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Floristical and ecological characterization of the polar desert zone of Greenland

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Abstract. Species composition and biomass of four plant communities were investigated in two coastal polar desert areas in eastern North Greenland, bordering the North East Water Polynya – an ice-free sea area kept open by upwelling – and compared with inland areas in North Greenland. Herb barren, the poorest type, has a species richness of 6 species/m^2, a cover of 0.7 %, and an above-ground biomass of 0.6 g/m^2 (vascular plants). The richest type, *Saxifraga oppositifolia* snowbed, has 10 species/m^2, 5.0 % cover, and 11.2 g/m^2 biomass.

A floristic and vegetation boundary exists a few kilometres from the coast. The coastal areas bordering the North East Water Polynya had an impoverished flora and vegetation compared to areas near the ice-covered sea, possibly caused by very low summer temperatures and high frequency of clouds.

A new delimitation of the polar deserts of Greenland is proposed on the basis of the number of vascular plant species, the occurrence of species with a specific inland distribution in North Greenland and the dominating life forms. At present the polar desert zone includes only areas within a zone up to ca. 15 km from the outer coast of high arctic Greenland - north of ca. 80° N. Large areas formerly classified as polar deserts in eastern North Greenland, as well as in Washington Land in western North Greenland, are excluded. New floristic data confirm that Greenland is correctly included in the Canadian province of the arctic polar deserts, whereas there is no reason for subdividing the polar deserts of the Canadian province.

Keywords: Arctic; Floristic delimitation; Phytogeography; Plant community; Vegetation type.

Nomenclature: Böcher et al. (1978).

Introduction

Botanists have divided the northern circumpolar High Arctic into zones based on floristic and vegetation characteristics. Young (1971), Aleksandrova (1988), Bliss (1993) and Yurtsev (1994) have proposed floristic and phytogeographical zones for the entire Arctic. Regional studies of Canada (Edlund 1990; Edlund & Alt 1989), North America (Komarkova & Webber 1978), Greenland (Bay 1992), Svalbard (Elvebakk 1989) and Russia (Aleksandrova 1988; Matveyeva 1994) have outlined regional delimitations of these zones.

Most authors assign the northernmost areas of the Holarctic with an impoverished flora and vegetation to the arctic polar desert zone (e.g. Aleksandrova 1988; Matveyeva 1994; Bliss 1988; Bliss & Svoboda 1984; Bliss et al. 1984; Edlund 1980). The concept of arctic polar deserts has been discussed by Aleksandrova (1988) and others (e.g. Bliss et al. 1984; Funder & Abrahamsen 1988). Landscapes of the northernmost coastal parts of the High Arctic are considered Arctic polar deserts; they are without continuous plant cover, have a low number of species and lack certain plant groups otherwise characteristic of the circumpolar High Arctic. The total cover of vascular plants in this patchy vegetation is generally < 2 %, only locally exceeding 5 %, whereas the cryptogam cover may be as high as 75 %. Characteristic features of the polar desert zone are the absence of woody species which are otherwise widely distributed in the High Arctic, e.g. *Salix* spp., *Dryas* spp. and *Cassiope tetragona*. In addition to vascular cryptogams, aquatic and salt marsh species and representatives of the plant families *Asteraceae* and *Cyperaceae* occur.

The primary ecological factors controlling the impoverishment of flora and vegetation of the coasts around the Arctic Ocean are low temperatures and a short growing season (Young 1971; Edlund 1983; Elvebakk 1985; Funder & Abrahamsen 1988). Aleksandrova (1988) estimates the annual radiation balance to be < 10 kcal/cm^2. Bliss (1988) suggested that the basic control of polar deserts is the combination of the geological substrate, low nutrient levels and cryoturbation causing a poor soil development and a low moisture retaining capacity during the short summer. However, Bliss & Matveyeva (1992) later modified this view by stating that a low summer temperature and a short growing season, with surface soils that dry out in mid-season, are also important.

The present study was part of a project focusing on the terrestrial ecology of land bordering the open water area off the coast of easternmost North Greenland. For comparison an inland area was included in the study. The present paper aims to describe the flora and vegetation of the polar desert zone of Greenland, present a new delimitation of the zone and update the delimitation of the polar desert zone in the circumpolar Arctic.

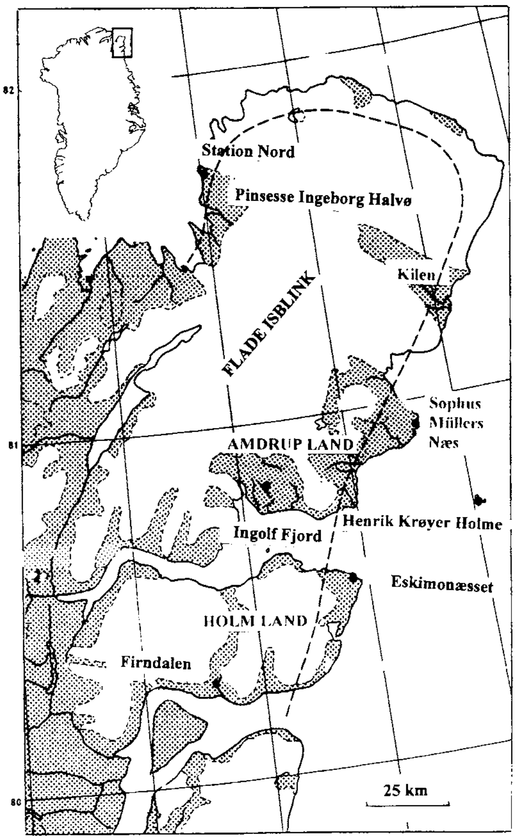

Fig. 1. Study areas (black dots) in eastern North Greenland with localities mentioned. The new delimitation of the polar desert zone of eastern North Greenland is indicated by the dashed line.

Study areas

Two areas in the coastal part of eastern North Greenland (ca. 81° N) south of the ice cap Flade Isblink (Fig. 1) were investigated in July and August 1993 during the NEWLand project, which focused on the terrestrial ecology of the land areas bordering the North East Water Polynya just off the coast between 79° N and 82° N.

Sophus Müllers Næs is situated at the coast of easternmost Amdrup Land (80° 57' N, 14° 40' W); the study area comprises the flat foreland up to 10 km from the coast (Fig. 2). The other main locality is situated in the central part of western Amdrup Land (80° 49' N, 17° 35' W) ca. 25 km from the outer coast and 8 km from Ingolf Fjord, which is ice-covered all year round (Fig. 5).

Grazing pressure from mammalian herbivores at Amdrup Land is negligible as the density of herbivores is extremely low and non-existent at the coastal localities.

In addition, investigations were carried out in July and August 1986 at the peninsula Prinsesse Ingeborg Halvø west of Flade Isblink (81° 36' N, 16° 39' W), and the results are included for the comparison of the flora, vegetation, and climatic data from a coastal area bordering a mostly ice-covered sea with a coastal area under influence of the polynya. These areas, occurring within the floristic province of North Greenland and including a coastal zone up to 50 km inland, were classified as polar desert (Bay 1992). Data collected on Henrik Krøyer Holme, Eskimonæsset, Firndalen, and from the semi-nunatak Kilen are also included (Fig. 1).

For comparison, available floristic data from a distant inland area within the interior floristic district of North Greenland by Centrum Sø, Kronprins Christian Land (80° 10' N) are compiled from Bay (1992), in addition to material collected by others.

Climate

Only a few meteorological data sets are available from North Greenland north of 80° N. Of the stations recording daily temperatures, only Station Nord and Kap Moltke have been recording for more than 15 yr (Table 1). Very limited information on precipitation is available and only from the manned stations with long recording periods. Mean summer temperature and mean annual temperature are given in addition to the precipitation. Summer is defined as July and August, which are the only months with a mean temperature above zero.

The mean annual temperature is related to latitude, the exception being Henrik Krøyer Holme, situated in the polynya, which has a markedly higher annual temperature corresponding to the temperature recorded at Danmarkshavn 450 km to the South on the East coast. However, the summer temperature is not correlated with latitude but with the distance to the sea; inland localities have a mean temperature of 3 - 4 °C, whereas in the coastal areas the values are just 0 - 2 °C (Bay 1992).

Precipitation is low, showing a significant difference between the outer coast and the inland locality, ranging annually between ca. 200 mm in coastal areas and ca. 25 mm in inland areas. The snow cover in coastal areas lasts for a longer period, postponing the onset of plant growth and reducing the length of the growing season.

Geology

The coastal areas at Sophus Müllers Næs consist of Upper Palaeozoic and Mesozoic limestone, locally covered by Quaternary glacial and marine sediments (Håkansson et al. 1993). The bedrock at the Amdrup Land locality consists of carboniferous limestone and sandstone, which only exceptionally penetrates the till (Fredskild 1995). In the study area at Prinsesse Ingeborg Halvø the carboniferous bedrock is covered by raised marine silt, beach ridges and glacial deposits.

Material and Methods

Plant communities

Analyses were carried out during the period from mid-July to mid-August, when the vegetation optimally developed and the standing crop maximal. Plant communities were identified on the basis of ground survey and floristical observations during one week of field work in each area. Plant communities were then characterized by species composition, dominant species and life forms, and physical parameters such as topography, exposure, soil water content and texture.

In each plant community distinguished, three analyses were performed randomly by establishing 15 plots of 50 cm × 50 cm and recording cover and frequency. Only one stratum was recognized, and cover was estimated to the nearest 1 % for vascular plant species and for the total of each: bryophytes, organic crust including lichens, bare soil and stones. Species represented by very few plants or leaves, cover < 1 %, received an arbitrary cover value of 0.5 %. Species contributing with very small values are not included in the tables, but their numbers and cover are given in addition to the number of species in the types.

Above-ground live biomass of vascular plants was harvested in every third plot. Vascular plant material was sorted by species, and pre-dried in the field to avoid carbon loss due to respiration. In the laboratory samples were dried for two days at 50 °C and the dry biomass was recorded. Since biomass figures are related to cover values they are not included (but are available on request).

Soils

Soil pits were dug in one of the stands of each plant community in Amdrup Land and Sophus Müllers Næs. Samples were collected at different depths to study vertical differences in the chemical properties of the soils, although no profile development was observed. Samples were collected at 0 - 1 cm and for each 10 cm down to a depth of 30 - 40 cm, and air-dried in the field. pH (H_2O), total carbon, nitrogen, phosphorus, organic carbon, and carbonate were analysed by Statens Husdyrbrugsforsøg, Ministry of Agriculture. Organic carbon was determined as total carbon burnt in a Leco instrument. The samples were checked for carbonate by adding acid. If signs of $CaCO_3$ were traced, the content of $CaCO_3$ was determined. Total nitrogen content was determined by the Kjeldahl method; total phosphorus was determined by digestion with perchloric and sulphuric acid.

Phytogeography

Plant collections kept at the Greenland Herbarium in Copenhagen (see Bay 1992) and later collections by Daniëls & Alstrup, Berg & Kapel and Schwarzenbach were used to delimit the polar desert zone in Greenland.

Table 1. Climate data for the summer (July and August) in North Greenland north of 80° N computerized by the Meteorological Institute of Denmark and compiled from Bay (1992) and Kristensen & Kristensen (1993). HKH = Henrik Krøyer Holme; PIH = Prinsesse Ingeborg Halvø; KM = Kap Moltke; KMJ = Kap Morris Jesup; HL = Hall Land. M.a. temp. = Mean annual temperature; M.s. temp. = Mean summer temperature; M.a. prec. = Mean annual precipitation.

Locality	HKH	PIH	KM	KMJ	HL
Location	80°13' N 13°43' W	81°36' N 16°40' W	82°09' N 29°57' W	83°38' N 33°22' W	81°44' N 59°00' W
Recording periods	1985-87 1990-92	1961-72 1975-87 1990-92	1974-82 1984-87	1981-87	1983-87
M.a. temp. (°C)	– 12.9	– 17.0	– 15.7	– 19.0	– 20.0
M.s. temp. (°C)	1.5	2.5	4.2	0.2	3.3
Degree days > 0 °C	203	221	305	70	276
M.a. prec. (mm)		227	25*		

* Precipitation at Kap Moltke recorded at the nearby locality Brønlundhus during 1948-1950.

Results

Plant communities

Four types of plant communities were identified at Sophus Müllers Næs; they only cover small areas (Table 2). None had a continuous plant cover, and no woody species were present. Amdrup Land has six types with a higher species diversity, higher percentage cover and with woody species occasionally dominating (Table 3). Three plant communities were identified at Prinsesse Ingeborg Halvø; one is characterized by a woody species (*Salix arctica*) (Table 2).

Sophus Müllers Næs

A rich *Saxifraga oppositifolia*-dominated plant community is closely associated with the few large snowdrifts in the area and is consequently a rare type (Fig. 3). The soil is silty, occasionally with gravel and wet throughout the growing season. Except for monocots, the species composition is closely related to the *Saxifraga oppositifolia-Papaver radicatum* plant community, but the cover and biomass of all plant groups are larger.

On fine textured soils a *Saxifraga oppositifolia-Papaver radicatum*-dominated plant community occurs, being the most frequent type in the study area. It occurs on moist polygon soils as well as on non-sorted soils.

The third type with *Saxifraga oppositifolia* and *Papaver radicatum*, 'herb barren', is the poorest plant community in North Greenland, regarding cover, diversity, species frequency and biomass. It covers vast areas on mesic silty or sandy soils.

No true fens dominated by sedges, i.e. *Carex* spp. or

Eriophorum spp., are present, but along melting streams below snowdrifts narrow stripes of graminoid vegetation occur.

Amdrup Land

The hummocky *Salix arctica*-dominated snowbed community has the highest standing crop value and number of species; it covers small areas on east and south-facing slopes (Fig. 4).

On slopes with a long-lasting snow cover a mossy snowbed is found. Bryophytes are prominent with a cover of 56 %; the total number of vascular species is 25.

Fens occur along streams and at the edge of ponds. They are species-rich but mainly composed of almost pure stands of *Arctagrostis latifolium* and *Carex stans* (Fig. 5).

The open *Salix arctica* community is the most widely distributed community at Amdrup Land. It differs from the herb barren by the presence of *Salix arctica* and *Carex nardina* in addition to a larger cover, biomass and a higher number of species.

The *Phippsia algida*-dominated community on wet solifluction soils occurs below snowdrifts and on slopes with silty soils that are wet throughout the growing season.

Large areas are wind-exposed and snow-free or with a thin snow cover during winter; they are bare or have a herb barren vegetation. The soil is dry, well-drained, and mostly silty. Herb barrens have a vascular species cover of only 1.5 %, whereas bryophytes are almost absent.

Prinsesse Ingeborg Halvø

The most common plant community on Prinsesse Ingeborg Halvø is the herb barren, which occurs on wet to mesic soils. The soil surface is under the influence of solifluction and only few herbaceous plants can establish. On mesic, silty soil a *Saxifraga oppositifolia*-dominated herbaceous community occurs with an organic crust. On sheltered south and west-facing slopes in the non-coastal areas of the peninsula, i.e. at least ca. 5 km from the seashore, a relatively rich *Salix arctica*-dominated plant community with an organic crust occurs.

Soils

Soils are alkaline; pH varies between 8.8 and 9.3 at Sophus Müllers Næs and between 7.3 and 9.3 at Amdrup Land (Table 4). Organic matter content from the soils at Amdrup Land mostly shows a decrease from the soil surface downwards in all plant communities. This is not the case for the two *Saxifraga oppositifolia* communities

Table 2. Plant cover and diversity of plant communities at Sophus Müllers Næs (SM) and Prinsesse Ingeborg Halvø (PI). 1 = *Saxifraga oppositifolia* snowbed; 2 = *Saxifraga oppositifolia-Papaver* comm.; 3 = Herb barren; 4 = *Phippsia algida* comm.; 5 = Herb barren; 6 = *Saxifraga oppositifolia* comm.; 7 = *Salix arctica* comm.

Locality	SM 1	SM 2	SM 3	SM 4	PI 5	PI 6	PI 7
Saxifraga oppositifolia	3.5	0.8	0.2			2.5	0.2
Papaver radicatum	0.5	0.3	0.1		0.3	0.3	0.1
Stellaria crassipes	0.1	0.1					0.1
Draba bellii	0.3						0.1
Saxifraga cernua	0.1	0.2	0.1	0.1	0.4		
Draba subcapitata	0.1	0.1	0.1		0.4		
Draba adamsii		0.1					
Cerastium arcticum			0.1				
Phippsia algida ssp. *algidiformis*		0.1		0.2	0.5		0.1
Colpodium vahlianum				0.5			0.1
Saxifraga platysepala						0.1	0.1
Salix arctica							8.7
Number of other vascular spp.	4	3	1	0	10	10	1
Total number of vascular spp.	10	10	6	3	14	13	9
Total vascular plant cover (%)	5.0	1.8	0.7	0.8	1.7	4.4	9.6
Bryophyte cover (%)	6.6	1.6	0.1	0.1	0.0	1.5	5.6
Organic crust cover (%)	14.6	2.5	0.6	50.3	0.1	94.1	85.4
Total plant cover (%)	26.2	5.9	1.4	51.2	1.8	97.2	100.5

Table 3. Plant cover and diversity of plant communities at Amdrup Land. 1 = *Salix arctica* snowbed; 2 = Mossy snowbed; 3 = Fen comm.; 4 = Open *Salix arctica* comm.; 5 = *Phippsia algida* comm.; 6 = Herb barren.

Plant community	1	2	3	4	5	6
Saxifraga oppositifolia	0.5	0.5	0.1	0.1	0.3	
Papaver radicatum	0.3	0.4		0.2		0.2
Stellaria crassipes	0.3		0.2		0.1	
Draba bellii	0.2			0.1		
Saxifraga cernua	0.2	0.5	0.4		0.3	
Draba subcapitata	0.1					
Draba adamsii	0.2	0.4			0.2	
Cerastium arcticum	0.2		0.1	0.1		0.1
Phippsia algida[1]		0.3			0.6	
Salix arctica	6.5		0.1	1.0		
Alopecurus alpinus	0.2	0.2				
Festuca hyperborea	0.4					
Poa pratensis[2]	0.1	0.1				
Carex nardina	0.1			0.3		
Juncus biglumis	0.2	0.1	0.4		0.1	
Potentilla rubricaulis	0.2					
Minuartia rubella	0.3	0.1		0.1	0.1	
Cerastium regelii	0.1	0.2			0.2	
Potentilla hyparctica	0.1					
Taraxacum pumilum	0.1					
Braya purpurascens	0.1			0.1		
Luzula arctica		0.1	0.1			
Puccinellia angustata		0.2				0.1
Sagina intermedia		0.1				
Carex stans			0.6			
Eriophorum scheuchzeri			0.1			
Eriophorum triste			0.1			
Juncus triglumis			0.1			
Arctagrostis latifolia			0.6			
Pleuropogon sabinei			0.1			
Ranunculus sulphureus			0.1			
Saxifraga foliolosa			0.1			
Cardamine bellidifolia			0.1			
Equisetum arvense			0.1			
Poa abbreviata				0.1		0.4
Potentilla pulchella						0.2
Melandrium triflorum						0.1
Taraxacum phymatocarpum						0.3
Number of other vascular spp.	16	12	5	11	9	8
Total number of vascular spp.	36	25	21	20	17	15
Total vascular plant cover (%)	10.5	4.4	3.6	2.7	2.1	1.5
Bryophyte cover (%)	36.6	56.0	99.0	0.1	10.5	0
Organic crust cover (%)	45.2	33.0	0	36.0	77.6	6.2
Total plant cover (%)	92.3	93.4	102.6	38.8	90.2	7.7

[1] ssp. *algidiformis*; [2] var. *colpodea*

at Sophus Müllers Næs. Generally, the organic material constitutes only 1 - 3 %. A maximum of 5.2 % was found in the mossy snowbed community at Amdrup Land.

Nitrogen levels at all sites are low: 0.03 to 0.04 % at Sophus Müllers Næs and 0.02 to 0.25 % at Amdrup Land. The nitrogen content decreases from the soil surface to a depth of 40 cm at Amdrup Land. Phosphorus levels vary from 226 to 304 ppm at Sophus Müllers Næs and 275 to 519 ppm at Amdrup Land.

The mean values of phosphorus and nitrogen are higher at Amdrup Land compared to Sophus Müllers Næs, 391 vs. 269 ppm, and 0.13 vs. 0.04 %, respectively.

Discussion

Plant communities

The low summer temperatures prevailing at the coast and the presence of the open water polynya giving a high frequency of cloudy and foggy weather during the growing season are the major physical factors responsible for the impoverishment of the vegetation, in respect to species diversity, plant cover and biomass. In large areas the soils originating from easily weathered limestone give rise to a coarse textured, well-drained soil which inhibits plant growth. On silty soils with water available partly or during the entire growing season, four types of plant communities are identified.

The average vascular and cryptogam cover in vegetated areas at Sophus Müllers Næs are 2.1 % and 3.8 %, respectively. The plant cover of polar deserts in high arctic Canada is two to three times larger: 5.3 % and 9.3 % for vascular and cryptogam cover, respectively (Bliss et al. 1984). Aleksandrova (1988) stated that the general plant cover is much larger in polar deserts of the Barents province than in the eastern part of high arctic Russia. These rich 'nanocomplexes' and the open aggregations have a cover varying between 85 - 90 % and 1 - 70 %, respectively, with a contribution of vascular plants of only 1 - 9 % and 1 - 7 %, respectively. The climatic differences between the polar deserts of the Canadian province and the Barents province might explain the difference in cryptogam cover. A branch of the Gulf Stream reaches Svalbard resulting in open water conditions during summer with cloudy and humid weather with frequent precipitation. The annual mean temperature, – 5 °C to – 10 °C, is lower than the value of ca. – 18 °C mentioned for comparable areas in Canada (Bliss & Svoboda 1984) and North Greenland (Bay 1992). Aleksandrova (1988) states that the lichen crust is of much greater importance in the formation of the plant aggregations in the Barents province than in the Siberian province, where the climate is distinctly continental.

A comparison of the plant community herb barren, which covers the largest area and is characteristic of both the Canadian, Greenlandic, and Russian polar deserts, shows that the total plant cover is 2 - 3 %. The biomass in all polar desert communities is very low, ranging from 0.6 g/m^2 in herb barrens to 11.2 g/m^2 in *Saxifraga oppositifolia* snowbeds. The above-ground vascular plant biomass in Canadian polar deserts was 15.5 ± 18.1 g/m^2, 82.9 ± 35.2 g/m^2 and 169.7 ± 143.8 g/m^2 in herb barrens, cushion plant communities and snow-flush communities, respectively (Bliss et al. 1984).

The number of vascular species in the plant communities in the polar desert site near the polynya varies between 3 and 10, whereas it is between 9 and 14 at the polar desert site at the ice-covered sea at Prinsesse Ingeborg Halvø. *Saxifraga oppositifolia* and *Papaver radicatum* are the most frequent species followed by *Saxifraga cernua*, *Stellaria crassipes* and *Draba subcapitata*. The diversity in the plant communities in the semi-polar desert area at Amdrup Land is between 15 and 36, *Salix arctica* being the most frequent species in mesic and dry plant communities, whereas *Carex stans* and *Arctagrostis latifolia* dominate in the wet habitats.

Table 4. Soil chemistry of samples from different depths at two study sites. Org. m. = organic matter.

Community	Depth (cm)	pH	C_{tot} (%)	Org. m. (%)	CO_3-C (%)	N_{tot} (%)	P_{tot} (ppm)
Sophus Müllers Næs							
Saxifraga	0-1	9.0	10.30	2.35	7.95	0.4	298
oppositifolia-	10-20	8.8	10.59	2.05	8.54	0.4	304
Papaver comm.	30	8.8	10.39	2.54	7.85	0.3	293
Saxifraga	0-1	8.8	8.03	0.80	7.23	0.4	260
oppositifolia	10-20	8.8	7.53	1.04	6.48	0.4	261
snowbed	30	8.9	7.25	1.11	6.14	0.4	266
Herb barren	0-1	9.0	7.26	1.52	5.74	0.4	226
	10-20	9.2	7.58	1.27	6.31	0.4	247
	30-40	9.3	7.04	1.00	6.04	0.3	266
Mean		8.9				0.4	269
Amdrup Land							
Open *Salix arctica*	0-1	8.4	4.15	2.69	1.46	0.23	426
vegetation	10-20	8.6	1.55	0.73	0.82	0.07	364
	30-40	8.8	2.47	0.36	2.12	0.04	322
Salix arctica	0-1	8.0	4.61	3.67	0.94	0.21	406
snowbed	10-20	8.5	4.23	2.20	2.04	0.19	404
	30-40	8.2	3.20	1.74	1.47	0.14	422
Mossy snowbed	0-1	7.3	5.15	5.15	-	0.25	485
	10-20	8.3	2.32	2.32	-	0.19	480
	30-40	8.3	2.27	2.27	-	0.18	519
Herb barren	0-1	8.9	2.45	1.20	1.25	0.10	367
	10-20	9.2	4.54	0.14	4.40	0.02	275
	30-40	9.3	2.58	0.24	2.34	0.03	310
Phippsia algida	0-1	8.5	1.69	1.33	0.36	0.11	346
snowbed	10-20	8.5	1.10	1.01	0.08	0.09	361
	30-40	8.5	1.25	1.12	0.14	0.09	378
Mean		8.5				0.13	391

Fig. 2. Herb barren landscape at Sophus Müllers Næs bordering the North East Water Polynya. Black stripes in the center are *Phippsia algida* communities along melting water channels. *Colpodium vahlianum* and *Saxifraga cernua* are the only other vascular plants occurring.

Delimitation and distribution of polar desert zone in Greenland

Holmen (1957) divided the vegetation of eastern North Greenland into two districts according to physical conditions, distribution of selected species and characteristic vegetation types. The 'high arctic desert district' includes mostly inland areas characterized by its extremely continental climate and the presence of mineral soils without accumulations of organic material, and the vegetation is characterized by certain species: *Dryas integrifolia* and *Kobresia myosuroides* in dry habitats and *Carex stans* in wet sites. The species list given by Holmen includes species which, in other parts of Greenland, are distinctly related to inland areas with low precipitation and high summer temperatures (Bay 1992; Fredskild 1996), e.g. *Carex maritima*, *Erigeron compositus*, *Braya thorild-wulffii*, *Lesquerella arctica*, *Poa hartzii* and *Calamagrostis purpurascens*. The other type, 'the fell-field district', occurs both in inland and coastal regions. It is of a more humid character, organic matter is accumulating and *Cassiope tetragona* is a key species. Surprisingly, both districts comprise inland areas as well as coastal areas. This classification is in disagreement with the findings from other parts of Greenland, where there are distinct differences in the flora and the composition of the vegetation between coastal and inland areas.

Funder & Abrahamsen (1988) reviewed the discussion of the high arctic desert concept in Greenland and

Fig. 3. The rich *Saxifraga oppositifolia* communities at Sophus Müllers Næs occur on wet soil associated with permanent snow banks. *Saxifraga oppositifolia* forms a network in the rims of the polygons. Other important species are *Papaver radicatum*, *Stellaria crassipes* and *Draba bellii*. The frame covers 0.25 m^2.

Fig. 4. *Salix arctica* snowbeds occur on west and south-facing slopes. This community is the most lush and species-rich at Amdrup Land. Other important species are *Festuca hyperborea*, *Minuartia rubella*, *Stellaria crassipes* and *Papaver radicatum*.

define polar deserts in agreement with Edlund (1983) as areas where low temperatures in the growing season restrict and nearly inhibit the growth of vascular plants. Consequently, vast areas of interior North Greenland do not belong to the polar desert zone according to this definition, as a relatively lush vegetation occurs locally, where the water regime is favourable during summer, and the species diversity is high, i.e. 60 - 90 species of vascular plants (Aastrup et al. 1986; Bay 1992; Daniëls & Alstrup 1996). The summer temperature inland is markedly higher and the physical factor mainly controlling the low plant cover is the low annual and summer precipitation. In addition, several middle arctic species and even low arctic species are occasionally found (e.g. *Cardamine pratensis*, *Empetrum nigrum* ssp. *hermaphroditum*, *Epilobium arcticum*, *Pedicularis flammea* and *Tofieldia coccinea*).

Several authors have proposed a delimitation of the polar desert zone in Greenland in connection with a general classification and zonation of the flora and vegetation of the Arctic (Young 1971; Komarkova & Webber 1978; Aleksandrova 1988; Elvebakk 1985; Yurtsev 1994). As no botanical evidence has been published in the period from 1957 (Holmen 1957) to the mid-1980s (Aastrup et al. 1986; Funder & Abrahamsen 1988), none of the delimitations of the polar desert zone in these papers are based on recent botanical documentation. Aleksandrova (1988) and Elvebakk (1985) include only coastal areas of western North Greenland and Peary Land north of ca. 82° N in the polar desert zone,

Fig. 5. Relatively lush fen vegetation occurring on moist soil in depressions in the landscape at Amdrup Land, 25 km from the outer coast. *Carex stans* and *Arctagrostis latifolia* are the dominating species followed by *Eriophorum scheuchzeri*, *E. triste* and *Juncus biglumis*.

whereas Young (1971) considers only the northernmost Peary Land (ca. 83 ° N) as belonging to the polar desert zone. Funder & Abrahamsen (1988) show in their palynological study that areas in eastern North Greenland south of 82° N also belong to the polar desert zone. On the other hand, they exclude all areas west of Peary Land from this zone. Yurtsev (1994) does not include any part of Greenland in his High-Arctic tundra subzone which otherwise coincides in other parts of the Arctic with the polar desert zone proposed by others.

Based on the distribution patterns of those vascular plant species (124 spp.) in North Greenland, only occurring in the inland, where they reach their northern distribution limit, Bay (1992) divided the floristic province North Greenland into two districts. The coastal district delimits the polar desert zone of Greenland. The present investigations show, however, that this delimitation should be revised: the polar desert zone of Greenland includes only the most coastal areas, i.e. a zone up to ca. 15 km wide (Fig. 6). The Amdrup Land locality was originally classified as belonging to the polar desert zone of North Greenland (Bay 1992). The high species diversity, the occurrence of 18 species classified as distinctly related to the warm continental inland of North Greenland, the presence of woody species (*Salix arctica*, *Dryas integrifolia*, *D. octopetala*, and *Cassiope tetragona*) and aquatic species (*Pleuropogon sabinei* and *Ranunculus hyperboreus*), in addition to fens with *Carex stans* and two species of *Eriophorum*, strongly imply that this area does not belong to the polar desert zone. Likewise, Prinsesse Ingeborg Halvø is divided into a coastal and an inland zone based on the distribution of key taxa. The following species are only found in sheltered inland habitats: *Salix arctica*, *Dryas integrifolia*, *Braya purpurascens*, *B. thorild-wulffii*, *Carex misandra*, *C. nardina*, *Oxyria digyna* and *Ranunculus sulphureus*.

A comparison of a coastal locality in Peary Land (82°30' N) including areas up to 5 km from the coast (Fredskild et al. 1992) with a luxuriant locality only 10 km further inland, confirms the narrow coastal delimitation of the polar desert zone. The delimitation of the polar desert zone at Holm Land (Fig. 1) is based on a comparison of the total number of species and the number of inland species at two localities at approximately the same latitude. 51 species, of which 23 are inland species, were found at Firndalen during a short stay, whereas the number of species at the outer coast locality, Eskimonæsset, has only 17 species of which none are classified as inland species. Mølgaard in Håkansson et al. (1993) divides the semi-nunatak Kilen into floristic regions based on floristics. His ca. 5 km broad coastal zone belongs to the polar desert zone.

The southern border of the polar desert zone in eastern North Greenland is at ca. 79° 30' N as coastal localities further to the south have a richer flora including woody species, sedges and vascular cryptogams (Bay & Fredskild 1991). The southern border in western North Greenland is at ca. 82° N in Hall Land (Fig. 6). This new delimitation of the arctic polar desert zone of Greenland excludes Washington Land from the previous delimitation by Bay (1992). The western delimitation joins the border line of the Canadian polar desert zone proposed by Edlund (1990).

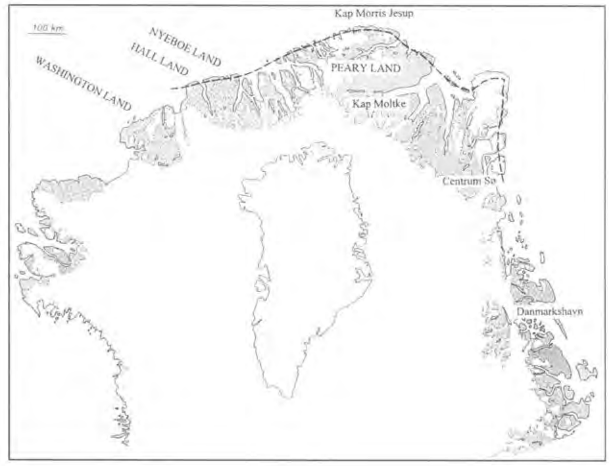

Fig. 6. Distribution of the Arctic polar desert zone in Greenland.

Soils

pH values correspond to values reported from the Canadian polar deserts, where they vary from 7.9 to 8.5; the same holds for the nitrogen level. However, the phosphorus level is much higher in the Greenland sites (Bliss & Svoboda 1984). This may be explained by the different methods used.

Comparing the chemical properties of the soils of the two study sites representing a polar desert and a polar semi-desert shows that there are large similarities and only minor differences. This disagrees with the conclusion by Bliss et al. (1984) that soil conditions are the major factor influencing the impoverishment of the plant cover in polar deserts.

The mean pH of the areas differs by 0.5. There is a gradual decrease in the content of organic matter from the top to the bottom in all the plant communities at Amdrup Land and in the herb barren community at Sophus Müllers Næs.

There is a mean difference of 122 ppm of phosphorus between the coastal and inland part of Amdrup Land and the mean total nitrogen content is 0.04 - 0.13 in coastal and inland parts of Amdrup Land, respectively.

Species diversity of the arctic polar desert zone

Most species, i.e. 60 - 70 %, have an arctic-alpine or arctic circumpolar distribution (App. 1) and species with a low arctic distribution are absent from the arctic polar desert zone. Different numbers have been given for the total number of vascular plants within the polar desert zone. Young (1971) mentions 50 vascular plant species, and the number from the Russian polar desert zone is between 17 and 75, giving a total of 98 species for all Russian polar deserts (Aleksandrova 1988).

The coastal floristic district of North Greenland has 55 species (Bay 1992). As the present investigations have altered the delimitation of this district, some species previously considered as occurring both in the coastal and continental district of North Greenland are excluded. 33 vascular species occur in the Greenlandic polar desert zone (App. 1). The bioclimatic zone 1 by Edlund (1983), including areas north of the northern limit of prostrate shrubs and sedges, has less than 35 vascular species. Elvebakk (1989) and Aleksandrova (1988) listed 44 species from the polar deserts of Svalbard and 50 from the Barents province of Russia.

Rannie (1986) dealt with the relationship between summer air temperature and number of vascular species in arctic Canada and showed a strong correlation and a vascular species diversity gradient of 24 - 26 species per degree. From her regression, the July temperature of a locality can be estimated from its vascular species richness to a standard error of 0.5 °C. For the three study sites the mean July temperature is calculated as 2.7 °C, 3.3 °C, and 4.5 °C for Sophus Müllers Næs, Prinsesse Ingeborg Halvø and Amdrup Land, respectively. Meteorological data are only available from Prinsesse Ingeborg Halvø. The mean July temperature for a 27-yr recording period was 3.2 °C, which corresponds well to the calculated mean July temperature (3.3 °C). Judging from this calculation only the two first mentioned sites are within the polar desert zone according to the temperature regime used by Edlund (1983). She defined the 'mini-treeline' by a July mean temperature of less than 3.0 - 3.5 °C and designated areas north of this to be in zone 1, which merges with the zone defined as the polar desert zone by others (Young 1971; Aleksandrova 1988). The evaluation of Amdrup Land as being classified high arctic semi-desert from the temperature regime matches the biological facts that three woody species occur, among which *Salix arctica* is dominant in some of the plant communities, the vascular species diversity of 73 is more than double the number for polar deserts given by Edlund (1983), and both sedges (five *Carex* spp., two *Eriophorum* spp. and *Kobresia myosuroides*) and aquatic species (*Ranunculus hyperboreus* and *Pleuropogon sabinei*) are present.

A comparison of the number of vascular species at well-investigated localities within a latitudinal range of ca. 150 km along a climatic gradient from the inland to the coast, a distance of 50 km, shows a close relationship between the number of vascular species and the temperatures during summer (Table 5). The total number of vascular species and the number of species classified as inland species judging from their distribution pattern in the North Greenlandic floristic districts (Bay 1992) are compared with the recorded and estimated mean July temperature. In addition to the localities studied in 1986 and 1993, the only other well-investigated localities in the region, Centrum Sø and Kilen, are taken into consideration. The number of species varies between 81 in the continental inland and six species on the islands in the polynya. Centrum Sø and Amdrup Land differ significantly from the other localities in respect to both the total number of vascular species and the number of inland species. None of the other localities have any inland, woody or aquatic species, and sedges are absent or rare (App. 2). The number of species in the outer coast localities ranges between 40 and 6. The localities bordering the open water at the North East Water polynya have a smaller number of species compared to the coastal locality at Prinsesse Ingeborg Halvø at a partly ice covered sea (21 and 23 vs. 40. The most impoverished area is found in the polynya with only six species of vascular plants. The same number of vascular species was found on a small island at the coast of northernmost Greenland (Andersson et al. 1980).

Using Elvebakk's (1990) index of thermophily for defining the biogeographical zone confirms that the areas in Greenland with the species composition given in App. 1 should be classified as arctic polar deserts, as only two species classified as weakly thermophilous are found only rarely within the zone.

The investigations of the polar deserts at Sophus Müllers Næs, support the hypothesis by Young (1971), Edlund (1983) and Funder & Abrahamsen (1988) that the primary ecological factor controlling the impoverishment of the flora and vegetation at the coasts around

Table 5. Northern latitude (N lat.), Distance from the outer coast (D-coast), Number of vascular species: inland (S-inland) and total (S-total), and July temperature (July temp.; based on Rannie 1986). CS = Centrum Sø; AL = Amdrup Land; PIH Prinsesse Ingeborg Halvø: SMN = Sophus Müllers Næs; KCP = Kilen, coastal part; HKH = Henrik Krøyer Holme.

Locality	CS	AL	PIH	SMN	KCP	HKH
N lat.	80°10'	80°45'	81°36'	80°55'	81°10'	80°40'
D-coast (km)	150	25	0-5	0-5	0-5	0
S-inland	36	17	0	0	0	0
S-total	81	73	40	23	21	6
July temp. (°C)	4.8	4.5	3.3	2.7	2.6	2.1

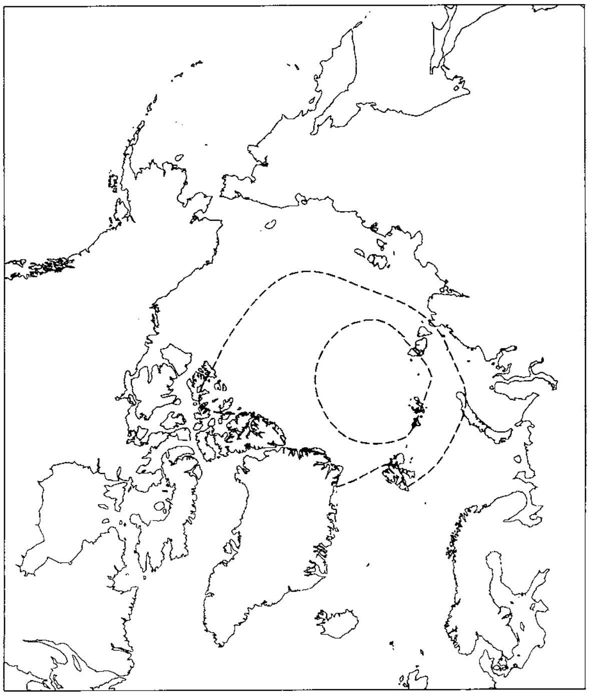

Fig. 7. Distribution and subdivision of the polar deserts in the Arctic based on Aleksandrova (1988), Elvebakk (1989), Edlund (1990), Bay (1992) and the present study. Only the northernmost islands in high-Arctic Russia are included in the northern belt of the polar desert zone of the circumpolar Arctic.

the Arctic Ocean is the low temperatures during the short growing season, because a very low plant cover and species diversity were also recorded in areas with silty soils and adequate water supply during the growing season. The low summer temperatures are supposed to be the main limiting factor for plant establishment and growth in the Greenlandic polar deserts. The conditions recorded in the continental polar deserts of Queen Elisabeth Island, Canada, where the surface soil is dry in the mid-season and is believed to be a major controlling factor responsible for the impoverished flora and plant cover (Bliss & Matveyeva 1992), do not occur in the coastal polar deserts of Greenland.

Conclusions

The circumpolar distribution of the arctic polar desert zone as presented by Aleksandrova (1988) has to be changed for three areas: central Svalbard, eastern North Greenland, and the western Canadian high-Arctic archipelago (Fig. 7). The *Papaver dahlianum* zone comprising the polar deserts in Svalbard (Brattbakk 1986) was slightly altered by Elvebakk (1989) by using his Index of Thermophily and now includes only coastal parts of Nordaustlandet, easternmost Spitsbergen, eastern Barentsøya and Edgeøya. Consequently, the polar desert zone of Svalbard is extended as far to the south as 76° 30' N. The delimitation to the west roughly coincides with the 2 °C July isotherm (Elvebakk 1989).

The polar desert zone of Greenland includes the main parts of the coastal floristic district of North Greenland (Bay 1992) except for a few areas in eastern North Greenland, now comprising a much larger area than that proposed by Aleksandrova (1988) and Elvebakk (1985).

Edlund & Alt (1989) showed a congruence of the Canadian polar desert zone and the 2 °C isotherm. There is no evidence, according to Edlund (1990), that the Canadian high arctic archipelago should be divided into two polar desert subzones as proposed by Aleksandrova (1988). The Canadian polar deserts are all included in the southern belt of the arctic polar deserts.

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App. 1. Comparison of the vascular plant flora of the arctic polar desert zone of the Canadian (C) and Barents (B) provinces for the areas Greenland (G) based on Bay (1992), Håkansson et al. (1993) and the present study; Canada (C) based on Edlund (1983) and Edlund & Alt (1989); Svalbard, Norway (N) based on Elvebakk (1989); and Zemlya Frantsalosifa, northwestern Russia (R) based on Aleksandrova (1988). The Canadian list is not complete. x = frequent; r = rare. Distribution types: A = Arctic, A-A = Arctic-alpine, HA = High Arctic, Circ = circumpolar, Amp-A = amphi-Atlantic, NAm = North American, Eura = Eurasian. Thermophily indication for some species according to Elvebakk (1989): DT, MT, WT = Distinctly, Moderately, Weakly thermophilous.

App. 2. List of vascular plant species and their occurrence in the study areas and localities: CS Centrum Sø, AL = Amdrup Land, SM = Sophus Müllers Næs, HKH = Henrik Krøyer Holme, PIH = Princesse Ingeborg Halvö, KCP = Kilen, coastal part. Data from Kilen taken from Håkansson et al. (1993); data from Centrum Sø compiled from Bay (1992) and additional material collected in 1993. The frequency is given as: 5 = very common, 4 = common, 3 = occasional, 2 = rare, 1 = very rare. The data from Kilen are given in the categories: A = abundant, R = sparse, and L = local, i.e. recorded at one or two sites.

App. 1

Area Province	G C	C C	N B	R B	Distribution type
Alopecurus alpinus	x	x	x	x	A-A, Circ
Arctagrostis latifolia DT				x	A-A, Circ
Braya purpurascens WT		x			HA, Circ
Cardamine bellidifolia	x	x	x	x	A-A, Circ
Carex ursina WT				x	A, Circ
Cerastium alpinum/ arcticum	x	x	x	x	A, Amp-A
Cerastium regelii	x		x	x	HA, Circ
Cochlearia groenlandica/arctica	x	x	x	x	A, Circ
Colpodium vahlianum	x		x	x	HA, Circ
Deschampsia alpina			x	x	A-A, Circ
Deschampsia caespitosa ssp. *glauca*				x	A-A, Circ
Draba adamsii	x		x		HA, Circ
Draba alpina		x		x	A-A, Circ
Draba bellii	x	x	x	x	HA, Circ
Draba kjellmanii				x	HA, Eura
Draba lactea			x	x	A, Circ
Draba micropetala	x				HA, Circ
Draba nivalis			x		A, Circ
Draba oxycarpa			x		A-A, Amp-A
Draba pseudopilosa				x	A-A, Amp-A
Draba subcapitata	x	x	x	x	HA, Circ
Dupontia fisheri s.l. MT		x		x	A, Circ
Dupontia psilosantha			x		A, Circ
Festuca baffinensis		x			HA, Circ
Festuca brachyphylla s.l. WT		x			A, Circ
Festuca vivipara			x		A, Circ
Juncus biglumis	x	x	x	x	A, Circ
Luzula arctica	x	x	x	x	A, Circ
Luzula confusa	(x)	x	x	x	A-A, Circ
Minuartia rossii WT	(x)				HA, NAm
Minuartia rubella	x	x	x	x	A, Circ
Oxyria digyna	(x)	x	x	x	A, Circ
Papaver radicatum s.l.	x	x	x	x	A, Circ
Phippsia algida	x		x	x	A, Circ
Phippsia concinna			x	x	A, Eura
Pleuropogon sabinei				x	HA, Amp-A
Poa abbreviata	x	x	x	x	HA, Circ
Poa alpigena s.l.				x	AA, Circ
Poa alpina			x		A, Amp-A
Poa arctica s.l.		x	x	x	A, Circ
Poa pratensis var. *colpodea*	(x)		x	x	HA, Circ
Polygonum viviparum			x	x	A, Circ
Potentilla hyparctica	(x)	x	x	x	HA, Circ
Potentilla pulchella WT	(x)				HA, Amp-A
Puccinellia angustata	x		x	x	HA, Circ
Puccinellia bruggemanni	x				HA, NAm
Puccinellia phryganodes		x	x		A, Circ
Ranunculus hyperboreus			x	x	A, Circ
Ranunculus sabinei				x	HA, NAm
Ranunculus sulphureus			x	x	A, Circ
Sagina intermedia			x	x	A, Circ
Salix arctica	(x)			x	A, Circ
Salix polaris			x	x	A-A, Amp-A
Saxifraga caespitosa s.l.	x	x	x	x	A, Circ
Saxifraga cernua	x	x	x	x	A, Circ
Saxifraga foliolosa		x	x	x	A-A, Circ
Saxifraga hyperborea	(x)		x	x	A, Circ
Saxifraga nivalis	x	x	x	x	A, Circ
Saxifraga oppositifolia	x	x	x	x	A-A, Circ
Saxifraga platysepala	(x)		x	x	HA, Circ
Saxifraga rivularis		x		x	A, Circ
Saxifraga tenuis	(x)		x	x	A, Circ
Silene acaulis				x	A-A, Amp-A
Stellaria longipes s.l.	x	x	x	x	A, Circ
Number of species	33	28	44	50	

App. 2

Locality	CS	AL	SM	HKH	PIH	KCP
Alopecurus alpinus	x	4	3		3	R
Arctagrostis latifolia	x	4				
Braya purpurascens	x	4			1	
Braya thorild-wulffii	x	3			1	
Cardamine bellidifolia	x	3			3	L
Cardamine pratensis		1				
Carex misandra	x	4			1	
Carex nardina	x	4			2	
Cassiope tetragona	x	1				
Cerastium arcticum	x	4	4		4	R
Cerastium regelii	x	4	3		4	A
Cochlearia groenlandica		3	2	x	3	A
Colpodium vahlianum	x	4	2		2	
Draba adamsii	x	3	4	x	3	A
Draba arctogena	x	2			3	
Draba bellii	x	4	4		4	
Draba lactea		2				
Draba micropetala		2	3			
Draba subcapitata	x	4	4		4	A
Dryas integrifolia	x	4			2	
Dryas octopetala	x	1				
Eriophorum triste	x	3				
Festuca hyperborea	x	4			3	
Festuca vivipara		1				
Juncus biglumis	x	4			3	
Luzula arctica	x	4				
Luzula confusa		1				L
Melandrium apetalum	x	4				
Minuartia rossii	x	3			2	
Minuartia rubella	x	4	3		3	
Oxyria digyna	x	3			3	
Papaver radicatum	x	5	5	x	5	A
Pedicularis hirsuta	x	4				
Phippsia algida ssp. *algidiformis*	x	4	4	x		A
Poa abbreviata	x	4	3		4	A
Poa arctica		1				L
Poa pratensis var. *colpodea*	x	4	1			
Polygonum viviparum	x	4			1	
Potentilla hyparctica		2			1	R
Potentilla pulchella	x	4	1		1	
Puccinellia angustata	x	4	3		3	A
Puccinellia bruggemanni	x		1		1	
Ranunculus sulphureus	x	4			1	
Sagina intermedia		3			1	
Salix arctica	x	5	1		4	
Saxifraga caespitosa	x	2	3		4	A
Saxifraga cernua	x	5	4	x	4	A
Saxifraga hyperborea		1			2	L
Saxifraga nivalis		3	2		3	L
Saxifraga oppositifolia	x	5	5		5	A
Saxifraga platysepala	x	2			4	
Saxifraga tenuis		3			3	R
Stellaria crassipes	x	4	3	x	3	A
Taraxacum arcticum	x	3				
Taraxacum arctogenum	x					
Taraxacum phymotocarpum	x	4				
Taraxacum pumilum	x	3				
Total number of inland species	36	18	0	0	0	0
Total number of species	81	73	23	6	40	21

Inland species	CS	AL		CS	AL
Armeria scabra	x		*Braya humilis*	x	
Calamagrostis purpurascens	x		*Carex atrofusca*	x	
Carex maritima	x	3	*Carex rupestris*		1
Carex stans	x	3	*Carex supina*	x	
Chamaenerion latifolium	x				
Deschampsia brevifolia	x	4	*Draba arctica*	x	3
Elymus hyperarcticus	x		*Epilobium arcticum*	x	
Equisetum arvense	x	3	*Equisetum variegatum*	x	1
Erigeron compositus	x		*Erigeron eriocephalus*	x	
Eriophorum callitrix	x		*Eriophorum scheuchzeri*	x	4
Eutrema edwardsii	x	3	*Festuca baffinensis*	x	
Juncus castaneus	x		*Juncus triglumis*	x	2
Kobresia myosuroides	x	2	*Kobresia simpliciuscula*	x	
Lesquerella arctica	x	1	*Melandrium affine*	x	
Melandrium triflorum	x	4	*Pedicularis flammea*	x	
Pleuropogon sabinei	x	4	*Poa glauca*	x	3
Poa hartzii	x		*Potentilla rubricaulis*	x	3
Ranunculus hyperboreus	x	4	*Saxifraga aizoides*	x	
Saxifraga foliolosa		3	*Silene acaulis*	x	
Trisetum spicatum	x				