticity. We sampled Arctic charr from five localities around the Arctic Station in Godhavn/Qeqertarsuaq on the Greenlandic west coast, where climate data have been recorded since 1990. To isolate homogeneous populations we performed Principal Component Analysis and Cluster Analysis on multiple morphological characters and feeding biology. Two populations met the criteria of homogeneity and consequently only these were used in further statistical climate modelling by multiple linear regression. The multiple linear regression incorporated back-calculated growth rates from otoliths sampled in both 1990 and 2004. Results show ample evidence of a complex coupling between growth rates and fluctuations in mean annual temperatures and mean annual precipitation. Additional studies comparing life history growth show statistical proof of changes in growth conditions between 1990 and 2004 populations. We argue that differences in growth conditions are a consequence of climate change.

**Keywords:** *Salvelinus alpinus*, otolith, morphology, statistical modelling, climate impact, global change.

## Introduction

Studies of the Arctic charr (*Salvelinus alpinus*, L.) have a long tradition at Arctic Station located on Disko Island/Qeqertarsuaq off the west coast of Greenland. As early as in 1910, the founder of the research station, Morten P. Porsild, published a scientific paper on the Arctic charr's migratory patterns on Disko Island/Qeqertarsuaq (Porsild, 1910). Besides discussing migratory patterns, Porsild also noted the great phenotypic variability of the Arctic charr.

This diversity of phenotypes varies considerably within and across localities on Disko Island (Hansen *et al.*, 1983; Mordhorst & Due, 1990) and throughout the Arctic charr's holarctic distribution. This worldwide variation has led to what has become known as 'the charr problem' (reviewed in Jonsson & Jonsson, 2001). On Disko Island, dimorphic populations in rivers with an anadromous morph and a resident morph have been described (Hansen *et al.*, 1983; Mordhorst & Due, 1990), but whether these morphs are reproductively isolated remains unclear. In addition, two localities with landlocked populations where fish have evolved specialized features have been identified. Because fish are

isolated in the same locality throughout their entire lifecycle the resident and landlocked populations pose a unique possibility for investigating effects of abiotic factors such as climate.

Long-range transport of pollutants and global warming are processes causing fundamental changes in regions far from direct anthropogenic impact. Ecological and physiological studies of Arctic charr from high mountain lakes in the Alps have shown that combinations of both types of processes endanger fish populations by leading to highly elevated metal accumulation (Köck *et al.*, 1996). For instance, levels of cadmium and lead in the liver of Arctic charr from a high mountain lake were comparable to those of fishes from waters receiving metal-polluted industrial effluents. The water temperature has shown to be the driving force in this excessive metal accumulation (Köck *et al.*, 1996). At increased temperature it is not only accumulation of metals that play a significant role. Fish are ectotherms and hence, in contrast to endotherms, like mammals, rely on external sources of heat. Metabolic produced heat is rapidly lost through the gills and the epidermis and consequently, body

temperature of fish fluctuates in close correspondence with the ambient water temperature (Jobling, 1996). Since the enzymatic rate in animals is strongly temperature dependent (Eckert *et al.*, 1988), the ambient water temperature influences all physiological processes in fish. For example, Brett (1971 in Larsson, 2002) studied different physiological responses of sockeye salmon (*Oncorhynchus nerka*) to increased temperature. For all eight general functions studied (tolerance, preference, metabolism, performance, growth, appetite, digestion and circulation) temperature had a marked non-linear effect with an optimum. Additionally, it was found that all general functions, but appetite, peaked at the optimum temperature. Magnuson *et al.* (1979) has gone one step further and argues that the thermal niche of a fish should be treated equally to a food resource. This argument has been further strengthened by evidence of temperature having a crucial regulating factor in Arctic charr reproduction. For example, Gillet (1991) found that ovulation in charr was inhibited above 10 °C and slowed down above 8 °C. Fertilized eggs and developing embryos did not tolerate exposure to high temperatures, and mortality was high in eggs incubated at 10 °C. Moreover, other studies showed that if the temperature remained above 5 °C for several weeks, quality of the eggs was relatively poor because of over-ripening (Jungwirth & Winkler, 1984; Steiner, 1984). Therefore, only small changes in temperature lead to profound changes in both accumulation of heavy metals, physiology and fecundity of the Arctic charr. As a result, changes in temperature will have drastic consequences for populations in Arctic and as such, we believe the charr can function as a sensitive bioindicator for global warming.

The Arctic represents a very sensitive ecosystem, where major changes in climate already have been observed and climate models predict further high-latitude amplification of enhanced greenhouse effect in future (Nielsen *et al.*, 2001; Humlum *et al.*, 2002; Hansen *et al.*, 2003; Box, 2002). Nine of the ten warmest years globally have occurred between 1990 and 2001 and it is very likely that the decade of the 1990s was the warmest in the past 1000 years. This global warming is further evident in Arctic by the fact that Greenland ice-sheet melt between 1865

and 1990 has contributed about 3.0 +/- 1.6 cm to global sea-level rise (Box, 2002). Furthermore, studies indicate that sea ice thickness in the Arctic is decreasing because of increasing melt seasons (Laxon *et al.*, 2003). The decrease throughout the last years has been to such an extent that it is having effects on the locale Inuit communities, who are having difficulties in continuing their old traditions of sea ice hunting.

In the present study, we propose that warming in the Arctic already has had effects on the cold adapted Arctic charr. To evaluate the validity of this proposal we have sampled fish and otoliths from populations at a series of localities on Disko Island, with a special emphasis on the area around Arctic Station. Here the climate has been closely monitored since 1990 and is showing increasing temperatures (Hansen *et al.*, 2003). Furthermore, fish from a number of the investigated localities has already been sampled in 1990. Therefore, the study incorporates a temporal aspect with data from both 1990 and 2004. After performing Principal Component Analysis and Cluster Analysis on parameters from sampled fish, we chose to solely investigate otoliths sampled from two landlocked homogeneous localities. We sought to find the proposed connection between climate and somatic growth through careful multiple linear regression modelling between annual rings in otoliths and climate data. Our investigation shows such a connection and furthermore shows striking evidence of changing growth rates of the Arctic charr from 1990 to 2004.

## Materials and methods

### Study sites

The study was carried out in the summer of 2004 on Disko Island/Qeqertarsuaq (69° 15'N, 53° 31'W) off the west coast of Greenland. The study sites (four lakes and two rivers) were chosen after literature studies and investigations of satellite and airplane photos, with a special emphasis on the possibility of landlocked populations of Arctic charr.

The climate data was obtained from a weather survey station placed at the Arctic Station located in Godhavn/Qeqertarsuaq on Disko Island. The data obtained forms a continuum from 1990 to 2001 with respect to wind, temperature, precipitation and albedo. Similar climate data from 1981 to 1989 was obtained from recordings



monitored at the climate station in Egedesminde/Aasiaat and later extracted from the Danish Meteorological Institute ([www.dmi.dk](http://www.dmi.dk)).

#### Sampling and treatment of material

Water temperature and depth was measured at all study sites. Sampling with gill nets (Faarups Specialnet, Denmark) was conducted during July and August 2004 (see table 1). Multimesh gill nets were used of a type proposed for monitoring use in Nordic countries (referred to as 'biological survey gill nets'; Nordic Norm). The nets were 40 meters long respectively, and composed of 12 mesh sizes: 29, 35, 5, 15.5, 24, 12.5, 8, 55, 10, 6.25, 19.5 and 43 mm. The sampling was carried out using random pelagic and littoral settings for each locality with exception of rivers. The pelagic nets were placed parallel to the shore, while the littoral nets were set perpendicular to the shore. Specimens from Nipisat elv were obtained by angling, while Røde elv was examined by hand net and multimesh gill net.

Fork length, mouth depth, weight and colour were recorded for all fish. Furthermore, randomly selected fish were more thoroughly examined to determine gender, gonad maturity, diet and parasite load. Otoliths (sagittae) were sampled for investigation of chronological parameters. Together with jaw length, fork length to nearest millimetre was measured. Weight was measured to nearest gram, while gonad maturity was ranked from 0-5, where 0 was assigned when no gonads could be detected and 5 when the fish had just finished spawning.

Otolith analyses were carried out at the Danish Institute for Fisheries Research, Charlottenlund. Each otolith was mounted using resin, sulcus facing down, on a glass slide at 140 °C. Following mounting, otoliths were polished to enhance annular ring structure. Digital video microscopy and Image Pro Plus 5.0 were used to estimate age by count of annual rings. Same system was used in making transects for quantifying distance between annular rings (Fig. 1a). Transects were placed as close to a downward angel of 90° to rostrum as possible in all examinations. Furthermore, Image Pro Plus 5.0 was used to conduct a Fourier analysis quantifying intra and inter-population differences in otolith morphology.

#### Assessment of population structure

In order to choose suitable populations for further climate studies, the individual variation in

fish morphology and stomach content within and between populations were recorded. From these results three Individual-Character matrices [ $n \times C$ ] were constructed with varying degree of resolution on the qualitative description of individuals. Characters included in analyses of population structure were treated either as quantitative variables or categorical variables. Morphological quantitative characters were: Fork length (FL), weight (W), condition index (CI), age, mouth depth (MD) and mouth depth relative to fork length (rMD). CI was calculated by the following equation:

$$CI = \frac{W}{FL^3} \times 100$$

where  $W$  is weight in g and  $FL$  is fork length measured in cm. Categorical characters used in the study were colour, sex and gonadal maturity (GM). Feeding behaviour was assessed by analysis of stomach content and treated as a categorical character. Presence/absence was noted for following three categories: Chironomidae, pisces and benthic invertebrates (Ostracoda, *Lepidurus arcticus* and bivalves).

Mentioned in order of decreasing information resolution, the matrices were a [ $36 \times 12$  C], a [ $60 \times 11$  C] and a [ $156 \times 6$  C] matrix. The first mentioned matrix contained all mentioned parameters, while the [ $60 \times 11$  C] matrix was without the age-parameter and the [ $156 \times 6$  C] matrix consisted solely of the morphological characters FL, W, MD, CI, MD, rMD and colour. In this multivariate approach, we imported ecological statistical tools of pattern clarification as applied traditionally by community analysts. A Principal Component Analysis (PCA) was applied using PCord-4 to investigate for otherwise undetectable variation gradients in the dataset. The assumption of an underlying linear trend in the dataset was accepted untested, and the charr morphs were, consequently, abstractly regarded as groups separated in an one-dimensional space. The assumption of normality for the included parameters was tested by calculation of skewness and kurtosis. Tests of linearity between parameters were conducted by visual interpretation of a scatter plot matrix. The cross-product matrix in the PCA was calculated using correlation coefficients. When consistent output was found, the two axes of major explanatory

**Table 1.** N.L. = Northern latitude; W.L. = Western longitude; M.A.S. = Meters above surface; E-fish = Fish caught at the locality; I-fish = Fish used in internal investigation; \*Maximal depth was not reached while recording temperature; \*\* Fish caught by angling.

Locality	Nipisat	Porsildsø	Mellemso and Langesø	Kangarsuk	Røde elv
Date	20/7 2004	20-21/7 2004	22-24/7 2004	28/7 2004	2-3/8 2004
Type	River	Lake	Lakes	Lake	River
N.L.	69°26'	69°24'	69°31'	69°16'	69°16'
W.L.	54°13'	53°48'	53°41'	53°50'	53°29'
M.A.S.	0-8 m	119 m	16 and 12 m	10 m	90-100 m
Max. depth	2 m	not known	36 m	7 m	≥ 3 m
Surface temp.	10.1 °C	10.8 °C	11.01 °C	10.1 °C	8.4 °C
Min. temp.	10.1 °C	10.7 °C *	4.3 °C	8.3 °C	8.4 °C
E-fish	10	65	52	14	14
I-fish	5	9	10	14	14
Range in size	289-424 mm**	70-473 mm	53-545 mm	220-367 mm	82-169 mm
Landlocked	-	-	-	+	+

power were used depicting the resulting condensed data information in two-dimensional space.

A hierarchical, polythetic agglomerative Cluster Analysis was conducted using PCord-4. Sørensen (Bray-Curtis) distance measure was used in combination with nearest neighbour group linkage method. The resulting groups were characterized by the calculated distances between pruning points in the cluster dendrogram.

The morphological variation in otolith shape was examined using Image Pro Plus 5.0 and Leica IM 50 Image manager using the AOI manager-tool in combination with Elliptic Fourier Analysis Program in corporation with Henrik Mosegaard at the Danish Institute for Fisheries Research. The output was 242 fourier harmonics for each otolith. The data combines in clusters of four harmonics to describe a feature of the otolith shape. The clusters were arranged hierarchically, with the first ones describing the rough outline of the otolith producing an elliptic morphology, the succeeding clusters combines to produce the evolution of rostrum, antirostrum and so forth. As the information on primary characteristics of the otolith shape appeared to be condensed in the first number of four-group clusters, we conducted the Principal Component Analysis on the first 5 clusters. The computation was done in PCord-4 as

described for assessment of population structure.

#### Assessment of somatic growth

Measurements of otolith radius ( $O_t$ ), FL and age at time of capture were used in constructing an Individual-Character matrix ( $I \times C$ ) for each investigated locality, which later were pooled for all five localities into one matrix. We applied a new model for growth back-calculation developed by Morita and Matsoishi (2001), which take into account that fish growth may be allometrically uncoupled to otolith growth. Combining growth-effect with an age-effect in the back-calculation algorithm, the following equation has been obtained:

$$O_r = \alpha + \beta \times L + \gamma \times t$$

where  $O_r$  is the otolith radius,  $L$  is measured fork length at age  $t$  of capture.  $\alpha$ ,  $\beta$  and  $\gamma$  are constants obtained from multiple regression analysis on the  $I \times C$  matrices. The multiple regression analyses were conducted using SYSTAT 8.0 and the coefficients were imported into the following applied back-calculation formula:

$$L_t = -\frac{\alpha}{\beta} + \left( L_T + \frac{\alpha}{\beta} + \frac{\gamma}{\beta} \times T \right) \times \frac{O_t}{O_T} - \frac{\gamma}{\beta} \times t$$



where  $L_t$  is the back-calculated fish body length at age  $t$ ,  $L_T$  is fish body length at time of capture  $T$ ,  $O_t$  is otolith radius at annulus (age)  $t$ ,  $O_T$  is otolith radius at time of capture and  $\alpha$ ,  $\beta$  and  $\gamma$  are the determined coefficients from the above mentioned multiple regression. The back-calculated fork lengths were applied in calculation of estimates on growth rates using the simple relationship between body sizes at succeeding years:

$$GR = FLE_{t+1} - FLE_t$$

where GR is calculated growth rate, and  $FLE_{t+1}$  and  $FLE_t$  is fork lengths estimated by back-calculation at age  $t$  and  $t + 1$  year. To allow detection of signals from climate conditions on growth rates, the effect of ontogenetic development on every individual needed to be extracted from GR-values. As there was no evidence of earlier attempts to solve this problem, we developed a calculation procedure assuming a simple additive relationship between the effects of ontogenetic development and environmental conditions on the realized growth rate of the individual:

$$GR = f(OnGe) + g(EnCo)$$

where OnGe is ontogenetic stage, EnCo is the sum of environmental conditions and  $f$  and  $g$  are mathematical functions. Thus, to reveal the effects of climate, which is inherent in the EnCo, we simply subtracted the OnGe-impact from the estimated GR, and obtained what was termed GRR, growth rate residuals:

$$GRR = GR - f(OnGe)$$

The functional values of OnGe was computed for each locality, and for the total pooled data set by fitting a logarithmic function to the age-determined growth-tendency for the individual sample. This was done by curve-fitting using least-squares-method. The resulting GRR-values for each individual were assigned to the concurrent calendar year hereby obtaining the final time-Individual matrix ( $t \times I$ ) consisting of the GRR-series for each individual. The mean tendency in the population was calculated and contrasted to variation in climate variables.

#### Modelling growth and climate variation

Three levels of analysis were conducted. At first the constructed time series for fish growth and climate variation, assessed by the parameters mean annual temperature (MAT), mean summer temperature (MST), mean winter temperature (MWT) and mean annual precipitation (MAP), were depicted graphically for visual tendency interpretation. The Product Moment Correlation Coefficient  $r$  was calculated for opposed time series of fish growth and climate variables.

Secondly, multiple linear regressions were carried out using SYSTAT 8.0 regressing GRR<sub>*t*</sub> for each locality on MAT, MST, MWT or MAP, incorporating a factor of autocorrelation (GRR<sub>*t-1*</sub>) consisting of vertically displaced GRR-values from the previous year. The General Linear Models were hence constructed on the following formula:

$$GRR_t = \alpha + \beta \times PAR + \gamma \times GRR_{t-1}$$

where GRR<sub>*t*</sub> is growth rate residual subtracted the effect of ontogenetic stage at time  $t$ , GRR<sub>*t-1*</sub> is previous year, PAR is the mean climate parameter for temperature and precipitation, and  $\alpha$ ,  $\beta$  and  $\gamma$  are constants estimated from the multiple regression analysis. The linear models were constructed by complete analysis with default settings with  $r^2$  values and degree of significance automatically computed.

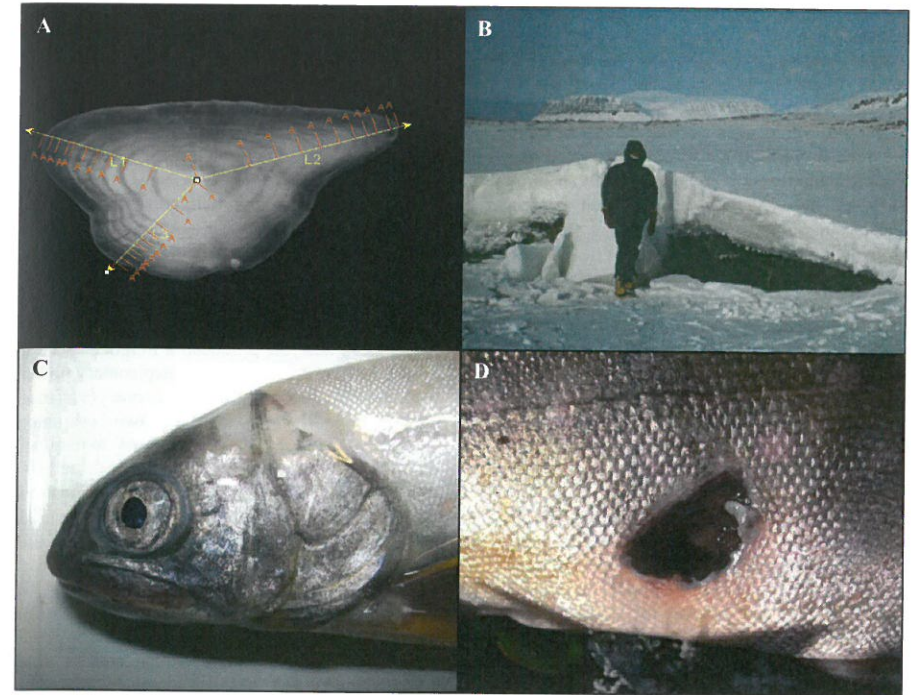
Finally, to evaluate the impact of long-term climate change, we compared estimated growth curves between the two sampled time periods 1982-1989 and 1995-2003 within each of the landlocked populations investigated. The population means of the individual fork length estimates were tested by an ANOVA test and plotted with corresponding standard errors of the estimate for each year. A statistical level of significance of 5% ( $p \leq 0.05$ ) was chosen for all results.

#### Results

##### Assessment of population structure

##### Qualitative survey of localities

The statistical modelling requires fish from more or less homogenous populations with uniform life cycles. Thus, to evaluate the homogeneity of the populations we analysed the populations both qualitatively and later quantitatively by PCA and Cluster Analysis. The qualitative survey split the fish populations into



**Figure 1.** (A) Polished otolith during assessment of age and ring structure. Notice the three transects, which were used to estimate age by count of annual rings and growth by quantifying the distance between annular rings. Throughout the study transects were placed like transect L3 as close as possible to a downward angle of 90° to rostrum. Rostrum is seen as the extension in the right side of the otolith. (B) Picture show spring explosion cause by a cold homothermic spring originating inside the lake at Kangarssuk. Notice how the spring water has lifted the ice cover. Picture taken by Ole Frimer March 1992, Arctic Station. (C) Arctic charr sampled at Røde elv. Notice the large eyes and ventrally placed mouth, which are unique features for the morph evolved in Røde elv. (D) External infection wound on Arctic charr sampled at Kangarssuk.

two categories: Landlocked and those with access to the sea. In Røde elv fish were landlocked by a series of waterfalls, while large rocks in the outlet from the Kangarssuk lake to the sea isolated fish in the lake (for further morphometric information about the localities see table 1). When considering the investigated fish populations, the two landlocked localities Røde elv and Kangarssuk also morphologically represented the most homogeneous populations.

**Røde elv** Individuals from Røde elv all had parr marks, which is characteristic for fish that have not smoltified. They were all small ranging in size from 82 to 169 mm with large eyes

and ventrally placed mouths (see table 1 & Fig. 1c). Despite the small size, a number of fish in Røde elv were ready to spawn, a feature common to all populations investigated. In addition, fish in Røde elv were uniform in external colour and had solely fed on chironomids.

**Kangarssuk** The charr population in Kangarssuk had parr marks, a characteristic feature also witnessed in the Røde elv population. In all other localities parr marks were only found on small juvenile individuals. Individuals in Kangarssuk were large, ranging in size from 220 to 367 mm and a considerable number were ready to spawn. Like fish in Røde elv all individuals



were very uniform in external colour. Uniquely for fish sampled at Kangarssuk were large external wounds presumable from fungal, viral or bacterial infections (Fig. 1d). Furthermore, all individuals caught at Kangarssuk were more than 5 years old, while ages of individuals in other populations were more uniformly distributed. All had eaten chironomids and additionally a large number of individuals had preyed on benthic ostracods and *Lipidurus arcticus*.

**Nipisat** Fish from Nipisat were caught just off the river mouth of Nipisat elv. All were silver coloured anadromous fish ready to go up river and spawn. We did not catch any of the previously described resident individuals (Hansen *et al.*, 1983; Mordhorst & Due, 1990).

**Porsildso, Mellemso and Langeso** A small stream permeable for fish connected the populations in Langeso and Mellemso. Thus, fish in the two lakes were considered one population. The populations in Porsildso, Langeso and Mellemso were similar and dominated by a large number of anadromous fish ready to spawn. Besides the large anadromous individuals in the three lakes, a number of smaller fishes with mature gonads were caught. Characteristic for these populations were also considerable variation in external colour, stomach content and size (results not shown). Thus, Porsildso, Langeso and Mellemso all have very heterogeneous populations of charr with access to the sea.

#### Morphological and ecological morph identification by Principal Component and Cluster Analysis

To further support the qualitative survey we employed PCA and Cluster Analysis to evaluate the sampled populations with respect to homogeneity, and hence suitability for further climate analyses. The W, CI, MD and rMD parameters incorporated in the [156 n x 6 C] and [60 n x 11 C] matrices used for the PCA violated the assumptions of normal distribution. Moreover, the colour parameter violated the assumption of linearity and hence both matrices were excluded from the analysis. In addition, we also found the level of resolution for these samples to be at too small a scale for consistent group identification. The introductory analysis of the [36 n x 12 C] matrix revealed that CI and rMD in this sample likewise were unable to meet the criteria of

$|\text{skewness}| < 1$  normally applied (McCune *et al.*, 2002) and these parameters were consequently deleted from the matrix. The pisces category was likewise problematic but was kept in the analysis due to the expected information value. As the aim of the PCA was merely descriptive, the assumption of inter-parameter linearity was relaxed and the categorical variables were kept in the analysis despite their violation of the linear assumption. The PCA was therefore conducted on a [36 n x 10 C] matrix consisting of the following descriptive parameters: fork length, age, weight, mouth depth, colour, sex, gonadal maturity, pisces, chironomids and benthic invertebrates.

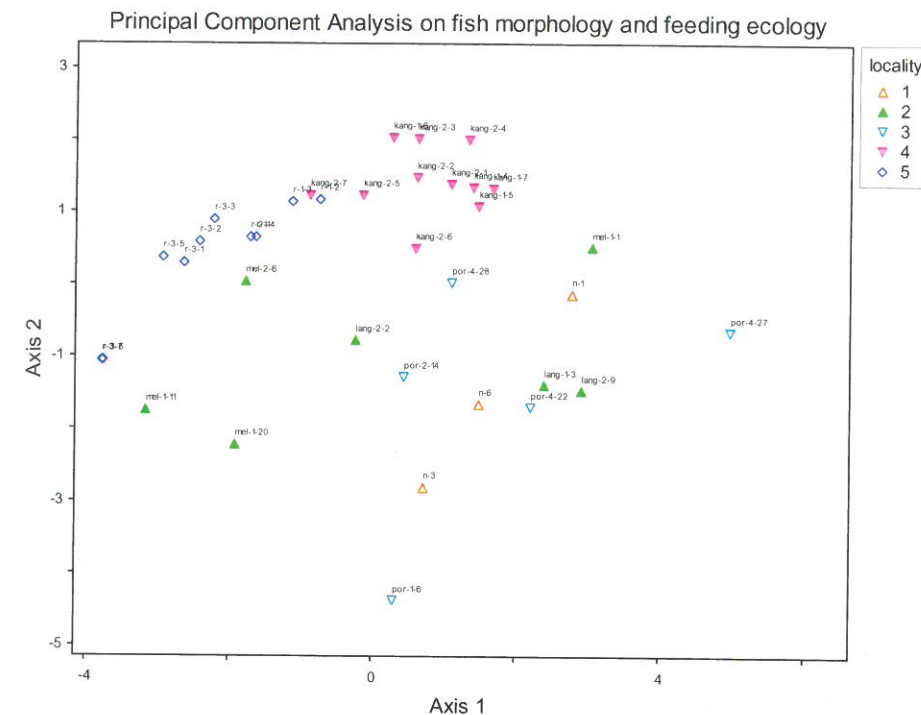
The PCA analysis produced a number of axes, where the two with the greatest explanatory power were used. These were axes one (variance extracted 43.4 %) and axes two (variance extracted 22.1 %), which combined to explain 65.4 % of the original variation in the 10-dimensional space. Coefficients of determination for axes one and two were respectively  $r^2 = 0.75$  and  $r^2 = 0.23$ . The PCA show clear support of the preliminary qualitative study with Røde elv and Kangarssuk as the only populations with individuals clustering together (Fig. 2 & table 2). To further strengthen the results, we performed a Cluster Analysis creating a dendrogram that complemented the PCA-ordination. Clustering was therefore not conducted for the two low-resolution matrices, which were excluded from the PCA. The Cluster Analysis further established the results by clustering populations from Røde elv and Kangarssuk together (Fig. 3). Additionally, the Cluster Analysis placed fish showing clear anadromous traits from other localities in the centre of the dendrogram together with two ocean caught individuals from Nipisat elv. Likewise, individuals presumed to be small resident morphs caught in Mellemso were clustered together with the landlocked small fish sampled in Røde elv. Hence, the statistical analyses performed clearly separate individuals with different life histories, showing evidence of separate morphs evolved in Røde elv and Kangarssuk and a dimorphic population inhabiting Mellemso and Langeso complex.

#### Otolith group identification by Principal Component Analysis

To supplement the already performed statistical analyses we introduced a novel approach in this study. An introductory assessment of the variation

between individuals in otolith shape indicated a high level of dissimilarity between populations.

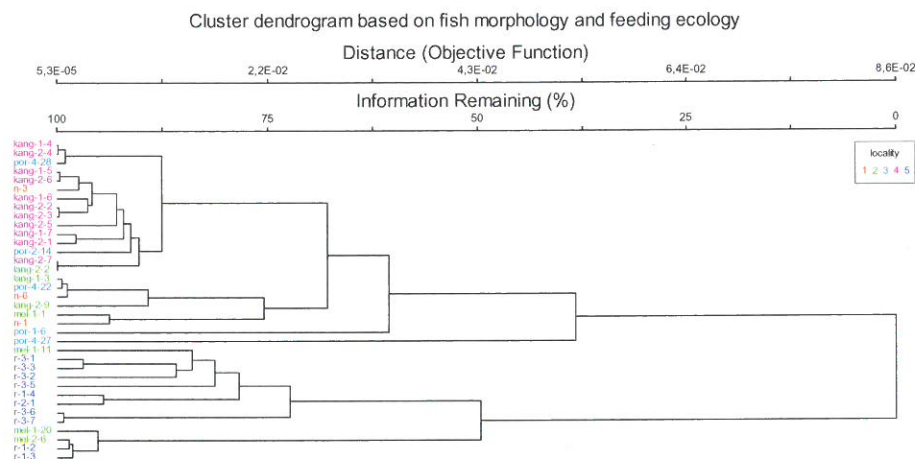
Thus, we conducted a PCA on otolith shape on 38



**Figure 2.** Principal Component Analysis of individual fish morphology and stomach content, showing the two axes of greatest explanatory power. Notice how Kangarssuk and Røde elv individuals are closely scattered together indicating more homogeneous populations compared with the other sampled populations (for axis one variance extracted = 43.4 % and for axis two variance extracted = 22.1 %; Locality: 1 (n) = Nipisat; 2 (lang/mel) = Langeso/Mellemso; 3 (por) = Porsildso; 4 (kang) = Kangarssuk; 5 (r) = Røde elv. Data labels represent locality, net number and fish number respectively.  $r^2$  for axis one = 0.75 and axis two = 0.23).

**Table 2.** Results from PCA ordination on individual fish morphology and stomach content. Notice the difference between SEM from Kangarssuk and Røde elv compared with the other more heterogeneous populations (mean = ordinated mean population scores on the axes of greatest explanatory power; SEM = Standard error of the estimated means; n = Number of individuals included in the ordination).

Locality	Kangarssuk	Røde Elv	Nipisat	Langeso/Mellemso	Porsild Sø
Mean	0.749	-2.308	1.651	0.172	1.798
SEM	0.23	0.32	0.56	0.98	0.86
n	11	10	3	7	5



**Figure 3.** Dendrogram constructed from the Cluster Analysis based on fish morphology and stomach content. The Cluster Analysis established further the results obtained from PCA ordination showing Kangarsuk and Rode elv as the only homogenous populations (Locality: 1 (n) = Nipisat; 2 (lang/mel) = Langsø/Mellemso; 3 (por) = Porsildso; 4 (kang) = Kangarsuk; 5 (r) = Rode elv. Data labels represent locality, net number and fish number).

individuals for which an intact right otolith could be obtained. The analysis was based on 14 harmonics as a test for normality and linearity prompted us to exclude six single-harmonics from the analysis.

The ordination produced the diagram depicted in Fig. 4, where the two axes of greatest explanatory power are shown. The first and second axes explained 29.4 % and 19.2 % of the original variance and combined they explained 48.6 % of the variance. The coefficients of determination were for axes one and two respectively 0.285 and 0.291. Emphasizing the ability to explain original variation in the dataset, the first axis was chosen to represent the ordination output, and the mean population scores on the first axes were calculated (table 3). The ordination did not reveal as clear results as the PCA on morphological and ecological parameters, but a separation of Rode elv and Kangarsuk with the other more heterogeneous localities scattered in between is evident.

#### Modelling of fish growth rate and climate variation

The preliminary investigations of population structure showed clear evidence of only one morph inhabiting respectively Rode elv and Kangarsuk. Therefore, only individuals sampled

from these two populations were chosen for further modelling of climate parameters, with annual growth patterns obtained from analysed otoliths.

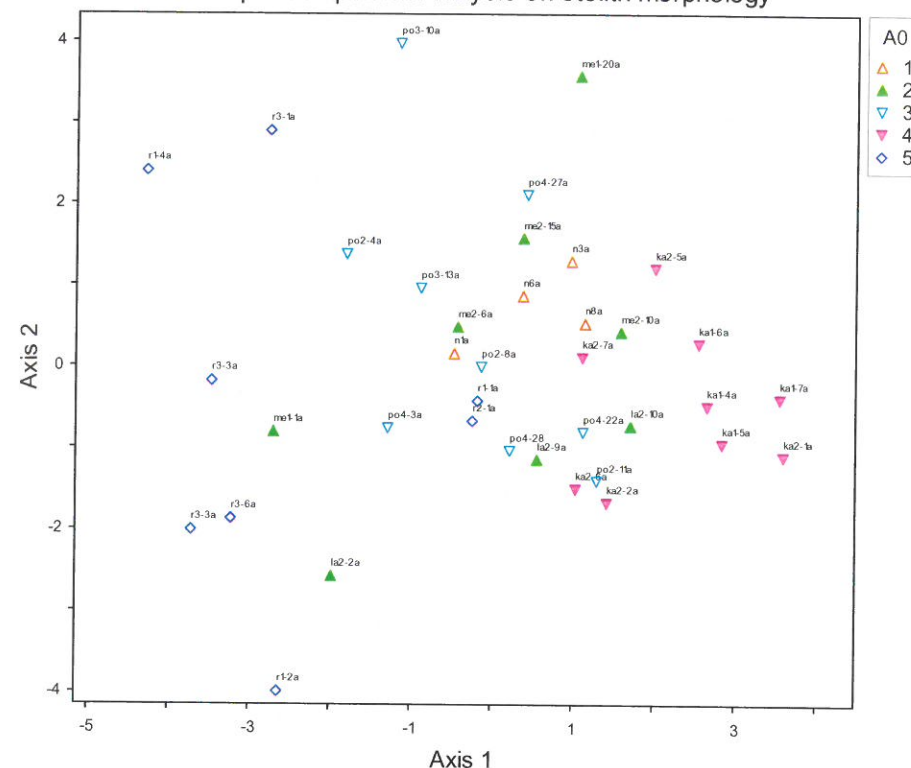
#### Rode elv 2004

Otolith analyses of Rode elv individuals caught in 2004 showed a correlation between GRR and MAT from Godhavn ( $r = 0.882$ ; d.f. = 5) within a 0.01 level of significance. Further exploration resulted in creating a model by multiple linear regression:

$$GRR_t = -42.132 - 13.341 \times MAT + 1.592 \times GRR_{t-1}$$

which showed a negative effect of MAT on GRR together with a non-significant autocorrelation ( $r^2 = 0.917$ ;  $P_{MAT} = 0.051$ ;  $P_{GRR_{t-1}} = 0.105$ ). Thus, results indicate a strong relationship between MAT and growth rates in Rode elv, which is also evident when considering patterns visible in Fig. 5a. Further data exploration resulted in Fig. 5b, which shows connection between GRR and MST. This prompted us to compute a model by multiple linear regression now incorporating MST and autocorrelation:

#### Principal Component Analysis on otolith morphology

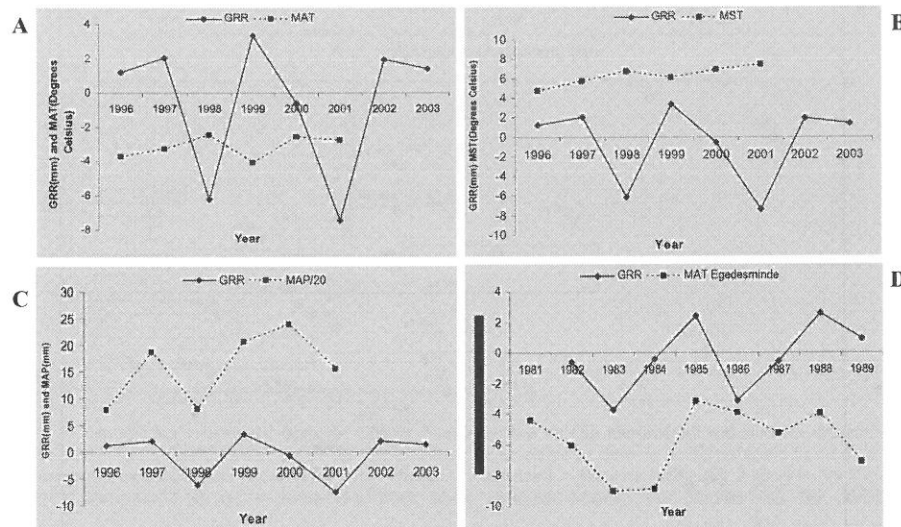


**Figure 4.** Principal Component Analysis on otolith morphology showing the two axes of greatest explanatory power. This novel approach further confirmed results from previously obtained results from PCA and Cluster Analysis showing especially individuals in Kangarsuk as a homogeneous population (for axis one variance extracted = 29.4 % and for axis two variance extracted = 19.2 %;  $r^2$  for axis one 0.75 and axis two 0.23; localities: 1 (n) = Nipisat; 2 (la/ml) = Langsø/Mellemso; 3 (po) = Porsildso; 4 (ka) = Kangarsuk; 5 (r) = Rode elv. Data labels represent locality, net number and fish number).

**Table 3.** Results from PCA ordination on otolith morphology. Results are not as distinct as for the PCA ordination on individual fish morphology and feeding. Still, Kangarsuk is scattered with least standard error in consensus with other results (mean = ordinated mean population scores on the axes of greatest explanatory power; SEM = Standard error of the estimated means; n = Number of individuals included in the ordination)

Locality	Kangarsuk	Rode Elv	Nipisat	Langsø/Mellemso	Porsildso
Mean	2.300	-2.574	0.500	0.019	-0.250
SEM	0.32	0.55	0.37	0.57	0.37
n	9	8	4	8	9





**Figure 5.** (A) Data obtained in 2004, showing GRR in Arctic charr from Røde elv plotted against fluctuations in MAT (GRR = Growth rate residuals; MAT = Mean annual temperature;  $r^2 = 0.917$ ;  $P_{MAT} = 0.051$ ;  $P_{GRR,t-1} = 0.105$ ). (B) Data obtained in 2004, showing GRR in Arctic charr from Røde elv plotted against fluctuations in MST (GRR = Growth rate residuals; MST = Mean summer temperature;  $r^2 = 0.729$ ;  $P_{MST} = 0.177$ ;  $P_{GRR,t-1} = 0.722$ ). (C) Data obtained in 2004 showing GRR in Arctic charr from Røde elv plotted against fluctuations in MAP divided by 20 (GRR = Growth rate residuals; MAP = Mean annual precipitation;  $r^2 = 0.571$ ;  $P_{MAP} = 0.300$ ;  $P_{GRR,t-1} = 0.595$ ). (D) Data from otoliths obtained in 1990 showing GRR in Arctic charr from Røde elv plotted against fluctuations in MAT data from Egedesminde/Aasiaat (GRR = Growth rate residuals; MAT = Mean annual temperature;  $r^2 = 0.264$ ;  $P_{MAT} = 0.303$ ;  $P_{GRR,t-1} = 0.618$ ).

$$GRR_t = -35.721 - 5.747 \times MST - 0.206 \times GRR_{t-1}$$

Despite the clear tendency in Fig. 5b the results only showed a non-significant evidence of an effect of MST on GRR ( $r^2 = 0.729$ ;  $P_{MST} = 0.177$ ;  $P_{GRR,t-1} = 0.722$ ). Additionally, we investigated whether there was any significant statistical correlation between GRR and MAP. The results showed a firm correlation ( $r = 0.819$ ; d.f. = 5) within a 0.05 level of significance. To confirm this we once more computed a model using multiple linear regression incorporating MAP and autocorrelation:

$$GRR_t = -10.862 + 0.029 \times MAP - 0.382 \times GRR_{t-1}$$

which only showed a weak effect on GRR ( $r^2 = 0.571$ ;  $P_{MAP} = 0.300$ ;  $P_{GRR,t-1} = 0.595$ ). In spite of this, we believe that Fig. 5c shows ample evidence

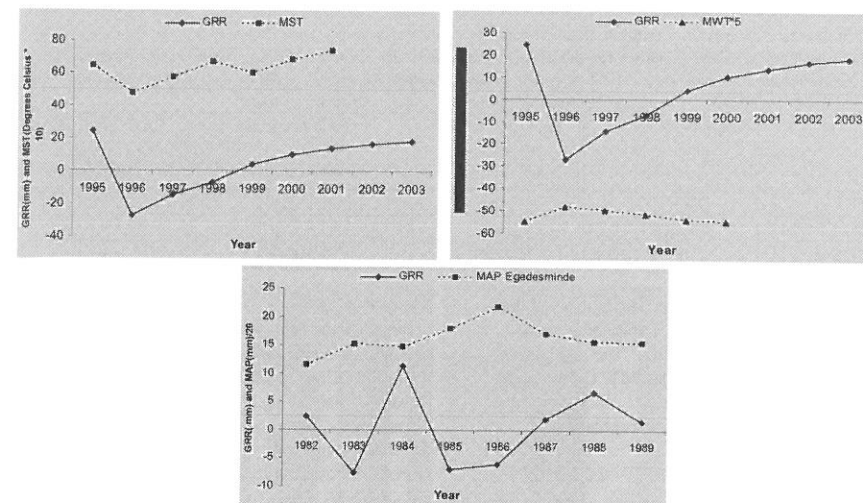
of a positive relationship between precipitation and GRR.

#### Røde elv 1990

Otolith analyses of the annual GRR from Røde elv individuals caught in 1990 showed no significant correlation with available average temperatures from Egedesminde ( $r = 0.459$ ; d.f. = 7). Still, the clear evidence of a relationship between MAT and GRR in Fig. 5d impelled us to compute a model by multiple linear regression:

$$GRR_t = 2.822 + 0.545 \times MAT - 0.249 \times GRR_{t-1}$$

Not surprisingly, the model showed only a very weak effect of MAT ( $r^2 = 0.264$ ;  $P_{MAT} = 0.303$ ;  $P_{GRR,t-1} = 0.618$ ). Still, the observed relationship is



**Figure 6.** (A) Data obtained in 2004 showing GRR in Arctic charr from Kangarsuk plotted against fluctuations in MST (GRR = Growth rate residuals; MST = Mean summer temperature;  $r^2 = 0.802$ ;  $P_{MST} = 0.04$ ;  $P_{GRR,t-1} = 0.725$ ). (B) Data sampled in 2004 showing GRR in Arctic charr from Kangarsuk plotted against fluctuations in MWT multiplied by 5. (GRR = Growth rate residuals; MWT = Mean winter temperature;  $r^2 = 0.997$ ;  $P_{MWT} = 0.002$ ;  $P_{GRR,t-1} = 0.153$ ). (C) Data obtained from otoliths collected in 1990 showing GRR in Arctic charr from Kangarsuk plotted against fluctuations in MAP divided by 20 from Egedesminde/Aasiaat (GRR = Growth rate residuals; MAP = Mean summer temperature;  $r^2 = 0.570$ ;  $P_{MAP} = 0.122$ ;  $P_{GRR,t-1} = 0.184$ ).

convincing, when taking into consideration that the available climate data originates from Egedesminde. Additional exploration did not reveal any significant relationships between GRR and MAP, MST or MWT.

#### Kangarsuk 2004

For individuals caught at Kangarsuk in 2004 we had some difficulties calculating an accurate estimation of fork length. Applying the back-calculation formula yielded overestimated values of somatic growth. The problem arises because the population was very diverse in annual otolith growth patterns, and hence it was hard to prepare a proper model for the ontogenetic development used in prediction of individual growth rates.

Although we had some difficulties in obtaining good estimates of fork length, the analysis of

annual GRR showed two very persuasive relationships with the mean temperatures. When correlating the GRR with MST the result was a significant signal ( $r = 0.778$ ; d.f. = 6) within a 0.05 level of significance. Additional investigation revealed a correlation of GRR with MWT showing a negative relationship ( $r = -0.724$ ; d.f. = 6) within the 0.05 level of significance. These results together with the observed tendencies in Fig. 6a & b called for additional statistical modelling. Investigation of the relationship between MST and GRR by means of a multiple linear regression incorporating autocorrelation:

$$GRR_t = -97.660 + 15.154 \times MST + 0.086 \times GRR_{t-1}$$

**Table 4:** Statistical P values from multiple linear regression modelling between growth rate residuals, autocorrelation and climate parameters. Only P values for the climate parameters are shown (MAT = Mean annual temperature; MST = Mean summer temperature; MWT = Mean winter temperature; MAP = Mean annual precipitation; P = positive impact of parameter; N = negative impact of parameter; + no relationship evident).

Locality	Kangarsuk 2004	Kangarsuk 1990	Rode elv 2004	Rode elv 1990
MAT	÷	÷	0.051(N)	0.303(P)
MST	0.04(P)	÷	0.177(N)	÷
MWT	0.002(N)	÷	÷	÷
MAP	÷	0.122(N)	0.300(P)	÷

showed a significant connection that explained the results of the correlation ( $r^2 = 0.802$ ;  $P_{MST} = 0.04$ ;  $P_{GRR-1} = 0.725$ ). To examine the negative correlation between GRR and MWT we once more computed a model incorporating autocorrelation by multiple linear regression:

$$GRR_t = -275.986 - 25.882 \times MWT - 0.07 \times GRR_{t-1}$$

The model showed a very significant statistical effect of MWT on GRR ( $r^2 = 0.997$ ;  $PMWT = 0.002$ ;  $PGRR-1 = 0.153$ ). Thus, GRR show a significant negative relationship with MWT and a significant positive relationship with MST, without any significant autocorrelation.

#### Kangarsuk 1990

Otolith analyses of the annual GRR from Kangarsuk individuals caught in 1990 showed no significant relationship with available average temperatures from Egedesminde. The most promising results were obtained, when correlating GRR with the mean precipitation although the result was outside any level of significance ( $r = -0.49$ ; d.f. = 7). Likewise, creating a model by multiple linear regression:

$$GRR_t = -32.995 - 0.097 \times MAP - 0.535 \times GRR_{t-1}$$

showed an effect of MAP and autocorrelation on GRR ( $r^2 = 0.570$ ;  $P_{MAP} = 0.122$ ;  $P_{GRR-1} = 0.184$ ) but not within any level of significance. Still, taking the persuasive tendencies in Fig. 6c into consideration and a  $P_{MAP}$  of 0.122 there seem to be a relationship between the climate data from Egedesminde and the GRR from Kangarsuk in 1990.

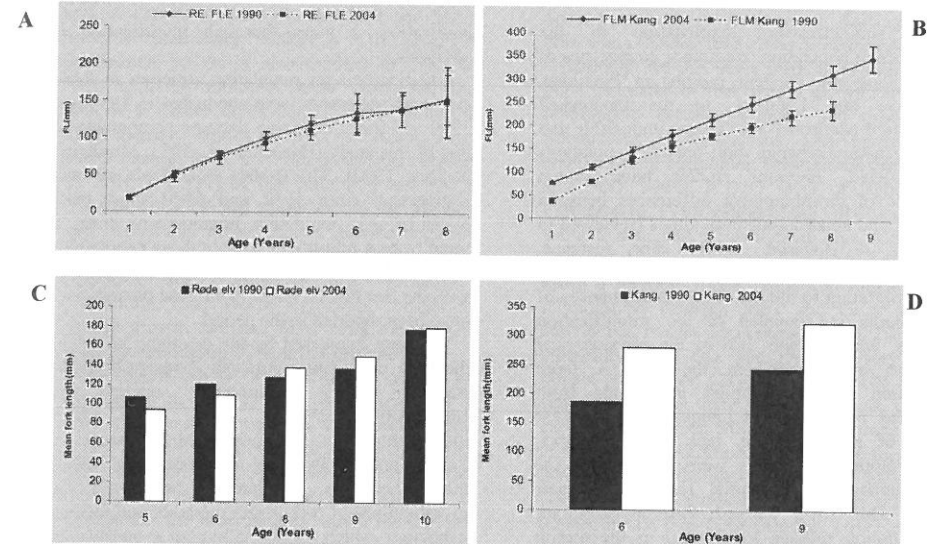
#### Comparison of mean growth rate from the two time series

The modelling of weather impact on fish growth

showed significant evidence of a relationship between fish fitness and climate. Furthermore, changes in mean values of fork length estimated means (FLEM), and thereby growth, during life history of fish living in 1982-1989 and 1995-2003 respectively, suggested a highly significant difference in growth between the two time periods. Consequently, we went on and performed an ANOVA test to statistically evaluate the difference between the two time series.

When applying the ANOVA test, and thereby assuming observations to have equal variance and approximately normal distribution, results showed that samples for Rode elv 1982-1989 and 1995-2003 can not be considered to be drawn from populations with equal means ( $p = 0.008$ ; d.f. = 7) (Fig. 7a). Using the same method on observations from Kangarsuk 1982-1989 and 1995-2003 shows an even more pronounced separation ( $p = 0.0004$ ; d.f. = 7) (Fig. 7b). Rode elv plots show a relative smaller FLEM in the period of 1991-2003 compared to 1982-1989. The opposite is true for Kangarsuk showing a relatively large FLEM in the period of 1991-2003, compared to 1982-1989.

To validate growth differences in the two periods, and thus avoiding back-calculating, FLM from equally old fish were compared between data from 1990 and 2004 (fig. 7c & d). Results from Kangarsuk showed a clear trend towards equally old charr being larger in 2004 compared to 1990, which is in consensus with the ANOVA results. On the other hand, there was no clear trend towards timescale separation in the charr population from Rode elv. Thus, especially the population in Kangarsuk has grown increasingly faster and got increasingly bigger since 1990.



**Figure 7.** (A) Changes in values of fork length estimated means showing growth during life history of fish living at Rode elv in 1982-1989 and 1995-2003 (RE = Rode elv; FL = forklength; FLE = Values of fork length estimated means; error bars:  $\pm 95\%$  C.L.; ANOVA:  $p = 0.008$ ; d.f. = 7). (B) Changes in values of fork length estimated means showing growth during life history of fish living at Kangarsuk in respectively 1982-1989 and 1995-2003 (Kang. = Kangarsuk; FL = forklength; FLM = Values of forklength estimated means; Error bars:  $\pm 95\%$  C.L.; ANOVA:  $p = 0.0004$ ; d.f. = 7). (C) Changes in fork length means (measured not back-calculated) from equally old fish, living at Rode elv in 1982-1989 and 1995-2003. (D) Changes in fork length means (measured not backcalculated) from equally old fish, living at Kangarsuk in 1982-1989 and 1995-2003 respectively (Kang. = Kangarsuk)

#### Discussion

##### Sampled localities differ markedly in population structure

The landlocked populations at Rode Elv and Kangarsuk are homogenous

The conducted PCA and cluster analysis produced results supportive of the conclusions from the qualitative survey (Fig. 2 & 3). Thus, results indicate a difference between population homogeneity. The landlocked populations in Rode elv and Kangarsuk are both ordinated with small-scale distances between individuals and hence appear homogenous in population composition. Contrarily, populations in Porsildso, Mellemsø and Langesø are ordinated with large distances between individuals, taken as a clear tendency of population heterogeneity. The individuals from Nipisat elv are, like the two landlocked populations, ordinated with small distances on the explanatory powerful first axes. This was expected due to similarity in analysed features e.g.

fork length and colour. This was not surprising, when considering that Nipisat individuals all were of the anadromous morphotype.

The populations' mean on the first axes in the ordination space and the standard error of this estimate (SEM) – which is an indirect measure of population variability – further indicates tendency of an essential difference in the character of the populations (table 2). Rode Elv and Kangarsuk are assigned mean population scores of respectively -2.3 and 0.75 and SEM-values of 0.32 and 0.23. Comparing these values with the same values obtained from Porsildso, Mellemsø and Langesø (mean scores 1.80 and 0.17; SEM-values of 0.86 and 0.98) provides clear evidence of a high degree of similarity between individuals in the two landlocked populations compared to populations in localities with connection to the sea. The anadromous individuals caught at Nipisat likewise appear to be homogenous (mean score: 1.56; SEM: 0.56).



The straightforward explanation to the difference in population structure is coexistence of anadromous and resident morphs in Porsildsø, Møllemsø and Langesø. In the landlocked populations anadromy is of course impossible and hence genetic exchange with outside populations is restricted. Previous studies have shown evidence of morphological differences between resident and anadromous individuals (reviewed in Jonsson & Jonsson, 2001). For instance, anadromous individuals have all lost parr marks, while migrating to the sea. The disappearances of parr marks are coupled to the smoltification process, which adapts fish to the physiological different environment in the sea. A large proportion of the sampled individuals from Porsildsø, Møllemsø and Langesø presents clear labels of anadromy e.g. lack of parr marks. Furthermore, individuals were found in these populations with residential features like parr marks. Due to a marked shift in strontium concentration relative to calcium in the otolith annuli from the time of anadromy, an analysis of chemical composition of otoliths from the heterogenic populations would further clarify the exact composition of anadromous and resident individuals (for details see Halden *et al.*, 1996).

A Cluster Analysis was conducted to supplement results of the PCA. The results are visualised in the comprehensible dendrogram (Fig. 4). The information in the dendrogram further establishes the results from PCA with a tight clustering of individuals from both Røde elv and Kangarssuk and with the anadromous fish from all localities established in the centre of the dendrogram.

Because we observed a high degree of morphological variation between otoliths from different localities, we incorporated a gradient analysis based on otolith morphology in an attempt to investigate the population structures. Such investigations are performed on otolith shape to map complex population dynamics in other fish species (Cardinale *et al.*, 2004). Yet thorough literature investigations did not reveal any similar attempts to solve questions related to population structure of Arctic charr. As presented in Fig. 4 and table 3 we retrieved some information from the PCA with a close scattering of especially individuals from populations in Røde elv, Kangarssuk and Nipisat. Not surprisingly, these populations were also, visually, those with most characteristic otolith morphology. For future

application, a more thorough investigation is advisable.

Investigations on population structure in Røde elv and Kangarssuk were conducted in 1982 and 1990 yielding qualitative datasets comparable to that of this study (Hansen *et al.*, 1983; Mordhorst & Due, 1990). The studies from Røde elv and Kangarssuk from 1982 and 1990 show clear evidence of population homogeneity, thus, it seem to be a robust character in these populations at least 22 years back in time. This is consistent with the fact that no major geological disturbances have been reported in the period.

We were impressed by the resolving power of the PCA and Cluster Analysis, both multivariate statistical tools traditionally applied by community analysts. These and related instruments like Nonmetric Multidimensional Scaling and TWINSpan (McCune *et al.*, 2002) may show to supplement the traditional investigations of fork length modality and feeding behaviour, which are normally used in analyses of polymorphism in Arctic charr populations.

#### *Detection of climate influences require homogenous populations*

Impacts of climate on animal populations have been demonstrated for several species in the Arctic e.g. musk oxen, reindeer, vole and wolf (Post & Forchhammer, 2002). In these studies target species have been morphologically and ecologically uniform compared to the Arctic charr, which represents one of the most polymorphic animal species (Adams & Huntingford, 2004). Consequently, several difficulties would be anticipated addressing the modelling analyses without consideration for known variation in life history characteristics for different morphs – e.g. anadromous and residents. We therefore focused analyses presented in this paper on the clearly homogenous populations in Røde Elv and Kangarssuk.

#### **Climate has a significant impact on population growth**

##### *Somatic growth in Røde Elv fluctuates with the temperatures and precipitation*

In the present study, we have proposed the pronounced cold adapted Arctic charr as a bioindicator for the climate on Disko Island. Our results establish the fish as a bioindicator with a close connection between MAT and annual growth rate of individuals in Røde elv from

2004. A correlation between the GRR and MAT shows a relationship within a 0.01 level of significance, which is also evident in Fig. 5a. When applying multiple linear regression the result is a further confirmation, which shows a strong negative impact of MAT on Arctic charr growth rates in Røde elv. The model answers for 91.7% ( $r^2 = 0.917$ ) of the variability and has a  $P_{MAT}$  value of 5.1% just above the 5% significance level. Additional investigations showed negative effect of MST on growth rate with an  $r^2$  accounting for 72.9% of the variability. Furthermore, there was a significant correlation between growth rate and MAP with the created model accounting for 57% of the variability.

The results show a significant impact of temperature on growth rate, which leads to a series of interesting questions with implications for how to view growth rates of Arctic charr. The central question is of cause, how to explain the temperature effect on the charr in Røde elv? It could be that the invertebrates, which the fish are feeding on, fluctuate with temperature. Of cause, this just leads to a new unanswered question: Why do invertebrates fluctuate with temperature? When looking at the graph in Fig. 5c, and statistical results, there is a positive agreement between the GRR and precipitation. It could be, that increased precipitation causes increasing feeding possibilities in the Røde elv delta. Such scenarios have been described before in the literature (Aass *et al.*, 2004), but whether this in our case is a pitfall, created by an interdependent relationship between temperature and precipitation, is difficult to determine. On the other hand, if we assume no significant rise in biomass of invertebrates by the increase in temperature and torrent in Røde elv, then increase in temperature could solely account for the observed negative effect on the charr. The increase in temperature leads to increase in periods with high metabolic rates consuming more energy. If these increased periods of high metabolic rate in the warmer water are not accompanied by an increase in food resources, then the net outcome would be a fall in fitness and hence growth rate (Russell *et al.*, 1996). Together with the fact that Røde elv already represent an unfavourable habitat, indicated by the small individual size (table 1), higher temperatures could solely cause a fall in growth rate because of higher metabolic rates in the turbid waters of Røde elv.

##### *Somatic growth in Kangarssuk fluctuates with both mean summer and winter temperatures*

Although we had some difficulties in obtaining good estimates of fork length growth, there is a relationship between climate and growth rate fluctuations in Kangarssuk. Our investigations show a strong correlation between the growth rate and MST within a 0.05 level of significance. Furthermore, a correlation of the GRR with MWT showed a negative relationship just outside the 0.05 level of significance. Additional studies using a multiple linear regression model of the relationships between MST and GRR revealed convincing results accounting for 80.2% of the variability (Fig. 6a). We found a very strong impact of MST on GRR within the 0.05 level of significance, thus there seem to be a very strong connection between MST and the growth of fish in Kangarssuk. Additionally, when we focused on the negative relationship between MWT and GRR, the model showed an even more significant impact of MWT on GRR (see Fig. 6b). The model accounted for 99.7% of the variability and had a  $P_{MWT}$  value under 1%. Thus, growth rates in Kangarssuk are strongly affected by both summer and winter temperature.

Kangarssuk is only 7 m at its maximal depth, and approximately 3 meters in average with much of the lake being shallow, which seems to create a possibility for a strong impact of temperature. In cold winters lakes with a depth of less than 2 m freezes to the bottom potentially killing all fish (Christoffersen, pers. comm.). Consequently, in midwinter fish in Kangarssuk are congregated in the deepest part of the small lake leading to tough competition. Such a scenario could cause a fall in overall fitness and hence growth rate, but this is not the case in Kangarssuk. Rather, we see a positive relationship between MWT and growth rate. The fact that the lake is very shallow would in theory also be a disadvantage for fish in warm summers. A very shallow lake is more likely to have elevated temperatures leading to fall in charr fitness compared to a larger lake. But once again this does not seem to be the case. Instead, our investigations showed a positive relationship with summer temperatures. Therefore, the summer temperatures do not exceed the optimal temperature for fish growth. This troubling issue of temperatures impact on the Kangarssuk population is further complicated by evidence of a natural occurring cold homothermic spring within the lake. Locals have described spring explosions

in winter, which was witness by the leader of Arctic Station Ole Frimer in 1992 (Fig. 1b). We will discuss this issue more thoroughly later. To summarise, we have found convincing results showing a significant impact of MWT and MST on the growth rate of Arctic charr from Kangarssuk.

#### *Earlier time series confirm climate impact on Arctic charr*

To further establish impact of climate, we incorporated otoliths from fish caught in 1990 at the same localities. Unfortunately, climate data from this period was not available from Godhavn. Thus, we were forced to use data from Egedesminde, which leads to a large amount of uncertainty in the models. In spite of the climate data, there seems to be a connection between the growth rate in Røde elv in the eighties and MAT from Egedesminde (Fig. 5d). Although the signal is pure, the multiple linear regression model leads to a  $P_{MAT}$  of 30.3%. Interestingly, this relationship is positive, which contradicts results obtained from 2004. It is not straightforward to hypothesise on such results, but it seems that the slight rise in temperature witnessed in the eighties did not affect the charr in the same way as in the nineties. There might be a threshold in the temperature impact leading to profoundly different effects. Accordingly, it has been shown that the definition of an optimum temperature for growth is only valid under the assumption that there is no food limitation (Jobling, 1981). Several studies have shown that the temperature at which growth rate is maximised is progressively shifted to lower temperatures, as the amount of available food is decreased (Russell *et al.*, 1996). Maybe fish in the eighties experienced an increase in fitness, and hence growth rate, because of increased temperature accompanied by not yet depleted food resources. When the temperature continued to increase in the nineties, fish reached a threshold where the energy resources could not sustain the now even higher metabolic rates. Consequently, there was a drop in fitness and hence growth rate.

The most compelling results from the eighties come from Kangarssuk (Fig. 6c). These show a negative effect of MAP on GRR ( $P_{MAP} = 0.122$ ). Taking into account the uncertainty of Egedesminde climate data, the effect is compelling. If we had access to climate data from Godhavn from this period it seems reasonable to assume more significant results. Still, it would

have been more satisfying to find a connection between MWT and growth rates taking results from 2004 into account. The results could be a consequence of different amounts of precipitations in the two periods. When comparing precipitation in the two periods and assuming equal precipitation in Godhavn and Egedesminde, there has been a 7.15 % decline in rainfall between the two decades (data not shown). It is possible that precipitation effect has dropped below a threshold value and ceased playing a significant role in regulating growth rate. Kangarssuk is located between the sea and steep mountains receiving water from the mountains before it enters the sea. Thus, sediment is carried from the mountains into Kangarssuk creating turbid waters affecting the Arctic charr. Similar scenarios for the Arctic charr have been proposed before (Aass *et al.*, 2004), but in our case it is of cause weakened by unreliable climate data. Another possibility is that the MAP effect on growth rate seen in our data from 1990 has drowned in the strong impact of MWT and MST witness in 2004.

#### **Analyses on large time scales indicates impact of global warming**

Analyses of growth rates from Røde elv and Kangarssuk clearly demonstrate that back-calculated fork length estimated means (FLEM) from the 1990 and 2004 time series differ. The 2004 charr population in Røde elv have experienced a relatively small fall in FLEM compared to 1990. Several factors such as elevated temperatures, increased turbidity or difference in prey composition may explain this tendency. We earlier discussed the consequence of longer summer periods on the cold adapted Arctic charr. Longer periods of warm water elevate the metabolic rate of the fish, but if no increase in food follows, the result is a lower growth rate. As mentioned before the definition of optimum temperature for growth is only valid under the assumption that there is no food limitation (Jobling, 1981). Hence, the temperature at which the growth rate is maximised is progressively shifted to lower temperature values, as the amount of available food is decreased (Russell *et al.*, 1996). Thus, we see compelling evidence of a threshold being breached, where the energy resources can no longer sustain the higher metabolic rates created by increasing temperatures. Consequently, there has been a drop

in fitness and hence growth rate. However, these results do not leave out the possibility that other parameters together with temperature can have an effect on growth in both landlocked localities. Hence, it is possible that increased metal accumulation together with the physiological stress of temperature leads to fall in growth rates (Köck *et al.*, 1996).

In the western Greenlandic region, higher temperatures are positively correlated to precipitation (Forchhammer *et al.*, 2002). The increased temperature and thereby precipitation will increase turbidity in a river system like Røde elv. During sampling, Røde elv showed great precipitation dependent turbidity with water turning completely red and turbid during even lighter rainfall (the name Røde elv means 'red river' in Danish). Our results show a weak positive connection between precipitation and growth rate and a much more significant negative impact of MAT on growth rate. These results contradict the fact that precipitation and warmer temperature should be positively correlated. However, the climate data obtained from the Arctic Station does not show any strong connection between precipitation and MAT (results not shown), which is in consensus with just mentioned results. Still, more research is needed to validate, whether feeding in Arctic charr rises during turbidity. Previous investigations on charr from Røde elv showed stomach content to be composed of surface insects and not chironomids as found at the present study (Chrisstoffersen, pers. comm.). Whether a rise in temperature or turbidity can induce a switch in prey types and thereby change growth rates needs further attendance.

Looking at results from Kangarssuk it is evident that FLEM values are considerably larger during the life history of the 2004 population compared to the population caught in 1990. This scenario is opposite to what was witnessed in the Røde elv population. As mentioned before, the back-calculation model for Kangarssuk 2004 series pose somewhat of a problem. This becomes evident, when the back-calculated fork lengths from time of capture are compared with true (measured) fork lengths at capture. The back-calculated FLEM's was larger than true values, which could result in the pattern observed in the figure. To avoid back-calculated data, FLM from equally old fish were compared between data from 1990 and 2004. Results showed a clear trend

towards equally old charr being larger in 2004 compared to 1990 (Fig. 7d). This validates the assumption that FLM differences are not solely a result of un-accuracies in back-calculation, but rather of a true character.

Why are back-calculated FLEM's from the most recent sampling different from observed values? Returning to the previously mentioned importance of population homogeneity, when using back-calculation models, lack of such homogeneity may explain our difficulties. Incorporated in the back-calculation model is a fitting of a trend line on FLE compared with age to evaluate ontogenetic development. If fish at the same age have a large variety in size, the result is a broad scatter, and a consequently low  $r^2$  value. A broad scatter and a low  $r^2$  value (0.875) were indeed observed at Kangarssuk 2004 series. This observation strongly implies some kind of heterogeneity in the 2004 population. During sampling, it was noted that several fish had large wounds caused by bacterial, fungal or viral infection (Fig. 1d). This may explain the lack of population homogeneity. If a fraction of a charr cohort for some reason becomes infected, it would result in slower growth in infected fish compared to the uninfected. This scenario would explain observed differences in size at equal age and consequently lack of accuracy, when applying the back-calculation model.

The large infections are also interesting when considering temperature dependence. Parasitic, viral and bacterial infections in fish are positively correlated to ambient temperatures (Decostre *et al.*, 1999, Cecchini *et al.*, 1998, Tucker *et al.*, 2000). Considering the low maximum depth, and the high water temperature measured at Kangarssuk, it is possible that the charr population has reached the limit with respect to temperature and pathogens. Studies conducted at Kangarssuk in 1990 did not reveal such massive infection in the population. The scenario becomes even more complicated, when considering the modelling by multiple regression and comparing life histories between 1990 and 2004, which revealed significant results showing that increasing summer temperatures have a positive impact on growth rates in 2004. However, when considering previous studies on Arctic charr temperature tolerance, it becomes clear that the Kangarssuk population is indeed living on the edge when it comes to reproduction. Gillet (1991) have found that ovulation in charr was inhibited above 10 °C

and slowed down above 8 °C. Moreover, if the temperature remained above 5 °C for several weeks, the quality of the eggs was relatively poor because of over-ripening. Furthermore, studies on Arctic charr embryonic survival at eyed stage have showed a reduced survival of 14.6% at 7 °C incubation compared to 2 °C (Huuskonen, 2003). The fact that it during sampling was impossible to catch fish below age 5+, and that breeding therefore not have been successful since 1999, strongly suggest that the population have limited breeding success caused by elevated temperatures. This becomes even more evident when maximum depth (7 meters) combined with temperature measurements are taken into account. In Kangarsuk surface temperature and minimum temperature were respectively 10.1 °C and 8.3 °C (see table 1). Comparing these results with the fact that Gillet (1991) showed a marked decrease in ovulation above 8 °C, reveals evidence of elevated temperatures having a direct effect on Arctic charr. Other recent studies have showed that small intensively feeding Arctic charr (c. 1 g) suddenly died during acclimatisation at temperatures 21-22 °C, while some fish that did not feed or fed at low rates survived the acclimatisation period. It has been proposed that fish, which did not stop feeding at high temperatures suffered from hypoxia – that is transiently low levels of oxygen (Larsson, 2002). Furthermore, older studies conducted by Jobling *et al.* (1993) have showed that rates of growth in juvenile fish are significantly depressed already at temperatures above 15 °C. Whether water temperatures in Kangarsuk can reach 21-22 °C along edges of the lake, killing fry, is unknown, but reaching 15 °C is surely a possibility. There is currently no data on how large or how warm the cold homothermic spring occurring inside the lake is, but in winter it creates large disruptions of the ice cover (Fig 1b). Still, most cold homothermic springs on Disko Island ranges from 1.5-4 °C (Kristensen, 1988). Thus, the spring could actually function as a buffer keeping the lake cold during summer and warm in winter. Despite the possible cooling effect caused by the spring, results still indicate that the Arctic charr population in Kangarsuk is suffering from a reproduction failure. In contrast, the somatic growth seems to have increased together with viral, fungal or bacterial infections.

To summarise, the increasing temperatures seem to cause an increase in infections, growth

rate and decrease in reproduction. Thus, we propose that the fish have reached their thermal limit when considering infection and reproduction, but not with respect to growth rate. This argument has been further strengthened by evidence of temperature having a crucial regulating factor in Arctic charr reproduction. Hence, we follow the argument of Magnuson *et al.* (1979) and see the thermal niche of a fish as equally important as the food resource. The unexpected increase in growth rates can be explained by the finding of relatively large numbers of *Lepidurus arcticus* at Kangarsuk in 2004. This is highly unusual considering that the species have not been observed at the locality in 1990 (Mordhorst & Due, 1990). Furthermore, coexistence of Arctic charr and this classic prey species has to our knowledge not been observed before in Greenland. This contradicts scenarios described from Greenland (Jeppesen *et al.*, 2001) but is in consensus with studies from Norway and Canada (Christoffersen, pers. comm.). Thus, a scenario where *L. arcticus* has been introduced at some point since 1990 could explain the following increase in fish growth. The major lake at Kangarsuk is connected by a small stream to a very shallow fishless pond (up stream), which seemed to be a classic habitat for *L. arcticus* with a maximal depth of around 1.5 m (Christoffersen, 2001; Rogers, 2001). It could be that *L. arcticus* have colonized the major Kangarsuk lake from this smaller pond that surely freezes to the bottom every year killing all fish.

To conclude, results from the present study show that global warming already have had a notable impact on the pronounced cold adapted Arctic charr populations. The two populations, investigated in the present study have been affected in different ways. Thus, our results show that the effect of warming on Arctic charr growth and reproduction success, depend on the magnitude of change and on local factors such as depth, geology, system morphometry (river or lake), pathogens and food resources. Our results have to be viewed in context with the fact that mean air temperatures in e.g. August at sample sites have steadily increased from 4.9 °C in 1991 to 9.1 °C in 2001 (Hansen *et al.*, 2003). Thus, it seems highly possible that some shallow arctic lakes, with landlocked populations like Kangarsuk, within a relatively short time span no longer will hold the Arctic charr.

## Perspectives

In the present paper we have not only focused on our results that document a relationship between climate and growth rates, but also tried to explain the biological connection between the fish and the climate. We have presented a series of hypotheses to explain these connections, which need further investigations to be confirmed. In addition, it is strongly advisable that more research is conducted in this field, especially when considering the importance of Arctic charr as food resource for local Inuit communities. The fact that annual otolith increments in Arctic charr correlate with temperature pose several interesting possibilities. One is the possibility of sampling old otoliths from sediment cores, and hence clarify past climate changes on a local scale. Such a study could maybe document whether the present switch in growth rate has happened before or is truly unique.

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# The effect of *Nysius groenlandicus* (Heteroptera: Lygaeidae) on seed weight and germination of *Melandrium triflorum* and *Silene acaulis*

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This study examined how feeding of the seed bug *Nysius groenlandicus* (Zetterstedt) (Heteroptera: Lygaeidae) affects seed mass, percentage of germination and germination speed (time from sowing to emerging of the cotyledons). Different densities of *N. groenlandicus* were placed in petri dishes and offered seeds of *Melandrium triflorum* and *Silene acaulis*. Afterwards the seeds were germinated and germination percent was determined. Mean seed weight and germination percent showed a negative correlation with increasing density of *N. groenlandicus*. A negative relationship between germination and weight loss was seen for seeds of *M. triflorum* and *S. acaulis*. Germination speed was not significantly affected by increasing densities of *N. groenlandicus*. A food preference experiment showed that when *N. groenlandicus* was given the choice between seeds of *M. triflorum*, *S. acaulis* and dead *N. groenlandicus*, cannibalism was preferred.

**Key words:** *Nysius groenlandicus*, *Silene acaulis*, *Melandrium triflorum*, seed mass, germination, food preference, herbivory.

## Introduction

Among threats to seeds are attacks by insects that pierce and suck on developing or mature seeds. The fate of the attacked seed depends on the intensity of the attack. Insects can kill seeds when repeated attacks deplete seed nutrients or kill the embryo (Ceballos *et al.* 2002). At lower intensities of attack seeds can often mature and germinate. However, these non-lethal attacks might have negative effects on seed germination speed and fitness of the resulting seedling (Ceballos *et al.* 2002). Seed size is an important feature of a plant's life history. The larger the seed the more nutrients are available for the embryo. Since the seed size affects a seedling's chance for establishment (Winn 1988; Leishman & Westoby 1994) a reduction in the nutrients stored in the seed should reduce fitness of the developing seedling (Ceballos *et al.* 2002).

*Nysius groenlandicus* (Zetterstedt) (Heteroptera: Lygaeidae) is a piercing and sucking insect living in Greenland. Outside Greenland *N. groenlandicus* has been reported in Iceland, Lapland, Sweden and Norway (Böcher 1976). The genus *Nysius* is cosmopolitan; there are 106 known species<sup>1</sup> of *Nysius* many of which are important agricultural and horticultural pests (He *et al.* 2003).

*Nysius vinitor* (Bergroth) is a key pest of sunflower (*Helianthus annuus* L.) (Forrester & Saini 1982) and cotton (*Gossypium hirsutum* L.) (Chinajariyawong *et al.* 1989). *N. plebejus* (Distant) is a serious pest of sorghum crops (Hong 1986) and *Nysius huttoni* (White) is an economically important pest of wheat and brassica crops in New Zealand (He *et al.* 2003).

Much has been published regarding *N. groenlandicus* (e.g. Böcher 1972, 1975, 1976; Böcher & Nachman 2001) but its effects on seeds have never been investigated. In this paper we look into how grazing by *N. groenlandicus* affects fitness of mature seeds of *Silene acaulis* and *Melandrium triflorum*. The following subjects was analyzed:

- (1) How does grazing by *N. groenlandicus* affect the seed weight?
- (2) How does grazing by *N. groenlandicus* affect the germination percent?
- (3) How does loss in seed weight correlate with germination? And does it affect the two species in the same way?
- (4) Do different densities of *N. groenlandicus* affect germination speed?
- (5) Finally it was studied which food item *N. groenlandicus* prefers when given the choice

between: *M. triflorum*, *S. acaulis* and dead *N. groenlandicus*.

## Materials and methods

### Species studied

#### *Nysius groenlandicus*

The arctic-alpine seed bug *Nysius groenlandicus* can be found practically everywhere in Greenland. It is usually absent from humid and north-facing localities, and the highest density are found on south facing herb fields and steppes, where the density can be found to exceed 100 individuals per square metre (Böcher 1976).

In Greenland, *N. groenlandicus* is univoltine and hibernates in the egg stage. The eggs enter a diapause, the stability of which appears to be influenced by the day length experienced by the adult female (Böcher 1975). After five nymph stages, the adults appear in late summer. Both nymphs and adults feed on a great variety of plant seeds and fruits (Böcher 1972, 1976). Böcher (1972) discovered that *N. groenlandicus* had a pronounced food preference among different seeds and a preference regarding the maturity of those. He also found that these preferences changed during the development of the bug.

The feeding mechanism of *N. groenlandicus* has not yet been investigated; however, a lot has been published regarding the feeding mechanism of other heteropterous insects. Doss (1980) suggests that they simply pierce immature seeds with their stylus and suck out the juices. This might not be possible in mature seeds and it is therefore suggested that the bug injects salivary juices containing enzymes. These enzymes digest the grain carbohydrate and/or protein so that solubilised nutrients can be drawn through the bug stylus. The salivary juices may also soften the husks and outer pericarp to facilitate bug stylus penetration (Every *et al.* 1990; Every & Stufkens 1999). The feeding stance and general feeding behaviour of *N. groenlandicus* is much as described for other lygaeids (Eyles 1964; Sweet 1964).

The population size of *N. groenlandicus* depends on the weather of the previous year. A warm and sunny summer with little snow permits development of a large population. The opposite will result in a too short active season which could

hinder *N. groenlandicus* to complete its life cycle by an effective reproduction. This would have a negative effect on the density next year (Böcher 1976).

#### *Melandrium triflorum* and *Silene acaulis*

*Melandrium triflorum* and *Silene acaulis* both belong to the family Caryophyllaceae. They both produce relatively small seeds with a cylindrical embryo curved around the endosperm (Warming 1966).

*M. triflorum* is common in dry places in Greenland from Kangerlussuaq over North Greenland to Scoresbysund (Génsbøl 1998). Up to ten individuals of *N. groenlandicus* have been found in a single capsule of *M. triflorum*<sup>1</sup>.

*S. acaulis* has a circumpolar arctic and alpine distribution. It is found throughout Greenland especially in fell-field and heath vegetation (Böcher *et al.* 1978). The individual plants form dense, convex cushions due to much branching of the shoots. Cushions with ripe capsules are often densely populated by *N. groenlandicus*<sup>1</sup>. *Silene acaulis* has no vegetative reproduction and individuals are assumed to have the capacity to be very long-lived (Philipp 1997).

## Experiments

Five experiments were conducted to find out how the germination of seeds of *M. triflorum* was affected by the grazing of *N. groenlandicus*. Another experiment was set up to find out which food item *N. groenlandicus* preferred when given the choice among: seeds of *M. triflorum*, seeds of *S. acaulis* and dead *N. groenlandicus*.

The experiments were carried out in the summer of 2004 at Arctic Station (University of Copenhagen) situated in Qeqertarsuaq/Godhavn (69°15'N, 53°34'W).

Seeds of *M. triflorum* were collected in one day and at one location in Kangerlussuaq/Sønder Strømfjord (67°04'N, 50°30'W). Seeds of *S. acaulis* were collected near the Arctic Station on two different days and at two different locations. Both kinds of seeds were found on the plants in open capsules – seeds of *M. triflorum* were from

<sup>1</sup> Source: <http://www.environment-hawaii.org/803c.htm>

<sup>1</sup> Source: personal comment by Jens Böcher



the present year whereas seeds of *S. acaulis* were from the previous year.

*N. groenlandicus* in nymph stage four and five were used in all experiments and were caught by means of an aspirator. They were caught at Sorte Sand in front of Arctic Station (69°15'00.8''N, 053°31'15.9''W) and next to the mouth of Røde Elv (69°15'03.9''N, 053°29'53.9''W). They were all caught in or around *Honckenya peploides*. In between the experiments the bugs were kept in plastic petri dishes of nine cm in diameter lined with filter paper. Water was supplied in small eppendorf tubes plugged with cotton (cf. Böcher 1972). To avoid starvation sunflower seeds with no husk were supplied. All experiments were carried out in a laboratory at 20-23 °C. None of the experiments were placed directly in sunlight but there were approximately 20 hours of daylight each day.

#### Germination experiments

*N. groenlandicus* in different densities were placed in plastic petri dishes of nine cm in diameter lined with filter paper. Water was supplied as described above. In each of the five experiments a fixed number of seeds were selected to be grazed upon.

Table 1. Different variables for the five experiments

Experiments	No. of seeds per petri dish	No. of replicates	Density of <i>N. groenlandicus</i>	No. of grazing days
<i>M. triflorum</i> I	30	4	0, 2, 8, 14, 20	7
<i>M. triflorum</i> II	20	3	0, 5, 15, 25, 50	4
<i>M. triflorum</i> III *	30	3	0, 5, 10, 25, 50	6
<i>S. acaulis</i> I	40	3	0, 2, 8, 14, 20	9
<i>S. acaulis</i> II **	20	3	0, 5, 15, 25, 50	6

\* The dead *N. groenlandicus* were only replaced with living ones once a day. After the seeds had been grazed upon, they were transported to Denmark, where they were set to germinate at 22-26 °C in a room with no direct sunlight but approximately 13 hours of daylight each day.

\*\* After having been grazed upon the seeds were transported to Denmark and set to germinate under the same conditions as described in *M. triflorum* III.

Before and after *N. groenlandicus* fed on the seeds the weight of the seeds were measured with a Mettler Toledo (MT5) microbalance. Four to five times each day the dead *N. groenlandicus* were removed from the petri dishes and exchanged with living ones. Eppendorf tubes were refilled with water when needed. The five experiments were conducted in the same way but with different densities of *N. groenlandicus*, numbers of seeds and time span of grazing. Three experiments were carried out on seeds of *M. triflorum* and two on seeds of *S. acaulis* (Table 1):

To determine how grazing by *N. groenlandicus* affected germination, the seeds from the above described experiments were placed on wet filter paper in petri dishes. During the germination the filter paper was kept wet. Every morning the numbers of germinated seeds were counted. Germination was defined when two cotyledons had emerged.

#### Food preference experiment

Five times 50 *N. groenlandicus* were placed in five plastic petri dishes of nine cm in diameter lined with filter paper. In each dish approximately equal amounts of seeds of *S. acaulis* and *M. triflorum* were mixed and scattered in the dish. Furthermore four dead *N. groenlandicus* were placed in each petri dish. Water was supplied as previously described.

Every 15 minutes it was noted how many bugs were grazing and on which item. When the dead *N. groenlandicus* were sucked dry by other *N. groenlandicus* they were exchanged with newly killed ones. If some of the living *N. groenlandicus* died during the experiment they were exchanged with living ones. Since the seeds were provided in what was considered great surplus, they were not renewed during the experiment. The experiment was carried out for approximately seven hours. Handling of the dishes did not seem to disturb the bugs much during their feeding.

#### Results

##### Seed weight

Mean seed weight differ significantly between seeds of *Melandrian triflorum* and *Silene acaulis* (paired t-test:  $p < 0.05$ ,  $n = 5$ ) (Table 2). We also found a significant difference in mean seed weight between *S. acaulis* I and *S. acaulis* II (t-test:  $p < 0.05$ ,  $n = 5$ ) (Table 2). No difference was found between *M. triflorum* I, II and III (t-test:  $p > 0.05$ ,  $n = 5$ ) (Table 2).

Table 2. Mean ( $\pm$ S.E.) seed weight ( $\mu$ g) of non grazed seeds.\*

Seed	Mean seed weight ( $\mu$ g) $\pm$ (S.E.)
<i>M. triflorum</i> I	175.7 $\pm$ (8.4)a
<i>M. triflorum</i> II	168.5 $\pm$ (7.5)a
<i>M. triflorum</i> III	171.9 $\pm$ (8.1)a
<i>S. acaulis</i> I	258.5 $\pm$ (23.5)b
<i>S. acaulis</i> II	341.1 $\pm$ (25.7)c

\*Means followed by the same letters in columns were not significantly different (paired t-test,  $p > 0.05$ ).

#### Effect of attack by *Nysius groenlandicus* on seed mass

Equations of linear regression fitted to mean seed weight as a function of density of *Nysius groenlandicus* show that there is a significant negative relationship for all the seeds (Table 3) (Fig. 1). There is no significant difference between the last three data points for *M. triflorum* I & II (one-way ANOVA,  $F_{df=2,7} = 4.25$ ,  $p > 0.05$ ). This results in a curved tendency which is not obvious for *M. triflorum* III, *S. acaulis* I and II where the last three data points are not significantly different ( $F_{df=2,7} = 4.25$ ,  $p < 0.05$ ).

Table 3. Equations of linear regression fitted to mean seed weight ( $\mu$ g) and density of *N. groenlandicus*.

Seed	Equation of linear regression $\pm$ (S.E.)	R <sup>2</sup>	p
<i>M. triflorum</i> I	$y = -4.9x \pm (1.1) + 171.4 \pm (13.2)$	0.87	0.023
<i>M. triflorum</i> II	$y = -2.3x \pm (0.4) + 151.1 \pm (10.6)$	0.91	0.011
<i>M. triflorum</i> III	$y = -2.1x \pm (0.3) + 180.1 \pm (8.6)$	0.93	0.008
<i>S. acaulis</i> I	$y = -2.6x \pm (0.4) + 252.1 \pm (4.8)$	0.93	0.008
<i>S. acaulis</i> II	$y = -3.7x \pm (0.5) + 333.6 \pm (12.9)$	0.95	0.005

#### Effect of attack by *Nysius groenlandicus* on germination

To determine if there are any significant differences between data points in each of the figures (a-e) in figure 2 a one-way ANOVA is used on data from *S. acaulis* (no difference between the variances) and a Kruskal-Wallis one-way test are used on data on *M. triflorum* (difference between the variances). The tests show a negative correlation between percentages of germinated seeds and the density of *N. groenlandicus* in all five experiments.

Figure 2 illustrates a difference between the control values (density of zero *N. groenlandicus* / interception point with y-axis) for *M. triflorum* and *S. acaulis*. All three data points for the control values of *M. triflorum* I, II & III (Fig. 2a, 2b & 2c) show a significantly higher germination percentage than those of *S. acaulis* I & II (Fig. 2d & 2e) (t-test:  $p < 0.05$ ,  $n = 3$ ).

No significant difference between the control values of neither *M. triflorum* I, II & III, nor between *S. acaulis* I & II was found (paired t-test,  $p < 0.05$ ).

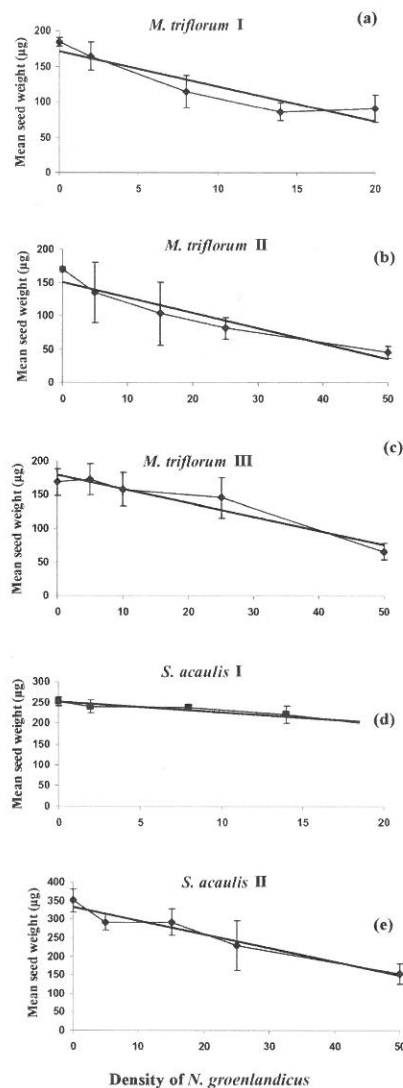


Fig. 1. Seed weight of *M. triflorum* (a-c) and *S. acaulis* (d-e) as a function of densities of *N. groenlandicus*. Number of grazing days and the number of seeds are different among the five experiments (See table 1). Equations of linear regression are fitted to mean seed weight as function of density of *N. groenlandicus*. Data points refers to sample means  $\pm$  S.E. (n=3).

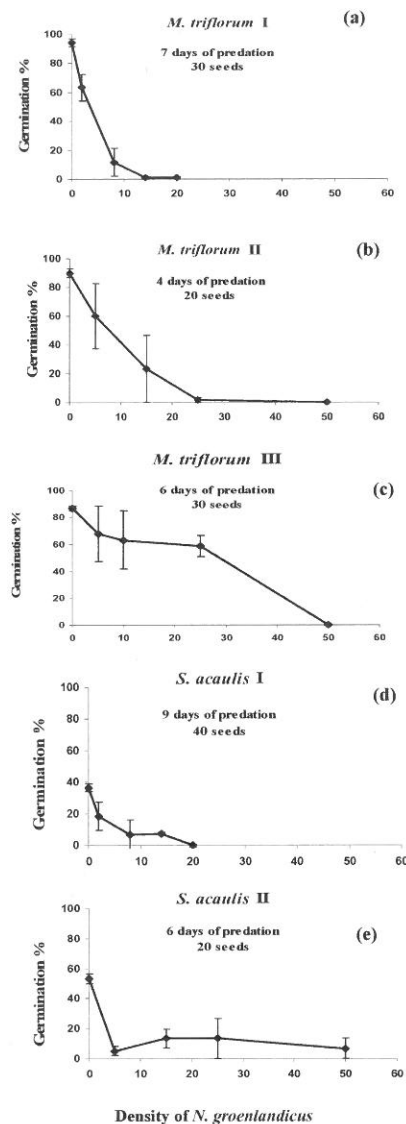


Fig. 2. Germination percent as a function of density of *N. groenlandicus*. Days of grazing varied from four to nine days between the experiments and the number of seeds varied from 20 to 40. Data points refers to sample means  $\pm$  S.E. (n=3).

#### Effect of seed weight loss on germination

For all the seeds used the percentages of weight loss have a significant influence on the percentage of germinated seeds ( $p < 0.05$ ; Tabel 4) (Fig. 3). T-tests between the regression lines confirm that there is no difference between the slopes (t-test:  $p > 0.05$ ).

Data points representing negative values on the x-axis can be explained by the fact that control seeds have gained weight due to water uptake (Fig. 3). *M. triflorum* has a tendency to tolerate greater weight loss than *S. acaulis*. *Silene acaulis* shows no germination after approximately 35 percent weight loss, whereas *M. triflorum* seems to tolerate a weight loss of approximately 60 percent (Fig. 3).

Tabel 4. Equations of linear regression fitted to  $\ln(\text{germination \%} + 1)$  and percentage weight loss (see Fig. 3).

Seed	Equation of linear regression $\pm$ (S.E.)	n	R <sup>2</sup>	p
<i>M. triflorum</i> I	$-0.08x \pm (0.004) + 4.39 \pm (0.15)$	5	1	0.00030
<i>M. triflorum</i> II	$-0.074x \pm (0.006) + 4.42 \pm (0.23)$	5	1	0.00090
<i>M. triflorum</i> III	$-0.099x \pm (0.002) + 4.56 \pm (0.05)$	5	1	0.00003
<i>S. acaulis</i> I	$-0.109x \pm (0.02) + 3.25 \pm (0.25)$	5	0.9	0.00700
<i>S. acaulis</i> II	$-0.088x \pm (0.02) + 3.55 \pm (0.46)$	5	0.8	0.02870

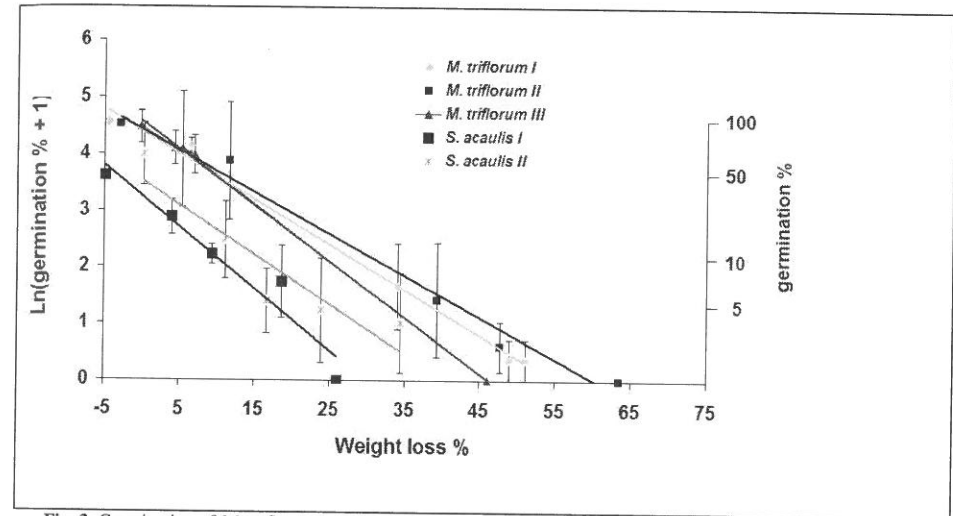


Fig. 3. Germination of *M. triflorum* I, II, III and *S. acaulis* I, II as a function of percentage weight loss. All regressions are significant at  $p < 0.05$ . Values on the primary y-axis are transformed to Ln-values. The secondary y-axis is logarithmic. Negative values on the x-axis can be explained because control seeds having gained weight due to water uptake. Data points refers to sample means  $\pm$  S.E. (n=3).



## Germination speed

In order to determine the germination speed and investigate whether the density of *N. groenlandicus* had an effect on germination speed, a germination index number was created. The index number indicates the mean percentage of germinated seeds divided by the maximum mean percentage of germinated seeds. According to a paired t-test on data from percentage germinated seeds in each experiments, there is no significant difference on germination speed among the densities of *N. groenlandicus* (paired t-test,  $p < 0.05$ ; Appendix B for *M. triflorum* II, III & *S. acaulis* II) (Fig. 4 a,b).

However there are two conflicting tendencies. One tendency shows that increasing density of *N. groenlandicus* has a negative effect on germination speed (*S. acaulis* I, II & *M. triflorum* III) (Fig. 4 b; Appendix B) and one showing that an increasing density of *N. groenlandicus* has a positive effect on germination speed (*M. triflorum* I & II) (Fig. 4a; Appendix B).

Figure 4 indicates that seeds of *S. acaulis* I need three more days to initiate germination boom than seeds of *M. triflorum* I. From the beginning of the germination *S. acaulis* I needs 11 days to reach maximum germination whereas *M. triflorum* I only requires five days (Fig. 4a-b). The tendency that *S. acaulis* needs more time to initiate the germination boom and to reach maximum germination is also evident for the rest of the experiments (Appendix B).

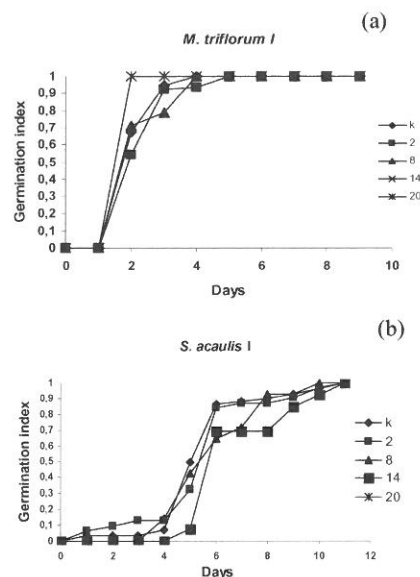


Fig. 4. Germination index of *M. triflorum* I (a) and *S. acaulis* I (b) as a function of days. The Germination index indicates the mean percentage of germinated seeds divided by the greatest mean percentage germinated seed.

## Preference

The results show a significantly higher intensity of attacks (average hit rate per 15 minutes) by *N. groenlandicus* on dead *N. groenlandicus* compared to attacks on seeds of *M. triflorum* and *S. acaulis* (Student z-test,  $p > 0.05$ ) (Fig. 5). The average hit rate per 15 minutes by *N. groenlandicus* is approximately three times as high on dead *N. groenlandicus* as it was on seeds of *M. triflorum* and *S. acaulis* (Fig. 5).

A z-test produced with a 90% confidence interval showed a significant difference in the intensity of attacks by *N. groenlandicus* between seeds of *M. triflorum* and *S. acaulis* - *N. groenlandicus* preferring seeds of *M. triflorum* ( $p = 0.07$ ) (Fig. 5).

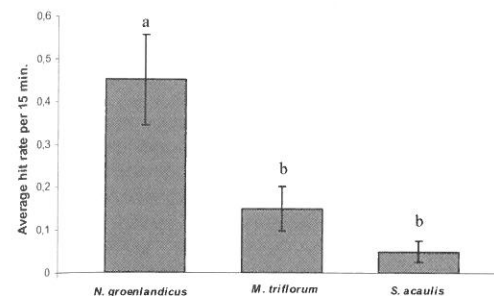


Fig. 5. Average hit rate per 15 minute on dead *N. groenlandicus* and seeds of *M. triflorum* and *S. acaulis* by *N. groenlandicus*. Different letters above histograms indicate significant difference (student z-test,  $p < 0.05$ ). Bars represent means  $\pm$  S.E. ( $n = 80$ ).

## Discussion

### Seed weight

The difference found in mean seed weight between the seeds used in the *Silene acaulis* I & II experiments (Table 2), could be explained by the fact that the seeds were collected on two different days, on different locations and under different conditions. The seeds used in the *S. acaulis* I experiment were collected in dry weather whereas the seeds used in the *S. acaulis* II experiment were collected after four days of rain. None of the seeds were dried before they were weighed and used. We suspect that the seeds in the *S. acaulis* II experiment had absorbed water and therefore were heavier than the seeds used in the *S. acaulis* I experiment. The differences in weight among seeds from the same species would possibly have been eliminated if we had dried (Leishman & Westoby 1994) and mixed them in a single pool.

As expected we found no significant differences in the mean seed weight between seeds used in the three *M. triflorum* experiments (Table 1). All the seeds were collected the same day, mixed and kept dry for some days before they were weighed.

Even though we found a significant difference in weight between seeds of *M. triflorum* and seeds of *S. acaulis*, the latter being heavier than the former, they are still both considered small seeds. The variation in size was not obvious to the eye.

## Effect of attack of *Nysius groenlandicus* on seed mass

As expected we found a negative correlation between mean seed weight and density of feeding *N. groenlandicus*. This correlation applied to all the experiments (Fig. 1). The strength of the effect depends on the intensity of the attack. The same was found by Ceballos *et al.* (2002) who studied the sucking insect *Hyalymenus tarsatus* and its effect on seeds of *Sesbania drummondii*. Since reduced seed mass leads to decreased fitness under competition (Winn 1988), the effect of sub lethal attack on seeds by *N. groenlandicus* can be described as parasitism.

The curved tendency seen in figure 1a & 1b (*M. triflorum* I & II) could indicate that all the seed mass is eaten and only the seed coat is left. Figure 1c (*M. triflorum* III) does not show this tendency. This could be explained by the fact that we did not exchange the dead *N. groenlandicus* more than once a day during the days they fed on the seeds compared to 3-4 times a day in the *M. triflorum* I & II experiments (Fig. 1a & 1b). The preference experiment showed that *N. groenlandicus* preferred cannibalism, implying that the bugs have eaten more on the dead bugs than on the seeds. This would explain why the seed weight does not decline in the same way in *M. triflorum* III as in *M. triflorum* I & II (Fig. 1a & 1b). Likewise the germination rate in *M. triflorum* III (Fig. 2c) stays high even at high densities of *N. groenlandicus*, which is consistent with the fact that the seeds do not lose much weight (Fig. 1c). It is interesting to note that the last data point in figure 1c is more or less the same as the last data point in figure 1a and 1b. This could support the theory that all the seed masses eventually are eaten and only the seed coats are left.

Figure 1d & 1e (*S. acaulis* I & II) show no curved tendency. This could be explained by the fact that the seeds of *S. acaulis* are heavier than the seeds of *M. triflorum* and as a consequence not all the seed mass is eaten. According to the preference study, seeds of *S. acaulis* are not as likeable as seeds of *M. triflorum*, which perhaps results in less grazing by *N. groenlandicus*.

Figure 1d & 1e show that at the highest densities of *N. groenlandicus* seeds of *S. acaulis* I & II have a percentage weight loss of approximately 25 %

and 50 % respectively. According to figure 3 this should cause a zero germination which is in consistence with figure 2e & 2d.

A factor which might affect the results of the small densities of *N. groenlandicus* is that the female *N. groenlandicus* feed more than three times as frequently as the males (Böcher 1972). If this means that the females also eat more than males, the sex ratio in experiments with small densities of bugs could thus influence the results. In experiments with a larger number of *N. groenlandicus* the distribution would be, statistically, more equal.

Another uncertainty factor that concerns all the experiments is that sometimes seeds were found underneath the filter paper in the petri dishes.

This could cause no grazing of those seeds and therefore a higher germination. It is notable that comparisons between the five curves in figure 1 are difficult because the experiments were conducted with different variables: different number of seeds and different number of days of predation. Each variable alters the curves independently. More seeds and/or less days of grazing cause a smaller seed weight loss and less seeds and/or more days of feeding make the seed weight drop further.

#### Effect of attack by *Nysius groenlandicus* on germination

It is evident that the percentage of germinated seeds can be related to the densities of *N. groenlandicus* (Fig. 2). This could be expected based upon figure 1 and figure 3. An increased density of *N. groenlandicus* causes an increase in weight loss (Fig. 1) and weight loss causes less germination (Fig. 3). Comparing the control germination percent (interception with y-axis) between *M. triflorum* (Fig. 2a, 2b & 2c) and *S. acaulis* (Fig. 2d & 2e) we found a significant difference. Control values for *M. triflorum* had a germination of 90-100 % whereas control values for *S. acaulis* had a germination of 40-60 %.

According to Winn (1988), we would expect that the control seeds of *S. acaulis* had a larger germination percentage than control seeds (non grazed seeds) of *M. triflorum* because they are heavier. An explanation why we see a relatively small germination by seeds of *S. acaulis* could be that the seeds are from last year. They might have

been exposed to different kinds of pathogens and attacks from *N. groenlandicus* in a longer period than *M. triflorum*, which were from the present year.

As pointed out before, the variables: number of grazing days and number of seed used, should be taken into consideration when comparing the five different curves in figure 2. Each variable alters the curves independently.

#### Effect of seed weight loss on germination

In concordance with Janzen (1976), who reported that herbivory on seeds lowered the germination percent; figure 3 confirms (as pointed out earlier) that loss in seed weight has a substantial impact on the percentage of germinated seeds.

The fact that there were no differences between the slopes of the regression lines indicates that the percentage of germination of *M. triflorum* and *S. acaulis* were affected equally by the percentage of seed weight loss. An explanation could be that both *M. triflorum* and *S. acaulis* belong to the same family. They have almost similar anatomy and physiology (Warming 1966) and therefore respond equally to the weight loss percentage.

We found that *M. triflorum* can withstand a seed weight loss of up to approximately 60 percent, whereas *S. acaulis* only can withstand approximately 35 percent before no germination is observed (Fig. 3). These values are exclusively determined by the control germination values since there are no significant differences between the slopes of the regression lines.

#### Germination speed

There are no significant effects of different densities of *N. groenlandicus* on germination speed (Fig. 4); it seems that the seed either germinates or it does not. If it does, it germinates at the same speed as the control seeds. This is not what we expected. found that feeding by a seed bug (Hemiptera: Lygaeidae) on seeds of *Gossypium sturtianum* and *Gossypium thurberi*, caused the seeds to germinate sooner than they otherwise would. That is if they were not destroyed. Karban & Lowenberg (1992) suggest that the mechanism of this enhanced germination speed simply is caused by seed coat rupture. The insects break the otherwise sealed seed coat and enables water and gases to reach the embryo faster. Only the data

obtained in *M. triflorum* I & II (Fig. 4a; Appendix B) seems (not significant) to support Karban & Lowenberg (1992). Otherwise the trend (not significant either) is that feeding by *N. groenlandicus* affects germination speed towards a slower germination speed at higher densities of bugs.

Further investigations are needed to establish if and how the germination speed is affected by *N. groenlandicus*. More seeds should be used in the experiments and as a consequence more germination would eliminate some of the uncertainties. It is worth mentioning that at some of the high densities of *N. groenlandicus* only a single seed germinated, which is statistically unsatisfying. As mentioned before, comparison between the data obtained in different set-ups is problematic due to the fact that the variables<sup>1</sup> are not the same among the set-ups.

#### Preference

The results from the preference experiment clearly shows that if given the choice between seeds of *M. triflorum*, seeds of *S. acaulis* and dead *N. groenlandicus*, cannibalism is preferred. It is important to point out that these results might only apply to nymphs of fourth and fifth instar since Böcher (1972) found that the preference changed with age.

Böcher (1972) noted that sometimes a bug, which was soft-skinned and unable to move away during ecdysis, was sucked dry by others. During our study we observed that *N. groenlandicus* also seemed to attack the weakest ones. This was especially observed in petri dishes with the highest densities of *N. groenlandicus* and may be due to the artificial situation with more stress. The preference for cannibalism could be caused by the larger nutrient concentration in the bodies of *N. groenlandicus* than in seeds (Hartley & Jones 1997), or because it is easier to pierce through the soft skinned part of the bug than a seed coat. Another possibility is that dead *N. groenlandicus* smell more and/or are larger than seeds and therefore easier to find. We tried to eliminate any difference in quantity between *S. acaulis*, *M. triflorum* and dead *N. groenlandicus* in the petri

dishes by using approximately equal amounts of seeds from the two plants and only four *N. groenlandicus* in each dish.

The tendency toward a preference for *M. triflorum* rather than *S. acaulis*, indicated in figure 5, might be a result of a thicker and/or a harder seed coat of *S. acaulis*. This needs to be further analysed.

#### Remarks

While this study only considered effects of *N. groenlandicus* on seed weight and germination, other effects of the attack should be mentioned. Not only are nutrient reserves in seeds of *S. acaulis* and *M. triflorum* reduced by *N. groenlandicus*, but damage to the seed coat can also facilitate transmission of pathogens (Harman 1983; Kremer & Spencer 1989; Mills 1983) or initiate biochemical changes that reduce seed fitness (Ceballos *et al.* 2002). Impermeability of dormant seeds to oxygen protects lipid and protein reserves from oxidative degradation. Oxygen entering pierced seed coat leads to deterioration, characterized by a reduction in levels of proteins, lipids, ATP pools, RNA, and polysaccharides and as a consequence, the metabolism of seedlings is seriously disrupted (Anderson & Baker 1983). As mentioned this might be one of the reasons why we see a reduced germination by seeds of *S. acaulis*, which are from last year and might have been exposed to different kinds of pathogens in addition to attacks from *N. groenlandicus*.

Cipollini & Stiles (1991) found that even if the seeds had relatively intact and functional cotyledons, some showed evidence of hormonal imbalance due to fractionated or excised embryo tissue. In our study we noted germination when the cotyledons were visible. According to Cipollini & Stiles (1991) this does not necessarily mean that the seedling would have survived.

Dormancy allows seeds to survive periods of the year that are unfavourable for seedling establishment. If this dormancy was to be ended at an improper time it could perhaps have a negative effect on seedling establishment. Ceballos *et al.* (2002) found that seeds whose coats were pierced by a piercing-sucking insect (*Hyalymentus tarsatus*) (Heteroptera: Alydidae) became permeable to water. The extent of this effect, in terms of rupture of dormancy, depends on the intensity of the

<sup>1</sup> Number of grazing days, the densities of *N. groenlandicus* and number of seed used.



attack. This was also found by Karban & Lowenberg (1992) who established that attacks by lygaeid and scutellerid seed bugs end the physical dormancy of seeds of *Gossypium sturtianum* and *Gossypium thurberi* and that the insects increased germination by breaking the impermeable seed coat. It could have huge ecological consequences if seeds germinate at an improper time. The importance of disrupt dormancy could be interesting to study further. In addition, it could also be interesting to see how attacks on developing seed affect seed fitness.

It should be mentioned, that this experiment was a pilot study and if we were to conduct similar experiments again, we would make sure to have less variation<sup>1</sup> among the set-ups. This would make it much easier to compare the data obtained in the different experiments.

## Conclusion

In summary, we found that the effect of attack of *Nysius groenlandicus* on seed weight was significant, with mean weight of seeds decreasing as intensity of attack increased. Loss of seed weight was correlated with germination - the more the seeds had lost in weight the less germination was observed. Seeds of *Melandrium triflorum* and *Silene acaulis* were equally affected by the percentage weight loss. Different densities of *N. groenlandicus* did not significantly affect germination speed (time from sowing to emergent), but two conflicting trends were observed (not significant). One showing that germination speed was positively affected by grazing of *N. groenlandicus*, another showing the opposite.

Finally it was found that if *N. groenlandicus* was given the choice among seeds of *M. triflorum*, *S. acaulis* and dead *N. groenlandicus*, cannibalism was preferred.

<sup>1</sup> Number of grazing days, the densities of *N. groenlandicus* and number of seed used.

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## Appendix 1



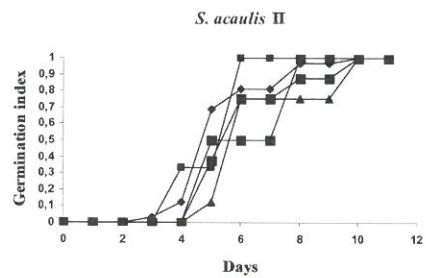
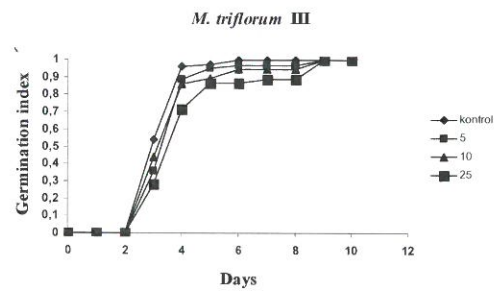
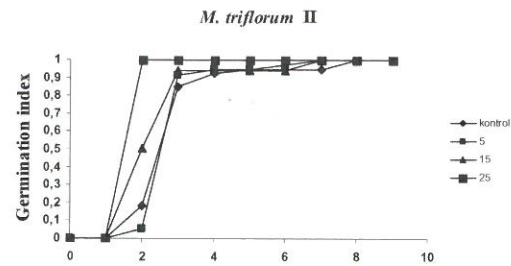
Experimental setup for *Silene acaulis* l.  
4 replicates with 5 densities of *N. groenlandicus*: 0, 2, 8, 14 and 20.



Petri dish with *Nysius groenlandicus* and seeds of *Silene acaulis*.



## Appendix 2



## Appendix 3



*Nysius groenlandicus* (fifth instar) sucking on a seed of *Silene acaulis*



Cannibalism



*Silene acaulis*  
(Tue-Limurt)



*Melandrium triflorum*  
(Treblomstret Pragstjerne)

# Analysis of a plant – flower-visitor network in north-western Greenland, Disko

Linnea H. Fosdal, Christina Løjtnant & Maiken Sønderholm

In this study we examine the interactions and species composition of a plant – flower-visitor network in a rich arctic shrub and herb valley on the arctic island of Disko. Three observation matrices are constructed: 1) a plant – flower-visitor matrix where 8 insect pollinated plant species were observed in approximately 200 minutes each, 11 insect genera were seen visiting the plants, forming a total of 43 interactions. 2) An insect – pollen matrix where 50 insects were caught. These were distributed on 21 species and 17 genera, pollen from 8 of the 11 plant species in question were recorded, and these formed 36 interactions. 3) A style – pollen matrix where styles from all 11 plant species in question were sampled, 23 interactions were recorded. The A/P-ratio, connectance, C, linkage level, L, nestedness and system temperature are calculated and discussed in relation to generalization vs. specialization, and compared to other high altitude, or latitude networks. For visualization, path length and calculations of one- and two-mode networks are made in Pajek. None of the matrices were significantly nested, which is probably due to undersampling. This means that insect species were feeding randomly on plant species or plant species were randomly visited by insect species. Generalist species is the dominating group in the system and plants are more generalized than insects, seen by the linkage levels of all matrices. The connectance of the insect – pollen matrix resembles studies from Zackenberg and especially Uummannaq. In the discussion we combine the insect – pollen matrix with the style – pollen matrix and thereby find some unseen interactions between *Phyllococe coerula* and *Pedicularis hirsuta* and their associated insects.

**Key words:** Plant – flower-visitor network. Connectance, and linkage level. Nestedness and system temperature. Generalists vs. specialists. Comparisons to other networks.

## Introduction

In all communities, the species within it interact with one another. Irrespective whether these interactions are classified as mutualistic, antagonistic or neutral, they all vary in space and time in their specificity and intensity (Elberling & Olesen, 1999).

Community studies are an ecological field with great traditions; most have focused on the patterns of abundance, species richness and prey – predator dynamics. The interest in ecological aspects of mutualistic interactions, such as plant-pollinator systems have not been great - pollination studies have primarily focused on description and classification and later the consequences of in- and outbreeding, mostly due to Darwin's (Jordano *et al.*, 2003) hypothesis of the coevolution of approximately 30 cm long-spored orchid (*Angraecum sesquipedale*) and the morphological specialized pollinator it ought to have – 40 years

later discovered to be a sphingid hawkmoth with a equally long proboscis. Since then, textbooks have viewed pollination interactions between

specialized plants and their pollinator species as paradigmatic of mutual specialization (Begon *et al.*, 1996).

It has long been thought that increased specialization is the course of evolution, but both deductive studies (Waser *et al.*, 1996) and theories tell that plant generalization is predicted as long as temporal and spatial variance in pollinator quality is substantial, and different pollinators do not fluctuate in unison and are equivalent in their pollination effectiveness. Pollination generalization is predicted when floral rewards are similar between plant species, because travel is costly and if constraints of behavior and morphology are minor, and/or pollinator lifespan is long relative compared to flowering of the individual plant species, the insect remains a generalist.

The study of pollination networks on community level was until the 1970's an ignored area, because thorough network analysis are both time and labour consuming, due to intensive observation and sampling periods and taxonomical difficulties with the pollinator taxa.

Jordano (Olesen & Jordano, 2002) analysed some of the first community data in 1987 where he

concluded that 1) facultative interactions of high generality are the rule; 2) the degree of connectance of mutualistic webs covaries with species richness in ways similar to that of food webs; and 3) most interactions are weak and when considering the mutual effects of animal and plants, which is strongly asymmetric. He also suggested that many of the null-interactions observed might be due to forbidden links.

Forbidden links are impossible interactions and therefore not observed in a system: This could e.g. be due to incompatible morphology, staggered anthesis with the pollinator activity and reduced phenological overlap or simply insufficient sampling!

One of the problems with the generalist vs. specialist perspective on pollination networks is how to quantify the terms. Generalization level (and specialization level) is a relative term and a pollinator or plant can only be classified as a generalist (or specialist) in comparison with other species within the network (Olesen & Jordano, 2002). A more comprehensive analysis of how to quantify and assess the terms is only in its very first phase (Olesen & Jordano, 2002).

Armbruster *et al.* (2000) in (Olesen & Jordano, 2002) distinguished between two types of specialization; the evolutionary and the ecological. The evolutionary is a process of evolving in the direction of more specialization - if a constant, predictable or uniform selection regime is present (Elberling & Olesen, 1999). The ecological specialization is a state and the organism is characterized by having only one to few interaction partners. It is only the latter that is possible to investigate in studies of our type.

Many textbooks (Olesen & Jordano, 2002) stress the generalized nature of pollination interactions and as pointed out by Olesen 2000 (Elberling & Olesen 2001); pollination systems and their plants and pollinators may be generalized (or specialized) in at least three ways 1) cumulatively over time and space, species interact with many mutualists and cumulatively over time the system acquires a high connectance. The latter is a measure of system generalisation and is defined as the fraction of realised interactions in the system; 2) species have simultaneously in the same habitat a random set of mutualists compared to the local pool of mutualists, and the system has a high fraction of species with a random set of mutualist species; and 3) species interact simultaneously in the same habitat with many mutualists and the system has a constant high

connectance. The most common way to measure generalisation level is a combination of 1 and 3. The variation through time and space also indicates generalisation level.

In a study, undertaken by Olesen & Jordano (2002), 29 complete plant-pollinator networks was analysed, they concluded that plants in higher latitudes are more generalized. No difference where found in the generalisation level among the pollinator taxa.

In another study by Olesen (unpub.) (Jordano *et al.*, 2003) he reviews 19 systems from 15 studies and he points out that lowland tropical and arctic systems are severely understudied. When compared to tropical systems the arctic networks are more manageable and have a greater simplicity due to fewer participating plants and flower-visitor species.

In this study we investigate a network of herbaceous plants and dwarf shrubs and their flower-visitors on the arctic island of Disko in the northern district of south-western Greenland, Qeqertarsuaq.

As with other islands, the species diversity is relatively low on Disko and Greenland because the found introduced species are mostly dependent on ocean currents or air born immigration from mainly Canada, Russia and Northern Scandinavia. Dangers from invasive exotic species are probably not an overhanging problem due to the harsh living conditions, which require special adaptations.

## Materials and Methods

### Study site

The project was executed on the island of Disko in Greenland, and the fieldwork took place from July 16<sup>th</sup> to August 6<sup>th</sup>.

The study site consisted of a 45 m<sup>2</sup>, homogenous plot, split into 3 × 15 m<sup>2</sup>, on the Southside of Disko (53°W, 69°N). The site was situated along a small homeothermic rivulet running SE below a steep hillside, at an altitude of 98 m a.s.l.

A typical Raunkiaer analysis was undertaken. A total of 30 samples were made with circles having an area of 1/10 m<sup>2</sup>, were only the flowering species in question was noted, when situated within the circles. A total list of higher plant species was constructed for the area (appendix 10).





Photo 1. Study site

### Sampling procedure

Observations were only made on sunny, calm days, in order to minimize effects of abiotic factors. Unfortunately the summer of 2004 turned out to be very cold and rainy, which considerably reduced the number of possible observation days. The dates of flower-visitor observations were July 20<sup>th</sup>, 23<sup>rd</sup>, 27<sup>th</sup>, 28<sup>th</sup>, and August 2<sup>nd</sup>. Observations were done in the peak of insect activity (10.00-17.00). Plants were observed in periods of 20 min, the succession of plants was in random order by drawing lots. In total each plant species was observed for approximately 200 min., ranging from 100 min. to 280 minutes, (3 plant species were never visited during the first 100 min. of the observation periods, and therefore excluded in the plant – flower-visitor matrix). Regardless of whether the insect was sun-basking or foraging for pollen and nectar, the visit was recorded when the insect was situated in the flower, because any visit is a potential pollination.

It was not possible to identify the insects in the field, so insects were subsequently caught by butterfly net, and preserved for later identification. The insects were identified by J. Böcher and V. Michelsen at Zoologisk Museum, Copenhagen. Voucher material is deposited at C. Løjtman.

In order to investigate the pollen deposited on the insects, pollen was removed from the insect by paralyzing it (see pollen pictures in appendix). This was done in the field by placing the insect in an Eppendorf tube, and lowering it into a thermos containing ice. After a couple of minutes, the insect was paralyzed, and it was possible to remove the pollen by rubbing it against a little piece of glycerol gelatine, while holding on to it with a pair of tweezers. The glycerol gelatine was subsequently placed on a microscope slide, melted with a lighter,

and covered with a cover glass. Paralyzing the insect made pollen removal easier and potential re-release of the insect possible.

Continuous style samples were collected for each of the plant species dealt with in the project, and the styles were preserved in glycerol gelatine on a microscope slide. Altogether we collected 4 styles from each plant species during the study period.

### Descriptive statistics

The number of animal species is denoted A, P the number of plant species, and I the number of interactions in the network. Network size is defined as  $M = A \times P$ . These numbers were calculated from our data, and compared to data from other fieldworks carried out in arctic, sub-arctic, and alpine network studies. The connectance,  $C = 100(I/(AP))$  is the percentage of all realized interactions within the network, and indicates the level of generalization in the network. In the corrected connectance,  $C_{corr} = 100((I - I_{min})/(AP - I_{min}))$  the minimum number of interactions needed to connect the network ( $I_{min}$ ) has been subtracted. Both were calculated, and so were mean linkage level of the visitor species ( $L_m = I/A$ ) and of the plant species ( $L_n = I/P$ ). Linkage level denotes the number of interactions per species, and indicates the generalization level per species. Linkage level  $L_m$  of animal species m, is the number of plant species visited by m, and vice versa  $L_n$  of a plant species n, is the number of animals visiting n.

### Network statistics

Nestedness and system temperature were calculated for the three matrices by the means of the program NestCalc (The Field Museum)

Nestedness is an analysis based on presence-absence data in the plant-animal matrix. In a pollination matrix, rows represent plant species, which are ranked in descending order of generalisation – the upper species having the highest linkage level. Columns represent animal species, are also arranged in descending order of generalization.

System temperature indicates the degree of nestedness. A perfect nested system has a temperature of 0°, whilst a system with a temperature of 100° is complete anti-nested. A system with a temperature above 55° is said to be random.

Pollination networks are nested if interactions of more specialized species are a proper subset of the

interactions already observed among the more generalized species. Therefore, all sets of interactions recorded for any species is nested within any other more generalized species. On the contrary networks are anti-nested if different plants attract different parts of the flower-visitor pool.

The networks were visualized in Pajek (Network/Pajek) (appendix 7, 8 & 9). The nodes symbolize organisms, whereas the lines connecting the nodes, represents the interactions. The plant – flower-visitor and insect – pollen matrix were transformed into two two-mode networks, with the flower-visitor species connected by lines to the plant species they visited, and likewise with the insect – pollen network. The style – pollen matrix was made as a one-mode network, because we only look at one factor (pollen), and not which insect species involved. The arrows point to which pollen there was found on the style.

All figures and tables were made in Excel.

### Results

#### Plant – flower-visitor matrix

A total of 11 animal genera were observed visiting the 8 flowering plant species (excluded is the 3 species that were not visited within the first 100 min.) forming a total of 43 interactions (appendix 1). The observed animals all belonged to Diptera, and the 8 plant species were distributed on 6 families. The linkage level,  $L_m$ , for animal species ranged from 1 to 8 interactions (mean  $\pm$  SD =  $3.9 \pm 2.30$ ). Linkage level for plant species,  $L_n$ , ranged from 3 to 8 interactions (mean  $\pm$  SD =  $5.4 \pm 1.51$ ).

Table 1. Average number of insect visits per plant species, calculated from the plant – flower-visitor matrix. Mean  $\pm$  S.D.

Plant species	No. of insect visits per plant species
<i>Alchemilla glomerulans</i>	9.4 $\pm$ 7.8
<i>Salix glauca</i>	5.7 $\pm$ 4.1
<i>Taraxacum</i> sp.	4.6 $\pm$ 4.4
<i>Polygonum viviparum</i>	4.3 $\pm$ 3.2
<i>Potentilla crantzii</i>	3.7 $\pm$ 3.5
<i>Tofieldia pusilla</i>	2.0 $\pm$ 1.3
<i>Erigeron humilis</i>	2.0 $\pm$ 1.5
<i>Pedicularis hirsuta</i>	2.0 $\pm$ 1.2

System temperature T (departure from perfect nestedness), was 30.37°, which is not significantly

lower than expected by chance (T in 1000 Monte Carlo simulations, mean  $\pm$  SD =  $43.94^\circ \pm 9.73^\circ$ ,  $P(T < 30.37^\circ) = 0.082$ ). Thus the network cannot be described as a nested structure.

The connectance, C, of the flower-visitor matrix was 48.9, and the corrected connectance,  $C_{corr}$ , was 41.6.

Species of Anthomyiidae, Scathophagidae and Muscidae visited more plant species and had a higher number of visits than the other dipteran families (Table 2).

Table 2. Average number of plant visits per dipteran family, calculated from the plant – flower-visitor matrix. Mean  $\pm$  S.D. \* the insects only visited 1 plant species, thus no S.D.

Families of Diptera	No. of plant species visited per Diptera sp.
Anthomyiidae	6.6 $\pm$ 6.9
Scathophagidae	6.5 $\pm$ 6.4
Muscidae	5.8 $\pm$ 5.4
Syrphidae	4.0 $\pm$ 4.4
Chironomidae	3.3 $\pm$ 1.0
Culicidae	3.0 $\pm$ 3.5
Dolichopodidae	2.5 $\pm$ 1.9
Calliphoridae	2.0 *
Ephydriidae	1.8 $\pm$ 1.0
Phoridae	1.5 $\pm$ 0.7
Mycetophilidae	1.0 *

#### Insect – pollen matrix

A total of 50 insects, belonging to 21 animal species, distributed on 17 genera, were caught for pollen identification (appendix 3). Pollen from 8 flowering plant species distributed on 7 families, were identified from the insects. Plants and animals formed a total of 36 interactions. The animals caught belonged to three orders (Diptera, Lepidoptera and Heteroptera), of which dipteran species were numerically dominant (appendix 3). *Salix glauca* was the most frequent pollen found on the animals (Fig. 1) which is consistent with the data in Table 3.

The linkage level,  $L_m$ , for animal species ranged from 0 to 4 (mean  $\pm$  SD =  $1.57 \pm 1.42$ ). Linkage level for plant species,  $L_n$ , ranged from 1 to 11 (mean  $\pm$  SD =  $4.50 \pm 3.30$ ).

System temperature T was 31.39°, which is not significantly lower than by chance (T in 1000 Monte Carlo simulations, mean  $\pm$  SD =  $37.93^\circ \pm 9.48^\circ$ ,  $P(T < 31.39^\circ) = 0.25$ ), and therefore the



network has no nested structure.

The connectance,  $C$ , of the insect-pollen matrix was 21.4, and the corrected connectance,  $C_{corr}$ , was 10.2.

#### Style – pollen matrix

Styles were collected from all 11 flowering plant species in question, distributed on 8 families and 23 interactions were recorded. *Salix glauca* was the most frequent pollen found on the styles (Fig. 1), and accounts for approximately 17% of the interactions.

By assuming that every pollen found is the result of a single interaction between a plant and an animal, the linkage level can be calculated.  $L_m$ , for animal species, ranged from 0 to 6 (mean  $\pm$  SD =  $2.09 \pm 1.81$ ).  $L_n$ , linkage level for plants, ranged from 1 to 4 (mean  $\pm$  SD =  $2.09 \pm 1.04$ ).

System temperature  $T$  was  $30.85^\circ$ , which is not significantly lower than expected by chance ( $T$  in 1000 Monte Carlo simulations, mean  $\pm$  SD =  $31.51^\circ \pm 10.90^\circ$ ,  $P(T < 30.85^\circ) = 0.48$ ), and thus the network is not a nested structure.

The connectance,  $C$ , was 23.2, and the corrected connectance,  $C_{corr}$ , was 13.6.

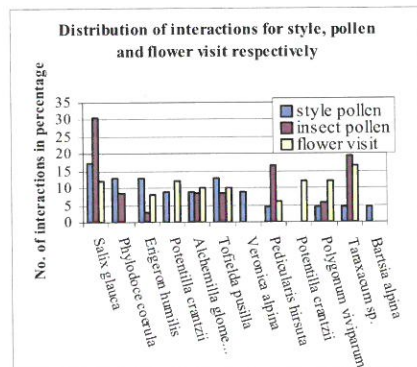


Figure 1. Frequency distribution of interactions among style pollen, insect pollen and flower visit interactions.

#### Raunkiaer circles

All of the studied species was observed in the samples, except *Alchemilla glomerulans*. The frequency analysis of the plot show no clear dominance of any specific flowering species and no species exceed to be present in over 20% of the total amount of samples. This corresponds to the visual impression of the area where the flowering species

were situated in small clusters of probably genets and/or ramets (see photo 1). Though no deductive measures were made, it was visually clear that the most frequent primary producers were *Salix glauca*, mosses and grasses.

The most common species, according to the Raunkiaer circles in the area were *Salix glauca*, *Potentilla crantzii*, and *Veronica alpina* (Table 3). When comparing the plant frequency data from Table 3 and the insect visitation data from Figure 1 it noticeable that one the most frequent plants (*Veronica alpina*) was excluded from the plant – flower-visitor matrix due to lack of interactions, this indicate that the plant frequency is not correlated with the level of insects visits.

Table 3. Frequency distribution of plant species in Raunkiaer circles.

Plant species	Hits	Frequency
<i>Salix glauca</i>	6	20.0
<i>Potentilla crantzii</i>	6	20.0
<i>Veronica alpina</i>	6	20.0
<i>Polygonum viviparum</i>	5	16.7
<i>Tofieldia pusilla</i>	5	16.7
<i>Pedicularis hirsuta</i>	3	10.0
<i>Erigeron humilis</i>	3	10.0
<i>Taraxacum sp.</i>	2	6.7
<i>Phyllodoce coerulea</i>	2	6.7
<i>Bartsia alpina</i>	1	3.3

Near the site was an area with a dense concentration of *Pedicularis hirsuta*. The valley, in which the site was situated, was dominated by *Salix*, *Harimanella*, *Phyllodoce*, and *Empetrum*. The area was very humid, with scattered shallow pools.

#### Discussion

In general, the harsh and unpredictable arctic environment has a small and simple flora and fauna compared to lower latitudes. Trees are missing, and the number of Lepidoptera, Hymenoptera and Coleoptera species is lowered. Herbs and shrubs are the dominating plant life forms, and Diptera species are by far the most common insect (Böcher; Elberling & Olesen, 2001). Under such environmental circumstances generalist species have an advantage compared to more specialized species, in that they do not depend on a single, or very few species for survival and reproduction.

It is not as crucial for insects to be as generalized as plants, because the plant community is more stable. The difference between plant and insect

generalization level (figure 2 & 3 and table 1, 2 & 4), could be due to the greater variance in insect composition from season to season and year to year (Bundgaard, 2003). Furthermore, the insects are dependent on the constant availability of food, so in that perspective the insects cannot endure great variation.

#### A/P-ratio

Each plant species had on average 1.4 times as many interactions as each insect species, which is rather low. Elberling & Olesen (1999) estimated the A/P ratio in a study from northern Sweden to 5.0, whereas a study by Lundgren (Lundgren, 2002) on the island of Uummanaq in north-western Greenland showed an A/P ratio of 1.53. Olesen & Jordano (2002) found that island networks showed a markedly lower ratio of animal to plant species (A/P) than mainland network. In this situation Disko cannot be considered an island, due to its size (the island has a length of about 160 kilometres, an area of 8,578 square kilometres) (The Free Dictionary.com by Farlex), and therefore this cannot be the explanation of our low A/P ratio. The similarity between the A/P ratio in Uummanaq and Disko is more likely due to underestimation of insect species as a result of difficulties identifying insect species in the field. Another reason could be their close geographical proximity to one another, along with unusually wet weather conditions in 2002 and 2004.

We found dipteran species to be dominating (appendix 3). In Greenland, Diptera is the dominating group of insects constituting about half of the total no. of insect species (Böcher), which is consistent with results from other high latitude systems. Elberling and Olesen (1999) concluded that the proportion of dipteran species of the total pollinator fauna increases with latitude, and since our study took place at high latitude, the dominance of Diptera is expected. Indeed, only dipteran species were observed in the plant – flower-visitor matrix, Hymenoptera was completely absent.

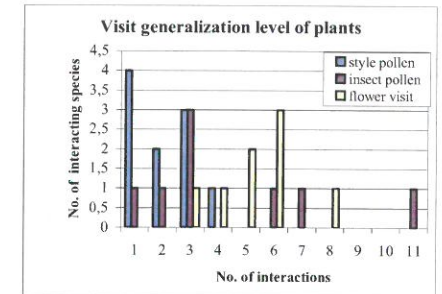


Figure 2 Distribution of generalization level, i.e. number of interactions per plant species. N (style pollen) = 10, N (insect pollen) = 8, N (flower visit) = 8.

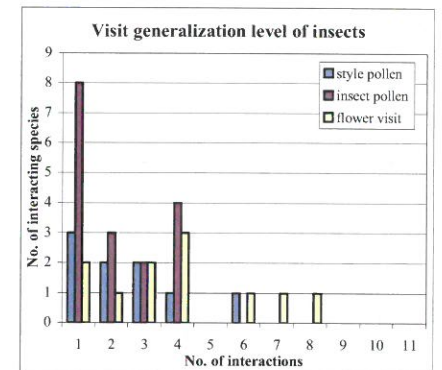


Figure 3 Distributions of generalization level, i.e. number of interactions per insect species. N (style pollen) = 9, N (insect pollen) = 17, N (flower visit) = 11.

#### Nestedness

None of the matrices in this study are significantly nested (appendix 4, 5 & 6), and therefore the plant species were visited randomly by animals, or animal species were feeding randomly on plants (Dupont *et al.* 2003). This is either because the pollination system is not nested at all or due to under sampling, because as Bundgaard (2003) concludes; the smaller or shorter time period the system is observed, the less interactions are registered and thereby the level of nestedness is reduced. Bundgaard (2003) refers to a study where all systems with a total of +78 species are significantly nested. That implies a reciprocal connection between nestedness and connectance, because larger networks yield lower connectance values.



## Connectance

The connectance of low latitude systems ranges between 3.4 and 28.1, whereas high altitude systems vary between 8.6 and 19 (Lundgren, 2002). We found the connectance of the plant – flower-visitor matrix to be 48.9, and the corrected connectance was 41.6. The use of  $C_{corr}$  is preferable because it allows one to ignore network size, and thus comparison between networks of different sizes is possible. The reasons for the extremely high connectance could be; 1) the insects were only identified to genus, which means that the number of different species is severely underestimated. Olesen and Jordano (2002) concluded that the connectance (C), decreased exponentially with species richness. 2) The matrix is very small, as a result of a small sample size. In general, connectance decreases hyperbolically with increasing matrix size and number of interactions. When networks become larger, the amount of possible interactions increases, whilst the percentage of each interaction decreases (Bundgaard, 2003). A larger sample size would thus probably result in a smaller connectance (Bundgaard, 2003). Additional observation time would probably increase the amount of so far not seen interactions, and thus higher connectance estimates. However, additional observation time would also add novel insect species to the matrix, decreasing connectance (Bundgaard, 2003).

Due to the previous mentioned sources of errors with the plant – flower-visitor matrix, it is more relevant and more informative to compare the connectance of the insect – pollen matrix, with the average connectance values of arctic areas (Table 4.). We consider the insect – pollen connectance to be the most reliable, because its animals, on contrary to the plant – flower-visitor matrix, were classified to species level.

The present study is located at 69°N, which is positioned within the range of other subarctic-arctic studies (60°N - 81°N) (Elberling & Olesen, 2001).

**Table 4.** Comparative table of results from other high latitude studies. S, sum of plant species and insects; A, number of animal species; P, number of plant species; M, network size (=AP); I, number of interactions recorded; C, connectance;  $C_{corr}$ , corrected connectance. \* Data from plant – flower-visitor matrix \*\* Data from insect – pollen matrix

Site	Latitude	S	A	P	M	I	$I_{min}$	$L_m$	$L_n$	A/P	C	$C_{corr}$	Source
Disko*	69°N	19	11	8	88	43	11	3.9	5.4	1.4	48.9	41.6	Own data
Disko**	69°N	29	21	8	168	36	21	1.6	4.5	2.6	21.4	10.2	Own data
Uummanaq	71°N	43	26	17	442	63	26	2.4	3.7	1.5	14.3	8.9	Lundgren 2002
Zackenbergl	74°N	107	76	31	2356	456	76	6.0	14.7	2.5	19.4	16.7	Elberling&Olesen 2001
Latnjajaure	68°N	141	118	23	2714	242	118	2.1	10.5	5.1	8.9	4.8	Elberling&Olesen 1999
Tenerife	28°N	49	38	11	418	108	38	2.8	9.8	3.5	25.8	18.4	Dupont et. al. 2003

The insect – pollen connectance ( $C = 21.4$ ), and the corrected connectance ( $C_{corr} = 10.2$ ) are very reasonable values. The Zackenberg study is the one that resembles this study the most, regarding the connectance ( $C = 19.4$ ) (Table 4). The corrected connectance, on the other hand, resembles Uummanaq the most ( $C_{corr} = 8.9$ ). This was expected, due to the fact that all three study sites are situated in high arctic environments.

## Insect – pollen matrix

The insect – pollen matrix may be the most reliable matrix, because insects are determined to species - on contrary to the plant – flower-visitor matrix - and all interactions are recorded because the method of removal of pollen is very efficient. The insect – pollen network was not significantly nested (appendix 5), and this is probably due to the small sample size, but maybe also to the fact that the weather in Greenland this year was rather abnormal – 4 times more precipitation than normal, which complicated the sampling. All insects were collected on sunny days, but 2/3 was collected on a day that followed several days of cold, rainy days. There was a smaller amount of pollen on these insects, so the network would probably look very different in a "normal" year. But as Bundgaard (2003) and Elberling & Olesen (2001) concludes: the between year and seasonal network-composition have significant fluctuations and this could also be expected of the present network. The present network does not give a description of the interactions in the total flowering period but merely a snap-shot of interaction in the final stage of the flowering period.

## Plant – flower-visitor matrix

Other studies of pollination networks concentrate their focus on the plant – flower-visitor matrix. To compare with these studies, we also conducted a plant – flower-visitor matrix. In order to cause as

little disturbance as possible, and avoid depletion of the insect population during the observation period, insects were not caught when interacting with the plants. This sample procedure made it possible for the insects to visit several flowers in the plot, and thereby to be observed several times. Still, this does not compensate for the insufficient insect identification performed in the field, which resulted in a plant – flower-visitor matrix, where insects were only identified to genus. Therefore, the level of information is low compared to other similar studies, and is thus almost impossible to compare, i.e. the connectance value (table 3), because our C value is unrealistically high. Whereas the connectance value of the insect – pollen matrix is more realistic and comparable with other studies.

The nestedness (appendix 4) of the plant – flower-visitor matrix is not significant. Reasons for this could be the lack of information from the insect identification, and the short observation period, because nestedness, and thus system temperature, increases with increasing observation period and network size (Bundgaard, 2003).

## Style – pollen matrix

To our knowledge, no one has ever examined the deposition of pollen on styles in a pollination network, so it is not possible to make any comparisons with other studies. The nestedness of the style-matrix is far from significant ( $P = 0.47$ ). We would also expect the matrix to have a low nestedness value due to our rather small sample size.

There are several problems to overcome when working with pollen deposition on styles; is our assumption about the 1 to 1 deposition (1 pollen species are deposited by 1 insect) at all realistic? Probably not, because an insect can carry pollen from several plant species (appendix 3) and thereby the grounds for our nestedness analysis are undermined!

Specialization is a mutualistic coevolution between plant and pollinator, but the purpose for the plant is not just to be pollinated, but also to reduce the amount of pollen that does not reach their destination - styles of the same species. Plants overcome this by placing the pollen on different parts of the pollinator, decreasing the chance of unintended deposition (Begon *et al.*, 1996). This increases the number of forbidden links when working with style – pollen matrices compared to the other matrices. Our motive to sample the styles was to catch some unseen interactions, by having

pollen from plant species A deposited on plant species B, that are not known to be visited by pollinators that visit species A. The reasons why we may not observe some interactions in the plant – flower visitor matrix, could be that the pollination takes place at other times of the day than our observation period, we could also miss the insects due their minute size or that the interactions are very rare.

Though it is not possible to directly extrapolate these findings to the plant – flower-visitor matrix, it is interesting to compare the style – pollen matrix with the insect – pollen matrix. This is demonstrated by *Phyllodoce coerulea* on which no visits were ever recorded during the observation period, and therefore excluded from the plant – flower-visitor matrix.

By looking at the style – pollen matrix (appendix 2), it is remarkable that *Phyllodoce coerulea* is the second most recorded, regarding pollen deposition on styles. When looking at the insect – pollen matrix (appendix 3), one finds three different insect species carrying pollen from *Phyllodoce coerulea*. The insects are: *Botanophila betarum*, *Aedes sp.* and *Clossiana chariclea*. By looking at the three matrices in combination makes it possible to make a deduction about possible unseen interactions between *Phyllodoce coerulea* and its associated pollinators.



**Photo 2.** Pollinator species of *Phyllodoce coerulea*, to the left *Clossiana chariclea*

<http://www.kolumbus.fi/esko.viitanen/images/ccharic.jpg>

to the right *Aedes sp.*  
[http://www.arbovirus.health.nsw.gov.au/areas/arbovirus/mosquit/mosqphotos/aedes\\_52.jpg](http://www.arbovirus.health.nsw.gov.au/areas/arbovirus/mosquit/mosqphotos/aedes_52.jpg)

Another example is *Pedicularis hirsuta*. Observations on this species were very sparse, but when looking at the insect – pollen matrix, an additional three pollinator species are detected: *Botanophila betarum*, *Aedes sp.* and *Helophilus goenlandicus* (appendix 3).

## Conclusion

Our study revealed that plants are more generalized than insects. The A/P ratio is 1.4 for the plant – flower-visitor matrix, and 2.6 for the insect – pollen matrix, which is within the range of other arctic network studies.

Dipteran species were found to be dominating, which is consistent with other high latitude studies.

Plants species can endure more variation than insects, because they are not dependent on a constant food resource, on the other hand insects can allow them self to be more specialized, because they have the advantage of being mobile and upon that plant societies is in general more stable than insect societies.

A characteristic property of other plant – flower-visitor network studies, is that interactions among species are not distributed at random. None of our matrices were nested which is possibly due to undersampling and underestimation of insects in the plant – flower-visitor matrix. This makes interactions randomly distributed among insects and plants, where insects feed randomly on plants or plants are visited randomly by insects. The plant – flower-visitor matrix showed an extremely high connectance, whilst the connectance of the insect – pollen matrix was more trustworthy, because the insects were identified to species level.

In the present study three kinds of matrices were investigated; plant – flower-visitor matrix, insect – pollen matrix and style – pollen matrix. By retrieving information from the three different matrices, it was possible obtain indirect information about the network in question, i.e. the unseen interaction between *Phyllodoce coerula* and *Botanophila betarum*, *Aedes sp.* and *Clossiana chariclea*.

It is not possible directly to combine the three matrices due to different taxonomical information levels. A more thorough investigation of styles and pollen deposited on insects would probably reveal a greater number of unseen interactions.

This study does not give a description of the interactions in the total flowering period but merely represents a snap-shot of interaction in the final stage of the flowering period.

We hope, in the future, to see other studies that combine these three matrices, to give a more differentiated picture of interaction networks.

## Acknowledgments

We are very grateful that we were selected and got the opportunity to experience real field work in such an interesting environment as Greenland. We would like to thank Arctic Station for a wonderful stay, in scenic surroundings. A special thank we send to our kind and always interested and helpful teachers, especially our project supervisor Marianne Philipp, lector at the botanical institute, Copenhagen University. We are in immense gratitude for the help with insect classification, kindly provided by Jens Böcher, research associate at Entomological Department at the Zoological Museum, and Verner Michelsen, Data Collation Manager of Fauna Europaea at the Zoological Museum. Master student at the University of Copenhagen, Rebekka Lundgren, was a valuable source of knowledge in the work with Pajek. Jens Mogens Olesen, associated professor at the Section of Ecology and Genetics, Institute of Biological Sciences, University of Aarhus, favoured us with literature suggestions and kindly invited us to the very interesting and rewarding Mother Nature Symposium at the University of Aarhus. Without the generous help from Svend G. Fiedler & Wife scholarship the project would never had become a reality.

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## Appendix 1

### Plant – flower-visitor matrix:

Diptera :		<i>Taraxacum</i> <i>sp.</i>	<i>Polygonum</i> <i>viviparum</i>	<i>Potentilla</i> <i>a. crantzii</i>	<i>Salix</i> <i>glauca</i>	<i>Alchemilla</i> <i>glomerulans</i>	<i>Tofieldia</i> <i>pusilla</i>	<i>Erigeron</i> <i>humilis</i>	<i>Pedicularis</i> <i>hirsuta</i>	Sum
Scathophagidae	<i>Scathophaga</i> <i>sp.</i>	3	10	1	9	20	4	1	4	8
Anthomyiidae	<i>Botanophila</i> <i>sp.</i>	3	4	6	11	20	1	1		7
Muscidae	<i>Spilogona</i> <i>sp.</i>	14		11	2		2	5	1	6
Ephydriidae	<i>Scatella</i> <i>sp.</i>	3		1			2	1		4
Dolichopodidae	<i>Dolichopus</i> <i>groenlandicus</i>		5			3	1		1	4
Chironomidae	<i>sp.</i>	3	4		4	2				4
Syrphidae	<i>Helophilus</i> <i>groenlandicus</i>	9		2	1					3
Culicidae	<i>Aedes</i> <i>sp.</i>	1	1		7					3
Phoridae	<i>Megaselia</i> <i>sp.</i>			1		2				2
Calliphoridae	<i>Calliphora</i> <i>uralensis</i>		2							1
Mycetophilidae	<i>sp.</i>	1								1
Sum		8	6	6	6	5	5	4	3	

## Appendix 2

### Style – pollen matrix:

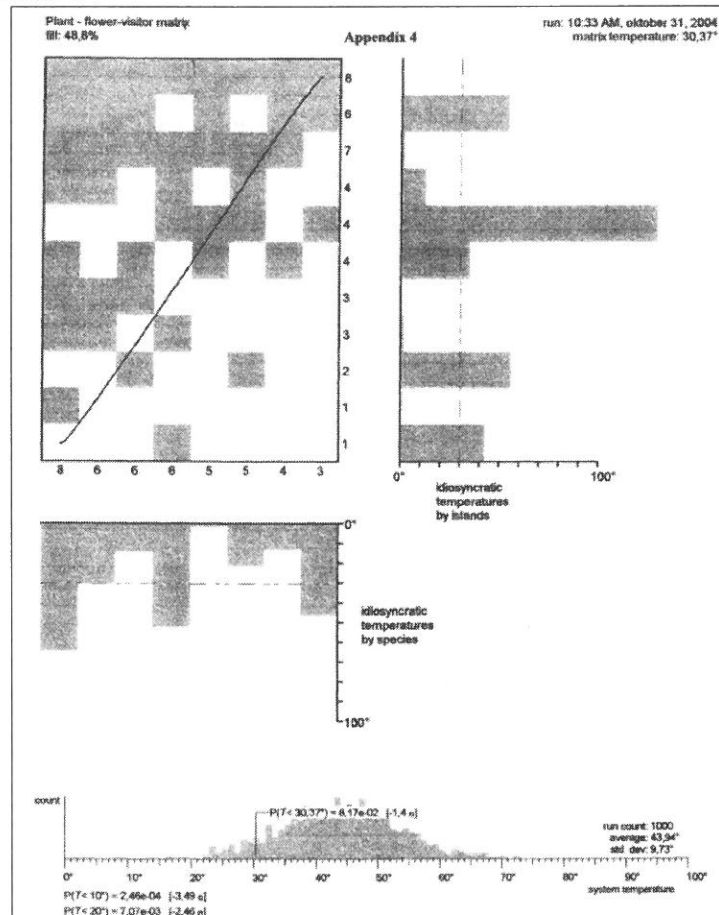
Pollen/Style	<i>Salix</i> <i>glauca</i>	<i>Phylodoce</i> <i>coerula</i>	<i>Erigeron</i> <i>humilis</i>	<i>Tofieldia</i> <i>pusilla</i>	<i>Alchemilla</i> <i>glomerulans</i>	<i>Potentilla</i> <i>crantzii</i>	<i>Veronica</i> <i>alpina</i>	<i>Pedicularis</i> <i>hirsuta</i>	<i>Bartsia</i> <i>alpina</i>	<i>Polygonum</i> <i>viviparum</i>	<i>Taraxacum</i> <i>sp.</i>	Sum
<i>Salix glauca</i>	X	X		X	X		X			X		6
<i>Taraxacum sp.</i>	X			X		X					X	4
<i>Potentilla crantzii</i>		X	X			X						3
<i>Pedicularis hirsuta</i>	X		X					X				3
<i>Erigeron humilis</i>			X		X							2
<i>Phylodoce coerula</i>	X	X										2
<i>Veronica alpina</i>							X					1
<i>Bartsia alpina</i>									X			1
<i>Tofieldia pusilla</i>				X								1
<i>Alchemilla glomerulans</i>												0
<i>Polygonum viviparum</i>												0
Sum	4	3	3	3	2	2	2	1	1	1	1	23

## Appendix 3

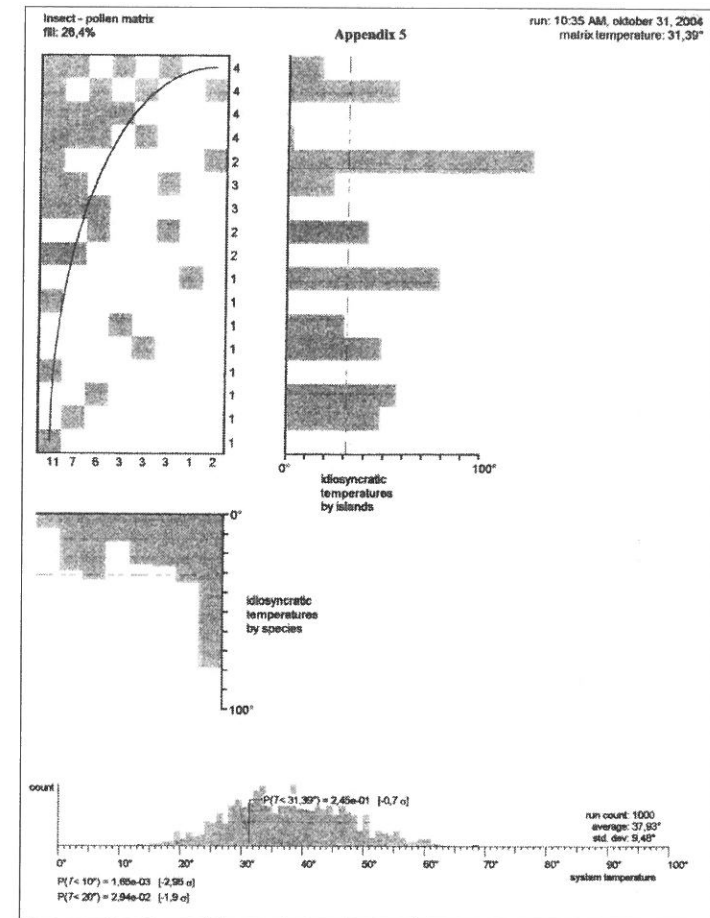
### Insect – pollen matrix:

Order	Family	Genus/ species	<i>Salix</i> <i>glauca</i>	<i>Taraxacum</i> <i>sp.</i>	<i>Pedicularis</i> <i>hirsuta</i>	<i>Phylodoce</i> <i>coerula</i>	<i>Alchemilla</i> <i>glomerulans</i>	<i>Tofieldia</i> <i>pusilla</i>	<i>Polygonum</i> <i>viviparum</i>	<i>Erigeron</i> <i>humilis</i>	Sum
Diptera	Anthomyiidae	<i>Botanophila betarum</i>	X	X	X	X					4
Diptera	Muscidae	<i>Spilogona arctica</i>	X	X			X	X			4
Diptera	Scathophagidae	<i>Scathophaga furcata</i>	X	X	X		X				4
Diptera	Culicidae	<i>Aedes sp.</i>	X		X	X			X		4
Diptera	Dolichopodidae	<i>Dolichopus groenlandicus</i>	X	X				X			3
Diptera	Syrphidae	<i>Helophilus groenlandicus</i>	X	X	X						3
Diptera	Muscidae	<i>Spilogona malaisei</i>			X			X			2
Diptera	Calliphoridae	<i>Calliphora uralensis</i>	X						X		2
Lepidoptera	Geometridae	<i>Entephria punctipes</i>	X	X							2
Diptera	Anthomyiidae	<i>Botanophila profuga</i>	X								1
Diptera	Anthomyiidae	<i>Zaphne frontata</i>	X								1
Diptera	Anthomyiidae	<i>Lasiomma picipes</i>	X								1
Diptera	Muscidae	<i>Spilogona sanctipauli</i>			X						1
Diptera	Ephydriidae	<i>Scatella sp.</i>		X							1
Diptera	Mycetophilidae	<i>sp.</i>					X				1
Lepidoptera	Scythrididae	<i>Scythris noricella</i>								X	1
Lepidoptera	Nymphalidae	<i>Clossana chariclea</i>				X					1
Diptera	Muscidae	<i>Spilogona trigonifera</i>									0
Diptera	Phoridae	<i>Megaselia sp.</i>									0
Diptera	Chironomidae	<i>sp.</i>									0
Heteroptera	Lygaeidae	<i>Nysius Groenlandicus</i>									0
Sum			11	7	6	3	3	3	2	1	

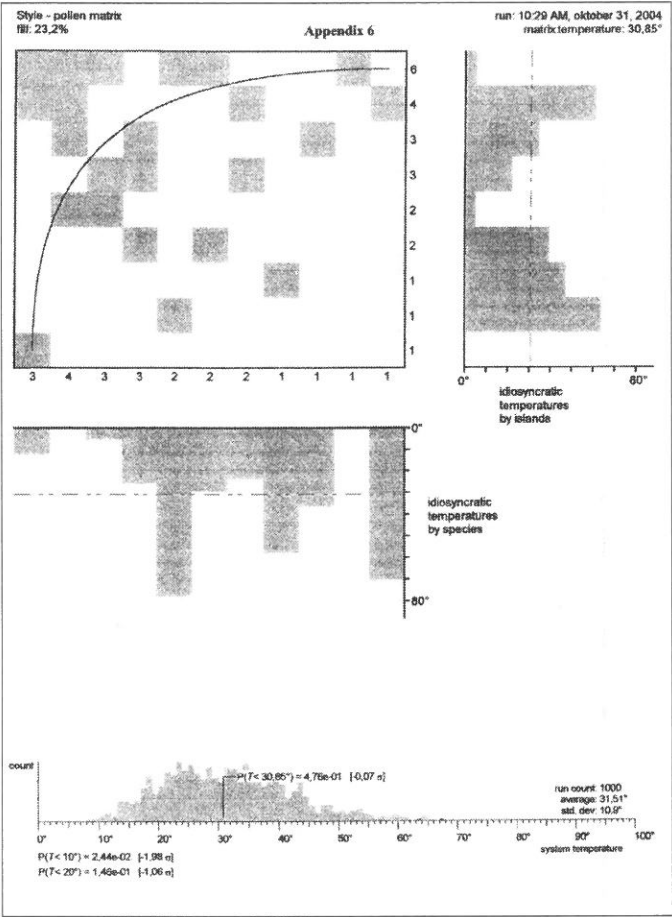
## Appendix 4



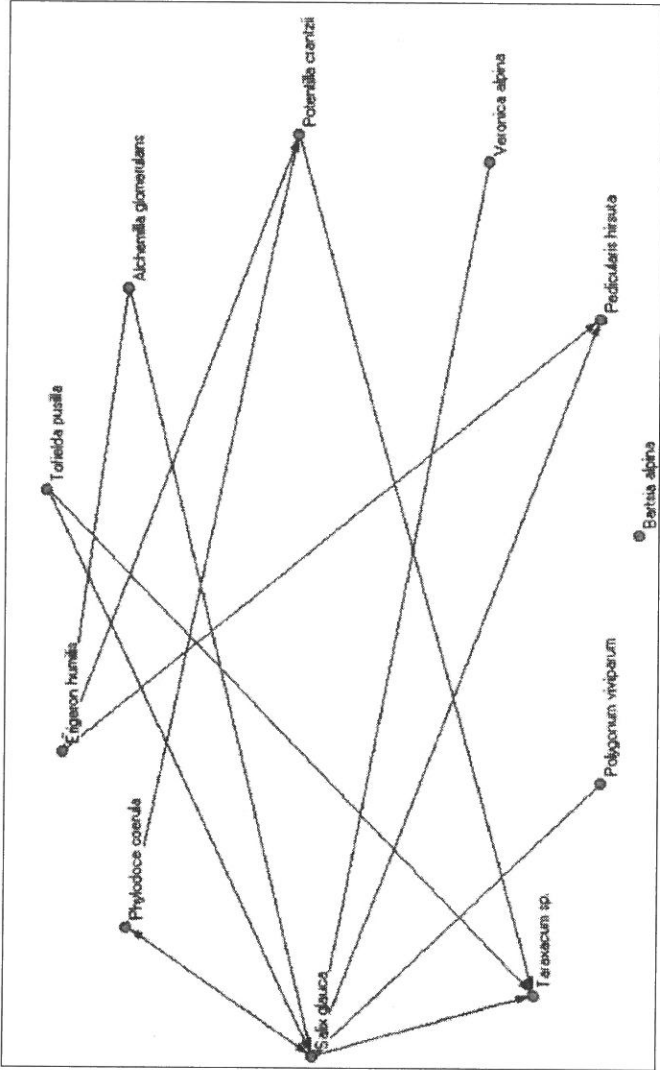
## Appendix 5



Appendix 6



Appendix 7







## Appendix 10

### Total list of plant species in the plot

*Alchemilla glomerulans*\*  
*Antennaria canescens*

*Barista alpina*\*

*Carex scirpoidea*  
*Cerastium arcticum*

*Empetrum hermaphroditum*  
*Equisetum arvense*  
*Erigeron humilis*\*

*Gentiana nivalis*

*Harrimanella hypnoides*  
*Huperzia selago*

*Luzula confusa*  
*Luzula groenlandica*  
*Luzula parviflora*

*Oxyria digyna*

*Pedicularis flammea*  
*Pedicularis hirsuta*\*  
*Phyllococe coerula*\*  
*Poa pratensis*  
*Polygonum viviparum*\*  
*Potentilla crantzii*\*

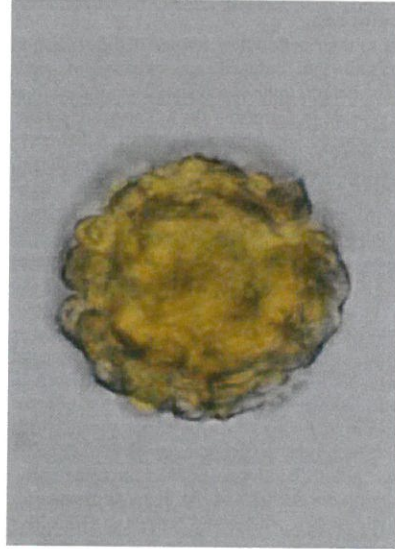
*Salix glauca*\*  
*Salix herbacea*  
*Sibbaldia procumbens*  
*Silene acaulis*

*Taraxacum* sp.\*  
*Thalictrum alpinum*  
*Tofieldia pusilla*\*  
*Trisetum spicatum*

*Vaccinium uliginosum*  
*Veronica alpina*\*

\* denotes the plant species in this project

## Pollen pictures



# Past, present and future of 4 boreo-alpine species in the global warming context.

Maria Moltesen<sup>1</sup>, Pablo Tejedo<sup>2</sup> & Jesus Vilellas<sup>3</sup>

An ecological comparison was made between four boreo-alpine species that have their northern limit in the Arctic and their southern limit in the mountains of the Mediterranean area. *Pyrola minor*, *Silene acaulis*, *Saxifraga oppositifolia* and *Arabis alpina* were studied in Disko Island (Greenland) and in the Pyrenees (Spain) in order to determine the main factors of their distribution and their ecological behaviour. In this sense, *P. minor* was different from the three other species, frequenting relatively stable substrates characterised by small slopes and high organic matter content. The other three species were found to belong to earlier succession stages. *S. acaulis* was the most generalist species, having an essential role in the development of its community and *S. oppositifolia* was the one presenting the largest specificity in habitat. Both *Arabis alpina* and *S. oppositifolia* were found in highly unstable and disturbed areas, but *S. oppositifolia*, with a slower growing-speed, has developed the ability to improve partially the conditions of its substrate, being able to stay longer in those areas. While *P. minor* and *S. acaulis* were found in different habitats in the Pyrenees and in Disko Island, *A. alpina* and *S. oppositifolia* occupied the same kind of environments. In all the species, differences in the life-strategy and/or in the morphology seem to occur between our study sites. As the arctic and alpine ecosystems are quite fragile, we have decided to take into account the global warming context in order to predict the possible future of the four species studied.

**Keywords:** *Arabis alpina*; Alpine; Arctic; boreo-alpine; Disko; Global warming; Physiological ecology; *Pyrola minor*; Plant morphology; The Pyrenees; *Saxifraga oppositifolia*; *Silene acaulis*; Succession

## Introduction

Due to their completely fragmented distribution areas and the reduced accessibility of their habitats, boreo-alpine species are less studied than other species of European flora. There are studies of particular populations (Abbott & Comes, 2004; Holderegger *et al.*, 2002; Takahashi, 1992) but not much information about the boreo-alpine species in a global context. The importance of studying such environments lies on their fragility, especially now, when all the predictions in relation to the global warming warn about the risks for the integrity of these habitats. The high mountains and the Arctic are isolated and slow-growing systems where the environmental damage takes long time to be repaired (Born & Böcher, 2001). Moreover almost 100% of the alpine and arctic plants are perennial plants which take several years to become established (Böcher *et al.*, 1968; Billings, 1974). In some way, comparing the Arctic and the Spanish mountains, we could predict what could happen in Greenland if the temperature increases in the next years, a relevant information for the conservation of these

species. We also can contribute with knowledge about which species have less genetic potential for changing its role in the ecosystem and being, therefore, more endangered.

We have studied *Pyrola minor*, *Silene acaulis*, *Saxifraga oppositifolia* and *Arabis alpina*, all of them boreo-alpine species which have their northern limit in the Arctic and their southern limit in Spanish mountains, and, specifically, we have sampled the populations at their distributional limits: Greenland and Spain. The study consisted in an edaphic and morphological comparison in order to determine which factors are important for the distribution of each species and whether their ecological behaviour is similar or not between regions. We also collected samples for genetic analyses but these are not presented here.

## History of the Alpine and Arctic flora

The origin of the alpine plants is based on different hypothesis (Billings, 1974). In the

Tertiary, new mountains were formed (Strahler & Strahler, 1997). In the Pyrenees, the second of the two orogenies that these mountains have undergone took place in this period: the alpine orogeny (Dendaletche, 1991; Pedrocchi, 1997). The raise of uninhabited habitats probably led to the evolution, in the beginning of the Quaternary, of different herbaceous genera, mostly from forests and grassland of the tertiary flora, on the newly formed mountains, as the trees failed to adapt to the high mountains.

In the Pleistocene, during the glaciations, there was also contribution from the arctic to the alpine floras due to back-migrations. During the long glacial isolations there was plenty of time for the evolution of alpine ecotypes in refuges (Billings, 1974). Later, as deglaciation has proceeded, areas available for alpine vegetation have become smaller as forests crowd upward. However, once the alpine plants had adapted to the low temperature and high light intensities, very little back-migration or evolution to the forest happened, because they could no longer compete in these kinds of habitats (Billings, 1974).

It is important to remark the fact that the building of the mountains and the occurrence of glaciations during the Pleistocene and up to the present time have speeded up the development of the alpine floras due to the migration and barriers of the mountains. This relatively rapid evolution has provided the means by which these taxa have achieved the characteristic adaptations required to be successful in alpine ecosystems.

The arctic flora is derived partly from the pre-existing Tertiary flora and also from ancestors that lived at high altitudes in mountain ranges to the south during the Tertiary (Abbott & Comes, 2004). The origins of the present arctic flora are supposed to be related to the new conditions created in the Arctic due to the global decrease in temperatures in the end of the Tertiary. Faced with such changes, plants had only two possibilities, adapt, or disappear (Stebins, 1950; Barry & Ives, 1974; Hewitt, 2001; Abbott & Brochmann, 2003).

It was proposed that by the late Tertiary many arctic plants had achieved circumpolar distributions (Hulten, 1937), which later were greatly affected by Pleistocene glaciations: species with previously wide and continuous

distributions in the Arctic would have suffered marked reductions in range size, as a result of the extension of ice-sheets over the north of Europe and North America (Abbott & Comes, 2004). Species became restricted to refuges, mainly at the periphery of ice-sheets but also in isolated nunataks. There is now strong evidence to support the proposal that Beringia was a major northern refuge for arctic plants during the Quaternary (Hewitt, 2001; Abbott & Brochmann, 2003). Such long distances and large geographical barriers would have caused fragmentation, with populations becoming isolated from each other. These populations would be expected to diverge over time because of the effects of chance and/or selection, although the origin of new species in such scenario is debatable.

Following the retreat of ice sheets at the end of a glaciation, many previously isolated periglacial populations possibly reunite with other conspecifics in secondary contact zones, with several possible consequences: first, the disappearance of differences between parent populations, if their hybrid offspring were fertile and backcrossed to the parents; second the maintenance of these differences, if the hybrid progeny in a contact zone had reduced fertility and/or vigour; finally, the origin of homoploid hybrid species or allopolyploid species, if recombination or chromosome doubling took place (Abbott & Comes, 2004).

## The Pyrenees

The Pyrenees are the most important mountainous chain in Spain, with the particularity that they are located in a very important position, both geographically and geologically. They separate the Iberian Peninsula from the rest of Europe, and they reflect the effects of the movements of the Iberian plate in respect to the European one. In geological terms, we can divide the Pyrenees in two main areas: the central axis has Palaeozoic material; on both sides, the materials come from the Secondary and early Tertiary Age, and their basic component is limestone (Dendaletche, 1991; Pedrocchi, 1997).

There are three main climatic regions in the Pyrenees, the Western, the Central and the Eastern Pyrenees, but all the populations treated occurred in the central part, which is supposed to be the most representative of the three for alpine systems, and the one with the highest peaks

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(Villar *et al.*, 2003). This central part has continental climate, with more extreme temperatures, and precipitation in the form of summer storms, mostly in the southern slope, where all our populations were located. The Western Pyrenees have Oceanic climate, and the Eastern part has Mediterranean climate (Pedrocchi, 1997). Obviously, the influence of the alpine climate increases with the altitude: the humidity, the precipitation (snow and rain), the wind and the irradiance increase, while the temperature decreases. In general, we can say that the plant life is more determined by the weather conditions as the altitude increases.

In relation to the altitude, we can divide the Pyrenees in three main vegetation areas, the basal floor, the medium mountain and the high mountain (Dendaletche, 1991; Pedrocchi, 1997). The importance of the altitude for the vegetation results from the changes, for instance, in climate, in the growing period length, in the fertility and maturity of the soils, or in the human pressure.

Only one of the four species studied, *Pyrola minor*, lives in the medium mountain belt, which expands until 1700 m approximately and contains forests with *Pinus sylvestris*, *Fagus sylvatica*, *Abies alba* etc, apart from pastures and scrublands. The rest of species studied live in the high mountain, which is more similar to the boreal and arctic areas in Europe. It has evergreen forests, scrublands with plenty of mosses and lichens, pastures, and some boreo-alpine species. In the upper part, the alpine floor, there are important limitations to the plant existence, such as soil instability, rocks, snow, wind and low temperature. At the actual peaks, only patches of sparse vegetation can survive, in rock crevices or in small shelves.

*Pyrola minor* was measured in two places: one population was measured in Pineta Valley, in a forest with *Pinus sylvestris* and *Abies alba*, located in the centre of the Central Pyrenees. It is influenced by weakened oceanic storms from the west and continental climate (slightly affected by mediterranean climate). The other population was sampled in Salenques, a forest with *Fagus sylvatica* and *Abies Alba*, in the eastern Central Pyrenees.

The rest of species were measured at three sites.

The first of the three populations was sampled in the calcareous area of the peak Bisaurin, in the western part of the Central Pyrenees, where the Atlantic climate and the Continental Mediterranean climate get in contact. Another population was measured in the middle of the Central Pyrenees, in the area of Urdiceto Valley, with a typical continental climate. The peak, Punta Suelza, is calcareous. The last population was sampled in Ballibierna, a limestone area in the eastern central Pyrenees also with continental climate.

#### Disko Island

Disko Island is situated west of central mainland Greenland, further north than the Arctic Circle. The island is part of the Tertiary volcanic province of West Greenland and is mainly made up by lavas. The landscape is a plateau basalt landscape with cirque carved lava plateaus and U-shaped valleys and fjords. The ice covers most of the central part of the island. The island belongs to a zone of continuous permafrost; the occurrence of open system pingos and numerous rock glaciers (Humlum, 1982) supports this idea.

Disko Island, as part of the coastal area of Greenland, has a tundra climate, which is a little less extreme than the harsh climate in the central part of Greenland (Lopez *et al.*, 1992). The mean annual temperature in Disko is below zero ( $-4^{\circ}\text{C}$ ). The climate in the Arctic is dominated by the annual cycle of solar radiation, with periods of permanent light and others with total darkness in winter. The low temperatures are due mainly to the low position of the sun in the sky. The radiation is oblique so it is more dispersed. Moreover, the radiation is reflected by the ice, so less heat is retained (Ives & Sugden, 1994). The humidity from the Atlantic Ocean has allowed Greenland to maintain its current state of glaciation for a long time (Holmes & Holmes, 1987) (although it has been observed now that ice might be starting to melt due to global warming).

As for the flora, Disko Island is particularly interesting, as it is positioned where the limits of the low and middle arctic flora meet. Therefore, it has relatively high species diversity. The low arctic zone is characterised by lowlands almost totally covered by vegetation, dominated by willow scrubs and herb slopes; the vegetation gradually disappear as we continue further north

to the high Arctic (Born & Böcher, 2001).

We made the measurements in two different places in Disko Island. One of the populations was sampled in the south, in the surroundings of Qeqertarsuaq (Godhavn), and the other further north, in Kangerluk (Diskofjord). As the southern part of Disko Island is located at the limit between the low and the middle Arctic, some species are supposed to disappear in Diskofjord, so the species richness is expected to decrease.

#### Comparison between arctic and alpine environments

Very extreme climates characterise both areas: high exposition to solar radiation, cold temperatures, etc. Therefore, plants have developed extraordinary adaptations to survive in such harsh conditions, avoiding them or improving them by creating more favourable micro-environments. In this sense, perennial herbs, prostrate shrubs, cushion forms, mosses and lichens are the most common life forms (Billings & Mooney, 1968; Bliss, 1971). Moreover, most of the volume of arctic and alpine vegetation is underground (Billings, 1973).

There is a decrease of species richness from the middle-latitude alpine habitats to the arctic tundra, possibly due to slightly higher summer heat totals, but much is due to their diversity of habitats, relative age and glacial history (Billings, 1973). However, we have studied species that, except for *P. minor*, grow in high altitudes in the Pyrenees, so the species richness is considerably reduced: according to Gomez *et al.* (2003), around 58 taxa disappear every 100m of altitude between 1200 and 3404m. This fact, together with the special location of Disko Island in the convergence of low and middle Arctic, causes that the difference in species richness that we could expect *a priori* is

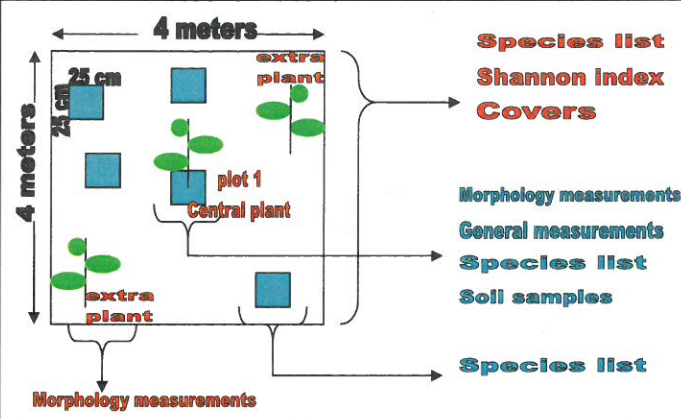
reduced.

There is a climate characteristic that both alpine and arctic areas share: a low daily mean air temperature during the growing season, although it is due to different reasons (Billings, 1973). The length of the growing season, however, varies between arctic and alpine habitats, because it depends not only on the temperature, but also on the length of the snow-free season (Billings, 1973). The length of the growing season in Disko Island might be similar to the length in the highest peaks in the Pyrenees, but it is definitely shorter than the one in lower altitudes in the Spanish mountains. However, this is compensated in a way by permanent light in the arctic summers.

Analysing the histories of both arctic and alpine flora and attending to the similarities and differences between the arctic and alpine habitats we can conclude that the composition and characteristics of the present boreo-alpine flora is the result of the interaction of many different factors (Hewitt, 1999). The past events and the present environments determine the current distribution of these species, although their future in the global warming context is not easily predictable. There are several consequences associated with the current rise in temperatures, such as ice-melting and permafrost melting, and there might be different possible consequences: the flowering period could advance its beginning and postpone its end due to the lower presence of ice and higher temperatures, although there are not going to be changes in the light regime. Another possible effect is the destabilisation of the substrate due to the melting of the permafrost. In any case, it seems that there are going to be disturbances in the arctic and alpine habitats and that the plants are going to face them sooner or later.

**Figure 1**

Variables measured at different scales: 4X4 m square and 25X25 cm plots. Notice two kinds of plots: 1: located around the central plant and the other four, randomly distributed. Notice also two kind of plants. The central one where all the measurements were focused, and two extras just used for morphological measurements.



## Materials and Methods

### Studied species

*Silene acaulis* (L.) Jacq. Caryophyllaceae. Perennial plant with an alpine, subarctic and arctic distribution. It grows in densely packed cushion form, and it can be found in several exposed habitats, like rocky areas and open tundra. No presence of mycorrhiza (Michelsen, 1998). Its well-developed roots allow the plant to anchor firmly to the substrate, and the cushion form creates a relatively favourable micro-environment for other organisms. (Villar *et al.*, 2003; Aizpuru *et al.*, 2000; Castroviejo *et al.*, 1989; Böcher *et al.*, 1968)

*Saxifraga oppositifolia* L. Saxifragaceae. Perennial plant with arctic and alpine distribution, being found in such extreme habitats as the highest peaks in the Pyrenees and the northernmost area of Greenland (Holmen, 1957). It has a prostrate form, and strong roots to attach to the unstable substrate, as this species usually lives in rocky slopes or crevices. Very fast in flowering after the ice-melt. (Villar *et al.*, 2003; Aizpuru *et al.*, 2000; Castroviejo *et al.*, 1996; Böcher *et al.*, 1968)

*Arabis alpina* L. Cruciferae. Perennial plant with reptant rhizomes and basal rosettes. Presence of mycorrhiza is described but with less importance than in *Pyrola minor* (Michelsen, 1998). It has an alpine and arctic distribution, occurring in highly disturbed places, such as the surroundings of torrential rivers, rocky slopes or man-disturbed areas. (Villar *et al.*, 2003; Aizpuru

*et al.*, 2000; Castroviejo *et al.*, 1993; Böcher *et al.*, 1968)

*Pyrola minor* L. Pyrolaceae. Rare circumpolar species living mainly in cool temperate to subarctic regions of the Northern Hemisphere (Takahashi, 1992). It is indirectly semi-saprophytic due to the association with fungi in mycorrhiza (Michelsen 1998). It lives in vegetation protected areas, like forests in the Pyrenees and scrub and herb-slopes in Greenland. It has a characteristic rosette with few leaves giving one flowering stem. (Villar *et al.*, 2001; Aizpuru *et al.*, 2000; Castroviejo *et al.*, 1993; Böcher *et al.*, 1968)

### Sampling design

Since the main idea was to make an ecological characterization to compare species and regions, we needed to homogenize some factors. For example, we measured first in the Pyrenees, and later in Disko, because we tried to measure in both regions in equivalent moments of the growing season. We also stratified the measurements inside each locality in different altitudes, trying to measure in the altitudinal upper and lower parts of each locality. At each population we measured 10 different soil points, five at the upper limit and five at the lower one<sup>8</sup>.

The first criteria when measuring one

<sup>8</sup> List of the populations where this was not possible: *A. alpina* in Bisaurin and Diskofjord. *S. oppositifolia* in Diskofjord. For *P. minor* there was no sense to divide the populations.

subpopulation was to find a place where many individuals could be found. Then we chose five different individuals, with at least three mature flowers in good conditions and with a distance of at least four meters between them. A 4X4m square was located around each of the five plants (figure 1). We took all community and soil samples within the square. The morphological measurements were undertaken at the central plant and on two extra plants located as close as possible to the central one.

In order to make a proper ecological characterization we measured many different factors. Some of the variables are not shown here because there was no time to process and interpret them.

### Sampling

We sampled from middle June (2004) to middle July in the Pyrenees and from middle July to beginning of August in Disko Island. In the Pyrenees we did the field work in Bisaurin (42° 47'N, 0° 36'W; from 16.06 to 21.06); Ballibierna (42° 34'N, 0° 41'E; from 24.06 to 26.06) and Punta Suelza (42° 38'N, 0° 17'E; from 30.06 to 02.07) measuring *Arabis alpina*, *Saxifraga oppositifolia* and *Silene acaulis* there. In the last week in the Pyrenees, we found *Pyrola minor* in Salenques (42° 37'N, 0° 44'E; 04.06) and Pineta (42° 37'N, 0° 11'E; 03.06). After field measurements in each population we always went to the Instituto Pirenaico de Ecología in Jaca, where we measured and dried leaves, as well as dried and processed the soil. In Disko Island we measured first in Diskofjord (69° 33'N, 53° 36'W; from 21.07 to 26.07) and later in the area close to the Arctic Station in Qeqertarsuaq (69° 16'N, 53° 33'W; from 28.07 to 03.07). We used the facilities of the Station to process our material in the same way as in the Pyrenees.

### Measurements

**General measurements:** Altitude, general and concrete slopes, orientation, concrete GPS of the central plant (figure 1).

**Soil measurements** (sieved fraction <2mm; dried at 105° 40hours): pH (7.5g, 2 hours shaken in water); [calcium] (by atomic absorption spectrophotometry in the Institute of Biology, University of Copenhagen); loss on ignition (sample ignition at 550°-6h in the Institute of Biology, University of Copenhagen); covers (estimated by the same person in the field); fraction < 2mm (weighting the two fractions).

**Community measurements:** Richness (all the species in the 4X4m square); Shannon index -  $\sum p_i \ln p_i$ , where  $p_i$  is the frequency of species  $i$  estimated by the frequency in 5 25X25cm plots (Figure 1).

For a description of the *Morphology measurements*: see table 1.

### Statistics

The data presented and discussed here are those which fit well with the statistical requirements (normality, variance similarity).

ANOVA: Used for most analyzes to compare the mean of different groups. In some cases, although the data didn't allow traditional statistical comparison, are included because the differences are obvious due to none overlapping of the ranges. Those cases are marked in the result tables with N in the beginning when it is referred to the whole comparison, and marked with (N) when it is referred only to one species.

Regressions: Few regressions are used in order to determine dependency between variables.

Binomial test: Used to determine differences in Leaf Damage Index. The compared frequency is the perfect leaves frequency.

Comparison of matched samples: Used to determine if the difference between two matched samples is different to 0. Used for concrete and general slope comparison and between flowering and non flowering stem in *S. oppositifolia*.



**Table 1:** Morphology measurements

*For all the species		
Flower number, diameter and length	---	3 mature flowers
Leaf Damage Index	LDI	Damaged leaves/ total leaves, used here as binomial variable q=perfect leaves; p=damaged leaves
Leaf length, width and length to the widest part	---	3 basal for <i>A. alpina</i> and <i>P. minor</i> and 12 for <i>S. acaulis</i> and <i>S. oppositifolia</i>
Seasonal Development Index	SDI	SDI= (0*young flowers + 1*mature flowers + 2*old flowers)/2*total flowers
Surface Leaf Index	SLA	3 leaves together for <i>P. minor</i> and <i>A. alpina</i> and 12 for <i>S. acaulis</i> and <i>S. oppositifolia</i>
Wide Index	WI	Length to the widest part/total length.
*For <i>Pyrola minor</i> :		
Flower Ratio	FR	Flower number/ inflorescence length
Inflorescence Ratio	IR	Inflorescence length/ stem length
Length of bract	---	Of measured 3 flowers
Length of inflorescence	---	Of the measured flowers
Stem length	---	Individuals have only one flowering stem
*For <i>Silene acaulis</i> :		
Leaf Ratio	LR	Leaf number/stem length
Number of leaves	---	Of the selected stems
Stem length	---	Stems of measured 3 flowers
*For <i>Saxifraga oppositifolia</i> (both for non flowering and flowering stems):		
Green ratio	GR	Green length/total stem length
Green length	---	Length of the green part of the stem
Leaf Ratio	LR	Leaf number/green length
Number of leaves	---	Of the selected stems
Total stem length	---	The 3 largest non flowering stems and the stems of measured 3 flowers
*For <i>Arabis alpina</i>		
Basal leaves number	---	Of the selected stem
Caulinar leaves number	---	Of the selected stem
Flowering stem number	---	Of the plant
Leaf Ratio	LR	Caulinar leaf number/stem length. Of the selected stem
Rosette number	---	Of the plant
Stem length	---	Biggest one

## Results and Discussion

Due to the large amount of numeric results presented in this report, we consider it easier to introduce them along with the discussion. The results are presented in individual tables per species (tables 6, 7, 8 and 9). The comparison between regions and species is also presented in a table (table 3). For region comparison we do not include data from *Pyrola minor*, because while the other three species were measured in places close to each other inside each locality, *P. minor* was measured in another vegetation zone, even in different geographical areas. In tables 2 and 4 some interesting results are presented (altitude,

slope and *S. oppositifolia* flowering-vegetative stem comparisons).

In the following discussion we separate *P. minor* from the rest of the species due to its different altitudinal distribution in the Pyrenees. Although we have data from different populations, here we only discuss the results valid for comparison at region level.

**Table 2.** Comparison of altitude in the Pyrenees with all the populations measured in 2 altitudes.

ALTITUDE		Down		Up
pH	***	7,37	>	7,08
Loss on ignition (%)	ns	8,3	=	9,09
Richness	***	10,39	>	3,52
Shannon index	ns	2,03	=	1,85

Table 2. \*\*\*p<0,001; ns=non significant differences

The altitude has been an important factor in the design of our study. Since the mountains in Greenland are not high, most of the peaks are covered by ice and we couldn't find the studied species there. The altitudinal subdivision of the populations in Greenland turned out not to be realistic in most of the cases. Anyway, in the Pyrenees it was always possible to divide the populations in to subgroups with 400-500 meter difference between them. The idea was to measure the lowest altitudinal limit from the species and the highest, close to the tops, in order to get the maximal differences.

But in the preliminary analyses, we found out that the altitude has no special relevance, because for most of the variables measured the populations did behave as one independently of the altitude (data not shown). The results (table 1) show, however, higher richness in the lowest altitudes than at the tops, and also lower pH which fits with the general situation in alpine sites (Villar *et al.*, 2003). But unexpectedly, Shannon diversity is not statistically different between the altitudes (table 2), suggesting that the higher richness in the lower plots is just an effect of locally occurring species coming from the near plant communities. Obviously, the effect of the presence of these species at the tops is lower because there are a lower number of species and communities there (Villar *et al.*, 2003).

## Richness and diversity

Although in the Pyrenees there are generally more species than in Greenland, we actually found more species in the plots measured in Greenland, for *Silene acaulis* and *Saxifraga oppositifolia*. When we, on the other hand compare the Shannon index, we see that the differences disappear (table 3). This fact is quite surprising, first because we shouldn't expect less species in the Pyrenees and second because even if there are more species in the plots in Disko Island, there is no diversity difference between the two regions.

As we discuss along the article, *A. alpina* and *S.*

*oppositifolia* are found in very specific environments, while *S. acaulis* shows more plasticity. Due to their actual boreo-alpine distribution, all of them are proposed to be components of the vegetation group surviving in the refuges and close to the ice during the last glaciations. It is accepted that those species experienced post-glacial migration to the north in latitude and to the tops of the mountains in altitude (Hewitt, 1999). Nowadays in the Pyrenees, there is almost no ice cover and high alpine ecosystems are restricted to the very high part of the mountains. Thousands of years ago when the ice retreated these species migrated upwards towards the mountain tops to localities without any species. But in the Arctic, in Disko Island in this case, the convergence of many postglaciation migration routes gives a high number of plants adapted to these alpine-arctic systems (Abbott & Brochman, 2003). So, although in the Pyrenees there are quite a lot more potential species to appear in our plots, they didn't because the extreme environmental conditions of the places where the studied species are growing doesn't allow them to appear.

But the Shannon diversity, although it is higher in Greenland than in the Pyrenees (table 3), is not statistically different. Since we are moving in very low and narrow ranges of the Shannon index, we might not have enough samples or data to detect small differences. But this result also suggests that the communities, both in Disko and the Pyrenees are characterized by few dominant species and a variable number of secondary ones. In this way, the richness changes more than the Shannon indexes when the amount of this secondary species varies, because the Shannon index tries to reflect also equitability

**Table 3.** Mean comparison with ANOVA between Regions (a) and Species (b).

	REGION				SPECIES							
		P		G		P	S	A	X			
pH	***	7.2	>	6.2	***	P = 4.61	<	S = 6.47	ns	A = 6.88	=	X = 7.08
Calcium (ppm)	***	166.8	>	86.14	***	A = 95.4	<	X = 136.2	=	S = 170.3		
Loss on ignition (%)	*	8.5	>	6.6		A = 4.93	:	X = 7.06	<	S = 10.49	:	P = 12.42
<2mm (%)	***	63	>	52	***	A = 0.48	:	X = 0.57	<	S = 0.7	=	P = 0.74
Rock cover (%)	ns	45	=	45	**	P = 4(N)	<	S = 41.5	=	A = 42.3	<	X = 53.4
Veget. Cover (%)	***	27	<	36	**	X = 22.4	=	A = 25.3	<	S = 44.9	<	P = 76.3(N)
Moss cover (%)	N	3.3	<	26.4	***	A = 6.7(N)	<	X = 12.7	=	S = 18.2	<	P = 37.4
Lichens cover (%)	N	12.4	<	40.4	+++	P = 8.5	:	A = 11.8	:	X = 24.6	:	S = 35.2
H. plant cover (%)	ns	24	=	27.7	***	X = 19.7	=	A = 20.6	<	S = 36.3		
General slope (°)	*	33.6	<	36.9	+++	P = 22.43	:	S = 29.9	:	A = 31.8	:	X = 43.4
Plant slope (°)	ns	28.9	=	29.4	***	P = 18.2	:	A = 22.5	<	S = 27.6	<	X = 37.6
Richness	***	11.9	<	15.1	***	X = 11.6	=	A = 13	<	S = 15.4	<	P = 19.62
Shannon index	ns	1.89	=	1.91	***	A = 1.82	:	X = 1.8	<	S = 2.1	<	P = 2.3
SDI	***	0.43	<	0.59	***	P = 0.33	<	S = 0.44	=	A = 0.45	<	X = 0.76
Total flowers					N	P = 8.8	<	X = 25.3	<	A = 73.3	<	S = 101.7

Table 3. Mean comparison with ANOVA between Regions (a) and Species (b). \*P<0.05; \*\*P<0.01; \*\*\*P<0.001; ns=non significant differences. +++Values not comparable; N and (N) See ANOVA in methods. For region (a), P=The Pyrenees and G=Greenland. For plants (b), P=*Pyrola minor*, S=*Silene acaulis*, A=*Arabis alpina*, X=*Saxifraga oppositifolia*.

Comparing species we can define some general patterns. The vegetation around *Saxifraga oppositifolia* never gets higher diversity values than around *Silene acaulis*. This differentiation is very interesting because we used to sample both species next to each other. *S. oppositifolia* seems to be restricted to areas where the competition with other plant species is reduced. Further it seems to be well adapted to rocky, steep and not fixed substrates. Our soil data support this explanation, because *S. oppositifolia* grows in places with higher general slope, with more bare rock, and soils with bigger particles, all of them not commonly good conditions for plant growth. Our data suggest that *S. oppositifolia* is a poor competitor but has solved this problem by adapting to extreme conditions.

In the quadrates around *Arabis alpina* we find a higher variability in richness and Shannon index through the populations than for the other species (data not shown). *Arabis alpina* thus shows very broad richness and Shannon index values, but the general values are as low as *Saxifraga oppositifolia*. We primarily found *A. alpina* in two different kinds of systems, very rocky slopes (often close to the tops) and next to narrow rivers (often in the lowest limit of the sampling area). Obviously, the plots measured in the rivers have higher diversity, specially, when they belong to low altitudes. But we have the impression that *A. alpina* was not growing randomly along the river, but in very concrete and inaccessible holes. Moreover, looking at the diversity averages and at the soil parameters (table 3), *A. alpina* seems to

behave similar to *S. oppositifolia* with very low capacity to compete with other species but with the ability to grow in places impossible for others.

#### Vegetation cover

One basic difference between Disko Island and the populations measured in the Pyrenees is the higher green cover in the arctic sites (table 3). The general data for lichens and mosses show 3-4 times higher percentage of land covered by them in Disko (always in the studied squares). Moreover, the higher cover of higher plants confer also 10% more in Disko than in the Pyrenees, although the bare rock is similar in both regions. In the Pyrenees we measured sometimes next to the rivers, paths and even a dam, and adding all these covers, the difference in plant cover is compensated. It is well described the high lichen and moss canopy in arctic tundra (Born & Böcher, 2001) and it is also shown in our results.

The freezing-melting processes in the mountains have intense erosive action, traduced in soil movements and instability (Strahler & Strahler, 1997). In the arctic the snow cover is longer than in Pyrenees (Born & Böcher, 2001; Villar *et al.*, 2001) protecting the soil against freezing-melting processes. In the Pyrenees, since the lower limit of the study area (2000-2400m) is still part of the sub-alpine zone, all our squares were placed on slopes suffering high erosion. Obviously, in such unfavourable systems as the alpine and alpine mountainsc, stable

**Table 4.** Comparison of matched Samples.

	a <i>S. oppositifolia</i> flowering-non flowering stem comparison (mm)					b General-concrete slope comparison (°)			
	Stem tot length	Green length	Nm of leaves	L.R.	G.R.	<i>A. alpina</i>	<i>S. oppo...</i>	<i>P. minor</i>	<i>S. acaulis</i>
H0: mean=0	***	***	***	**	**	***	***	***	Ns
H1: not equal	F=V+3	F=V+3.14	F=V-6.17	F=V-1.6	F=V+0.1	G=C+9.4	G=C+6	G=C+4.2	G=C

Table 4. ns=non significant differences. \*\*\*P<0.001. a) F=flowering stem. V=vegetative stem. b) G=general slope. C=concrete slope.

substrates are quite appreciated. It seems that the substrate allows higher canopy in the arctic than in the mountain slopes due to the stability conferred by the longer snow cover.

Clearly, *Silene acaulis* grows in places with more vegetation cover than *Arabis alpina* and *Saxifraga oppositifolia* (table 3). This difference exists basically because there are more higher plants, but mosses and lichens are also found in higher amounts. There is an interesting difference between *S. oppositifolia* and *A. alpina* in the moss and lichen cover. In the squares with *S. oppositifolia* the vegetation cover ranges are similar to the ranges around *S. acaulis*, but the plots including *A. alpina* has, definitely, lower ones. Since the presence of lichens and mosses in the rocks are often an indicator of the stability of the substrate (Margalef, 1995) we can suggest that *A. alpina* and *S. oppositifolia* are plants living in extreme places. *A. alpina* tolerates better the substrate instability. It doesn't mean that *S. oppositifolia* doesn't, but it looks like *A. alpina* does better. The fact that *A. alpina* was found preferably in very rocky and steep slopes besides next to rivers, supports also the same idea. The water level of the alpine rivers fluctuates a lot during the year, and especially, in springtime, it carries a lot of water and strength, removing the land next to it (Margalef, 1995). The same happened when the snow melts in the steep rocky alpine slopes.

#### Soil

Soil is one of the basic factors for plant growth, because it provides nutrients and substrates for them (Lambers *et al.*, 1998). In the arctic and alpine systems, the soil characteristics limit dramatically the development of plant communities. In fact this can be easily noticed looking at the general landscape with many areas without any vegetation.

Temperature is one of the keys to understand this soil limitation. The erosive effect of snow

melting and the frost movements of the soil particles are also well described (Strahler & Strahler, 1997). All this together with a number of other factors, explains the low cover of vegetation in those systems, which also acts as negative feedback since there is no soil protection and nutrient input.

In the regions presented in this study, all these general patterns are seen, but by analyzing them into detail, we find interesting facts.

The first thing to notice is that the general slope is higher in our quadrates in Disko Island (table 3). This is due to the fact that there is a geomorphological difference between the alpine Pyrenees and the Disko mountains shape. The alpine Pyrenees are characterised by steep and sharp peaks with narrow valleys and in Disko the common landscape are glaciers on flat tops falling down in steep slopes which attenuate close to the sea. In the Pyrenees this slope attenuation happens in the mountain passes. As explained in methods, we carried out our measurements in two different altitudes. In the Pyrenees we found the species in the mountain passes, we didn't in Disko, so, the higher subpopulation in Disko has steep slopes, while, in the Pyrenees, the higher subpopulation has attenuated slopes. Therefore the differences in general slope is because, in general, Disko lacks vegetation in mountain tops so we didn't measure there. Of course, this slope comparison is limited to the habitats concerning the studied species. The fact that we found larger soil particles in Disko (table 3) also fits with this slope consideration. As the slope gets steeper, the sedimentation is more difficult, and therefore, the soil layer above the rock will be very thin and the particles in general bigger.

But, being the general slope higher in Disko, the concrete one measured where the plant grows, becomes similar between both regions (table 3).



Obviously, when the slopes are high, the plants will tend to find microhabitats with attenuated slope. Actually, we find clear independence of the plants to the general slopes except for *Silene acaulis* (table 4). *Silene acaulis* has very peculiar growing strategy fixing itself with long and strong root system, but developing the aerial part forming a cushion in the surface of the substrate, often bare rocks. In this way, for *S. acaulis*, the slope is not a big problem. *Arabis alpina* and *Saxifraga oppositifolia* have the same broad range for slopes as *S. acaulis*, but both of them are sensitive to high general slopes and grow in lower concrete slopes. But both differ in the range of concrete slope they tolerate. While *S. oppositifolia* grows in very high concrete slopes (higher than *S. acaulis* in average), *A. alpina* does in relatively lower ones (lower than *S. acaulis*). Probably, these differences have to be explained by functional traits of the species such as root system or competitive abilities.

In our samples the soil in the Pyrenees is composed of smaller grains than the soil from Disko (table 3). Smaller grain size appears to be better for plant requirements, as these soils can hold more water, and they provide more area for bacteria to attach, which could cause more decomposition. Although the data only provides information about two basic categories (> and < 2mm), it gives us some information since we can detect some differences. Studies of soil particle size often require more detailed classification, but, in the present localities the small particles are represented by low percentages compared to other particle sizes.

A basic substrate in the Pyrenees explains some soil differences found between the Pyrenees and Disko. The pH is one of the most important ecological factors behind the plants distribution as it modifies the availability of many nutrients (Lambers *et al.*, 1998). Although the studied species present neutral pH ranges (except *Pyrola minor*), the pH is 1 point higher in the Pyrenees than in Disko (table 3). This gives us the impression that the species in Disko grow in more acidic situations. This could be due to differences in accumulation of organic matter in both regions. In the Arctic, in the places where the organic matters are stored, the decomposition takes place slowly. As level grounds are more common in the arctic than in the alpine systems, we expect more

humus, and therefore lower pH (Krebs, 1985). But when we look at the loss on ignition, we find actually the opposite, more organic matter in the Pyrenees. Although these results look contradictory, we should consider them in the concrete context of the communities under study. The steep and rocky slopes with unstable substrates and very poor nutrient input characterizes definitely those systems, conferring them more similarities between regions (Disko-Pyrenees) rather than with other systems inside each region. In this case, the organic matter amount is so low that it has no important effect on the pH. Anyway, as we discuss afterwards, although organic matter has not a relevant influence in pH differences at region level, it does have a secondary influence in concrete soil samples.

Table 5: Linear regressions.

	P	G
Ph-calcium	Ns	*** R=0,6
Ph-loss on ignition	* R=0,31	*** R=0,64
Calcium- loss on ignition	*** R=0,64	*** R=0,75

Table 5: All the significant relations are positive. \*\*\* P<0,001. ns= differences non significant. R= correlation coefficient. P=The Pyrenees. G=Greenland

Calcareous soils are usually basic (Lambers *et al.*, 1998) and we shouldn't forget that the populations we studied in the Pyrenees are on both sides of the central axis, where the materials come from the Secondary and early Tertiary Age, and whose basic component is the limestone (Dendaletche, 1991). Attending to the calcium values, we see double average amount in the Pyrenees, indicating that the acidic background in Disko could be due to the lower amount of basic minerals there, rather than an organic matter effect. It is also interesting to see, how the calcium-pH relation changes between regions when we look at the local soil samples (table 5). If the calcium, as indicator of basic minerals, is the main pH modulator here, it should be reflected also in the concrete soil samples. This happens in Disko but not in the Pyrenees. Although the R value indicates that other factors apart from calcium concentration influence the pH, any calcium input has relevance in Disko due to the low levels of basic cations. Opposite, in the Pyrenees, where the calcium values are very high, the variation in calcium levels do not have a significant effect on the pH.

But, of course, the organic matter has to have importance in such limiting systems. The organic matter gives structure to the soil, recruiting nutrients and improving the texture (Scott, 1996; Krebs, 1985) and its abundance in the soil varies from the early colonisation to later stages of succession. The relation in both regions (table 5) between calcium and loss on ignition shows that the organic matter in the soil is recruiting more calcium and influences in the soil texture. Definitely, the fact that calcium is less leached and is kept in the soil in presence of organic matter can be extrapolated to other nutrients, and this is crucial for the ecosystem development. Looking at the data (table 5), we found a significant regression between loss on ignition and the pH, both in Disko and the Pyrenees. The correlation coefficient becomes, however, higher in Disko than in the Pyrenees. This is another proof of the calcium strength modulating the pH, because even if there is more organic matter in the Pyrenees (always in low general ranges), the effect on the pH is neutralized because a higher content in calcium.

All this together puts the calcium as important modulator in those systems, since high amounts of this nutrient can dominate the effect of other small factors over the pH. Besides, low amounts of organic matter seem to be enough for recruiting nutrients and improve the substrate.

#### *Pyrola minor* L.

Without any doubt, *Pyrola minor* is the most surprising species of all of them. We quickly noticed the obvious difference concerning its habitat in the two regions. While in the Pyrenees it is growing in low altitudes in forests, preferably evergreen, but also deciduous, the situation was different in Disko, where we found it in more open areas most often next to willows, suggesting, maybe that they also prefer areas protected by vegetation there.

Probably, the most interesting question coming out from this general observation is why this habitat divergence happened. We should go back in time and follow the steps of *Pyrola minor* since last glaciation. Like for other species, latitudinal migration from southern alpine refuge like the Pyrenees to the north is also proposed for *P. minor*. Therefore, it presents now the typical

fragmented distribution area for boreo-alpine species. We think that in the maximum of the last glaciation *P. minor* was living in the Pyrenees in similar habitats to those where is found now in Disko. The surprising event is why this taxon was able to migrate to northern latitudes, but not up in the mountains, as the other species studied here. Billings (1974) propose the origin of alpine species as species not able to compete with other plant species and as a consequence migrated out of forest or grasslands and adapting to more extreme environments. In this way, the theory proposes that returning to the original habitat was quite complicated. Although this theory fits with the other species, it doesn't with *P. minor*, as it is living now in the forest.

Table 6: Mean comparison with ANOVA for *P. minor*

		P	G
pH	**	4,8	> 4,4
Plant slope (°)	*	23,4	> 13,3
Loss on ignition (%)	*	10,9	< 14,17
<2mm (%)	ns	0,75	= 0,73
Rock cover (%)	N	5,9	> 2,2
Veget. Cover (%)	++	62	90
Moss cover (%)	+	43,4	31,7
Lichens cover (%)	N	3,5	< 21,8
H. plant cover (%)	++	54,4	78,5
SLA (mm <sup>2</sup> /mg)	**	1,45	> 1,23
LDI	ns	0,77	= 0,72
Richness	ns	20,2	= 19
Shannon index	ns	2,2	= 2,4
SDI	++	0,25	0,39
Total flowers	**	11,6	> 6,4
Leaf length (mm)	N	29,4	> 16,2
Leaf width (mm)	N	23,8	> 14,6
WI (%)	N	58	> 49
Flower diameter (mm)	**	4,8	< 5,2
Flower length (mm)	**	5	> 4,5
Bract length (mm)	**	3,8	< 5,2
IR	Ns	0,18	= 0,19
FR	**	0,24	< 0,29
Stem height (cm)	**	14,8	> 9,65

Table 6: Mean comparison with ANOVA for *P. minor*. \*P<0,05; \*\*P<0,01; \*\*\*P<0,001; ns=non significant differences. ++Values not comparable; N and (N) See ANOVA in methods. P=The Pyrenees and G=Greenland

As many other species in the arctic-alpine zone, *Pyrola minor* have mycorrhiza (Michelsen, 1998). Due to this mycorrhiza, *P. minor* can use, as well as other nutrients, also soil carbon as nutrient and the species is considered indirectly semisaprophytic. This agrees with the idea of this species being a weak competitor in the past, for the light in this case, trait that could have been compensated with a specialization in obtaining also carbon from the soil through the mycorrhiza. Its basal rosette with few leaves also suggests low photosynthetic activity.

The dependence on the organic matter is clear, not only because this species shows higher values of organic matter (table 3), but also because the values remain high across populations. The reason for the higher values in Disko (table 6) is a slower decomposition rate, rather than less input. The temperature conditions (warmer), the pH (higher) and the duration (longer) of the growing season are more favourable in the montane zone in the Pyrenees than in Disko tundra. But *Pyrola minor* doesn't need only large pools of organic matter, its tiny and weak roots suggest also that they need very stable substrate. Actually, even though the slopes measured in *P. minor* plots are less steep than for the other species, a difference between the general and concrete slope is still found, suggesting a need for more level ground (table 3). Obviously, at steeper slopes the accumulation of organic matter is more difficult and the substrates trend to be less stable.

In fact, this slope-organic matter dependence turns to be the explanation for the present localization of the plant in the Pyrenees. When the alpine communities started to move up to the tops with the warming, they found steeper slopes, and the accumulation of organic matter decreased. In this context, *Pyrola minor* could not follow the alpine species, not because of the climate conditions, but because of the soil requirements. Therefore, there is a limiting altitude in the Pyrenees where the species stopped in its way up. The surprising event is that the species was able to cope with the arrival of the forest, probably because they also confer quite stables substrates with abundant organic matter. Besides, *P. minor* seems to be less affected by light limitation in the forest than other small species, due to the

semisaprophytism conferred by the mycorrhiza.

Anyway, this strategy of *Pyrola minor*, specialized in stable places with abundant organic matter, decreases the frequency of the plant, and almost all around the world it is considered a rare species.

As we already said *Pyrola minor* is growing in areas protected by vegetation. Both in the Pyrenees and in Disko it is a species growing in communities with higher Shannon index and richness values than the others species (table 3). Only *Silene acaulis* in the Pyrenees is similar. This is because *P. minor* is growing at lower altitudes in the Pyrenees in communities with more advanced succession stages than the other species. It is the only one presenting high values of moss cover in the Pyrenees and also it is the one with the highest vegetation cover which also points in the same direction. Moreover, forests are considered a later succession stage and the soil measured for *P. minor* in Disko can belong to "tundra soil" (considering the classification of Born and Böcher, 2001), which is also a propriety of quite developed communities in the Arctic.

Although the LDI (Leave Damage Index) seems similar in both populations, our morphological data suggest that the populations in the Pyrenees are growing in better conditions (table 6), probably represented by temperature and length of growing season. Having better growing conditions in the Pyrenees, *Pyrola minor* is able to allocate more resources to photosynthetic tissue which means bigger leaves and secondarily higher SLA. In the same way, the stems are higher and with more and larger flowers in the Pyrenees.

The ratio between the flowering part of the stem and the total stem length (IR) remains constant between populations and regions (table 6). This descriptive evidence appears to hide a biological meaning, specially, after realizing that the lower number of flowers in Disko results in more condensed inflorescences and doesn't change this proportion (table 6).

The large variation between regions of the bract length and the differences in the shape of the widest part of the leaf can be used as a morphological marker in further studies with other populations (table 6).

#### Are we in front of an extinction process?

Finally, a very interesting event should be introduced, in order to stimulate further studies. Such event is the fact that *Pyrola minor* is hybridizing in Disko with the related species, *P. grandiflora* Rad. The problem for *P. minor* is that *P. grandiflora* is very abundant, so there is a potential risk of genetic assimilation of the former species into the latter.

The future of this species is, among the four, the most uncertain. On one hand, in Disko, the warming could favour *P. minor*, if the woody species start to grow more and generate more forest-like systems. But, on the other hand, due to this hybridizing effect, the situation doesn't look very favourable now. With the present data we can not predict which of the two possibilities will come through.

In the Pyrenees it is also difficult to predict the future of *Pyrola minor*. Neither the global warming nor the increasing anthropogenic pressure gives the best future scenario for the maintenance of the stability which *P. minor* appears to need.

#### *Silene acaulis* (L.) Jacq.

The compact cushion form of *Silene acaulis* is definitely the most characteristic vegetative trait of this species and determines completely the role of the species in the alpine and arctic systems.

*Silene acaulis* grow in the same kind of soils in both places, since there are small differences in organic matter and particle size between Disko and the Pyrenees (table 7). The pH is, due to the explained basic background in the Pyrenees, higher in the Pyrenees. Probably more interesting is the large range that the species shows for the pH. In the same way, the calcium amount is higher in the Pyrenees; but the important effect is that, due to the slightly, although not significant, better soil quality in the alpine site -organic matter, grain size - more of this calcium can be stored. And since more calcium is stored, we can also extrapolate that more minerals are stored. Moreover, having more organic matter, we also expect more organic substrate for microorganisms, which will transform it into available molecules for the plants.

Concerning the community variables, the cover

values are higher in Disko, except for bare rock. Vegetation in general, but also lichens, mosses and higher plants individually are more represented in Disko in the communities where *Silene acaulis* was found. These data agrees with the richness, which is also higher there. As explained in the beginning of the discussion, the Shannon index is compensated because the richness differences are in secondary species with low presence and not in dominants.

Table 7. Mean comparison with ANOVA for *S. acaulis*.

		P	G
pH	**	7,1	> 5,4
Calcium (ppm)	*	199	> 130
Loss on ignition (%)	ns	9,9	= 12,3
<2mm (%)	ns	0,72	= 0,67
Rock cover (%)	**	50,5	> 28
Veget. Cover (%)	**	34,5	< 60,5
Moss cover (%)	N	3,9	< 39,5
Lichens cover (%)	N	20	< 58
H. plant cover (%)	**	31,2	> 44
SLA (mm <sup>2</sup> /mg)	**	1,5	< 1,75
Plant slope (°)	*	30,8	> 22,3
Richness	**	12,9	< 19,15
Shannon index	ns	2,08	= 2,26
SDI	**	0,36	< 0,57
Total flowers	N	127,	> 57,2
Flower diameter (mm)	**	8,4	< 9
Flower length (mm)	ns	6,95	= 6,88
Leaf length (mm)	N	4,4	< 6,3
Leaf width (mm)	N	0,84	< 1,2
Stem height	**	5,56	< 8,3
Leaves	**	11,7	< 13,5
LR	**	2,27	> 1,8

Table 7: \*P<0,05; \*\*P<0,01; \*\*\*P<0,001; ns=non significant differences. +++Values not comparable; N and (N) See ANOVA in methods. P=The Pyrenees and G=Greenland

Comparing *Silene acaulis* with the other studied species, we found important differences. In most cases, we measured individuals close to places where *Arabis alpina* and *Saxifraga oppositifolia* also grew. The surprising result is that, being that close, the differences in soil and community between species are marked supporting the idea that *S. acaulis* plays a very different role in those boreo-alpine systems.



Although the diversity values are not high for *S. acaulis*, they are definitely higher than the ones for *Arabis alpina* and *Saxifraga oppositifolia* (table 3). In the same way the area covered by vegetation is higher. Apart from this, there is a better quality in the soil under *S. acaulis* cushions. The size of the particles is smaller and the organic matter content is higher than below *S. oppositifolia* and *A. alpina* plants.

*Silene acaulis* also behaves differently with the slope. Although it can grow in steep general slopes, these are not as steep as where we found *Saxifraga oppositifolia* and *Arabis alpina*. But the difference between them is that *S. acaulis* doesn't present difference between the general slope and the concrete one (table 4). This is explained because the cushions stick to the soil or rocks and spread over the surface, avoiding many restrictions that other species find in these systems. Obviously, since it can use almost any kind of substrate, *S. acaulis* has an advantage in order to colonize and spread.

Opposite to what we could expect, the SLA ranges indicate that *Silene acaulis* has slower growing strategy than *Saxifraga oppositifolia*. The clue could be again the packed cushion which allows the plant to allocate to growth rather than to strengthening the structure. The long, flexible and quite randomly spread woody stems in *S. oppositifolia* are also resistant to soil instability, maybe even more than *S. acaulis* cushions; but are more sensitive to damage. So it is reasonable to think that, in general, *S. oppositifolia* uses more resources to maintain the structure than *S. acaulis*.

The first impression in the field is that, in general, *Silene acaulis* is more dominant in the communities we found in the Pyrenees. The SLA information helps to understand the behaviour of *S. acaulis*. The higher SLA in Disko (table 7) suggests that the individuals there allocate more resources to photosynthesis than in the Pyrenees. The fact that there are more and bigger leaves in Disko and that the stems are also longer is an evidence in the same direction. At this point we need to remind that the general slope, cover and diversity measurements support the idea of a more stable growing place in Disko than in the Pyrenees (table 7). Remark also, that the species richness is quite higher in the Pyrenees (Villar *et al.*, 2003), so the competition in favourable environments

here should be higher than in Disko tundra. In this context, we propose a different role of the main pool of individuals of this species in the different regions. While in the Pyrenees it has been replaced from advanced stages in the succession, and forced to live in earlier stages, in Disko it is competitive enough to maintain in more advanced communities, but reducing the number of individuals due to the competition. This theory fits also with the SLA differences because in the rocky habitats in the Pyrenees *S. acaulis* should allocate more resources to the structure whereas in Disko allocation to photosynthetic tissue is more necessary in order to compete better.

It is worth mentioning that *Silene acaulis* has large variation for many of the environmental factors measured (data not shown) meaning that it has more generalist life form than the others.

All this together presents *Silene acaulis* as a key species in the development of alpine and arctic communities. First it is able to colonize easily many variable environments and to compete with other species. Second, it has tremendous improving effect over the substrate which other species use to establish.

The future of *Silene acaulis* doesn't look especially complicated. It is widely distributed and seems to possess good dispersal possibilities (Born & Böcher, 2001). We must consider that *S. acaulis* is the species presenting the highest number of flowers per individual among the four. If we also add the good colonising ability and the possibility of competing in advanced stages of succession, it doesn't look like *S. acaulis* is going to be especially sensitive to the global warming. We can, however, think in a progressive change of strategy in Disko. In the Pyrenees the main *S. acaulis* individual pool grows in places with lower richness and more rocks because of the high competition in favourable environments. If the global warming involves increase in competition in Greenland, we could also expect *S. acaulis* to move to more rocky places.

#### *Saxifraga oppositifolia* L.

The small differences in the soil structure of *Saxifraga oppositifolia* between Disko Island and the Pyrenees suggest high habitat specificity. In the alpine site, the pH is more basic, and contains more calcium (tables 2 and 7). However, the

proportion of soil grains smaller than 2 mm, the slope and the organic matter content doesn't vary. The latter, together with the fact that there are no differences in bare rock and vegetation cover point out that *S. oppositifolia* lives in places with quite specific characteristics, independently from the region where it is growing. In relation to this, Abbott *et al.*, (2004) stated that the subspecies of *S. oppositifolia* occupy a similar range of harsh environments, which is the reason why selection favoured similar morphology in the regions.

**Table 8:** Mean comparison with ANOVA *S. oppositifolia*

		P	G
pH	**	7,5	> 6,3
Calcium (ppm)	**	167,	> 93,9
Loss on ignition (%)	ns	8,3	= 6
<2mm (%)	ns	0,59	= 0,53
Rock cover (%)	ns	50,8	= 57,2
Veget. Cover (%)	ns	19,3	= 27
Moss cover (%)	N	2,3	< 27
Lichens cover (%)	**	11,4	< 44,5
H. plant cover (%)	*	16,1	< 25
SLA(mm <sup>2</sup> /mg)	++	1,26	1,05
Plant slope (°)	ns	36,8	= 37,8
Richness	ns/	10,2	< 12,8
Shannon index	*	1,9	> 1,63
SDI	N	0,63	< 0,99
Total flowers	**	31,1	> 16,8
Leaf length (mm)	**	4,34	> 3,72
Leaf width (mm)	*	1,72	< 1,83
WI (%)	**	78	> 73
Total stem length & (cm)	ns	14,8	= 14,7
Green stem & (cm)	ns	10	= 9,7
Leaves &	N	21,6	> 12,1
LR (Leaves/cm)	**	2,43	> 1,9
GR	ns	0,69	= 0,67
LDI	ns	0,39	= 0,34

Table 8: \*P<0,05; \*\*P<0,01; \*\*\*P<0,001; ns=non significant differences. +++Values not comparable; N and (N) See ANOVA in methods. P=The Pyrenees and G=Greenland. &=Same results with the vegetative and flowering stems separately.

Our data show, indeed, several similarities between the regions in morphology. There is equality in the LDI, in the total length (of both the flowering and the non-flowering stems) and in the ratio between the green part and the total length

(of both the flowering and the non-flowering stems). This supports the idea that hard environments selected similar morphological traits in Greenland and the Pyrenees.

We must remark, that the similarity in GR (Green Ratio) and Total stem length for both, the flowering and non-flowering stems (table 8), suggests that the plants invest similar amount of resources to both the vegetative and the reproductive structures in the alpine Pyrenees and Disko tundra sites.

*Saxifraga oppositifolia* uses the first part of the growing season in completing the flowering and the second part in beginning the next one. As other alpine species, *S. oppositifolia* produce floral primordia the summer before (Billings, 1974). This should involve a change in the metabolism of the plant, since in the beginning of the season it is focused in completing the life cycle, but in the end it starts the new cycle with other stems. Our comparisons of flowering and non flowering stems support clearly this idea (table 4). Since we were measuring in the early middle of the growing season, the fact that the SDI (Seasonal Developmental Index) is quite high reflects that *S. oppositifolia* finishes the life cycle quite fast. In table 4 we see that both the values for the total length and the green part of the stem are higher for the flowering stems, which grow first in the very beginning of the season. In the same way, the ratio of the green part over the total stem is also higher for the flowering stems. But the clue for the change in activity in the second part of the season comes when we see more, and more compacted leaves, in the vegetative stems. These shorter stems are ready now to grow and due to the larger amount of leaves they will be able to allocate more resources to the new primordia.

This strategy seems to be adaptative, since the snow cover starts quite early in winter, because it gives two possibilities to the plant in order to flower properly. If the summer is shorter than usual, there is still a chance to produce some flowers in the next growing season.

There is also some data suggesting that the plants could have better resources in the alpine site. The flower production is higher, there are more leaves, and more leaves per stem length

(table 8). This could be related to the presence of a higher concentration of calcium in the alpine soils, because this nutrient boosts the growth (Scott, 1996). Moreover, *Saxifraga oppositifolia* seems to have an important association with calcium, as it has some calcareous secretions at the tips of the leaves. In addition, the SLA seems to be higher in the Pyrenees, which could point towards a faster strategy of growing, in relation to the proposed higher nutrient availability.

There is another morphological difference between the plants of both regions that could be used as morphological marker in the future: the leaves in the Pyrenees are longer and thinner than the leaves measured in Disko (table 8).

Although there are some differences between regions that could contradict the above mentioned statement of Abbott *et al.* (2004), if we compare between species, we can see that *Saxifraga oppositifolia* is the species with lowest variability between regions, in morphology, habitats and strategies, so it is necessary to look at the importance of these dissimilarities in a relative manner. We shouldn't forget either that we are comparing the northern and southern limits of the distributional area.

For the future predictions, see the end of the next section, *Arabis alpina*.

#### *Arabis alpina* L.

There are some differences in the substrate that indicate better conditions in the Pyrenees. In the quadrates around *Arabis alpina* the slope is steeper in Greenland (table 9) and, probably as a consequence, there is less organic matter in the soil and a higher percentage of bare rock. Moreover, there is more calcium and smaller soil particles in the alpine site, which, together with the organic matter, can indicate higher nutrient richness. pH values are quite neutral in both regions, being higher in the Pyrenees due to the basic rocks.

*Arabis alpina* presents slower growing strategy in Disko, where it concentrates in structure and gives fewer but larger flowers (table 9). If we look at the morphological data, the plants have smaller flowers, more rosettes, more caulinar leaves, more caulinar leaves per stem length, higher LDI and higher SLA in the Pyrenees, but there are no

**Table 9.** Mean comparison with ANOVA for *A. alpina*.

		P	G
pH	**	7,1	> 6,5
Calcium (ppm)	N	135,	> 34,6
	8		
Loss on ignition (%)	*	5,5	> 3,74
<2mm (%)	N	0,57	> 0,33
Rock cover (%)	**	37,8	< 51,5
Veget. Cover (%)	ns	27,8	= 21,5
Moss cover (%)	N	2,6	< 12
Lichens cover (%)	**	18,7	> 7,3
	5		
H. plant cover (%)	N	24,8	> 12,25
SLA(mm <sup>2</sup> /mg)	*	2	> 1,31
Plant slope (°)	**	19,3	< 27,23
	4		
Richness	ns	12,6	= 13,55
Shannon index	ns	1,8	= 1,8
SDI	ns	0,42	= 0,5
Total flowers	N	95,8	> 39
LDI	**	0,56	> 0,25
Leaf length (mm)	++	20,4	18,2
	+		
Leaf width (mm)	++	7,2	6,9
	+		
WI (%)	**	79	> 68
	*		
Flower length (mm)	**	6,8	< 9,1
	*		
Flower diameter (mm)	**	6,5	< 8
	*		
Stem height (cm)	++	13,7	12,3
	+		
Caulinar leaves	N	6	> 4,2
Basal leaves	ns	8,7	= 8,2
Rosettes	N	9,7	> 3,8
Flowering stems	N	11,5	> 3,3
LR	N	0,48	> 0,36

Table 9: \*P<0,05; \*\*P<0,01; \*\*\*P<0,001; ns=non significant differences. ++Values not comparable. N See ANOVA in methods. For region, P=The Pyrenees and G=Greenland

differences in number of basal leaves between the arctic and alpine sites (table 9). Some of the results are statistically better than others, but almost all of them point in the same direction: it seems that *A. alpina* in the Pyrenees allocates more to establishing and expanding -more rosettes-, which would imply a faster growth (related to higher SLA, which is characteristic of fast-growing strategies (Lambers *et al.*, 1998)). In order to confirm this, we descended to the level of populations. We found that the alpine population Bisaurin differs in many variables from the others. It has better substrate conditions than the rest of populations, and the morphology of the *A. alpina* individuals growing there have the morphological traits that most clearly follow the fast-growing strategy patterns (data not shown). Therefore, it

seems that the theory about faster growth in the best substrate is confirmed. We have to take into account that even if the soil in the Pyrenees seems to be more favourable, the soils in both regions are very poor and instable compared to others in general and also compared with the ones measured in this study.

Apart from this, the information about LDI in the Pyrenees reminds us about the risks of a fast-growing strategy, which consists of quick allocation of resources to photosynthetic tissue, and decreasing allocation to protective and defensive compounds (Lambers *et al.*, 1998). The leaves are thus more vulnerable and the consequences are leaves with more damage (higher LDI). The fact that the flowers are smaller in the Pyrenees still needs an explanation. Probably, the clue is again the growing-speed strategy: the flowers are sacrificed in order to maximize the fast-growing strategy.

We also have to mention that there is a difference in leaf morphology between the Pyrenees and Disko: the LR (Length Ratio) is bigger in the Pyrenees, although there might not be any selective force responsible for it. This difference in the shape of the leaves, however, could be used as a morphological marker in further studies (table 9).

It seems that *Arabis alpina* is not belonging to any particular community. This is suggested by the fact that while the improvement of the soil conditions in the Pyrenees reinforces the fast-growing strategy, the change in the community is in the opposite direction, towards a more complex and diverse state (which would be characterized by more stability and slower growth). *A. alpina* might have some plants in its surroundings, but they are probably not part of the same community. Strong evidence supporting this theory is the fact that we found *A. alpina* in many different habitats, such as the proximities of rivers, rocky slopes, villages, even in the surroundings of an old dam.

**Table 10.** Proposed evolution of each species during the succession. Since it is a general comparison, we consider here succession as development from unstable to more established situations

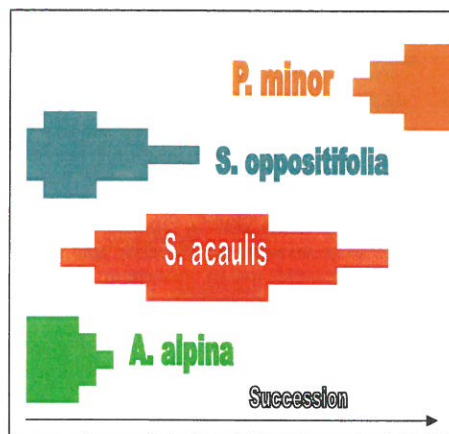
Very few species have the characteristics of *A. alpina* in order to be able to live in such unstable and irregular places.

*Arabis alpina* presents very large range of tolerance in order to colonize new substrates and probably will not survive when the community develops. When we relate the substrate characteristics to the general plant and lichen community living near *A. alpina*, there are no differences between the Pyrenees and Disko in vegetation cover, species richness or the Shannon index (table 9). Although the soil is better in the Pyrenees, *A. alpina* colonizes quite unfavourable environments, which doesn't allow many species to grow, so this soil difference between regions is not important enough for most of the species around. Consequently, we propose *A. alpina* as a pioneer in many limiting situations, but specialized in punctual small habitats next to variable water currents or unstable slopes.

*Arabis alpina* seems to be a plant species that will show independence from the changes that follow the global warming. Because of its wider range of habitats, it will be, probably, the less affected of the species studied in this article. The future of *A. alpina* seems to rely more on the presence of disturbed sites than on any other factor, and this is quite an important guaranty for survival, assuming that the global change will probably cause many disturbances in the alpine (Dimböck *et al.*, 2003) and arctic habitats, and that both habitats recover very slowly from disturbances (Billings, 1973).

*Saxifraga oppositifolia* might have similar prospects for the future, because it also lives in disturbed areas. However, its requirements are probably not as extreme as those of *Arabis alpina*, so the flexibility and chances of survival to future changes may be less clear in the case of *S. oppositifolia*.





### Final considerations for the future of boreo-alpine species in the global warming context.

We present some general considerations we consider important, in order to orientate further works with these species and clarify some incognitos about the future of the studied species.

A typical adaptation in arctic and alpine plants is to have the flowering primordia ready the year before, and these primordia can stay under the snow even for three years (Billings, 1974). This allows the plants to flower as soon as the snow is gone, but also makes primordias more sensitive.

We have to take into account that the growing season of the plant is not only determined by the temperature, but also by the light regime. Obviously, the light regime is not going to change with the global warming. As with some alpine *Oxyria* ecotypes (Billings, 1974), we can say that the plants studied here will grow more during this period, but maybe the period won't be longer.

Anyway, we think that it could have an effect in *Saxifraga oppositifolia*, even in *Silene acaulis*, if the snow cover is reduced in the global warming context. On one hand, since the plant will stay for a longer time with next year primordia exposed to environmental variations at the end of the growing season, this adaptation could become useless. But, on the other hand, a longer growing season benefits clearly the growth of the plant.

### Conclusion

For the substrates in early stages of the succession of the vegetation in the Pyrenees, the higher amount of basic minerals than in Disko, have a general effect raising the pH. Since the amount of basic minerals is high in the Pyrenees, variations on the calcium levels does not affect the concrete pH, but, it does in Disko, where the levels are lower. The general effect of the organic matter on pH is less than the effect of calcium, since organic matter is not very abundant in these systems. Moreover, the accumulation of organic matter in punctual places has stronger effect recruiting nutrients and establishing the soil than modulating the pH.

The studied species are adapted to the steep general slopes that characterize the areas where they live. In fact, they prefer specific microhabitats with more attenuated concrete slopes within the general steep areas. *Silene acaulis* is a rare example of a species which is not that sensitive to the slope.

The table 10 was produced in an attempt to clarify the differences among the species we studied. The following conclusions are easier to understand having this table in mind.

*Pyrola minor* is a species appearing in low frequency in advanced stages of the succession in habitats with high quantities of organic matter and very stable substrates.

The closed and solid cushions of *Silene acaulis* have a very important role in the succession both in the Pyrenees and Disko, fixing the soil and recruiting nutrients. While *S. acaulis* has been restricted to rocky and steep places in the Pyrenees due to the strong competition in favourable areas, in Disko it still can be easily found as a component of mature communities.

*Saxifraga oppositifolia* is a species with very specific habitat demands, a fact that limits its variation and allows high adaptative similarities even between geographically largely separated populations. Its developed root system together with the pre-production of flower primordia in the late summer, allows *S. oppositifolia* to be a pioneer in very harsh and exposed extreme habitats.

*Arabis alpina* doesn't seem to survive when the

plant communities develop and is consequently pushed to disturbed substrates, presenting large range of ability to colonize them. This general pattern is seen in both regions. *A. alpina* has in the Pyrenees a faster growing strategy, linked probably with the better soil conditions.

In the Pyrenees *Saxifraga oppositifolia*, *Silene acaulis* and *Arabis alpina* have the population nuclei in high altitudes and they spread down to the valleys. In Disko they concentrate at low altitudes and spread up to the tops. *Arabis alpina* is the species among the three with the largest spreading range.

*Saxifraga oppositifolia* and *Silene acaulis* share the cushion form and the occurrence in highly exposed habitats. Both present strong roots that attach the cushion firmly to the substrate, in order to minimize the disturbances from the soil movements, although *S. oppositifolia* belongs to earlier stages in the succession.

*Saxifraga oppositifolia* and *Arabis alpina* inhabit very extreme places, where other plants cannot arrive as peaks, torrential rivers or rocky slopes. In unstable substrates each species behave slightly different. *Arabis alpina* has a clear fast-growing strategy, while *S. oppositifolia* has a slower growth rate. Being both in early stages of succession, *A. alpina* hardly changes the substrate, while *S. oppositifolia*, due to its cushion shape, improves in some way the conditions of the substrate where it is living.

It is difficult to state which site, whether the Pyrenees or Disko, offer a better environment for the studied species. In fact, when we compare regions, we do not try to consider this, but to know the differences. Instead of organizing them

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into a hierarchy, we should better bear in mind that they grow in different habitats, the alpine and the tundra habitat, which, despite sharing many species, have different characteristics, and the performance of each species in each site differs from each other.

Since many alterations are described and predicted in alpine and arctic systems in the global warming context, and since is not possible to predict without any error about the future real trends of the ecosystems, the attention for them has to be intensive in order to be able to react with adequate conservational efforts.

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## Do the Greenland white-fronted geese stand a chance against the invasive Canadians?

Authors: Nette Levermann & Katrine Raundrup

Fieldwork was done in Aqajarua - Sullorsuaq (Mudderbugten and Kvandalen, 69°45'N; 52°00'W), Disko, West Greenland in July and August 2004. A helicopter survey covering the entire area was made in order to count moulting Greenland white-fronted geese (*Anser albifrons*) and Canada geese (*Branta canadensis*) and localise the geese flocks, thereby finding the best suited area for further observation studies. Behavioural observations of the geese were used to make activity budgets, and this was done for allopatric as well as sympatric situations in two specific lakes. The frequency of plant species was determined in the foraging patches and vegetation and faecal samples were collected. The vegetation samples and faeces were analysed post fieldwork to examine for feeding selection in the two species.

**Keywords:** Blisgæs, *Anser albifrons*, Canadagæs, *Branta Canadensis*, interspecifik konkurrence, fourageringsøkologi, områdebrug, Jacob's præference indeks, Disko

### Introduktion

Såvel blisgæs (*Anser albifrons*) som canadagæs (*Branta canadensis*) foretager lange træk mellem vinter- og sommerkvarterer (Boertmann, 1994). Velankommet til sommerkvarterne bruger både ynglende og ikke-ynglende fugle det meste af deres tid på fouragering (Madsen & Mortensen, 1987; Prop & Vulink, 1992). Dette er især gældende i fjerfældningsperioden, hvor gæssene skal indtage store mængder af høj-kvalitets føde for at erstatte de fældede fjer (Madsen & Mortensen, 1987, Fox *et al.*, 1998b). Gæssene selekterer i denne periode for føde med et højt proteinindhold, men kvælstof er imidlertid ofte den begrænsende faktor i arktiske terrestriske miljøer (Jefferies *et al.*, 1994; Fox *et al.*, 1998a). Denne mulige begrænsning i føderessourcen, samt det faktum at blisgæs og canadagæs anvender samme typer af områder at fouragere i, skaber potentiel mulighed for interspecifik konkurrence (Kristiansen & Jarrett, 2002).

I de seneste år er antallet af canadagæs steget betragteligt i Vestgrønland (Fox *et al.*, 1996), og bestanden talte 1700-3500 ynglepar i 1999 (Malecki *et al.*, 2000). Denne invasion af canadagæs er visse steder fulgt af en nedgang i antallet af den endemiske blisgås (Bennike, 1990; Kristiansen, 2001). På Disko er antallet af canadagæs steget fra én observation i 1979 (Frimer & Nielsen, 1990) til at tælle 199 og 87 hhv. rastende/fældende og ynglende fugle i 2001 i

området ved Aqajarua - Sullorsuaq (Mudderbugten og Kvandalen) (tabel 1 og 2). Dette område blev i 1988 udlagt som et af tre Ramsar områder på Disko (International Ramsar Site no. 385) og anses for at have international betydning for den totale bestand af blisgæs (Egevang & Boertmann, 2001). Bestanden i Grønland er i 1999 estimeret til at tælle ca. 33.000 individer (Malecki *et al.*, 2000).

	1989	1992	1994	1995	2001
Blisgås	254	397	385-450	372	468-637
Canadagås	13	22	8	128	199

Data fra: Egevang & Boertmann, 2001

**Tabel 1.** Rastende eller fældende gæs i Aqajarua - Sullorsuaq (Mudderbugten og Kvandalen).

	1989	1992	1994	1995	2001
Blisgås	5	2	13	5	34
Canadagås	1-3	-	-	-	87

**Tabel 2.** Ynglende gæs (par) i Aqajarua - Sullorsuaq (Mudderbugten og Kvandalen).

Tidligere studier i Isunngua, Kangerlussuaq (67°05'N; 50°30'W) i Vestgrønland har vist, at

konkurrencen mellem de to arter først og fremmest er fødekoneurrence (Jarrett, 1999; Kristiansen & Jarrett, 2002), og at den største negative effekt er at finde hos blisgæs. I områder med sympatrisk fouragering ændrede blisgæs adfærd i forhold til allopatriske områder. Dette kom bl.a. til udtryk i et højere indtag af lavkvalitets føde, bredere fødeniche og lavere indtagelsesrate i forhold til canadagæs. Agonistiske interaktioner i sympatrisk områder blev udelukkende vundet af canadagæs.

I Nordfjord (69°55'N; 54°15'W) på Disko (International Ramsar Site no. 386) tyder invasionen af canadagæs på at have haft drastisk indvirkning på antallet af blisgæs. Hvor der for blot nogle år siden blev observeret utallige blisgæs (D. Boertmann pers. komm.), ses der nu få eller ingen i området (J. Madsen pers. komm.).

Litteraturen giver mange eksempler på, at forholdet mellem en invasiv og en endemisk art kan have negativ indvirkning på den ene art (Donlan *et al.*, 2003). Vi ønskede med dette projekt at undersøge for fødekoneurrence mellem den endemiske blisgæs og den invasive canadagæs på en tidligere undersøgt lokalitet i Vestgrønland (Frimer & Nielsen, 1990; Malecki *et al.*, 2000; Egevang & Boertmann, 2001; Boertmann & Egevang, 2002).

## Materialer og Metoder

Den overordnede projektmålsætning var: (1) at fremskaffe kvantitative data vedrørende de to gåsebestandes fourageringsadfærd og valg af vegetationstype i allopatriske samt sympatrisk situationer på Disko i Vestgrønland, (2) at undersøge for artsforskelle i ovenstående data og (3) at koble feltundersøgelsens materiale til den allerede eksisterende litteratur om gåsebestanden udnyttelse af fælles habitat og populationsdynamik gennem de sidste 20 år i hhv. Grønland og Canada.

Til opfyldelse af målsætning 1 skulle følgende praktiske studier udføres:

I. Adfærdsstudier (aktivitetsbudget for fourageringsadfærden, valg og tidsmæssig udnyttelse af vegetationstype i allopatriske samt sympatrisk områder) af blisgæs og canadagæs i Aqajaruq - Sullorsuaq (Mudderbugten og Kvandalen), Disko i perioden fra anden uge af juli til starten af august 2004.

II. Bestemmelse af plantearter og fordelingen af disse i de udvalgte observationsområder.

Til opfyldelse af målsætning 2 skulle følgende analyse udføres:

III. Kendte statistiske analysemetoder anvendes på adfærdsstudierne efter feltperioden for at undersøge for eventuelle artsforskelle i fourageringsadfærd og udnyttelse af vegetationen (Haccou & Meelis, 1994).

Til opfyldelse af målsætning 3 skulle følgende data analyseres:

IV. Sammenkobling af litteraturstudie- og feltdata, så populationsdynamikken hos de to gåsebestande kan kvantificeres og fortolkes (Royama, 1992; Lindsey, 1997).

## Gridkort & feltområdet

På baggrund af kort fra GEUS (1:50000) blev der lavet UTM-gridkort over området i grids af 1000x1000 m (appendiks A-D). Disse kort blev både anvendt i forbindelse med en helikopter survey over området og ved de daglige observationer.

For en udførlig beskrivelse og fotografier af områdets topografi og vegetationssammensætning henvises til Egevang & Boertmann (2001).

Appendiks E giver en oversigt over periodens udførte feltarbejde.

## Helikopter-survey i Mudderbugten og Kvandalen d. 8. juli

Der blev fløjet i ca. 300 fod med en hastighed af 60 knob (~110 km/t). I de østligste dele af deltaet i Mudderbugten blev der fløjet i transekter á 5-10 km's længde i øst/vest gående retning. Dette fulgte så vidt muligt fysiske karakterer i landskabet f.eks. elvløb i deltaet. Efter surveyen i den ydre del af deltaet blev der fløjet langs den nordlige bred ind i Kvandalen. Dalen blev fulgt mod nord ved forgreningen. Derefter blev fløjet ind i Charles Polaris Dal, og den sydlige bred blev fulgt tilbage mod Mudderbugten. I alt blev brugt omkring 1 time på overflyvningen af området under følgende vejrforhold: sol, skydække 4/8, vind 4-5 m/s.

I helikopteren var de to observatører placeret i hver sin side. Når gåseflokkene blev observeret, var det aftalt med helikopterpiloten at flyve ved siden

af flokken, således at gæssene ikke blev talt af begge observatører. Ved optælling af blisgæs og canadagæs blev følgende indtalt på diktafon: GPS-position, art, antal af ikke ynglende fugle (i flokke uden unger), ynglende fugle og unger (i familieflokke). Unger var svære at tælle, men da alle observerede adulte blev talt, kan antallet af unger senere estimeres ud fra optællinger af kuld størrelser observeret fra land.

## Scanningsdata: Mudderbugten/Kvandalen d. 11. og 24. juli

Den 11. og 24. juli blev der lavet total optællinger (SCAN 1 og 2) af gæs fra to gennemgående observationsposter (OP1 og OP2) og yderligere to områder (OP3, UTM-position zone 22: 7734289N, 0453281E, ca. 3 km fra OP2 og OP4, UTM-position zone 22: 7734707N, 0452097E, ca. 4,2 km fra OP2) længere inde i Kvandalen.

## Aktivitetsbudget & fourageringsadfærd: Mudderbugten/Kvandalen d. 9. juli-1. august

Følgende undersøgelser blev foretaget i såvel allopatriske som sympatrisk områder og bygges på en artikel af Kristiansen & Jarrett (2002).

Indledningsvis blev der foretaget en fælles definition af UTM-gridområderne, hvor tydelige topografiske punkter i landskabet udgjorde markeringspunkter i hvert grid. Antallet af gæs i de enkelte grids blev optalt mindst 2 gange i løbet af perioden. For at få mere nøjagtige UTM-positioner af såvel gæs som vegetation og grids kunne dette have været understøttet af trianguleringspunktsætning af gæs i deltaet. Dette blev imidlertid ikke fuldført grundet vanskeligheder ved vandring i deltaet og for ikke at skræmme gæssene, der i denne periode normalt vil flygte ved synet af mennesker allerede på 1,5 km afstand (D. Boertmann pers. komm.).

To observationsposter blev valgt på grundlag af overflyvningen. Den ene lå på nordsiden af deltaet ca. 2 km fra havet (OP1; UTM position zone 22: 7734074N, 0460514E). Gæssene blev her observeret på afstand mellem 1,5 og 3 km. Der blev foretaget scanninger af hele elvdeltaet med optællinger af alle synlige gæs. Den anden observationspost blev valgt længere inde i Kvandalen ca. 1 km fra Lymnaeasøen (OP2; UTM position zone 22: 7733760N, 0456202E) med 1-1,5 km's afstand til gæssene. Denne observationspost lå 30 m over to udvalgte søer, som sammen med elven og andre

omkringliggende søer dagligt blev scannet for gæs. De egentlige adfærdsobservationer blev primært foretaget ved to af søerne: Venstresøen og Totalssøen (fig. 1, appendiks F).

Observationer og optællinger af gæs i allopatriske samt sympatrisk situationer blev foretaget fra et skjul (lille oversejl) fra en højtliggende position. Samtlige gæs i den observerede flok / de observerede flokke blev scannet hvert 5. minut, og art, antal og adfærd blev noteret. Observationer blev foretaget med kikkert (Kite Wing 10x42, field 6,5°; Focus Olympic 8x42, field 6,2°) samt spotting-scopes (Focus Target 70x50; Kova TSN-1 30xwide). Der blev skelnet mellem følgende adfærds kategorier: fouragering, hvile / sovn, gå, løbe, svømning, preening (fjerpuksning og badning), head up (agtpågivende), agonistisk adfærd og stå. Agonistisk adfærd blev derudover også noteret ad hoc. Afstande i gåselængder mellem individuelle gæs (både indenfor arten og mellem arterne) og afstande til vandkanten blev noteret. Der blev skelnet mellem ynglende og ikke ynglende fugle, og antallet af fugle på land og i vand blev opgjort. Hvor det var muligt, blev ankomsttidspunkt og fældeperiodens start og slut for blisgæs og canadagæs noteret.

## Udnyttelse af habitat & vegetationsanalyser: Mudderbugten/Kvandalen d. 9. juli-1. august

Observationsperiodens længde afhang af muligheden for observationer af allopatriske samt sympatrisk situationer. Feltarbejdet blev derfor fokuseret på at opnå så høj en dækning, som det var praktisk muligt. Efter endt observationsperiode blev arbejdet med fæcesindsamling og vegetationsbestemmelse foretaget i løbet af to dage.

Ved at anvende Raunkiaer cirkler (1/10 m<sup>2</sup>, radius: 17,8 cm) blev fordelingen af plantearter i fourageringsområdet estimeret med inddeling i følgende grupper: mos; padderokke; halvgræsser: f.eks. star, græsser: f.eks. rapgræs (poa), tokimbladede: f.eks. pil, birk. Der blev udlagt transektlinjer vinkelret på vandkanten, og med 5 m's intervaller blev frekvensen af de forskellige plantearter undersøgt i Raunkiaer cirklen. Antal og længde af transekter blev vurderet i felten og afhang af gæssenes fourageringsafstand til vandkanten (J. N. Kristiansen pers. komm.).

Gæssenes anvendelse af vegetationstyperne blev undersøgt ved at estimere fæcestæthed i områder, hvor gæssene fouragerede. Langs de

udlagte transektlinjer blev fæcestætheden (pr. 2 m<sup>2</sup>) optalt med 5 m's intervaller (Kristiansen & Jarrett, 2002). Der blev indsamlet i alt 24 fæcesprøver, hvoraf den ene halvdel blev soltørret og opbevaret i papirposer, og den anden halvdel blev opbevaret i 96 % ethanol. Indsamling af plantereferencemateriale til epidemistræk blev ligeledes opbevaret ved både konservering i 96 % ethanol og ved tørring og opbevaring i papirpose. De tørrede planter blev anvendt til artsbestemmelser, mens eksemplarer konserveret i ethanol blev brugt til epidermispræparater. Inden selve præparatet blev lavet, blev referencematerialet udvandet i postevand.

#### Laboratoriearbejde & dataanalyse

Der blev taget fotos af epidermis fra udvalgte plantegrupper ved brug af Olympus digitalfotomikroskop (mikroskop: Olympus model Bx60, kamera: Olympus DP10 og software: Olympus DP-Soft, DP10). Alle billeder blev taget ved 20x eller 40x forstørrelse (appendiks G).

Gæssenes fødepræference blev analyseret ved at undersøge de indsamlede fæcesprøver. Ved mikroskopering af epidermisrester i prøverne kunne frekvensen af de enkelte plantearter i føden udregnes. 100 tilfældige epidermisrester blev optalt i hver af prøverne (Owen, 1975). Som referencemateriale anvendtes epidermistræk fra arter, der voksede i fourageringsområdet (Kristiansen & Jarrett, 2002). Gæssenes fødepræference kunne derefter udregnes vha. Jacobs' præference indeks,  $D = (d-f)/(d+f-2df)$ , hvor  $d$  er frekvensen af arter i føden (fæces), og  $f$  er frekvensen af arter i vegetationen.  $D = -1$ : total undgåelse,  $D = +1$ : total præference (Jacobs, 1974). Samtidig kunne niche-bredden for de to gåsearter bestemmes vha. Levins' standardiserede ligning  $B_A = ((1/\Sigma p_i^2) - 1)/(n-1)$ , hvor  $p_i$  er frekvensen af hvert fødeemne i diæten, og  $n$  er det totale antal fødeemner.  $B_A = 0$ : smal niche-bredde,  $B_A = 1$ : bred niche-bredde (Krebs, 1999).

Forskelle i frekvensen af plantearter mellem de to søer blev testet ved en parret t-test. Varianshomogenitet blev undersøgt ved en  $F_{\max}$  test. Frekvensen af planter blev arcsin $\sqrt{x}$  transformeret.

Fæcestætheden og dermed gæssenes udnyttelse af vegetationen omkring søerne blev analyseret ved en variansanalyse, hvor fæcestætheden indgik som den afhængige variable, mens område (de to søer) og afstand til søbredden var uafhængige variable. Indledningsvis blev der foretaget en  $F_{\max}$

test for at undersøge for varianshomogenitet. I analysen er fæcestætheden  $\log(x+1)$  transformeret for at normalisere data.

Forskelle i afstande til vandkant og distancer mellem individuelle gæs (begge afstande udtrykt i gåselængder) i allopatiske og sympatiske situationer blev analyseret ved Kolmogorov-Smirnov Two Sample Test. Samme procedure blev brugt til at teste for forskelle i adfærdsformen fouragering hos de to arter i sympatiske og allopatiske situationer.

Til statistiske analyser blev SYSTAT version 10.2 (SYSTAT Software Inc., 2002) og S-PLUS version 6.2 (Insightful Corp, 2004) anvendt.

#### Resultater

Indsamlingen af adfærdsdata blev til dels besværliggjort af de fysiske forhold i observationsområdet. De individuelle søer var ikke isolerede men forbundne af utallige vandløb. Derudover var vegetationen omkring søerne høj, og dette medførte, at gæssene uhindret og ubemærket for observatørene kunne bevæge sig mellem vandområderne.

Ydermere var sommerens feltsæson præget af ustadigt vejr. Der blev ikke registreret vejrdato i forbindelse med feltarbejdet i Mudderbugten / Kvandalen, og data fra Ilulissat (station nr. 04221 ca. 50 km fra Mudderbugten) og Aasiaat (station nr. 04220 og 04224 ca. 100 km fra Mudderbugten) er derfor anvendt. I juli var gennemsnitstemperaturen i Ilulissat 0,5 °C lavere end normalt, og skydækket var generelt højere i løbet af sommermånederne end tidligere observeret. Nedbørsdata er ikke registreret på klimastationen i Ilulissat, men data fra Aasiaat vidner om betydelige nedbørsmængder. I juli og august faldt der henholdsvis 48 mm og 56 mm nedbør (normalt hhv. 27 mm og 34 mm). Sommeren var yderligere præget af kraftige storme med vindstød af indtil 18 m/s (juli) i Ilulissat og 20,6 m/s i Aasiaat ([www.dmi.dk/dmi/index/gronland/vejrarkiv-gl.htm](http://www.dmi.dk/dmi/index/gronland/vejrarkiv-gl.htm)). Samlet set betød det, at der var flere dage med dagsregn og dage med meget tåge, som trak ind i Kvandalen fra Disko Bugt. Disse resulterede i 25 % vejrligsdage uden observationer (appendiks E).

#### Helikoptersurvey

Under helikoptersurveyen blev der talt 72-97 ikke-ynglende canadagæs, 10-11 ynglende canadagæs, 47 ikke-ynglende blisgæs samt 2 blisgæs med unger (fig. 2). De største tætheder af

gæs blev set i den østlige del af Kvandalen samt i Mudderbugtdeltaet. Der blev ikke observeret gæs i den nordvestligste del af Kvandalen samt i Frederik Lange Dal og Charles Polaris Dal. De efterfølgende adfærdsobservationer af gæs blev derfor foretaget fra to observationsposter i hhv. Mudderbugt-deltaet (OP1) og i den østligste del af Kvandalen (OP2) (fig. 1).

#### Scanningsdata

Der blev løbende foretaget scanninger af det totale antal gæs fra begge observationsposter (fig. 1). I Mudderbugtdeltaet var gennemsnitsantallet af adulte canadagæs 86,6 (range: 15-185;  $n=12$ ), mens der var 76,3 blisgæs (range: 2-170;  $n=8$ ) og 53,1 uidentificerbare gæs (range: 8-79;  $n=8$ ) pr. total scan. Antallet af gæs faldt markant i Kvandalen, hvor der i gennemsnit var 17,0 canadagæs (range: 1-67;  $n=14$ ), 7,5 blisgæs (range: 1-20;  $n=15$ ) og 14,3 uidentificerbare gæs (range: 2-40;  $n=4$ ) pr. total scanning. Den 11. juli blev der foretaget scanninger ved såvel OP1 og OP2, mens der d. 24.7. ydermere blev vandret længere ind i Kvandalen (tabel 3). Under helikoptersurveyen blev der observeret gæs ved punkt 11-15 (fig. 2). I disse søer og områder var der nu ingen gæs.

Dato	OP1	OP2	OP3	OP4	Sum
Den 11. juli: SCAN1					
Blisgæs	2	2	-	-	4
Canadagæs	129	57	-	-	186
Gås sp.	50	0	-	-	50
Den 24. juli: SCAN2					
Blisgæs	114-170	12	0	18-19	134-201
Canadagæs	108-185	0	0	0	108-185
Gås sp.	675	0	0	149-179	824-854

**Tabel 3.** Totalscanninger af områderne ved observationspost 1, 2 samt OP3 og OP4. Blisgæs, canadagæs og ikke-identificeret gåseart grundet afstand, varmedis og genskin (min.-max.). Ingen observationsdækning er angivet med (-).

#### Fourageringsadfærd

Sammenlagt blev der observeret adfærd i 110 timer. Heraf blev 58 timer brugt på scanninger i allopatiske situationer (32 timer på blisgæs og 26 timer på canadagæs), mens der blev brugt 52 timer

på sympatiske situationer.

Observationerne startede oftest kl. 8:30 og sluttede kl. 22:30. Der blev lavet en observationsperiode ved OP1, der strakte sig over et helt døgn (d. 12.-13.7.) men pga. det ringe udsyn (tusmørke) blev dette ikke gentaget ved OP2.

Det gennemsnitlige antal adulte gæs, der blev observeret i flokkene ved OP2 varierede gennem perioden og afhang endvidere af hvilken art, der var tale om (fig. 3). Der blev generelt observeret færre blisgæs, og disse udviste lave fluktuationsudsving. Canadagæs fluktuerede mere gennem hele perioden, og nogle dage var de antalsmæssigt dobbelt så mange som blisgæssene. D. 24. juli begyndte vi at kunne se forskelle i Venstresøens størrelse, idet denne så ud til at blive gradvis mere udtørret. Antallet af gæs i denne sø faldt, og d. 28. juli blev der ikke registreret gæs i søen.

De observerede flokke af blisgæs og canadagæs varierede i størrelse afhængigt af mange parametre. Dels af om det var ynglende eller ikke ynglende grupper, dels af om det var allopatiske eller sympatiske situationer, og endvidere om udregningerne er baseret på antallet af synlige fugle gennem hele observationsperioden eller det maksimale antal individer, der blev observeret i flokken i løbet af perioden.

Flokstørrelsen hos ynglende blisgæs var  $\bar{x} = 2,1$  adulte individer ( $n = 20$ , modusværdi = 2, maksimum = 6), mens den hos ikke-ynglende blisgæs var  $\bar{x} = 7,8$  adulte individer ( $n = 21$ , modusværdier = 4 og 6, maksimum = 34). Hos canadagæs var flokstørrelsen hos ynglende gæs  $\bar{x} = 8,2$  adulte individer ( $n = 19$ , modusværdi = 2, maksimum 25), mens den hos ikke-ynglende canadagæs var  $\bar{x} = 9,8$  adulte individer ( $n = 18$ , modusværdi = 2, maksimum = 37). Disse data fortæller om antallet af gange en bestemt flokstørrelse er observeret, men ikke hvor stor en del af den total observerede tid den enkelte størrelse er registreret.

Den gennemsnitlige flokstørrelse for blisgæs og canadagæs i allopatiske situationer var hhv. 3,7 og 9,7 adulte individer. I sympatiske situationer ændredes denne hos canadagæs, hvor gennemsnitsflokkene var på 4,4 adulte individer. Størrelsen af blisgæsflokkene forblev den samme (3,6 adulte individer). Den største scannede flok var på 37 ikke-ynglende canadagæs.

Den gennemsnitlige kuld størrelse i de observerede flokke var for canadagæs  $\bar{x} = 3,2$



gæslinger ( $n = 40$ , modusværdi = 4) og for blisgæs  $\bar{x} = 3,1$  gæslinger ( $n = 24$ , modusværdi = 1). Flokke bestående af både adulte og juvenile individer, hvor familiestrukturen ikke har været tydelig for observatørene, er ikke indgået i denne beregning.

På grund af afstanden til de observerede gæs var fødeindtaget ikke muligt at bestemme udfra antallet af "pecks" pr. 10 sekunder. Denne observationsteknik (Kristiansen & Jarrett, 2002) blev derfor fravalgt.

Afstande til vandkant og mellem individuelle gæs i såvel allopatriske som sympatriske situationer er afbilledet i figur 4. I allopatriske situationer opholdt blisgæs sig tættere på søbredden end canadagæs (afstand til vand hos blisgæs:  $\bar{x} = 2,2$  gåselængder og hos canadagæs:  $\bar{x} = 3,7$  gåselængder,  $D = 0,158$ ,  $p < 0,05$ ). Dette forhold blev ændret mærkbart i sympatriske situationer, hvor canadagæs var nærmere vandkanten (afstand til vand hos blisgæs:  $\bar{x} = 4,0$  gåselængder og hos canadagæs:  $\bar{x} = 2,3$  gåselængder,  $D = 0,146$ ,  $p < 0,05$ ). Derudover var afstanden mellem individuelle gæs afhængig af, om der var tale om allopatriske eller sympatriske situationer. Når blisgæs blev observeret alene, var afstanden mellem individer  $\bar{x} = 15,3$  gåselængder, mens den for allopatriske canadagæs var  $\bar{x} = 21,2$  gåselængder ( $D = 0,219$ ,  $p < 0,05$ ). Samme tendens blev ligeledes fundet i sympatriske situationer (individuel afstand hos blisgæs:  $\bar{x} = 9,2$  og hos canadagæs:  $\bar{x} = 12,0$ ,  $D = 0,192$ ,  $p < 0,05$ ). Dog var afstanden mellem individuelle blisgæs ikke signifikant forskellige, når allopatriske og sympatriske situationer blev sammenlignet ( $D = 0,086$ ,  $p = 0,058$ ). Afstanden var derimod signifikant forskellig hos canadagæs ( $D = 0,174$ ,  $p < 0,05$ ). Dette tyder på, at afstanden mellem individuelle canadagæs blev mindre i sympatriske situationer.

Figur 5 viser aktivitetsbudgettet for blisgæs og canadagæs. Heraf fremgår det, at blisgæs og canadagæs fouragerede hhv. 25 % ( $n = 579$ ) og 20 % ( $n = 501$ ) af tiden i allopatriske situationer, hvilket er tæt på at være signifikant forskelligt ( $D = 0,083$ ,  $p = 0,051$ ). Til gengæld var fourageringsfrekvensen signifikant forskellig i sympatriske situationer, hvor canadagæs brugte 14 % ( $n = 500$ ) af tiden på fouragering, mens blisgæs brugte 28 % ( $n = 471$ ) ( $D = 0,172$ ,  $p < 0,05$ ). Canadagæs brugte signifikant mindre tid på at fouragere i sympatriske situationer i forhold til allopatriske ( $D = 0,117$ ,  $p < 0,002$ ). Denne forskel

så ikke hos blisgæs ( $D = 0,038$ ,  $p > 0,05$ ). Blisgæs anvendte betydelig mindre tid på at hvile end canadagæs uanset situationen. Den største forskel ser dog til at ligge i head up adfærd, hvor canadagæs udviste mere af denne adfærd end blisgæs under sympatriske situationer (tabel 4).

	Fouragerin g	Hvile	Svøm	Head up
Blisgæs	=	=	=	=
Canadagæs	-	-	+	+
s				

	Afstand til sø	Individ-afstand
Blisgæs	+	=
Canadagæs	-	-
s		

**Tabel 4.** Ændring i adfærd og afstande til søbred og andre gæs hos blisgæs og canadagæs i skift fra allopatriske til sympatriske situationer i Mudderbugten / Kvandalen. Fald er markeret med (-), stigning med (+) og ingen ændring med (=).

Der blev kun observeret få agonistiske interaktioner imellem gæssene. I alt blev der noteret 21 direkte (vingeslag, fremadgående bevægelse med sænket hoved og / eller strakt hals) agonistiske interaktioner, hvoraf 15 var mellem artsfæller (8 mellem canadagæs og 7 mellem blisgæs). Interspecifikke agonistiske interaktioner blev kun observeret i 6 tilfælde, hvoraf canadagæs stod som vinder i 4 af disse. I langt flere tilfælde opholdt begge gåsearter sig i samme områder, uden at der var agonistiske interaktioner (se eksempel på dette i "Beskrivelsesdata").

#### Vegetations- og fæcesanalyser

Der blev i alt udlagt 8 transekter (længde: 15-50 m) omkring de to søer, hvor adfærdsobservationerne var foretaget. Længs transekterne blev der fundet 25 forskellige planter, som blev bestemt til familie-, slægts- eller artsniveau. Af disse var der 13 arter tokimbladede, 4 arter enkimbladede (rapgræs *Poa* sp., tundra star *Carex stans*, Langes rørhvene *Calamagrostis hyperborea*) og arktisk siv *Juncus arcticus*, 2 arter karsporeplanter (ager padderokke *Equisetum arvense* og en bregne art), 4 ubestemmelige arter samt mos og lav (appendiks H). De uidentificerede arter udgjorde mellem 0 % og 5 % i vegetationen (i ét tilfælde var der 10 % uidentificerbare planter i en Raunkjær cirkel) og er ikke medregnet i de statistiske analyser.

Der er ingen signifikant forskel på de to undersøgte søer mht. fordelingen af planter ( $F_{\max} = 1,42$ ;  $t = -0,757$ ;  $p > 0,05$ ). I de efterfølgende analyser vil det samlede datasæt derfor blive anvendt.

Fæcestætheden og dermed udnyttelsen af

vegetationen var ens langs transekterne ( $\bar{x} = 3,0$  pr  $2 \text{ m}^2$ ,  $F_{\max} = 2,52$ ;  $F_{1,49} = 0,176$ ;  $p > 0,05$ ), og der var ingen forskel mellem de to søer ( $F_{1,49} = 0,136$ ;  $p > 0,05$ ).

Ved at sammenligne fordelingen af plantearter i vegetationen og i gæssenes føde (indirekte ved at undersøge fæces) blev det undersøgt, hvorvidt gæssene var selektive i deres fødevalg. Det var ikke muligt at skelne mellem fæces fra blisgæs og canadagæs. Ydermere var ingen af de observerede søer udelukkende allopatriske eller sympatriske. Resultaterne er derfor et udtryk for selektion hos gæssene generelt og er ikke arts- eller situationsspecifik. Der blev i alt indsamlet 24 fæcesprøver. Alle 24 prøver blev analyseret, og frekvensen af epidermisrester blev opgjort. Dog blev 2 af prøverne senere ekskluderet på baggrund af manglende planterester.

Jacobs' præference indeks,  $D$  viser gæssenes selektivitet i fødevalget. Som det ses i figur 6, er gæssene yderst selektive og præfererer rapgræs *Poa* sp. og tundra star *C. stans*, som udgør henholdsvis 19 % og 42 % af deres føde. Til gengæld undgås tokimbladede planter og mosser.

Niche-bredden for gæssenes føde er  $B_A = 0,227 \pm 0,029$  (gennemsnit  $\pm$ SE; minimum 0,060 og maksimum 0,572) og svarer dermed til en forholdsvis smal fødeniche.

#### Beskrivelsesdata

Ved observationspost 1 blev der foretaget døgnobservationer og tællinger af gæs i den ydre del af deltaområdet d. 12. og 13. juli. Vejret slog om fra regn og tåge d. 12 og indtil d. 13. om aftenen. Derefter blev det solskin og vindstille. Et meget stort antal af gæs (100+) af begge arter med gæslinger kom frem fra vegetationen mellem kl. 18 og midnat. De bevægede sig fra en sø til en mere østliggende sø. Dette foregik i blandede flokke bestående af mindre artsopdelte grupper af blisgæs og canadagæs. Vandringer til den nye sø krævede, at de krydsede en landtange mellem søerne, hvilket satte mange gæs i "venteposition" ved den første sø. Der var ingen tydelige agonistiske interaktioner eller lignende under denne vandring.

Under observationerne ved OP2 blev der ligeledes dagligt noteret store flux af gæs. De kom fra det øvre elvløb og svømmede nedad elven. Nogle tog ophold i observationssøerne, og andre svømmede forbi. Observationspostens tilstedeværelse virkede ikke umiddelbart til at have nogen betydning for gæssene eller på antallet

af gæs, så længe observationerne blev fortaget fra mindst 1 km's afstand. Opsættelsen af observationsposten ved Venstresøen den første dag skræmte dog gæssene bort, men der var atter gæs i søen efter to dage. Der blev generelt observeret stor bevægelse mellem søerne og elven. Dvs. gæssene var ikke stationære, men anvendte de forskellige søer uafhængigt af, hvor de havde opholdt sig den foregående dag. Det medførte, at der hverken var permanente allopatriske eller sympatriske situationer.

Der blev set flyvende gæs i området fra d. 8. juli. Der er i alt tale om 5 observerede tilfælde, hvoraf et tilfælde var af canadagæs, mens de resterende udelukkende var ikke-ynglende blisgæs. Canadagåsen blev set flyvende og kaldende over deltaet (8. juli). En blisgås blev set lette fra en sø og flyve mod øst i retning af Mudderbugten (19. juli), 11 blisgæs lettede fra en sø og fløj mod vest i retning ind i Kvandalen (21. juli), 2 lettede fra land og fløj et kort stykke ud på en sø (22. juli), mens yderligere 2 fløj til en sø i Kvandalen (28. juli).

Der var indtil flere polarræve (*Alopex lagopus*) i området omkring de observerede søer og i deltaet. De blev flere gange set løbende langs søerne med det resultat, at gæssene hurtigt svømmede ud på vandet. Kun en gang blev en succesfuld rævejagt observeret. Den 25. juli sent om aftenen blev en canadagæseunge taget af en ræv. Ræven havde fat i gæslingens hals tæt ved hovedet, og der sås gentagen "tovtrækning" mellem ræven og gåsen, mens de øvrige gæs lå på vandet tæt ved land nær den angrebne gæsling. Der var ingen direkte kontakt mellem gæssene på vandet og ræven, men situationen skabte en del tumult og lydproduktion hos gæssene. Ca. 30 minutter efter ræven havde trukket den døde gæsling på land, faldt der ro over de øvrige gæs, og de svømmede atter ud på søen. En rævegrav ved mindst to unger blev observeret d. 29. juli i en morænebank ca. 1 km vest for observationspost 2.

Den 25. juli blev der i ydre kanten af en canadagæseflok på godt 10 individer observeret en gås med tydelig hvid kind- og halsmarkering som en canadagås, men med lys blis og orange næb og ben som en blisgås. Enkelte individer i flokken af canadagæs udviste agonistisk adfærd overfor gåsen, som blev fulgt af en gæsling. Der er tidligere rapporteret om hybrider mellem canadagæs og grågæs (*Anser anser*) i Sverige, men de blev formodet sterile (Fabricius *et al.*, 1974).

Opportunistiske observationer af fugle og pattedyr i Mudderbugten og Kvandalen blev noteret og kan ses i appendiks I.

## Diskussion

Det kunne være interessant at undersøge gæssenes udnyttelse af området nærmere, idet dette års observationer viste en høj grad af mobilitet hos begge arter. Ligeledes var fordelingen af gæs i området forskellig, da gæssene anvendte deltaet i Mudderbugten mere end søerne længere inde i Kvandalen.

De lave tællinger fra helikoptersurveyen i forhold til de landbaserede observationer skyldes formentlig to ting. Dels at gæssene kunne skjule sig i vegetationen, og at de talte individer derfor hovedsageligt var gæs ude på søerne, dels at observatørene ikke havde meget erfaring i gæsesurveys.

En stor andel af gæssene var desværre så langt borte, at observatørene noterede dem som uidentificerbare. Samlet stemmer antallet af gæs i deltaet overens med tællinger fra 2001 (Egevang & Boertmann, 2001). Antallet af canadagæs talt under de to surveys (SCAN 1 og 2) er på nuværende tidspunkt tilsyneladende lig antallet af blisgæs i området. Dette indikerer, at de sidste 15 års stigning af canadagæs i området ikke er stoppet endnu.

På Jameson Land, Østgrønland er der observeret fodekonkurrence mellem kortnæbbet gås (*Anser brachyrhynchus*) og bramgås (*Branta leucopsis*). Det formodes, at bramgæs, som er negativt påvirket af denne konkurrence, er i stand til at huske hvilke områder, der i sæsonen før var optaget af kortnæbbede gæs og derved undgå disse steder (Madsen & Mortensen, 1987). Dette er formodentlig også tilfældet for situationerne i Vestgrønland. Hvis blisgæs i én sæson har oplevet konkurrence med canadagæs er det muligt, at de derefter undgår disse områder. Lokalt kan blisgåsen derfor forsvinde.

## Fourageringsadfærd

I forbindelse med registreringen af de forskellige adfærdsformer blev det hurtigt klart, at en del af disse ville blive underestimeret i aktivitetsbudgettet. Dette skyldtes bl.a. den høje vegetation omkring søerne, som hindrede udsynet til gæssene og dermed umuliggjorde tilfredsstillende betingelser for observationer i dette habitat. Ydermere blev adfærdsformen "fouragering" formodentlig underestimeret, når

gæssene fouragerede på vand. I tilfælde hvor der var mange fugle (gæs og ænder) på vandet ad gangen, og der i længere perioder blev fourageret med hovedet under vand og enden oppe, kunne det være svært at skelne mellem gåsearterne og mellem ande- og gåseender. Samtidig var der midt på dagen ofte varmedis, der hindrede ugeneret udsyn over de observerede gæs. Varmedisen besværliggjorde adfærdsregistreringerne, og kun enkelte af adfærdsformerne kunne bestemmes med sikkerhed (f.eks. "svømning" og "head up").

Registreringen af agonistisk adfærd synliggjorde, at der i observationsområdet ikke var tale om samme frekvens af interaktioner, som tidligere undersøgelser har vist (Kristiansen & Jarrett 2002). Her er kun medtaget 3 typer af agonistisk adfærd: vingeslag, sænket hoved og strakt hals. Det indsamlede datamateriale lægger dog op til, at en mere dybdegående analyse kan foretages. Det lille antal interspecifikke agonistiske interaktioner mellem gæssene i Mudderbugten / Kvandalen kan skyldes den store mobilitet, der var hos gæssene. I stedet for at indgå i agonistiske interaktioner trak gæssene til områder, hvor der var færre / ingen af den modsatte art. Der blev oftere observeret intraspecifik agonistisk adfærd end interspecifik.

Dette stemmer overens med resultater fra undersøgelser på kortnæbbet gås og bramgås (Madsen & Mortensen, 1987) og tidligere undersøgelser på blisgæs og canadagæs i Mudderbugten / Kvandalen (Boertmann & Egevang, 2002). Det er dog i modsætning til resultaterne fra Isunngua, Vestgrønland (Kristiansen & Jarrett, 2002).

De to gåsearters anvendelse af habitatet omkring og i søerne forandrede sig afhængig af situationen (allopatrisk og sympatrisk). Tabel 4 viser de fundne forskelle i adfærden i de to situationer fra OP1 og OP2. Tilsyneladende ses den største påvirkning i sympatriske situationer hos canadagæssene, idet disse brugte mindre tid på at fouragere og hvile, end når de var alene. De opholdt sig tættere ved søen, samtidig med at de var mere i bevægelse og agtpagivende i sympatriske søer. For blisgæs sås kun ændringer i afstanden til søbredden, idet de fik længere afstand dertil. Forskellen i afstand kan skyldes tilstedeværelsen af canadagæs, og kan være en ulempe for blisgæs grundet prædatorer som polarræv, der tydeligvis var i området. For gæssene fra Isunngua, Kangerlussuaq blev det observeret, at blisgæssene rykkede tættere til

vandet, hvilket blev forklaret med den dårligere føde, der var tilgængelig her. Vegetationen omkring dette studies to observationssøer var tæt og gik langt ned til søbredden. Den fundne tendens kan måske derfor forklares ud fra denne forskel i vegetationen.

Der blev observeret en forskel i flokstørrelse hos hhv. ynglende og ikke ynglende blisgæs. Samme flokstrukturændring var ikke tydelig hos canadagæs. Hos begge arter var modusværdien dog 2. Flokstørrelsen i de to situationer (allopatrisk og sympatrisk) blev kun ændret hos canadagæs, hvor denne blev halveret fra gennemsnitlig 10 til 4 individer. Hos blisgæs forblev den på 4 individer i begge situationer. Kuld størrelsen var størst hos canadagæs med gennemsnitlig 3 gæslinger og modusværdi på 4, selvom der også blev noteret par med op til 9 gæslinger. Blisgæs havde i gennemsnit 3 gæslinger og modusværdi på 1. Hos bl.a. edderfugle kendes til "tanteadfærd", hvor enkelte voksne individer passer på en større yllingeflok bestående af kuld fra flere par. Måske de store gæslingegrupper kan forklares på samme måde.

Kuld størrelsesestimatet kan være baseret på gentagne samples fra samme familieflokke, da hver dags observationer startede som nye dataindsamlinger. Det var ikke muligt at skelne mellem flokkene / familierne fra dag til dag, og vi observerede ikke døgnnet rundt.

Den tilbagevendende modusværdi på 2 for begge arters flok størrelse er værd at tage til efterretning, når vi diskuterer allopatriske og sympatriske situationer. Ca. 40 % af vore observationer er fra en gruppestruktur på 2 adulte, så det rejser tvivl, om hvorvidt det overhovedet er beskrivende at anvende disse betegnelser på så få individer.

## Vegetations- og fæcesanalyser

Der var ingen forskel i fæcestætheden mellem de to observationssøer. Dette kan skyldes, at der var tæt vegetation næsten ned til bredden af søerne hele vejen rundt. Til sammenligning fandt Kristiansen & Jarrett (2002) at fæcestætheder aftog gradvist med afstanden til søbredden.

Studiet i Isunngua, Kangerlussuaq (Kristiansen & Jarrett, 2002) viste, at gæssene generelt selekterede for poa og star, som udgjorde henholdsvis 46-57 % og 10-35 % af diæten. De undgik tokimbladede og mos (dog sås tendens til selektion af mos hos sympatriske blisgæs). Disse data stemmer fint overens med selektionen af føde

fundet under dette studie.

Den fundne nichebredde på 0,23 afspejler ligeledes data fundet i Isunngua (0,18-0,31) (Kristiansen & Jarrett, 2002).

### Videreudvikling

En grafisk analysemodel baseret på niche-teori videreudviklet af Chase & Leibold (2003) kunne være yderst interessant at afprøve på situationen i Mudderbugten / Kvandalen. Ressource tilgængelighed, prædator tæthed og stressintensitet f.eks. interspecifik konkurrence bliver udtrykt på en X og Y-graf. Linjernes skæring viser de forskellige faktors påvirkning og retning. Det vil dog kræve, at vi kan artsbestemme fæcesprøverne, hvilket pt. ikke er muligt.

### Genetiske undersøgelser af fæcesprøver

Det ønskes, at de spritkonserverede fæcesprøver kan blive analyseret genetisk for at gøre diætundersøgelsen artsspecifik. Tidligere undersøgelser har vist, at det er muligt at adskille blisgæs fra canadagæs vha. mitochondrielle DNA-sekvenser f.eks. af genet, der koder for cytochrome b (Paxinos *et al.*, 2002). På National Center for Biotechnology Information (<http://www.ncbi.nlm.nih.gov>) er det lykkedes at finde sekvenser, der koder for cytochrome b på hhv. 307 basepar for blisgæs og 306 basepar for canadagæs. Forskellen mellem de to sekvenser er på 8,8 % svarende til 27 basepar ud af de ca. 300. Forskellen er dermed ikke stor, men det er dog stadig muligt at adskille de to arter, hvis variationen indenfor arterne ikke er større (M. Poulsen pers. komm.).

### Konklusion

På baggrund af resultaterne i dette studie er det svært at vurdere, om det bliver canadagæs, der udkonkurrerer blisgæs eller omvendt, eller om de to arter overhovedet konkurrerer om føden og pladsen i Mudderbugten / Kvandalen. Som det ser ud i øjeblikket, er antallet af canadagæs i Mudderbugten / Kvandalen steget, men antallet af agonistiske interaktioner er fortsat meget lavt. Dette kunne tyde på, at området endnu ikke er "mættet" med gæs, og at der stadig er områder, som er tilgængelige for nyttilkommende. Genetiske undersøgelser af fæcesprøverne vil kunne klarlægge, om der er tale om et nicheskift i diæten for canadagæs og / eller blisgæs. Dette vil muligvis give indblik i den mere diskrete form for

konkurrence, som kan være svær at opdage ved et decideret adfærdsstudie.

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Fig. 1. Studieområdets placering. (a) Grønland med indramning af Disko. (b) Kort over Disko med indramning af Mudderbugten (Aqajarua) og Kvandalen (Sullorsuaq). (c) Detalkort over Mudderbugten og Kvandalen, hvor feltarbejds to observationsposter, OP1 og OP2 (o) og observerede søer (□) er markeret. Målestokken i højre side af kortet angiver størrelsesforholdet.

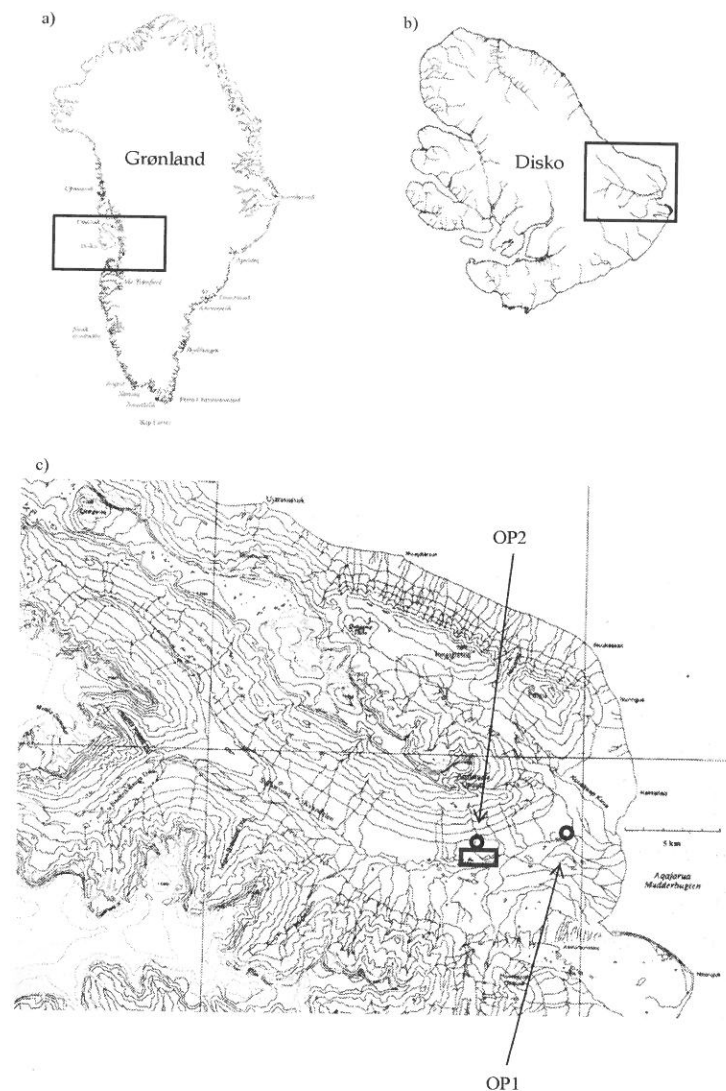


Fig. 2. Observationer af gæs fra helikoptersurvey d. 8. juli 2004. På kortet er de enkelte observationer markeret (blisgæs: ○, canadagæs: ●, sympatrisk situation: ⊙) og vedhæftet et waypoint-nummer. I tabellen oplyses antallet af den pågældende gåseart for hvert af de 17 waypoints. Målestokken i højre side af kortet angiver størrelsesforholdet.



Waypoint	Blisgæs ( <i>Anser albifrons</i> )			Canadagæs ( <i>Branta canadensis</i> )		
	Ikke-ynglende	Ynglende	Gæslinger	Ikke-ynglende	Ynglende	Gæslinger
1	6					
2				2		
3		2				
4				20-40		
5	15					
6					3	
7					3-4	2-3
8	2					
9	1			2		
10				6		
11				20-25		
12	20					
13				2		
14					4	2
15				20		
16	2					
17	1					
Total	47	2		72-97	10-11	4-5

Fig. 3. Det gennemsnitlige antal af adulte blisgæs og canadagæs i flokkene observeret ved Venstresøen og Totalssøen fra observationspost 2 (OP2) i løbet af feltperioden. (a) viser antal af adulte blisgæs (■) og (b) viser antal af adulte canadagæs (■). Dagens maksimale antal af observerede individer er markeret ved (-).

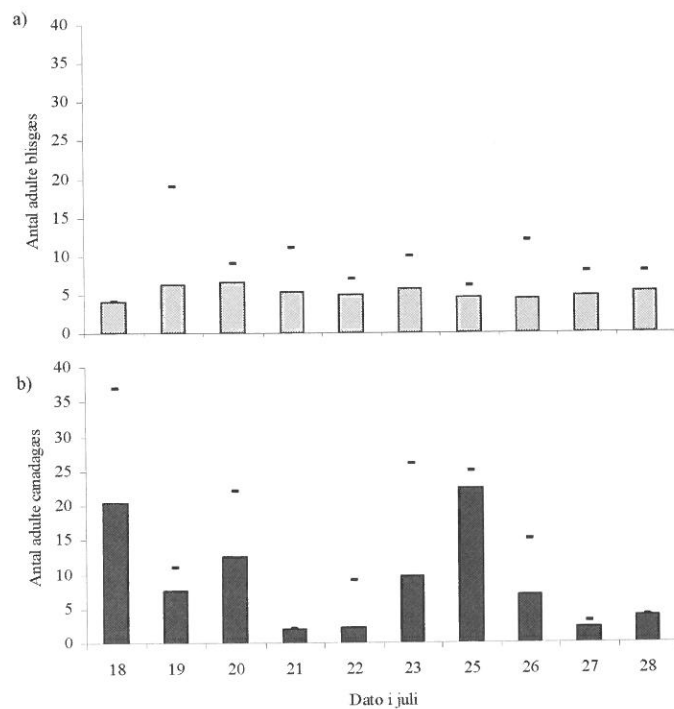


Fig. 4. Distance (gennemsnit og standard error) til (a) vandkanten og (b) mellem individuelle gæs i allopatriske (□) samt sympatriske (■) situationer. Alle afstande er målt i gåselængder. Forskellige bogstaver over søjlerne angiver signifikante forskelle fundet ved Kolmogorov-Smirnov Two Sample Test. Note: forskel på y-aksernes enheder.

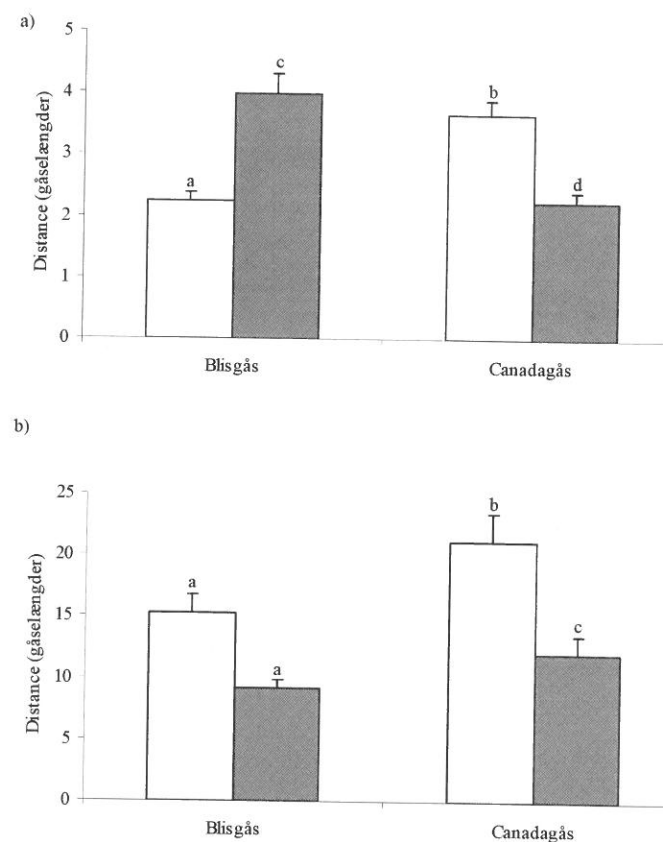




Fig. 5. Aktivitetsbudget med observeret adfærd i frekvens ( $\pm$  standard error) for blisgæs og canadagæs i allopatriske ( $\square$ ) samt sympatriske ( $\blacksquare$ ) situationer. Figur (a) er for blisgæs, og (b) er for canadagæs.

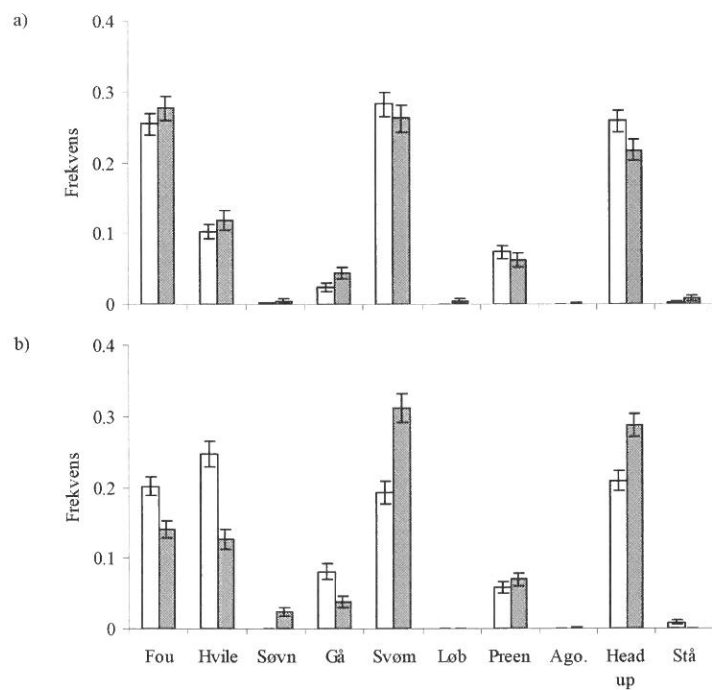
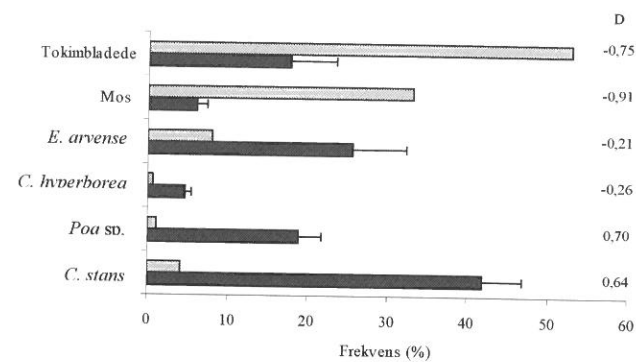
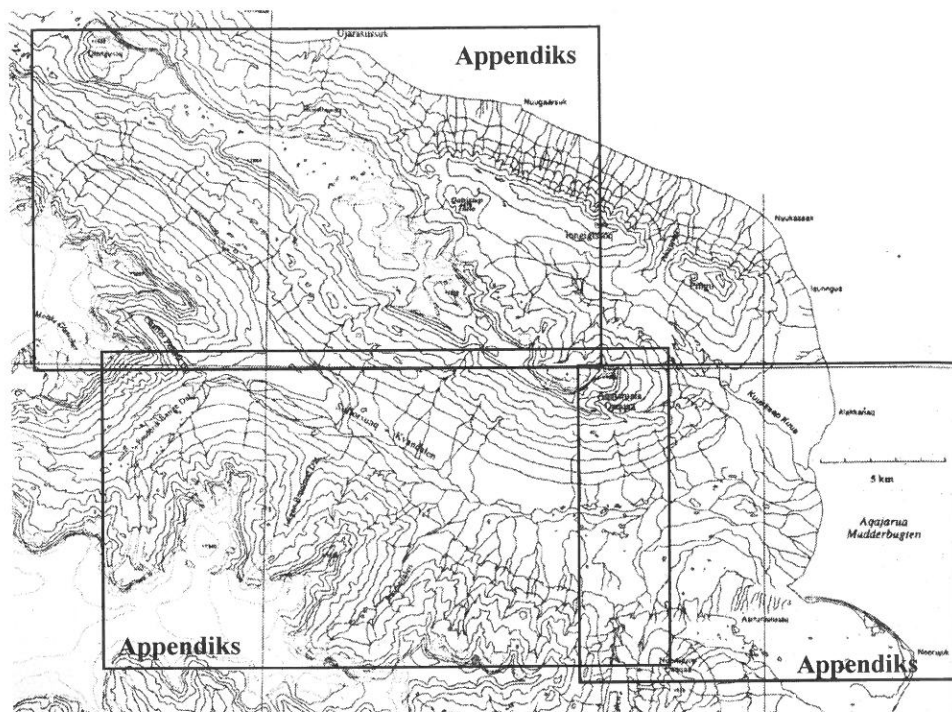


Fig. 6. Frekvens (%) af plantearter i fæces ( $\blacksquare$ ) hos blisgæs og canadagæs (gennemsnit og standard error) samt i vegetationen ( $\square$ ). Jacobs' præference indeks, D, indikerer graden af selektivitet og rangerer fra -1 (total undgåelse) til +1 (total præference).



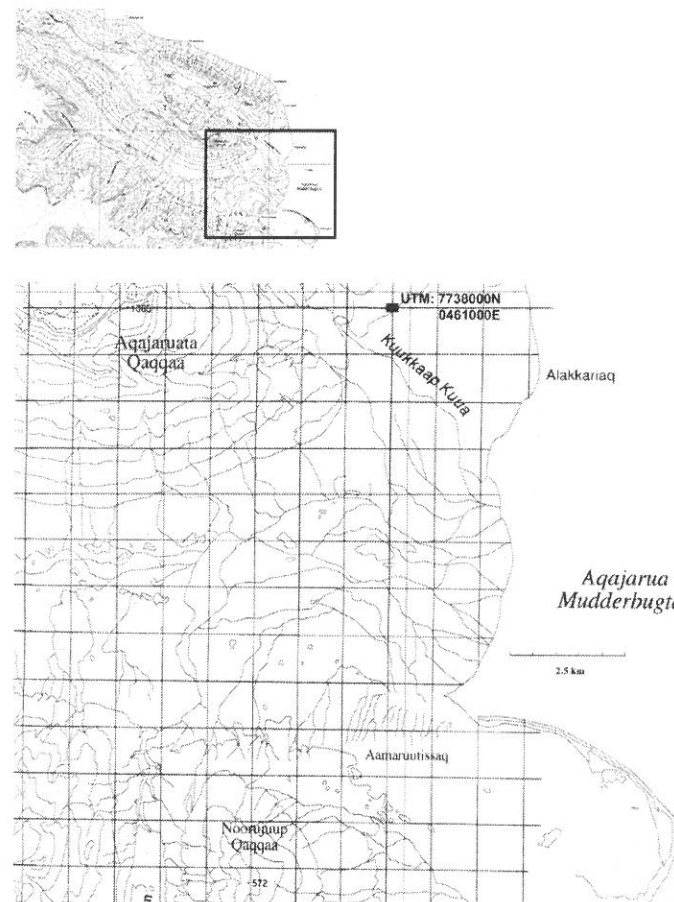
## Appendiks A

Placeringen af gridkort (appendiks B-D). Appendiks B dækker således over Mudderbugten (Aqajarua) og Kvandalens (Sullorsuaq) østlige del, mens appendiks C dækker Kvandalens sydlige udbredelse, og appendiks D er et uddrag af den nordligste del af dalsystemet. Målestokken i højre side af kortet angiver størrelsesforholdet.



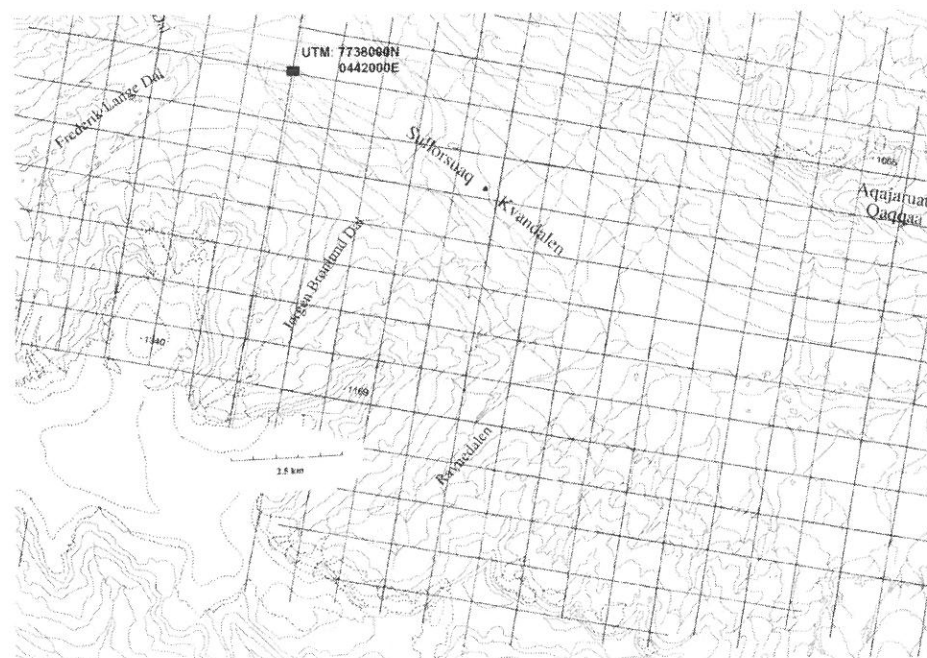
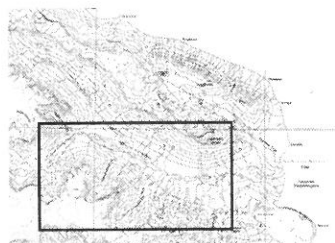
## Appendiks B

Gridkort over Mudderbugten med elvdelta og Kvandalens østlige del. Hvert grid er 1x1km og er lavet ud fra punktet UTM, zone 22: 7738000N, 461000E (■). Målestokken i højre side af kortet angiver størrelsesforholdet.



## Appendiks C

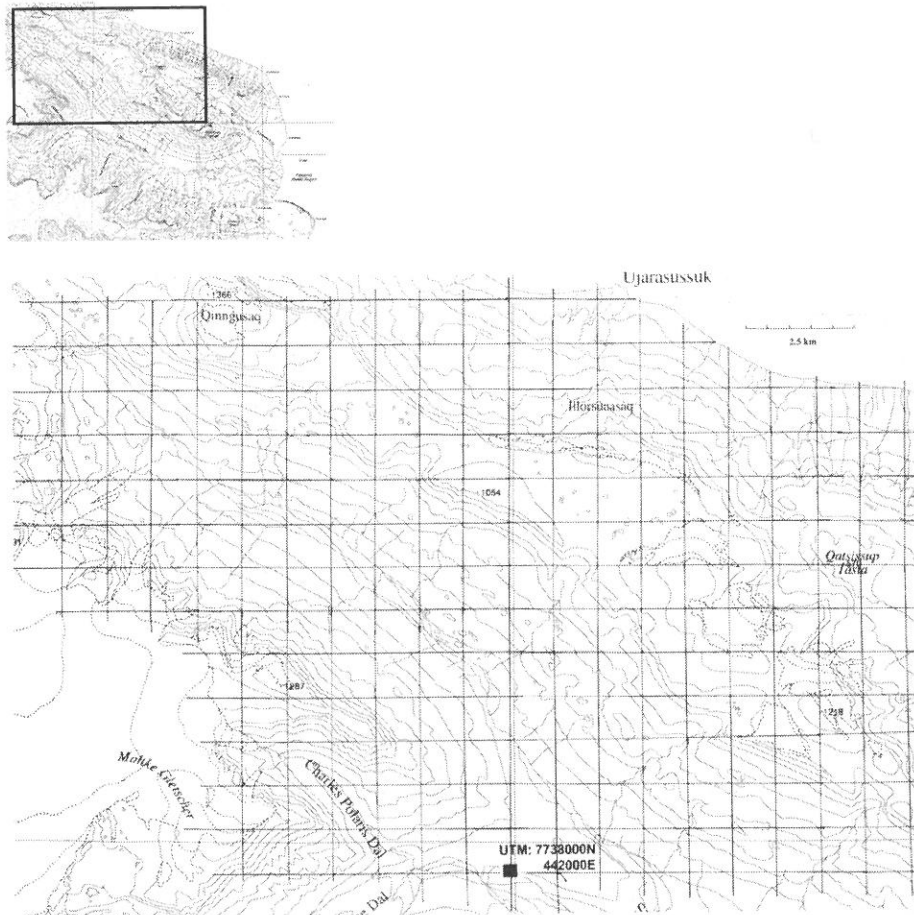
Gridkort over Kvandalens sydlige område. Hvert grid er 1x1km og er lavet med udgangspunkt i punktet UTM, zone 22: 7738000N, 442000E (■). Målestokken i venstre side af kortet angiver størrelsesforholdet.





## Appendiks D

Gridkort over Kvandalens nordlige dalsystem. Hvert grid er 1x1km og er lavet ud fra punktet UTM, zone 22: 7738000N, 442000E (■). Målestokken i højre side af kortet angiver størrelsesforholdet.



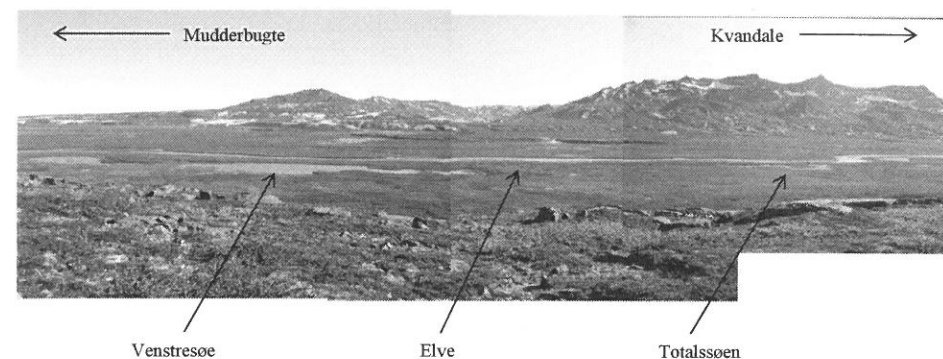
## Appendiks E

Opholdet i Mudderbugten og Kvandalen 8. juli – 1. august 2004.

Dato	Undersøgelse	Obs. post	Vejr
8.7.	Helikoptersurvey		Sol, skydække 4/8, vind 4-5 m/s
9.7.	Lavede lejr og observationspost 1	OP1	Sol, skydække 4/8, vind 4-5 m/s
10.7.	Vandrede ud til Fangsthytte		Sol, skydække 4/8, vind 4-5 m/s
11.7.	Vandrede ind til observationspost 2, Total-scanning 1	OP2, SCAN 1	Sol, skydække 4/8, vind 4-5 m/s
12.7.	Observationer og scanninger	OP1	Overskyet, plus tåge, havgus
13.7.	Vejrligsdag indtil sen eftermiddag		Regnvejr med enkelte pauser, stærke vindstød
14.7.	Vejrligsdag		Regnvejr og stærke vindstød
15.7.	Vejrligsdag		Regnvejr og stærke vindstød
16.7.	Vejrligsdag		Regnvejr og stærke vindstød. Klarede op til aften
17.7.	Lejr flyttes til OP2		Sol
18.7.	Observationer og scanninger	OP2	Sol
19.7.	Observationer og scanninger	OP2	Sol
20.7.	Observationer og scanninger	OP2	Sol og næsten ingen vind
21.7.	Observationer og scanninger afbrudt over middag	OP2	Tiltagende stærk vind
22.7.	Observationer og scanninger	OP2	Tåge, regn og sol skiftevis
23.7.	Observationer og scanninger	OP2	Regn og sol skiftevis
24.7.	Total-scanning 2	SCAN 2	Regn og stærk vind om aftenen. Sne på fjelde
25.7.	Observationer og scanninger	OP2	Sne på fjelde
26.7.	Observationer og scanninger	OP2	Stærke vindstød. Skyfrit
27.7.	Observationer og scanninger	OP2	Stærke vindstød. Skyfrit
28.7.	Vegetationsundersøgelser og fæcesindsamlinger	Venstresøen	Sol
29.7.	Vegetationsundersøgelser og fæcesindsamlinger	Totalssøen	Sol
30.7.	Lejr flyttes tilbage OP1		
31.7.	Flyttede lejr til Fangsthytte og opsamlingssted		
1.8.	Opsamlet af Porsild		

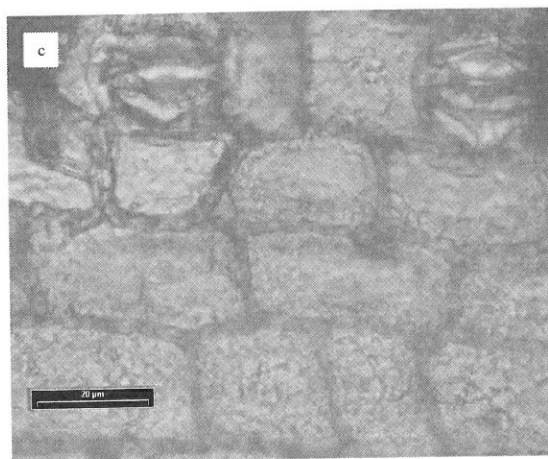
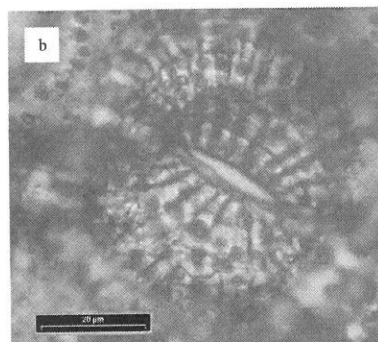
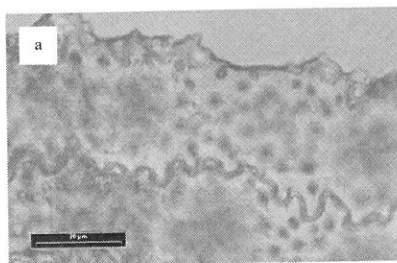
## Appendiks F

Diasbilleder af området ved observationspost 2. På billedet er retningen mod Mudderbugten (øst) og Kvandalen (vest) indtegnet. Derudover er Venstresøen og Totalssøen markeret.

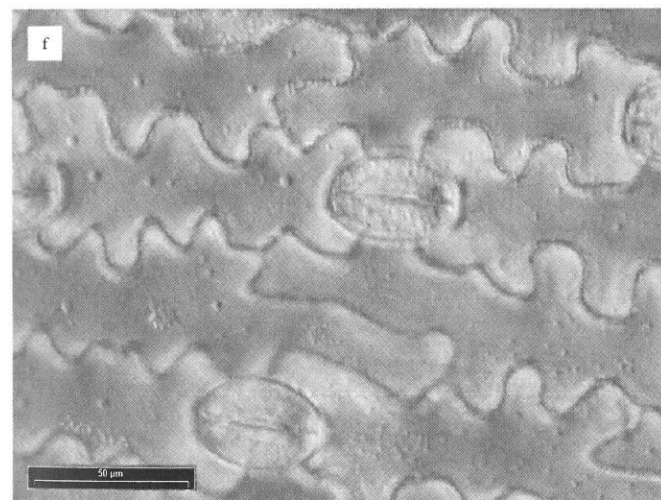
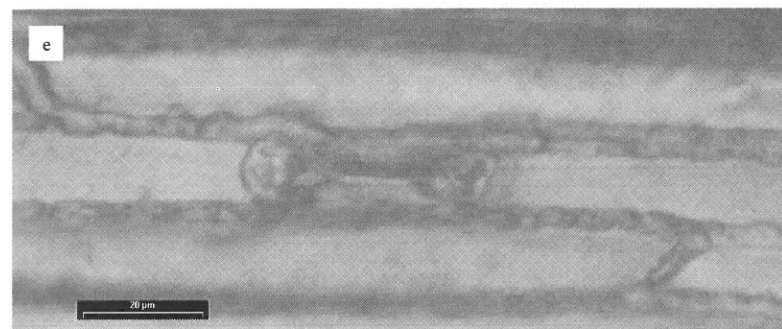
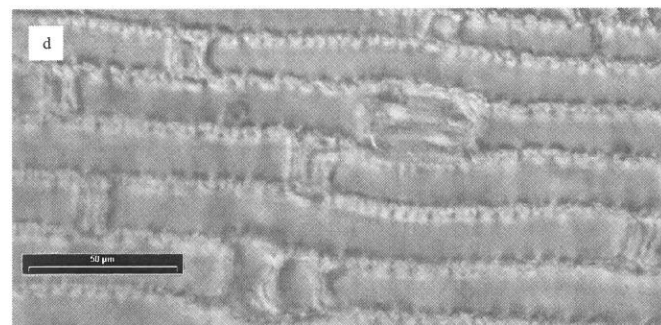


## Appendiks G

Digitalfoto-mikroskopbilleder af epidermis fra udvalgte plantearter fundet ved de undersøgte søer i Mudderbugten og Kvandalen, Disko, Vestgrønland. (a) Epidermiscelle med tydelige grønkorn hos ager padderokke, *Equisetum arvense*. Målestokken er 20 µm. (b) Læbecelle hos ager padderokke, *E. arvense*. Målestokken er 20 µm. (c) Korte, kantede epidermisceller og runde læbeceller hos tundra star, *Carex stans*. Målestokken er 20 µm. (d) Lange epidermisceller med tydelige celledammenføjninger og læbecelle hos *Poa*. Målestokken er 50 µm. (e) Læbe- og epidermisceller hos Langes rørhvene, *Calamagrostis hyperborea*. Målestokken er 20 µm. (f) Typiske læbe- og epidermisceller hos en tokimbladet (her er vist en fladstjerne, *Stellaria* sp.). Målestokken er 50 µm.



## Appendiks G fortsat





## Appendiks H

Planter fundet ved Venstresøen og Totalssøen, Mudderbugten/Kvandalen, Disko, Vestgrønland

Dansk navn	Latinsk navn
<b>2-kimbladede (13 stk):</b>	
Hestehale = Vandspir	Hippuris vulgaris
Trefliget ranunkel	Ranunculus hyperboreus
Arktisk pil	Salix arctica
Alpe tjærenellike	Lychnis alpina
Snefirling	Sagina intermedia
Fjeldrevling	Empetrum nigrum
Mosebølle	Vaccinium uliginosum
Fladstjerne	Stellaria sp.
Dværgbirk	Betula nana
Topspirende pileurt	Polygonum viviparum
Mosepost	Ledum palustre
Draba	Draba sp.
Troldurt	Pedicularis sp.
<b>1-kimbladede (4 stk):</b>	
Tundra star	Carex stans
Rapgræs	Poa sp.
Langes rørhvene	Calamagrostis hyperborea
Arktisk siv	Juncus arcticus
<b>Karsporeplanter (2 stk):</b>	
Ager padderokke	Equisetum arvense
Bregne (Alm. frynsebregne?)	Muligvis Woodsia ilvensis
<b>Mos</b>	
<b>Lav</b>	
<b>Svampe</b>	
<b>Ukendte (4 stk)</b>	

## Appendiks I

Opportunistiske observationer af fugle, pattedyr og fisk i felten Mudderbugten/Kvandalen, Disko, Vestgrønland.

Dansk navn	Latinsk navn
<b>Fugle</b>	
Almindelig kjøve	Stercorarius parasiticus
Blisgås	Anser albirons
Canadagås	Branta canadensis
Edderfugl	Somateria mollissima
Fjeldrype	Lagopus mutus
Havlit	Clangula hyemalis
Havørn	Haliaeetus albicilla
Laplandsværting	Calcarius lapponicus
Odinshane	Phalaropus lobatus
Ravn	Corvus corax
Rødstrubet lom	Gavia stellata
Sortgrå ryle	Calidris maritima
Stenpikker	Oenanthe oenanthe
Stor præstekrave	Charadrius hiaticula
Andefugle sp.	
Mågeflok (formentlig ride)	Rissa tridactyla
Ryler sp.	
<b>Pattedyr</b>	
Finhval	Balaenoptera physalus
Pukkelhval	Megaptera novaeangliae
Vågehval	Balaenoptera acutorostrata
Polarræv	Alopex lagopus
<b>Fisk</b>	
Trepigget hundestejle	Gasterosteus aculeatus





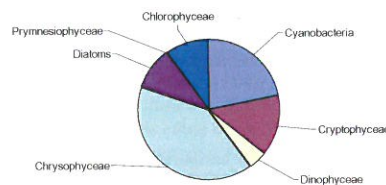
## Results

The average water temperature of the lakes ranged between 6.6°C and 12.2°C (Table 1). The two coldest lakes had an inflow of water from streams fed by melting ice and snow. Stratifications (defined as temperature decreases of more than 1°C m<sup>-1</sup>) were observed in three lakes (D5, D6 and D12), the stratification being most pronounced in D5 with a temperature decrease of 2.0°C m<sup>-1</sup> from a depth of 2.9 m to 6.2 m. This lake was also characterised by a marked decrease in oxygen concentration (14.5 to 5.6 mg l<sup>-1</sup>) and an increase in conductivity (58 to 98 µS cm<sup>-1</sup>) from the epilimnion to the hypolimnion.

Oxygen concentrations ranged between 13.5 mg l<sup>-1</sup> and 17.7 mg l<sup>-1</sup>. Conductivity varied more, with values between 31 µS cm<sup>-1</sup> and 516 µS cm<sup>-1</sup>. Only in three lakes (Di 1, Di 113 and Di 15) did conductivity exceed 100 µS cm<sup>-1</sup>. The overall pH was mean 6.5, four lakes exhibiting a pH lower than and five lakes a pH higher than 8, with the highest pH value occurring in Di 17 (pH 9.90). A few lakes were stratified (Di 5, Di 6 and Di 12) and thus had a strongly decreasing temperature gradient through the water column. Total phosphorous (TP) concentrations varied between 6 and 32 µg l<sup>-1</sup>, an exception being Di 17 where TP was 201 µg l<sup>-1</sup>.

Transparency (Secchi depth) ranged between 1 and 5 m and thus reached the bottom in all shallow lakes and ponds (Di 1, Di 8, Di 9, Di 11 and Di 14-17).

Chlorophyll *a* concentrations ranged between 0.5 and 10 µg l<sup>-1</sup> with an average value of 2.7 µg l<sup>-1</sup>. Chrysophytes dominated the phytoplankton community in terms of biovolume (Figure 2) and especially *Dinobryon*, *Ochromonas* and *Chromulina* were abundant but also a number of species belonging to cyanobacteria, cryptophytes, chlorophytes and diatoms were recorded (Table 3).



**Figure 2.** The quantitative (% of total biovolume) distribution of major phytoplankton groups averaged for all lakes.

The zooplankton communities included a number of different cladocerans species with *Daphnia pulex* as the most frequently found species but also *Alona*, *Bosmina* and *Chydorus* and copepods (*Cyclops* sp. and *Diaptomus* sp.) were recorded. In lakes where a fish population was present (see Jørgensen et al., this report and Table 1) there were no *D. pulex* or other large-bodied zooplankton present. Rotifers very frequently found in all lakes and were also the most abundant on a volumetric basis (data not presented). The total number of species/genera was 30 and the average abundance was 105 individuals l<sup>-1</sup> (data not shown).

The estimated average abundance of *Lepidurus* in Moræneso was 72 individuals m<sup>-2</sup> (data not shown) based on sampling events. The animals varied in size (11-25 mm), with an average length of 17.5 mm.

## Discussion

The low water temperatures of the investigated Disko lakes and ponds are clearly related to latitude and the inflow of cold melt water. The small inter-lake variations in average water temperature are mainly due to differences in the ratio between surface area and water volume. Stratification of the water column is not frequently observed in arctic lakes due to the cold climate, but when present it affects oxygen and pH conditions. Oxygen concentrations were relatively high in most of the study lakes, however.

The high conductivity recorded for several lakes and ponds (Di 1, Di 13 and Di 15) is probably caused by past or occasional inflow of sea water or perhaps by sea fog. The relatively high conductivity and total phosphorous of the lake located closest to the city of Qeqertassuaq (Di 17) is due to wastewater deriving from dwellings and faeces from chained dogs. Except for this particular lake, all the remaining study lakes had low TP values that are typical for arctic lakes (Christoffersen et al. 2002, Jeppesen et al. 2003, Hobbie et al. 1999).

The abundances and species composition of the phytoplankton communities is clearly related to the low nutrient availability which has also been

concluded in previous studies Sørensen and Pfeifer (1990). Also the chlorophyll *a* concentrations reflected the low nutrient conditions and match similar lakes at the west coast of Greenland (Jeppesen et al. 2003).

The zooplankton communities included most species that has previously been recorded by Roen (1962, Anonymous 1973 and Møller & Olesen (1992) as well as several "new" rotifer species – probably because these only been studied in few cases (Anonymous 1973). Møller & Olesen (1992) noted that the zooplankton diversity in a number of lakes and ponds had a trend towards dominance of either small-sized (rotifers and copepods) or large-sized species (cladocerans and copepods) and that this was related to the presence of fish. Fish occurred in several of the lakes in the present study (Jørgensen et al., this report; Table 1) and the top-down effect of Arctic charr and three-spined stickleback on *Daphnia* and *Lepidurus* observed in may other arctic lakes by Jeppesen et al. (2003) was also pronounced here.

It can be concluded that the investigated lakes and ponds at Southern Disko are all oligotrophic except in one case where human activity has increased the nutrient availability 10 fold. The plankton communities are relative rich in species when considering the overall presence but less so for individual lakes ecosystems. The presence of fish has a marked effect on the zooplankton communities and possible on the benthic organisms.

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**Table 1.** Basic characteristics of the investigated lakes. When existing, geographic names are given in brackets. The physiochemical values are the depth profiles means. A few lakes were stratified (denoted \*), i.e. with a change in temperature of at least 1°C m<sup>-1</sup> per metre. B = transparency to bottom, ND = no data. F = fish population present. "Depth" is not necessarily maximum depth, but denotes the point where sampling was undertaken (typically in the middle of the lake).

Lake ID	Position	Depth (m)	Temp (°C)	Oxygen (mg l <sup>-1</sup> )	Conduct. (µS cm <sup>-1</sup> )	pH	TP (µg l <sup>-1</sup> )	Secchi (m)	Chlorophyll (µg l <sup>-1</sup> )
Di 1	69°26'53.4"N; 54°13'55.4"W	ND	10.1	15.2	132	8.27	17	B	2.6
Di 2 (Porsild so) F	69°24'00.2"N; 53°48'23.1"W	ND	10.8	>15.4	40.5	7.69	22	2.5	1.5
Di 3 (Lillesø) F	69°31'11"N; 53°43'04"W	11	10.9	15.5	34	7.49	32	5.0	2.5
Di 4 (Mellemsø) F	69°31'26.6"N; 53°41'35.3"W	17	6.6	14.3	35.3	8.25	19	2.5	7.8
Di 5 *	69°32'19.0"N; 53°40'38.8"W	7	9.8	11.5	71.3	7.47	13	4.0	2.5
Di 6 (Langesø) *	69°32'27.3"N; 53°39'47.2"W	12	9.1	14.6	38.5	8.60	22	2.4	10.22
Di 7	69°32'02.6"N; 53°41'00.2"W	2.2	11.1	14.2	37	7.79	15	2.2	1.5
Di 8	69°32'08.4"N; 53°40'46.3"W	1	11.8	13.7	43	7.86	13	B	.6
Di 9	69°16'17.5"N; 53°50'00.0"W	ND	9.6	16.1	60	6.85	23	B	.9
Di 10 F	69°16'02.6"N; 53°49'24.3"W	5	9.1	17.7	62	7.13	24	2.0	6.6
Di 11	69°15'58.9"N; 53°49'44.2"W	1.5	12.2	15.8	58	6.75	8	B	.5
Di 12 (Sinifik so) * F	69°21'27.7"N; 52°56'57.2"W	21	8.3	15.1	30.5	6.48	13	5.0	.8
Di 13 F	69°21'22.1"N; 52°57'36.1"W	> 6	11.5	17.0	304.5	8.36	13	4.0	1.9
Di 14 (Moræne so)	69°16'09.5"N; 53°28'43.0"W	ca 3	9.9	13.5	61	7.55	13	B	1.8
Di 15 (Stations so)	Information missing	1.5	8.0	15.1	516	7.20	13	B	.5
Di 16 (Roens so)	69°15'22.7"N; 53°31'36.3"W	1	10.4	13.6	43	7.01	6	B	.6
Di 17 (Thygesens so)	69°14'44.0"N; 53°32'14.2"W	1	11.7	17.2	96	9.90	201	B	3.5

**Table 2.** The zooplankton species/genera recorded in the investigated lakes.

<b>Cladocera</b>	<i>Daphnia pulex</i>
	<i>Ceriodaphnia quadrangula</i>
	<i>Simoccephalus vetulus</i>
	<i>Bosmina coregoni</i>
	<i>Bosmina longirostris</i>
	<i>Camptocercus rectirostris</i>
	<i>Scapholeberis mucronata</i>
	<i>Alona rectangularis</i>
	<i>Alona quadrangularis</i>
	<i>Alonella nana</i>
	<i>Chydorus</i> sp.
	<i>Eurycercus glacialis</i>
	<i>Harpaticoidae</i>
<b>Copepoda</b>	<i>Cyclops</i> sp.
	<i>Diaptomus</i> sp.
<b>Rotifera</b>	<i>Filinia</i> sp.
	<i>Trichocerca</i> sp.
	<i>Lecane</i> sp.
	<i>Keratella cochlearis</i>
	<i>Keratella</i> spp.
	<i>Euchlanis</i> sp.
	<i>Brachionus</i> sp.
	<i>Lepadella</i> sp.
	<i>Polyarthra</i> spp.
	<i>Asplanchna priodonta</i>
	<i>Conchilus</i> sp.
	<i>Synchaeta</i> sp.
	<i>Notholca labis</i>
	<i>Notholca</i> sp.

**Table 3.** An overview of the phytoplankton species/genera recorded in the investigated lakes.

PROCHLOROTRICHACEAE	<i>Prochlorothrix hollandica</i>
NOSTOCOPHYCEAE	<i>Chroococcales</i> spp., <i>Cyanodictyon imperfectum</i> , <i>Cyanodictyon planctonicum</i> , <i>Anabaena</i> spp., <i>Anabaena heterospora</i> , <i>Anabaena lemmermannii</i> , <i>Planktolyngbya limnetica</i>
CRYPTOPHYCEAE	<i>Cryptomonas</i> spp., <i>Rhodomonas lacustris</i>
DINOPHYCEAE	<i>Dinophyceae</i> spp.
CHRYSTOPHYCEAE	<i>Chrysophyceae</i> spp., <i>Dinobryon bavaricum</i> , <i>Dinobryon cylindricum</i> , <i>Dinobryon divergens</i> v. <i>schauinslandii</i> , <i>Dinobryon hilliardii</i> , <i>Mallomonas acaroides</i> , <i>Mallomonas akrokomos</i> , <i>Ochromonas</i> spp., <i>Uroglena</i> spp., <i>Chromulina</i> spp.
DIATOMOPHYCEAE	<i>Centric diatoms</i> spp., <i>Aulacoseira</i> spp., <i>Rhizosolenia eriensis</i> , <i>Rhizosolenia longiseta</i> , <i>Diatoma elongatum</i> , <i>Fragilaria</i> spp., <i>Nitzschia acicularis</i> , <i>Synedra acus</i> v. <i>radians</i> , <i>Synedra nana</i> , <i>Tabellaria flocculosa</i>
PRYMNESIOPHYCEAE	<i>Chrysochromulina parva</i>
CHLOROPHYCEAE	<i>Botryococcus</i> spp., <i>Chlorella</i> spp., <i>Didymocystis bicellularis</i> , <i>Kirchneriella</i> spp., <i>Lagerheimia genevensis</i> , <i>Monoraphidium minutum</i> , <i>Oocystis</i> spp., <i>Tetraedron minimum</i> , <i>Elakatothrix viridis</i> , <i>Cosmarium margaritatum</i>

## Dagbog 12.juli – 6. august 2004

**Mandag d. 12. juli – onsdag d. 14. juli 2004**

Endelig er vi på vej. Seks lange måneder er gået, siden vi studerende blev udvalgt til at afprøve vores evner som feltbiologer.

Vi ankommer til Kangerlussuaq (Søndre Strømfjord) i strålende solskin efter den imponerende korte flyvetur på blot 40 minutter pga. tidsforskellen.

Kangerlussuaq forsøger desperat at tage sig godt ud i solskinnet, men det kan tydeligt ses, at det blot er barakbygninger, som er smækket op i hast af amerikanerne, som grundlagde byen i 1941 som militærbase.

Efter indkvartering på det luksuriøse hotel Musk Ox Inn har vi frit slag for underholdningen resten af dagen. De rige tager på motoriseret indlandsis-sightseeing, de mindre rige forsøger at give selv Lance Armstrong baghjul på de 72 km grusvej tur/retur til isen, og ja, de fattige kan gå en tur, hvilket heller ikke er at kimse af.

Vi går tidligt i seng efter et pragtfuldt måltid mad (jeg var selv med til at lave det), men vi har jo også fået 4 timer foræret, så det er jo ikke underligt, at vi er trætte.

Tirsdag, står på 30 km vandretur (ifølge Mads), som efter sigende kan klares på blot 4 timer og 13 minutter (det kunne vi ikke!). Turen går langs Watson River i Ørkendalen til en lille jægerhytte tæt ved indlandsisen.

Vi starter ud i samlet flok, i højt humør og med masser af energi, trods silende regn



Billede 1 På vej ud mod hytten ved indlandsisen. Turen går langs Watson River, vi er stadig i samlet flok da vi kun har travet ca. 5km

Efter vi har set afgrunden i øjnene på den eneste vanskelige bjergside, bliver vi sluppet løs - for de næste 25 km er jo ren søndagstur (ifølge Mads). Der går selvfølgelig straks sport i at nå hurtigst frem, og inden længe er de langbenede ude af syne. Selv ender jeg i bagtroppen – ankommer kun(!) 2 ½ time senere end de første - men så var der jo også tid til at studere flora og fauna.

Den skønne grønlandske natur har også sine luner såsom tue-pukkelpister, hvor selv en bjergged bliver sat på prøve, drilsk pilekrat og kildevæld, som har specialiseret sig i at trænge igennem enhver vandrestøvle.

Vi bruger meget tid og mange billeder på moskusokser og rendyr, både levende som døde, og diverse souvenirs bliver indsamlet.



Billede 2 Kadaver af moskusokse han. Formentlig faldet i vinterens løb.

Områdets moskusokser blev importeret fra østkysten i hhv. 1961 og 1963. Det drejede sig om i alt 27 dyr, og i dag er der 5-6000 individer! Det er disse prægtige dyr, og de skønne planter og laver, som gør smerterne i led og vabler udholdelige.

Efter hvad der føles som dages endeløs vandring, kan vi endelig ane en lille grønt hytte i det fjerne. Hvilken fryd! Hytten er gammel og faldefærdig. Om vinteren bliver den brugt som fangsthytte, så gulvet er blodpletet, og fluerne har kronede dage. Knogler og huder ligger frit draperet rundt omkring huset, og årsagen til at der også ligger 2 kadavere under huset, er stadig en gåde!?

Efter en spand vand og ild i pejsen, forvandler hytten sig til et helt palæ for os trætte sjæle, som velfortjent nyder et pragtfuldt måltid jægergryde fra pose. Efter maden bliver en Thule-boplads besigtiget, og det er da et meget imponerende hul i jorden! Thule-folket er et oprindeligt folkeslag, som boede i området for 5-800 år siden.

De standhaftige lystfiskere som møjsommeligt har slæbt deres stænger med hele vejen herud, får også rovfisket i søerne, desværre består fiskebestandene kun af 1000-brødresamfund (dvs. alle fisk har ca. samme størrelse på kun omkring 10 cm).

Men snart er alle gået omkuld overalt i huset for at restituere sig til morgendagens strabadser.

Friske, veludhvilede og næsten uden smerter, vågner vi med blod på tanden til endnu engang at indtage Grønland, for vi vil nemlig kravle den lidt længere og hårdere vej hjem, som går over bjergene. Hvordan vi fik den tossede idé, ved jeg virkelig ikke, nu da vi har prøvet søndagsturen! Lykkeligt uvidende om hvor ynkelige vi ville blive 9-10 timer senere, vandrer vi af sted i raskt tempo over stok og sten. Holdet som står for aftenmaden, er lettere presset, da de skal være tilbage inden butikken lukker kl. 17, så af sted går det for både dem og den bjergtrænede spaniergruppe, som kommer direkte fra 3 uger i Pyrenæerne. Aida skulle lige lave en lille afstikker, og kunne så ikke finde de andre igen, så hun brugte ca. 12 timer på at klatre over samtlige bjerge på hjemturen. Hvis man altså går den korrekte vej, så består ruten kun af én enkelt bjergstigning først på turen (ifølge Mads), men måske var det godt at vi ikke kendte til de sidste stigninger, for det ville nok have taget modet fra de fleste.

Jonas, Rune, Majken, Linnea og mit (Christina) motto på turen blev(!) "*hellere et bjerg for meget, end et bjerg for lidt!*". De utallige bjergbestigninger gav os et utroligt vue over de skønne bjerge, søer og indlandsisen.

Da vi når til Granatfjeldet, er humøret og kræfterne stadig lunkne, idet vi nu kan skimte masterne ved Ravneklippen, som vi troede lå tæt ved byen. Halvanden time senere er vi ved Store Saltvandsø. Det kan her fortælles at saltvandsøer er opstået ved at der ikke er noget til- eller afløb for vandet, så derfor forsvinder der kun vand ved fordampning, og diverse salte fra jorden opkoncentreres. Dette giver en helt speciel flora, hvor halofile (saltelskende) arter som Annelgræs og Saltensian findes. Det er dog også på dette sted at den sidste rest af energi forlader os, da vi ser Ravneklippen tårne sig høj og mægtig op over os. Det er kun ren viljestyrke og tanken om pizza, og anden skøn mad, som får de absolut ikke følelsesløse fødder til at tage de



langsomme skridt op ad bjerget. Det er også på dette tidspunkt at tanken om at iscenesætte en helikopter-redningsaktion virkelig begynder at virke tiltalende - for hvor ondt kan et brækket ben virkelig gøre? Men hvis det ikke så sort og endeløst ud for foden af bjerget, så er det dog ingenting ved siden af den skuffelse der æder den sidste rest af håb om overlevelse, da vi når toppen og ser hvor langt der endnu er til byen. Og selv om vi pisker de smertende fødder frem, kommer byen bare ikke nærmere.

Ved et rent lykketref er Linnea og jeg få hundrede meter fra vejen, da en bil stopper for at give os et lift - bilisten må enten være synsk eller sendt fra himlen! Det er som at få alle Tour de France-rytternes samlede dosis EPO på én gang, for vi sætter i et vanvittigt løb gennem pilekrattet, mens en ukendt lykkefølelse får os til at grine helt ustyrlig fjoget. Det var dog ikke alle, der var så heldige, så ca. 1 ½ time senere dukker de sørgelige rester af vores lille vandregruppe op på hotellet. Sjældent har jeg set så mange mennesker være så ynkelige og stivbenede. De eneste der tilsyneladende ikke bar mén af vandreturen er Pablo og Thomas K, og synet af dem forstærkede bare smerterne. Der går ikke længe efter aftensmaden, før roen sænker sig over Musk Ox Inn.

Men når alt kommer til alt, var smerter og vablerne det hele værd, for det var en utrolig smuk tur, og hvor er vi stolte i dag over at vi klarede strabadserne...

~ Christina

#### Torsdag d. 15. juli - fredag d. 16. juli

Efter vandreturen var vores ellers så storslåede gejst for aktiviteter slået en anelse ud af kurs og fjerdedagen blev en stille og rolig dag med diverse småudflugter, alt efter hvor kvæstede vi hver især var.

Flere valgte at betale de 475 kr. for at tage på den organiserede bustur til indlandsisen, som nogle allerede første dag havde deltaget i og kunne anbefale. Indlandsisen er på det højeste sted ca. 3500 m tyk, og der er noget ganske særligt ved at stå på toppen af denne enorme ismasse og skue ud over det hvide landskab, der strækker sig så langt øjet rækker. Denne uendelighed og storhed, som ikke kan findes i Danmark, men som er over alt i Grønland, er virkelig imponerende. På trods af den lidt høje pris, var cocktail på indlandsisen ikke inkluderet, og vi var flere, der ærgrede sig over at have glemt lommelærken. Whiskey med indlandsis er jo ikke at fornægte, men alt i alt var det nu en glimrende tur. Der var moskusokser i området, og da de imponerede dyr åbenbart bliver mindre skræmt af en stor hvid skrummelbus end af folk til fods, var det muligt at få nogle ganske gode fotos.

De fleste nåede i løbet af dagen et smut ud på fossilsletten. Det store øde område for enden af landingsbanen ligner mest af alt en flad ørken af grus, sporadisk perforeret af kløfter og nogle højspændingskabler. Ved nærmere eftersyn viser det sig, at der blandt sten og mudder findes utallige fiskefossiler af forskellig art og kvalitet. Fossilerne, der er dannet for 10.000 - 12.000 år siden efter sidste istid, bliver ivrigt indsamlet, og det lykkedes os på ganske kort tid at forøge vores overvægt i flyet mærkbart.

Fredag d. 16. juli gik turen videre med fly til Ilulissat (Jakobshavn) og derefter med færge til Qeqertarsuaq (Godhavn). I Ilulissat havde vi ca. fire timer og lagde ud med en mindre vandretur til den nærliggende Isfjord. En bræ fra indlandsisen løber ud i fjorden og enorme isbjerge med blåligt skær kunne ses som en smuk kontrast til de frodige grønne fjelde. Bræen har den største produktion af isbjerge på den nordlige halvkugle, den kælver 15.000 km<sup>3</sup> is om året. Ved isfjorden ligger desuden resterne af en gammel inuitboplads. Området har været eftertragtet pga. det milde klima og de gode fangstmuligheder, og gennem tiderne har folk fra Dorset-kulturen og senere Thule-kulturen holdt til her. Vandreturen over fjeldet gav os yderligere en introduktion til et meget omtalt sommerfænomen i Grønland, nemlig myggene. De var overalt, og deres ondsindede snabler fandt vej til selv de mindste stykker ubeskyttet hud. Forhåbentligt går der ikke længe før vi - som grønlænderne - er immune overfor deres stik.

Den seks timer lange sejltur til Qeqertarsuaq blev uventet forlænget med to timer, da færgen tog et smut forbi Asiaat. Det gjorde nu ikke så meget for solen strålede, og livet i liggestole på dækket - med kikkerten ved hånden i tilfælde af hvaler og mallebukker smukt svævende om skibet - er nu ganske udholdeligt.

Vi fik set nogle flygtige glimt af vågehvaler og en finhval, men intet der kunne måle sig med synet af de to pukkelhvaler, der boltrede sig i vandet foran Arktisk Station senere på aftenen...

~ Signe

#### Lørdag d. 17. juli

Vi stod forholdsvis sent op, idet alle var kommet ret sent i seng pga. gårsdagens lange sejltur. Efter en sund og nærende morgenmad viste Stationslederen (Rasmus) os rundt på stationens faciliteter, og efter frokosten drog vi i samlet flok ud i den vilde natur. Formålet med vandreturen var at lære området bedre at kende mht. geologi, flora og fauna. Vi lærte bl.a. at Disko består af gnejs og basalt.



Billede 3 Udsigt over arktisk stations hovedbygning og laboratorieafdeling. Bag skyerne tårner Lyngmarksfjeldet sig op!

Allerede tidligt på vandreturen stod det klart at stort set alle havde en lille botanikerspire gemt i maven, som brød ud i fuldt flor ved synet af alle de smukke blomster. Der blev fotograferet på livet løs, og de helt store, super potente linser kom i brug.

Turen bød desuden på fysiske udfordringer i form af lettere bjergbestigning, både ned af stejle bjergsider og op af frådende vandfald, som alle heldigvis klarede med bravour. Da vi ca. halvvejs på turen nåede Engelskmandshavn (en naturhavn), var nogle så heldige at få lov til at smage grillet hvidhval, som en grønlandsk familie tilbød. Det smagte efter sigende som en blanding af løg, bøf og fisk!?

For igen at blive lidt mere faglig, kan jeg oplyse at alle tre orkidé-arter, som er repræsenteret i området blev fundet; Satyrblomst, Hjertebladet Fliglæbe, samt Grønlandsk Gøgelilje.

På vej tilbage til Arktisk Station samlede vi en masse birkerørhatte, som skal indtages i aften sammen med Marianne Philipps hjemmebagte boller. Desuden blev der indsamlet en hel del sten med kvarts, og hvis vi fortsætter på den måde, får vi nok et problem med overvægt på hjemturen. Tidligere på vandreturen havde nogle endog rekvireret en del ryghvirvler fra slagtede hvaler, der lå på en strand.

I skrivende stund bliver jeg afbrudt af et råb der flenser stilheden i huset: "Hvaler, hvaler". Dette forvandler husets beboere til frådende hval-paparazzier, og nogle løber endog i fuldt firspring ned til stranden, fulde af forhåbning om det perfekte foto. Men hurtigt forsvinder hvalerne bag et isbjerg og livet vender atter tilbage til sin vante gang på Arktisk Station.

Følg med i morgendagens episode af "LOGBOGEN"; Vender hvalerne tilbage? Er vabler en truet dyreart? Bliver beboerne sat på slankekur pga. frygt for overvægt?

~ Majken





Billede 4 Mads viser sig som en af de mange fotofreaks med potente kameraer, her i gang med at forevige en fjeldkvan.

#### Søndag d. 18. juli

Dagen startede godt. Jeg vågnede til lyden af legende pukkelhvaler lige uden for vore vinduer, og solen skinnede fra en skyfri himmel. Nej hovsa!!! Det var da vist ikke en pukkelhval. Jeg måtte lige gnide søvnen ud af øjnene før det gik op for mig, at det derimod var David i underbukser og bardelignende morgenhår. Udenfor bød vejrguderne på Grønlandsk nationalvej, bestående af ca. 5 graders varme/kulde og regn. Den traditionelle morgenmad og resten af aftenens boller blev indtaget på vanlig vis.

I dag var vel sådan en dag der ikke bød på det helt vilde, og selv vores daglige obligatoriske døds-march blev aflyst pga. vejret (vabler og generel uvilje). Dette var egentligt en skam, da de fleste af os jo alligevel havde mistet alt følelse fra knæene og nedefter. Grupperne fik dog hidset sig op til en del planlægning, og dagen skred langsomt fremad. For vores gruppes vedkommende var dagens mest ophidsende tidspunkt nok det øjeblik, vi indså, at vores dyrt indkøbte gummibåd manglede en enkelt detalje nemlig pumpen. Vi havde næsten accepteret at sætte vores lid til Rasmus' enorme lungekapacitet, da Kirsten med ét fremtryllede en anden pumpe. Tingene blev pakket og den sidste forsøgsplanlægning færdiggjort.

Dagen var dog ikke helt kedelig. Vi mandede os op til en guidet tur igennem byen, hvor vi fik fyldt skoene med vand, og lommerne med slik ved den lokale købmand. Som kompensation for vejret, blev der serveret lækker hellefisk og havkat til aftenmad. Selv hvalerne viste sig ikke i dag. Det var nok også en del tørre nede i det dybe vand. Rygterne vil vide, at den søde tejtgruppe byder på kanelsnegle her til aften. De er nok ved at være færdige, og Rasmus (ædedolken) har nok snart inhaleret dem alle sammen. Hmmm! jeg tror jeg smutter...

~ Thomas R

#### Mandag d. 19. juli

Dette er en kold dag i Qeqertarsuaq, hvor skyer ligger tungt over byen og efter sigende sender sne over fjeldene. I morges vågnede vi (tejstpigerne) spændte idet, det var i dag feltarbejdet til vores projekt skulle påbegyndes. Efter morgenmaden mødtes vi med Kjeld (stationens tekniske leder), som er ansvarlig for udstyret. Han skulle introducere os til brugen af VHF-radio, vindmåler og (det som vi glædede os allermost til) jollen, som skulle transportere os til vores observationspost i Fortune Bay. VHF'erne skabte dog en del problemer, idet vi ikke kunne få dem til at virke. Hjælpen kom dog hurtigt springende i form af Mads og Rasmus (stationens videnskabelige leder), som syntes at være særdeles tilfredse med at få lov til at teste det elektroniske udstyr. Så der hørtes gentagende udbrud af "roger overs" og "kalder, kalder" i fjeldene omkring stationen (mænd og deres legetøj.....).

Det var med sommerfugle i maven, at vi i følgeskab med Mads og Kjeld begav os afsted til havnen og dernæst med jollen mod "destination tejt koloni". Sejlturen tog ca. 10 min. i slalom mellem isbjerge, indtil vores første koloni dukkede op. Velvidende at vi skulle tilbringe mange timer over de kommende uger på

observationsposten, havde vi store forventninger til stedet, som til fulde blev indfriet, da vi erfarede at kolonien lå perfekt lige over for en ø, hvor der til alles overraskelse lå en fangerhytte, som vi kunne benytte. Dette betød, at vi i stedet for et vådt og koldt telt kunne se frem til at overnatte i en lun hytte med hele to petroleumsøvn... (jubii!). Det var med et stort smil om læberne, at gruppen begav sig tilbage mod havnen. Her blev der sat turbo på båden, da vi toser på skift skulle fremvise vores evner - og uden tvivl medfødte talent - som bådskaptajner. Det var sjovt at se folkene i front af båden hoppe op og ned, når de i flyvende fart strøg over en bølgetop. Kun Mads syntes at være en smule skuffet over, at han ikke fik lov at styre båden. Ikke en eneste gang....

Efter frokost blev der, blandt pigerne, dømt shoppingtur efter smykker af udskåret ben, pelshandsker og andet chickse-guf. Det var tydeligt, at flere af pigerne var lettede over at få en mulighed for at lufte shoppinggenet. Efter shopping var der heftig aktivitet på syområdet, idet flere af os piger tidligere havde købt sælskind, som møjsommeligt blev stykket sammen af tandtråd. Aftenmaden bestod af frikadeller af narhvalkød, som blev fredsommeligt indtaget, indtil jeg pludselig spottede tre pukkelhvaler i bugten foran stationen. Denne begivenhed fik de mest hardcore whale-watchers til at springe op fra stolene, forlade middagsbordet og gribe kikkerter og kameraer. Det var et fremragende syn, at se de springende hvaler (er der noget bedre end en hval til aftenmaden??!).

Nu vil jeg glad og veltilfreds afslutte denne dags dagbog med maven fuld af kold aftenmad og med den gode nyhed i tankerne, at botanikpigerne har lovet os at bage frugtterne til aften... uhm... end of day!!

~ Anne-Mette

#### Tirsdag d. 20. juli

Endelig blev der fred. De tre tenorer (David, Thomas og Rasmus) drog omsider af sted på deres fejde. Denne glædelige begivenhed vil kaste lys over de næste seks dage og vil især betyde, at der er mere mad til mig, da Rasmus er væk.

Desværre har dagen ikke været én stor solstråle historie, da der til min store skuffelse ikke blev serveret kage til aften kaffen. Nå, men jeg har jo stadig en halv flaske whisky tilbage...

Solen skinnede fra en blå himmel i dag og på grund af de sidste tre dages regn og kulde skinnede den selvfølgelig ekstra kraftig.

Nysius (vores frøtæge) var i høj grad også glad for denne solskinsdag. Det er således, at Nysius er yndede solskinsbadende frøtæger, hvilket muliggjorde en besked fangst på ca. 250 stk. Nu er de sikkert rimelig trætte af solskin og muligvis også af os. Ikke nok med at vi fangede dem, vi smed dem også ned i en lille petriskål med alt for lidt mad, hvor de skal stå i 7 dage. Al den urimelighed blot for at finde en spiringsprocent på fire forskellige plantefrø.

Set fra vores perspektiv fik vi startet op på vores spiringsforsøg, men også kun lige startet op. Derudover har vi et par forsøg til i ærmet, som jeg har tænkt mig at lade Mikkel og Louise udføre, mens jeg fisker sammen med Thomas (og drikker Davids "whisky").

Jeg skal jo for øvrigt også snart til, at sy de dumme handsker, som jeg har ævlet om den sidste uge, og så er jeg er spændt på om Mads skænker mig et glas af hans Cognac i aften, som han har lovet (det gør han sikkert ikke).

~ Thomas K

#### Onsdag d. 21. juli

Vi havde tirsdag forladt vor elskede Arktisk Station for at tage på en længere felttur.

Porsild sejlede os til området Nipisat, hvor Kirsten og hendes slæng (Rune og Jonas) indsamlede vandprøver (zooplankton / so-gruppen), mens ørreddrengene fiskede med fiskestang efter fjeldørred til deres projekt i et område ved en elv.





Billede 5 Kirsten og al udstyret til en uges felttur er ved at blive bugseret ombord på Porsild.

Senere på dagen blev vi sejlet lidt længere ind i Disko Fjord hvor Ørred- og Zooplanktongruppen blev sat i land og overnattede, mens den spanske gruppe blev sat af i bunden af fjorden, hvor vi selv tog hen den følgende dag. Satte fiskenet i Porsild sø, som skulle stå natten over.

Zooplanktongruppen tog deres prøver og Ørredgruppen tømte deres net. Der var god fangst af ørreder, som blev målt, fotograferet, undersøgt for parasitter og der blev taget øresten- og vævsprøver. Blev hentet af Porsil og sejlet længere ind i fjorden.

~ Rasmus

#### Torsdag d. 22. juli

En dag i felten. Ørredgruppen, bestående af David, Thomas og jeg selv, Kirstens stygge håndlangere Rune og Jonas samt Spanierne Pablo, Jesus, Aida og Maria (DK) lå i lejr ved Disko Fjord, nær Langesø. Spanierne ravede rundt og lavede - under højlydt gestikuleren - uprovokerede målinger på en tilfældig højderyg, mens vi limnologer var engageret i indsamling fra en række søer i anden retning. Vi lå derfor i to lejre, men havde dog tid til enkelte visitter, hovedsageligt af praktisk karakter: la; "kan vi låne lidt brød", "et spil kort" etc.

Vejret var vanen tro skidt, men udsigten fantastisk. Vi ørreddrenge, også kaldet Charr-boys (selvudnævnt - red.), havde denne torsdag i to dage levet af tørfoder og havregrød og havde etableret en solid arbejdsrytme med morgenmad i lejren, 1 - 3 timers vandring, fiskeri med gællenet, 1 - 3 timers vandring og en afsluttende feltration på trangiaen i lejren omkring midnat. Nul frokost. Og ofte uhyggeligt små mængder vand, da iskoldt smeltevand ikke var det mest kærkomne, når lufttemperaturen i forvejen var nær de 5 grader. Tydelige tegn på dehydrering og lavt blodsukker var hyppige, men vi trøstede os med, at vi kun havde godt af lidt hårdt arbejde som kontrast til de foregående måneder i storbyen med tant og fjas. Det var dog en sikker konklusion blandt fiskerne, at dette bestemt ikke var en tur for studiner; de ville simpelthen aldrig klare sådan en mandfolketur!

Torsdag d. 22. juli var også dagen, hvor gællenettene blev sat i Lille- og Mellem sø under frisk vind og regn i en 10 fods Bombard gummibåd. Rune og Jonas havde slæbt båden de 6 kilometer i uvejsomt terræn fra lejren, mens vi Charr-boys sov længe. Pga. de to knægtes meget korte ben strandede de uhjælpsomt 27 højderygge og 13 frådende vandløb fra det aftalte mødested, hvor vi skulle have overtaget båden til fiskeundersøgelserne. Da vi fandt dem nogle timer senere, åd vi som straf størstedelen af deres medbragte Marabou-chokolade. Det blev alligevel en god dag.

~ Rasmus

#### Fredag d. 23. juli

Sikken en dejlig dag i dag ... Solen skinnede fra en sky fri blå himmel. Efter en solid morgenmad bestående af cheerios og Mads' gode hjemmebag tog både Pollen-pigerne og Nysius-gruppen straks i felten. De underskønne pollen-pigerne var efter flere dage med dårligt vejr temmelig pressede mht. dataindsamling

og havde besluttet at finde et andet perspektiv at arbejde med, hvis ikke det blev godt vejr i dag - så de åndede lettet op. Hele dagen jagtede de insekter for senere at undersøge hvilke pollen, der sad på dem.....

Nysius-gruppen havde efterhånden udtømt deres lager af "backup" nysius i laboratoriet og lå hele dagen hver med deres "suge-flaske" og blikket stift fikseret ned i den lave vegetation, for at finde de små bæster - de nåede op på over 500 stk. - hvilket dog ikke nærmer sig Jens Bøchers gamle rekord: 315 på et kvarter. Både tejt-holdet og fiskerne var fortsat i felten....

Til aftensmad blev der serveret ammasetter (en lille tynd fisk, man også giver hunde i tørret udgave) til stor glæde for nogle - andre synes, det var sjovt at prøve, meeen man kunne jo også varme lidt kødsovs fra dagen før! Kirsten brillerede med en banankage, der blev indtaget over sytojet (sælkskindsluffer, -sutsko, -tevarmer, -punge, -tasker og -veste ... jo jo, kun fantasien sætter grænser).

Aften sluttede for nogle af med en actionpacked Van damme film - mens andre (læs: pollen-pigerne) tog på byens eneste bar: "Nikiffik". Her var der fest og glade dage, da månedslønnen lige var udbetalt - "så skal der fanden tag mig drikkes...!" nej, det havde vist været stille og roligt med søde og rare mennesker - og diskokugle.

~ Mikkel

#### Saturday the 24th of July

My sister's birthday. I left the mobile phone at home, should I try to call her with the radio from Disko Fjord?

Yes, we are still in this lovely fjord: 4 people, 2 tents and lots of rugbrød to survive.

Today we got up at around 11 o'clock, because yesterday we were measuring in the field until 3 a.m. It may sound strange, but it's just an adaptation to the weather. And do we have problems of darkness? We are in Greenland, my friends, no worries about that.

There was not much work to do today, only 2 hours sampling *Pyrola grandiflora*; once finished, we went back "home" - the small tent where I had to fight for space with Pablo. Anyway, as we had a lot of time before the Porsild arrived (tomorrow Sunday), we converted the tents into hi-tech laboratories and we started the funniest part of the project: measuring leaves! Length, width and thickness of 1000 leaves. Wonderful, isn't it? At least, the rugbrød, accompanied by Spanish "lomo" made things much easier.

At some point we got tired of the leaves (surprise...) and went to visit our neighbours in Disko Fjord, the fishing- and lake-groups, but only Thomas, David and Rasmus were there. They had already finished their work and they were just letting the time go by until the Porsild takes us back to Arctic Station.

The best moment of the day was always the dinner. The simple thought of it keeps you alive all day long. Selvfølgelig, it has to be a good dinner, forget about cat-food-like only-add-water envelops. Let's take some mushrooms, fry them with onion, jamon serrano, and tomato sauce, and put all together with the pasta, rice or cous-cous. The menu can also include a healthy salad made with *Taraxacum lacerum* and *Oxyria digyna*. Mmmhh.....

Finally, with the stomach full of happiness, and after some more leaf measurements, we went to sleep. Ooops, maybe first I should take the leaves of *Saxifraga*, *Silene*, *Arabis* and *Pyrola* out from the sleeping bag. I forgot to tell that the labs had the bedroom included.

And then, with the pale-coloured sky of the Greenlandic nights above us, we start to dream about the comfort onboard Porsild...

~ Jesus

#### Søndag d. 25. juli

Da det altid er lyst heroppe, ignoreres søvnbehovet til fordel for forskellig former for hygning. Da søvnunderskuddet nu var kritisk, havde Mikkel og jeg bestemt, at vi skulle sove længe i dag (tægerne skulle også mærke, det var søndag). Thomas skulle op, før en vis en får morgensutter på og hente fiskehold samt den spanske gruppe, hjem med Porsild. Da vækkeuret på en meget ufin måde ringede kl. 9, var det nu ikke som om de ekstra timer kunne mærkes. Med meget små griseøjne kiggede vi ud af vinduet og blev mødt med en himmel, der associerede til regntøj, gummistøvler eller varm kamin og chokolade med masser af flødeskum. Mens vi lå trygt og overvejede mulighederne for at snue morgenen væk, kom Thomas farende meget energisk ind. Skipper kunne ikke gå ud i den blæst, så de forskellige grupper i felten, vandt lige en dag mere i telt i vejrgudens vold. Nu er det man bliver endnu mere henrykt over, man har valgt et projekt der kan nusses med i et varmt, tørt laboratorium.

Når det nu IGEN regnede, blev aftenen brugt på at forvandle uendelige bunker af skind til handsker, tasker, kaffevarmere mm, mens en stjernebefængt film rullede over skærmen. Endvidere fortalte Marianne om nogle af de projekter, hun havde været med i her og på Zackenberg.

Et meget vigtigt omdrejningspunkt heroppe er mad og kage, og det skal heller ikke undlades at fortælle at



dages ret - sæl i brun fiskelugtende sovs med grødris - var en oplevelse! Denne lækre(!) traditionelle grønlandske ret hedder Suaasat. Skægt som alle pludselig blev meget beskedne og havde spist sen STOR frokost. Det modsatte var dog tilfældet, da Kirstens tærte lidt senere kom på bordet...

~ Louise

#### Søndag d. 25. juli – Scener fra en felttur

Alle vågner adskillige gange i løbet af natten mellem d. 24 og d. 25 til lyden af vinden, der kaster den tætte regn på teltdugen og forårsager små lokale regndryp indvendigt. Vi sover dog trygt videre i lykkelig forvisning om, at vi vil blive afhentet af Porsild næste "morgen" kl. 14 og skal hjem til et længe ventet bad (ørredgruppen drømmer desuden om mad, da de i 5 dage har levet af havregrød med vand, og poser med frysetorret mad fra Aldi). Sover længe, da det planlagte feltarbejde er udført, og derfor blot mangler at pakke lejren sammen. Hører en skratten fra nabotellets VHF-radio, efterfulgt af "Ørredgruppen kalder Porsild, skifter..., Ørredgruppen kalder Porsild, skifter". Umiddelbart ingen respons, men Porsild skal også først være der om 4 timer – bliver liggende i soveposen. Scenariet gentages 4-5 gange den næste 1½ time før vi står op. Begynder at pakke sammen, og endelig er der svar – Rasmus lytter intenst til VHF'en, snakker lidt frem og tilbage for til sidst at afslutte med ordene: "I morgen? Ja okay, jeg tror, vi har mad nok". Lavtrykket over lejren får endnu et nyk nedad. Personen vi snakkede med er en grønlander, der sov i et telt 400m fra vores – han har haft kontakt med Porsild, som var blevet nødt til at vende tilbage til Godhavn pga. vejret, men ville forsøge at hente os den næste dag. Vi mødes med den spanske lejr og giver dem en friskfanget fjeldørred i bytte for en pakke ugegammelt rugbrød, som vi straks kaster os over. Humøret vender langsomt tilbage, og resten af dagen tilbringes i teltet med en bog, eller med lidt videnskabeligt lystfiskeri i fjeldene. Vender tilbage til en meget stille lejr kl. 00.30 og begynder at lave mad. Fra et telt lyder Rasmus' stemme "Fik du fanget flere fisk?" efterfulgt af "...Jonas, tror du ikke, du kunne stikke et par skiver rugbrød herind..."

~ Jonas

#### Mandag d. 26. juli

Vågner med en (om end lidt usikker) tro på, at vi bliver hentet i dag. En ekspedition sendes til den Spanske lejr da deres VHF har lidt bedre rækkevidde. Kommer tilbage med beskeden om, at Porsild skulle hente en anden gruppe et andet sted på Disko, og at vi derfor må blive en ekstra dag, men at vi kunne få forsyninger bragt ud fra den nærmeste bygd. At det var en simpel, dårlig joke øger humøret betragteligt. Står klar kl. 13.30, spændt på at se Porsild runde sidste pynt, hvilket blev foreviget på adskillige fotos. At de på Porsild så finhval og pukkelhval på udturen kan ikke ophidse os, og vi går straks ned i kabyssen og ser halvdårlige videofilm på hjemturen.

Hjemme igen er alle deltagere på Arktisk Feltkursus samlet for første gang i lang tid, men samme aften drager de søde og kloge Tejst-tøser i felten igen. Senere på natten støder man hist og her på rastløse deltagere fra feltturen, som har fået forrykket døgnrytmen grundigt af midnatssolen i kombination med at tilbringe mere end 20 timer i teltet den foregående dag.

De syv dage i felten ved Porsild Sø og Lange-, Mellem-, Lille Sø-komplekset var en kæmpe oplevelse. Vi så havørn, polarræv, vandrefalk, skallesluger, islom og så naturligvis rå mængder af fjeldørred. Fantastisk fiskevand!

Andre gode minder fra turen er selvfølgelig også Davids højtlesning fra Jan Gillou 'I nationens interesse', Thomas' hyr med myggene – han havde glemt begge (!) sine to myggenet på Arktisk Station – og til sidst men ikke mindst: lugten i teltet. En rigtig mandfolketur.

Jeg tror, vi alle sammen er blevet alvorligt glade for Grønland!

~ Jonas

#### Tirsdag d. 27. juli

Gruppedlemmerne fra projekt FUBAR (læs: Fish Utilization in Biological Arctic Research dvs. Ørredgruppen) havde fortjent valgt at sove længe pga. den sidste uges strabadser i felten i form af megen regn og voldsomme mængder af døde fisk. På trods af dette vågnede jeg forholdsvis tidligt med den nu fortlørlige lyd af Thomas Rohdes snorken i mine øre, som mest af alt leder tankerne tilbage til tiden i Søndre Strømfjord med de mange cirkulerende amerikanske Herkules transportfly. Efter at have ligget og nydt følelsen af at ligge i sin egen seng uden lugten af Rasmus' uge gamle sokker i den umiddelbare nærheden, stod jeg op og indtog et formidabelt morgenmåltid bestående af adskillige af Mads' ganske glimrende boller.

Vejret var fantastisk, hvilket de fleste af de andre grupper udnyttede til det yderste. Nysius-gruppen tulrede rundt med deres suge-anordninger i den evige jagt efter flere af deres tæger, som nok snart må antages at være mere eller mindre uddød i en radius af 2 km omkring stationen. Også plante-pigerne var at finde i felten

efter at have ligget brak med sytøjet i adskillige dage. Aftenen før havde været noget af et kulturchok, da vi efter 6 timers sejlads på det gode skib Porsild fandt alle feltkursusets deltagere i noget, som mest af alt lignede en samlet hyldelse til folkeskolens håndarbejds lærer. Any-way – senere på dagen skulle det sågar vise sig, at Thomas Rohde også skulle begive sig ind i handskemageriets fortryllede verden – noget jeg ellers hjemmefra ville have haft ondt ved at forestille mig.

Mens de andre grupper hyggede sig i det gode vejr, dissekerede ørred-gruppen nogle forholdsvis fermenterede fjeldørreder, hvorefter turen gik til kaffe-mik hos en bekendt af Mariannes fra hendes tid som leder af stationen. Hele holdet var blevet inviteret, og festlighederne centrerede sig om en ung mand på nu 15 år, som dog hurtigt forsvandt fra rampelyset. Mens den gæstfrie moder serverede sine stadigvæk mere og mere imponerende kager, underholdte den stolte fader med historier om den lidt sky unge fødselar. Det viste sig, at familien havde haft besøg af ordensmagten efter, den kommende "fanger" var begyndt at udrense den lokale ande-population. Efter en halvtimes tid, og én for grønlanderne bemærkelsesværdig enorm indtagelse af kage fra Linneas side, begav vi os glade hjemad.

Senere på dagen bevægede ørred-gruppen, samt vores lidelsesfæller Rune og Jonas fra projekt FUBAR-turen, mod Kuanit i det strålende solskinsvejr. Vi gik langs havet, mens snespurvene susede om ørerne på os og torden lød fra de strandede isbjerge. Fra højedragene kunne ravnens sagtnodige kalden høres – alt var således i den skønneste idyl! Efter at have vandret langs den stenede kyst i 1½ times tid begyndte vi at undres over, hvor Kuanit blev af. Med forfærdelses gik det op for mig, at jeg var ved at misse aftensmaden bestående af kyllingebryst, hvorfor Jonas og jeg tog den i galop tilbage mod stationen. Det skulle vise sig, at vi havde vandret lige forbi de berømte klippeformationer uden at tage nogen notiits deraf. Senere på aftenen tog plante-pigerne mod Lyngmarksbræen, mens jeg sneg mig til et ekstra glas rødvin og begyndte på dagbogen.

~ David



Billede 6 Udsigt ud over naturhavnen Bådsmandshavn fra Lyngmarksfjeldet.

#### Wednesday the 28<sup>th</sup> of July

10 degrees Celsius in the shadow! I went to the mountains behind the Station, trying to find *Saxifraga oppositifolia*. It is a wonderful plant when it is in flower, but impossible to find when it is not. Anyway, I was sent to the mountaintops, while the other three in my team were measuring leaves in the field, that is the way Pirigreen(?) works.

It was a sunny day, luckily. Other students had already been in the mountains and they said it was great. Unfortunately, after two hours turning every stone and cliff I didn't find *Saxifraga*, so, I lied down in the *Emprium nigrum* and *Salix herbacea* to have a rest.

Suddenly, a crow landed right next to me. This annoying creature had been flying over me on my way up,



pronouncing horrible sounds... I was, actually, close to hit it with a stone more than once.

But this time it was quite, looking at me, so I waited. It started to speak and I couldn't believe - I was able to understand! It was a really nice history I will like to share with you:

"Although this is just a short stay for you here, we live here all our life - it said. For example, you should know about the life of my little friend the polar fox. He is a lonely guy during the summer. Humans try to explain his behaviour in many different ways, but they always forget that, even foxes in the arctic have feelings. Today, for instance, 28<sup>th</sup> in July, he is standing in the rocks behind the Arctic Station. He is clever and he knows that three girls left two days ago by boat to the west. He also knows that five students and a teacher left the village to the east early in the morning. Actually, you can see them there between the two big icebergs. You see... yes, this small red point in the ocean is Porsild.

Yes, my friend, do not be surprised, he (the fox) sees all of you, although you do not see him. He also knows that two boys and a girl of your group were here early this afternoon and that the three girls, who are at the moment sewing in the Stations living room, were here last night.

Wait!!!, be patient!!!!... yes, yes, he needs to know exactly where everybody in the Arctic Station is ... Why? Come on!!! It is clear... No, no... is not because of the food. Why all of you think that he is around the Station because the food? I am getting nervous... Of course! If you put food outside the door he will take it, but it doesn't mean it is the reason of being around. Obviously, my friend, he is just afraid of you, crazy humans!! He just wants to go to beach. Yes!! He wants to go to the beach every day and for this he needs to find the best moment. Yeah! you are right, the best moment is when the cake is ready in the evening. At that moment, you don't care what happened outside your plate.

Ok, it looks like I need to explain everything. He is not going to the beach for fun, the same as you do. He is going there because he is trying to get news about his love, the little red fox living on the other side of the world, close to your country, I think. She lives in a beautiful forest close to Lisbon (Portugal). I was once there and it was so hot!! I think they really like each other and she is planning to jump in a boat and meet him here.

Why do you think that it is only humans who can love? We also want to enjoy our life. You should realize how dangerous it is for the fox (also for the post service) to be so close to town, on the beach. Here all people have rifles!! They want to kill the fox, and also the post service.

I can not believe that you do not know that there is an international post service!!! You are watching them everyday, between the icebergs. Why should they otherwise get so close to the guns? They are just coming with fresh news for the animals on the island. Almost once a week the fox gets news from Portugal.... Yes, I know! I know... people studying the whales say another thing... but they do not speak the wild-life language anymore. Neither do you when you study your plants!!!

The whales go around the world, in many directions, getting and giving information. That is why no animal wants to attack them. They are really useful. But now they have a new enemy. Yes, of course, you the humans... Hopefully, the fox will get some news today and he won't appear in a few days. It is becoming dangerous this place both for the whale and for the fox.

NO NO!!!, they can not meet in the cliffs, they have to talk so close each other, otherwise they can not communicate, that is why they have to meet on the beach!!

Ok, but if you are not tired anymore, continue your way to the top. It is really nice up there; you will feel free and also really small and tiny in front of such a view.

Enjoy, and do not throw stones against me anymore. Maybe I am not as blond as Danish girls, but black colour is also nice."

And it left. Now you know, if a crow stops close to you, listen to it - P.D.

Unluckily, as most of you know, the whale was shot few days later, and she had really good news for the fox, saying that the fox was coming by boat. But the fox never got this information and he just waits on the beach laughing while the Portuguese cries with the heart broken lost in an unknown harbour.

Culture or nature. The meeting was exceptional, but so was to see the whale too.

~ Pablo

#### Torsdag d. 29. juli

Jonas er nu hjemvendt fra "mandetur"(!), så jeg vågner ved lyden af hans modstræbende morgenkurren. Lavtrykkel ligger stadig tungt over Disko, så vi, de bedste af alle plantepiger er igen forvist til at laboratorie-nusse med at lave præparater og nogle pollen. Men så er det jo godt, at vi kan underholde os selv på et virkelig højt intellektuelt niveau!

I løbet af dagen viste solen sit lille generte ansigt, hvilket krævede øjeblikkelig handling: Spanierne fulgte den snart lange række af Lyngmarksbrø bestigere. Marianne fattede rundt ude på sin fodboldbane og spiddede sagesløse Tuelim-urter i 6½ time og de ellers utroligt friske og initiativrige Tejstøser, som just var

hjemkommet fra endnu en fuglekiggetur, gik i seng!

Jeg tror også, Nysiusgruppen havde en virkelig spændende dag, for de skulle nemlig til at begynde optællingen af spirede frø i deres spiringsforsøg! Til sidst men ikke mindst så gik Mads i lykkeligt selvsving, da han fik fingrene i Jörg's lækre digitale kamera (han er en tysk edderkopmand!), og så fik Mads jo også en god undskyldning for at flygte fra Plantepigernes platte vittigheder!

Ørredgruppen og Kirstens små slaver (Rune og Jonas) var på endnu en lille fisketur, hvor dagens store fangst bestod af stærkt parasit befængte hundestejler! Men jeg må give dem, at de er nogle "seje gutter", eller måske snarere "tøser i vaders", for de ser så søde ud når de sidder med nål og tråd og syr vanter til kæresterne derhjemme!

Efter et mindre madfråderi over resterne af den lækre fåreryg, holdt Rasmus (den videnskabelige leder) et spændende foredrag om hans tid i DMU, hvor han var med til styre implementeringen af habitatdirektivet i Danmark.

Nu sidder jeg i min lille bås og spejder efter det hvide stakit, som plejede at stå ca. 6 meter fra huset - tågen har spist det! Godt at Louise nu er kommet sikkert hjem. Lad os håbe at det bliver bedre vejr i morgen, så vi kan sejle til Brændevinsskærende.

~ Christina

#### Fredag d. 30. juli

Sent vågnet efter en dejlig nat i min egen private bås. Det er utroligt hvor meget man kan savne to kvadratmeters privatliv efter fire dage i en petroleumsstinkende hytte, hvor hver halve time afbrydes af alarmens "bip bip bip", som fortæller, at nu er det igen tid at tælle tejer. Den ene tælling afløser den anden i en uendelig spiral, hvor dag og nat går i et. Men der er dog også lyspunkter på øen, bl.a. den store mængde hvaler der dagligt svømmer forbi; Øen ligger åbenbart lige ved siden af hvalernes hovedvej.

Denne første dag hjemme fra hytten starter med de uheldige meddelelser at turen til Brændevinsskærene ikke kan gennemføres idag, og vores længe ventede fodboldkamp mod grønlandsmestrene desværre må udsættes til i morgen.

For vores gruppe er der desværre kun få emner på dagsordenen; indtastning af skemaer og indkøb. Efter veludført arbejde går tankerne på, hvad der nu skal ske: måske skulle man gå en dejlig lang tur, men nej, ideen bliver hurtigt droppet til fordel for mere seriøse sysler, for alle syprojekter er endnu ikke færdige. Hen af eftermiddagen er vi en gruppe, som beslutter os for at få en rundvisning på det lokale museum, hvor vi får et lille indblik i Godhavns historie.

Efter maden, der blev indtaget med en passende mængde øl, går toserne igang med at tygge skrå og drikke whisky, mens drengene uden muggen tager sytojet frem og går igang med pligterne. Tænk at man skulle helt til Grønland for at få indblik i dette urgamle, og lettere ukendte, konsollemønster. Det er virkelig kræst for en biospire, som jeg selv, at studere hvordan alfa-hunnerne, med deres dominerende attituder, får omega-hannerne til at makke ret, når pligterne skal fordeles.

Efter veloverstået arbejde går vi alle i gang med et spil trivial pursuit, der naturligvis spilles med en passende mængde alkohol ved siden. Jeg mener, at kunne huske fra de første år på biologi, at alkohol stimulerer hjernen til intelligente svar, eller måske var det noget andet. Efterhånden som spillet skrider frem står det hurtigt klart, hvor vinderne skal findes: Linnea, David, Jonas og jeg selv kører sejren i hus i overlegen stil med fem ud af seks rigtige svar på et kort.

Sejrens søde rus, eller måske alkoholens, fylder min krop til bristepunktet, jeg behøver en udledning, "...Twist again - like we did last summer..." musikken kommer som min sidste redning, min krop eksploderer i uhemmede dansebevægelser. Efter dansen er det tid til at gå videre i byen, hvor mon vi skal hen? Svaret er måske ikke det sværeste, eftersom der kun findes et sted i byen -Nikiffik, stedet hvor alle hænger ud. Musikken er en skøn blanding af 90'er techno og grønlandsk liveband. Kløkken tre om morgenen tændes de hyggelige lysstofrør, og jeg får igen øjnene op for de personer, jeg i mørket troede var Brad Pitt kloner. Jeg hører en sagte lyd af min bås, som kalder mig hjem, det bliver godt at sove længe igen.

~ Katrine

#### Lørdag d. 31. juli

Natten havde været lang for de fleste, og det kunne mærkes til morgenmaden. Selv morgenes højdepunkt (Mads' nybagte boller) lokkede kun de færreste ud af fjerene før hen ad middag - eller for nogle tættere på aftensmadstid.

Kirsten, Jonas og jeg skulle på vanlig sø-jagt, men heldigvis var det i dag en af de kortere, da Moræneso ligger under en times gang fra Arktisk Station. Det var rart for selvom vi er i toptræning, når det kommer til disciplinen gummibåds-fjeld-løft, så var kroppen i dag noget længere om at komme i omdrejninger. Endelig fremme, ved soen ventede et spændingens øjeblik - i knap et par uger har vi ved samtlige passerede og

undersøgte søer spejdet længselsfuldt mod søens bund efter et længe ventet kræ. Her fandt vi for første gang vor alles favoritdyr damrokken *Lepidurus arcticus* – et lille sjovt krebsdyr på op til 3 cm og ligner en smule miniature-udgaven af en dolkhale. Så kunne vi endelig indsamle nogle til undersøgelser og sætte fælder ud.

Først på aftenen oprandt endelig det store sus af en fodboldkamp mod det lokale hold. Arktisk Station stillede med et meget spraglet og sprudlende hold mod et blandet lokalt hold, der blandt andet halvt bestod af de berygtede skrappe old-boys spillere. Vores hold var godt blandet i både teknisk kunnen, køn og alder, og der blev stillet med både danske, spanske, tyske og grønlandske spillere. Trods hårde odds med tømmerrmand og dårligt fodtøj (gummi- og vandrestøvler) var der på vores ellers ikke kamprænede hold en del, der gjorde en flot profil. Grusbanens støv hvirvlede, og der blev scoret først et, så to mål i vores favør. Ved pausen stod den desværre uafgjort igen med 2-2. Vi havde blod på tanden, men selvom vi kørte med løbende udskiftninger, og de ikke gjorde, var 2x45 minutter ikke til vores fordel. Anden halvleg startede med spænding, og på trods af at flere fra holdet allerede mærkede trætheden, blev der bakked godt op fra sidelinien (det lokale hold havde desværre ikke nogle til at heppe, da kampen meget ustrategisk var lagt, mens der var TV-bingo). Man kan sige at vi toppede i første halvdel af første halvleg, hvor vi fik rystet modstanderne, men derefter gik det stødt nedad for os. Der blev scoret til 3-2, 4-2, 5-2 og i kampens sidste sekunder til 6-2. Men vi fik givet dem mere modstand end de fleste af os havde forventet, og det er ikke hver dag man får lov at spille fodbold mod et hold af forsvarende grønlandsmestre midt mellem fjelde og isbjerge. Fodboldbanen ligger lige mellem Arktisk Station og stranden Sorte Sand, hvilket betyder, at stranden starter lige uden for sidelinien, og det skete da også et par gange at tilskuerne måtte vende ryggen til banen for at se isbjerge kælle. En forrygende kamp! Sen aftenmad og midnatskage blev velfortjent nydt af de mange udmattede spillere.

~ Rune

#### Søndag d. 1. august

Endnu en grå dag med tunge skyer og blæst fra den forkerte retning truer pollen- og tejpigernes muligheder for at komme i felten, noget måtte der gøres!

En lille gruppe søgte derfor ly i byens kirke for at bede de højere magter om hjælp. Da vi nåede op til den lille rødmaledede trækirke, så vi at folk var klædt på til bryllup, der var folkedragter i alle størrelser fra den lille pige i farverigt broderet sælskindstøj til en ældre herre i hvid anorak, sorte bukser og kamikker. Bruden var dog i traditionel dansk brudekjole og gommen i sort-hvidt jakkesæt. Vi undrede os over hvorfor det var på en søndag, men det står åbenbart en frit for hvilken dag på ugen man vil giftes, bare præsten har tid.

Kirken ser ny og velholdt ud, men den gamle stil er holdt, og der ses ikke andet pynt end en konebåd hængende midtskibs og et alter i enkel stil. Præsten er en mand af mange talenter; han styrer både orgel og prædiken, hvilket resulterer i en næsten pendulagtig rute, da de synger en del flere sange, end vi normalt gør i den danske folkekirke. Besøgstallet kunne nok også få en standhaftig folkekirkepræst til at blive grøn af misundelse; 85 personer - næsten fuldt hus. Meeen, nu var der jo også bryllup og turister.

Lige efter gudstjenesten begyndte vielsen, der foregik efter nogenlunde samme model som i DK. Og de svarede begge deres aap (ja), og så var der ikke et øje tørt. Gudstjenesten var forbi, og vi drog hjemad til pollenprover og øresten, men der mødte os et sørgeligt syn af uldundertøjs klædte, men smækre(!) tejpiger, der på grund af vejret måtte vente til vinden vendte for at komme af sted til deres ø.

En større flok var tidligere på dagen sejlet ud for at hente gåse-pigerne i mudderbugten, de forventes først hjem engang i morgenaften.

Resten af dagen gik med forskellige huslige sysler og lidt hvirken om underholdning til på tirsdag. Senere på aftenen blev der serveret rødvin og franske specialiteter af David, en franskmænd som også bor her på stationen.

~ Linnea

#### Mandag d. 2. august og tirsdag d. 3. august

For tejpgruppen begyndte mandagen meget tidligt. Vi befandt os på vores lille tejp-observations-ø og var i fuld gang med vores allersidste observationsperiode, der gik fra søndag kl. 22 til tirsdag kl. 10.30. Det er rimelig lang tid, især når der i hele perioden kun er planlagt 2 gange 4 timers søvn. Det er ikke altid lige underholdende, at skulle kravle rundt i tåget tusmørke midt om natten og tælle 300 vildt flyvende tejpster! Faktisk må jeg indrømme, at der disse nætter var øjeblikke, hvor tejpsten ikke udelukkende blev omtalt som den vidunderlige fugl, den nu en gang er!

Men med pulverkaffe, pulversuppe, pulver-jægergryde og whisky i teen klarede vi os igennem minut for minut. Til sidst var natten gået, og solen ville have kigget frem, havde det ikke været overskyet.

Et stort lyspunkt i de sene natteimer er at vores projekt lader til at blive ganske vellykket. Vi får mange gode data, og selvom det har vist sig umuligt at tælle det præcise antal reder i kolonien, skal der nok komme

et godt projekt ud af det.

Efter endt sidste tælling kl. 10.30 havde vi allerede pakket alt vores grej ned og satte os demonstrativt foran hytten med vores bagage og stirrede med længsel i den retning, hvor Agaaraq med sin båd (og med ham vores vej tilbage til civilisation, bad, Mads' morgen-moskus-boller og alskens andre uundværlige materielle goder) nu hvert øjeblik kunne komme til syne. Men, oh ak og ve, klokken blev 10.40 og derefter 10.50 og gud hjælpe mig om den ikke også blev 11. Klokken 11.10 var vi fuldstændig overbevist om, at vi var blevet glemt af omverdenen og dømt til en langsom sultedød på øen med kun vore elskede tejpster som vidner. Noget måtte der gøres! Tommerflådebygning, nødbål og overlevelse blev ivrigt debatteret, men stagnerede en anelse i diskussionen om, hvorvidt vi - i altruismens ånd - ville lade de andre spise af vores afmagrede lig, og på den måde muligvis overleve den hårde vinter... alt håb var næsten ude, da den fjerne lyd fra en yamaha-motor pludselig kunne høres i det fjerne. Vi var reddet! Og var oven i købet så heldige at se smuk pukkelhval ganske tæt på båden på vejen hjem. Livet er nu alligevel ikke så slemt...

Vel hjemme på A.S. tog vi os et velfortjent hvil på en 3-4 timer. Vi skulle jo være friske til den store afskedsmiddag om aftenen, hvor alle samarbejdspartnere - danske som grønlandske - var inviteret. Det blev et herligt gilde med lammebov, helleflynder, mattak, hele 3 glas vin til hver (og 4-5 til de af os der var hurtige), taler og en - af de studerende meget velskrevet - sang (der forresten kan ses efter denne dagbog).

Efter maden blev bordene ryddet til side og dansegulvet åbnet. Porsild-teamet Erik, Søren og Skipper Fari hentede et gigantisk musikanlæg med mixerpult og kæmpehøjtalere, der blæste alle ikke dansende ud af lokalet. Men danset blev der, og det lige til klokken tre, hvor nogle mente, at det var på tide at sænke lydniveauet mærkbart. Vi fortrak ovenpå - pigerne til whisky og drengene til deres sytøj - hvor vi forholdt os rimeligt roligt, indtil Thomas R fik den idé at lave mande-ben-strip for pigerne. Det skulle han ikke sige to gange og under megen hujen og piften gik de - til at starte med en anelse bekymrede - fyre, ind for at forberede et show, der for al fremtid skulle blive kendt som A.H.P.S. (Arctic Hero Porn Show). Nu er dette jo en pæn dagbog, og detaljerede beskrivelser må desværre udelades, men jeg afslører vist ikke for meget ved at skrive, at showet er ufatteligt sexet, anbefalelsesværdigt og bl.a. involverer bodylotion, marabouchokolade, et langt plastikrør, en barbermaskine og adskillige whiskydrivende mandeben...

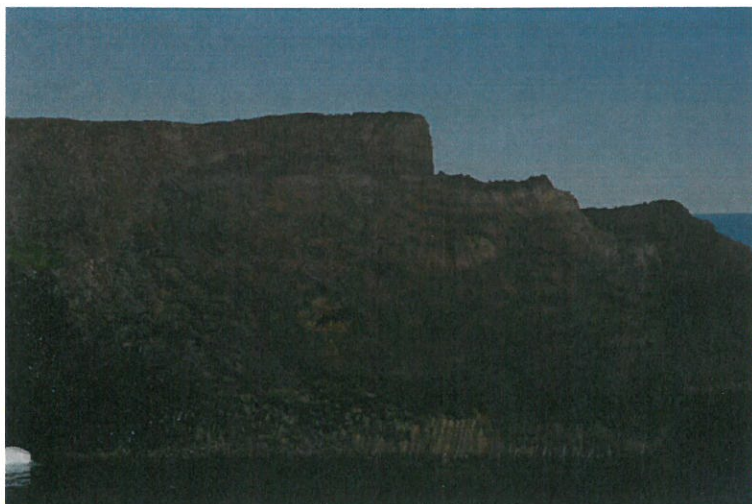
Alt i alt en fantastisk tirsdag...

~ Signe

#### Onsdag d. 4. august

Efter en god nats (og formiddags) søvn var vi klar til en ny dag. Der er nu kun få dage tilbage og alle virker opsatte på at nyde naturen i fulde drag den sidste tid. Jeg havde endnu ikke været ved Kuanit, og da solen strålede fra en næsten skyfri himmel, tog Jonas og jeg vandrestøvlerne på og begav os af sted. Det var en meget skøn tur. Klippeformationerne i Kuanit er helt anderledes, end hvad jeg før har set, og vi så mange tejpster (bl.a. én der svømmede under vandet med en fisk i næbbet) og et par finhvaler. Jeg havde desværre været så fjollet, at medbringe mit kamera uden film i, så meget af turen gik med at plage Jonas til at tage billeder af det ene og det andet smukke udsyn.





Billede 7 Kuanit, hvor den særprægede lavaformation er opstået pga. hurtig afkøling af den varme lava i havvandet.

Vi var tilbage ved en 17-tiden, og der viste det sig, at Marianne havde bestilt 20 kg edderkopkrabber til aftensmaden. De var lige ankommet i levende live i én kæmpe plasticpose. Det skramlede og rumsterede, når de imponerende dyr forgæves forsøgte at trække vejret eller bevæge deres ben og kløer. En af de heldige nåede ud af posen, kun for at blive grebet af Mads og båret huset rundt for at skræmme de søde blomsterpiger. Meta stod og så lidt forvirret på de resterende og viste ikke helt, hvad hun skulle gøre med dem. Det endte da med, at hun fik tændt op under et par gryder med vand, så krabberne kunne blive kogt.

Efter spisningen opdagede vi, at der var stort ståhej på havet foran Arktisk Station med masser af små både, der susede omkring. Der var blevet spottet vågehvaler og jagten var sat ind. Indbyggerne i Qeqertarsuaq må kun skyde tre om året, så det er en stor begivenhed, når det sker. Vi susede ned til havnen, hvor de allerede var igen fuld gang med parteringen. Alt kød, hud og spæk blev fordelt i 23 lige store bunker, der derefter blev fordelt mellem de 23 fangere, der havde deltaget i jagten. Det var meget spændende at opleve. De efterlod et stykke kød på 8 kg, som vi tog med hjem, og Maria og Marianne tilberedte det straks. Det smagte efter sigende himmelsk. Der blev også bagt pandekager med is, så vi var nogle mætte og tilfredse studerende, der trætte tumlede i seng omkring klokken tre.

~ Signe

#### Torsdag d. 5. august

På den igen!

Grundet en meget sen rituel vågehvalsslagtning, samt indtagelse af grove mængder kød fra selv samme, startede dagen sent for de flestes vedkommende. Ørredgruppen (project FUBAR), var dog som sædvanlig tidligt oppe og knoklede med behandling af fisk i laboratoriet. Det var nemlig i dag at de sidste resultater og rådata skulle indsamles fra de forskellige lokaliteter (man anede en smule panik). Det var dog ikke en dag som alle andre. Næ, der var noget særligt over denne solbeskinnede dag i Gudhavn. Det var nemlig den sidste hele dag på stedet inden afrejse til det ifølge vejrudsigten tropiske København. At det var den sidste dag skulle selvfølgelig fejres med både intern fodboldkamp samt en lille fest, til denne lejlighed var Majken og Christina ude efter lidt is til sjusserne – de kunne ikke få nok af det dejlige grønlandske havvand. Fodboldkampen var en ren fornøjelse altså lige bortset fra resultatet, der på mystisk vis faldt ud til fordel for det absolut dårligste hold! Især var det en ren fryd at følge Thomas R.J., der gang på gang med sine geniale driblinger, store overblik, og overlegne fysik sendte modstanderne til tælling. Efter endt fodboldkamp og et velfortjent bad, begyndte folkeskaren lige så stille at samles til lidt afskedshygge. Mange besynderlige sanglege blev afprøvet med større eller mindre succes. Alt i alt en underholdende aften/morgen, der blev afsluttet på behørig vis af de såkaldte Nutella-piger. Et virvar af regn, sol, sælskindshandskesyning, fjeldørred, kulde, laboratorium arbejde og endeløse gåture med alt for meget oppakning er ved at være slut. Ja, det har været uforglemmeligt, og lur mig om man ikke vil finde en lille tåre i øjenkrogen af de fleste studerende, når færgen stævner ud af Godhavn.

~ Thomas R

#### Fredag d. 6. august

Vores allersidste dag i Qeqertarsuaq; sidste dag med mosdækkede bjerge, rivende floder, springende pukkelhvaler, midnatssol og lyden af kæmpemæssige isbjerge, der brager i det fjerne. Det er mærkeligt og lidt trist at tænke på, at jeg i morgen aften er tilbage i min toværelses lejlighed på Vesterbro med udsigt til hhv. verdens mindste gård og den evigt åbne Flensborg kiosk, der sælger dåseøl til 5 kr! Sikken en forandring! Der er vist ingen tvivl om, at vi alle kommer til at savne Grønlands storslåede natur, der har overvældet os med sin skønhed. Men der er jo ingen vej uden om, så efter en dag hovedsageligt bestående af pakning, men heldigvis med indlagt afskedsmiddag bestående af kæmpe rensdyrkølle (Og dem kan vi aldrig få nok af!), drager vi om få timer af sted mod havnen, hvor færgen mod Aasiaat afgår kl. 19.30.

Tak for denne gang.

~ Signe



Billede 8 Færgen Sarpik Ittuk, som betyder "hval maskine", er på vej for at bringe os alle tilbage mod Danmark. Underkæberne fra en Grønlandshval markerer havnepladsen for Kongeskibet.

## Sang i anledning af fest på Arktisk Station 2004

Melodi: "I en kælder sort som kul"

1) På et fjeld så stort og vildt,  
vandred' hele flokken.  
Søndagsturen sku' gå så snildt,  
ikk' så meget mokken.  
Det kan nås på ingen tid,  
Mads han mente han var blid.  
Kroppen var som tæsket,  
det var godt for flæsket.

2) Kameraer er et hit,  
alt bli'r fotograferet.  
Billedet skal blive mit,  
mosser bli'r studeret.  
Vi vil ha' med superzoom,  
makrobilleder er et boom.  
Vi er entusiaster,  
tror vi er fantast.

3) Qeqertarsuaq er fin,  
her er rart at være.  
Stenhuset med smykker i,  
mange gode sager.  
Nikiffik, butik, café,  
der er meget man kan se.  
Kaffemik er godt,  
vi kan ikk' få nok!!!

4) Efter endt hård arbejdsdag,  
Meta kokkererer.  
Havkat, sæl og hval en-masse,  
fint hun os serverer.  
Men vi er en kræsen flok,  
ikke alt vi spiser op.  
Så vi vil ha' kage,  
hvem mon den skal bage?

5) Når vi så skal hygge lidt,  
pi'rne vil ha' whisky.  
Drengene de takker nej,  
nu skal de sælskind sy.  
Luffer, det skal kær'sten ha',  
hvad skal hun mon gi' tilbag'?  
"Arktisk helt" på banen,  
følger husmorvanen.

6) Porsild er et prægtigt skib.  
Aller dybest nede,  
findes der en køjeseng,  
hvor man den kan fede.  
Og når turen hjemad går,  
alle mand på dækket står.  
For man vil se hvaler  
- styrelsen betaler!

7) Heliporten – scenen sat,  
det store slag oprinden.  
Old-boys-holdet fra Nunat,  
får én pistol for panden.  
Samspil, gejst, cooperation,  
hele holdet får motion.  
I målet har vi Fari,  
fuld fart på – Ferrari!

8) Kirsten har en overlev'selsdragt,  
den er sørne orange!  
Bare hun ikk' ska' betale for meget i fragt,  
så bli'r der ubalance....(i regnskabet).  
Speedy Kirsten når det nok,  
bare hun ikke får en prop.  
Vi er hendes slaver,  
hvad tror I mon vi laver?

9) Morgen-bolle-moskus-Mads,  
mon blomster gør ham ivrig?  
I fodbold han den giver gas,  
og isbad gør ham livlig.  
Marianne er vor alles mor,  
kender alt der gror på jord.  
Syr luffer med dreng' og piger,  
ser sin limurt spire.

10) Ørreddrenge, plantepi'r,  
Nysius, og tejster.  
Byder jer på mad med mer',  
lige før vi rejser.  
Velkommen til denne fest,  
godt at have jer som gæst.  
Hæv nu jeres glas, ja,  
kasutta tamatta!!!

Hver gruppe har skrevet to vers