RAPPORTSERIE

Nr. 30 - Oslo 1986

TORSTEIN ENGELSKJØN:

Zonality of climate and plant distributions in some Arctic and Antarctic regions

NORSK POLARINSTITUTT

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Abstract. Engelskjøn, T. 1986. Zonality of climate and plant distributions in some Arctic and Antarctic regions.

The zonal climates are outlined on the stretch from North Scandinavia to northernmost Svalbard and Semlja Frantsa Josifa, and related to the distributions of 10 vascular plant species within the North Atlantic, Arctic sector. Four main categories of horizontal distribution were identified: a northern Arctic, a mesic Arctic, a maritime Arctic, and a hemi-Arctic. Moderately heat-demanding species of the latter category have extrazonal occurrences in the thermally favoured areas of Central Spitsbergen, which is relevant to the discussion of the Holocene climates of Spitsbergen.

Cassiope tetragona and Salix polaris are proposed as marker species for the sectional and zonal subdivision of this part of the Arctic. The altitudinal performance of various species is related to thermal requirements, and similar correlations appear as previously shown for the mountain flora of the North Scandes.

The climates of the Antarctic botanical zones are outlined from areas north of the Antarctic convergence, from Bouvetøya and other maritime Antarctic tracts, and from the coastal oases of Dronning Maud Land, Greater Antarctica to the nunataks of the adjoining parts of the Antarctic slope. Correlations with the distributions of one vascular and five cryptogamic species are suggested. Liverworts and some species of Bryum and Ceratodon show relatively high heat demands, whereas Grimmia spp. and Sarconeurum glaciale occur farther south and considerably higher in the mountains. An altitudinal belt subdivision of the Antarctic mountains is proposed according to the presence of mosses, various growth forms and species of lichens, and of thallose green algae and various cyanophycean growth forms and genera. Macroscopic plant life appears to cease at heat sum figures between - 800 and -1000, expressed as Degree-Days during December and January.

It is asserted that nunataks of continental Antarctica experience esentially more severe conditions for biota than those prevailing at high-alpine, Oroarctic and Arctic sites, and this was probably also the case during the Vistulan glaciation of the northern hemisphere.

INTRODUCTION

Contributions by the present author from North Scandinavia (Engelskjøn 1986 a), Bjørnøya, Svalbard (Engelskjøn 1986 b), Bouvetøya, South Atlantic (Engelskjøn 1986 c, cf. also Engelskjøn 1981, Engelskjøn & Jørgensen 1986), and Dronning Maud Land, Greater Antarctica (Engelskjøn 1986 d, cf. also Engelskjøn 1985), make up the foundation of the present concluding treatment.

A classical experience in phytogeography (Grisebach 1838) is the role of the world climates, especially their thermal components, for the poleward change of plant life, as well as for its transformation with elevation.

Within the Arctic and Antarctic botanical zones (Aleksandrova 1980, Smith 1984) there is both a meridional change of vegetation and a change related to the climatic differentiation into oceanic and continental sections of the same zone.

Whereas vascular plant species persist even on the northernmost lands (Holmen 1957, Fredskild 1966, Aleksandrova 1977), the extreme thermal conditions in the Antarctic zones lead to an eventual disappearance of all vascular plants (Smith 1982). In continental Antarctica there is only a non-vascular, cryptogamic vegetation, which is solely represented by microfungi and procaryotic organisms at the highest up and southernmost sites (Cameron _et al_. 1971).

Comprehensive observations are now available of highest and farthest north occurrences of vascular plant species in the North Scandes and adjoining Arctic regions. The present contribution attempts to relate prevailing thermal conditions to distributional limits of various life-forms and species. The existence of extra-zonal exclaves within the Arctic, e.g. in Svalbard, and in the North Scandinavian Oroarctic, are also worthy of discussion because of their paleo-ecological and chorological implications. The considerable number of vascular plant species in the North Atlantic Arctic and Oroarctic moreover necessitated a selection of representative species, 10 in all, for this discussion.

Within the Antarctic botanical zone, an eco-geographical analysis on similar principles will mainly be confined to the South Atlantic sector, which is parted by vast reaches of sea. Six species were selected: one vascular, one liverwort, one moss, two fruticose lichens, and one crustose lichen. All of them are taxonomically and phytogeographically well documented, considering the present state of exploration of the maritime and continental Antarctic.

THE NORTH ATLANTIC ARCTIC, ESPECIALLY THE NORTH SCANDES AND SVALBARD

Climates and their zonal change

Table 1 shows principal thermal parameters of 10 stations on the stretch from North Scandinavia and Kola to Spitsbergen and Semlja Frantsa Josifa. Monthly mean temperatures are provided, here for the Standard period 1931-60; heat sums are expressed as Degree-Days during July-August (DD-2) (Fig. 1) and some parameters of convective cooling are computed.

The zonal, sectional, and altitudinal climates of North Scandinavia were summarized by Engelskjøn (1986 a). An outline of the climates in the Svalbard - Barents Sea region is provided here (see Fig. 1).

One cannot speak of distinctly maritime or continental climates in the lands farthest north. The main features of the sea ice climate prevailing e.g. on Semlja Frantsa Josifa and Hopen are summer temperatures just above zero, and cold winters because the sea is covered by thick welded ice.

Conversely, Jan Mayen has a prolonged season with temperatures above zero, mainly due to the influence of the sea, whose own warmth also plays a role in autumn and winter. This climate may be denoted maritime Arctic. Bjørnøya is more low-temperate than Jan Mayen, but still maritime Arctic and extremely foggy (Engelskjøn 1986 b).

Sectional differences between coast and inland are evident in Spitsbergen, where fjords penetrate deeply. The interior valleys and heads of fjords experience a peculiar, extrazonal climate which leads to conspicuous peat accumulation in mires, such as in the valley of Reindalen, Nordenskiöld Land, or to the development of steppe vegetation fragments on calcareous loess in the valley of Gipsdalen, Bünsow Land (own observations, 1970 and 1985). These tracts of Central Spitsbergen also show an elevated snow line, or glaciation limit, of up to 800 m a.s.l. (Liestøl in Steffensen 1982), and presumably have least precipitation, wind, and cloud cover within the Svalbard archipelago. The continental Arctic climate is not well documented by local observations, as the station Longyearbyen is located only midway between the outer coast (Isfjord Radio) and the interior valleys (e.g. Gipsdalen). However, an appreciable temperature difference is observed between Isfjord Radio and Longyearbyen. The southern end of Spitsbergen, represented by the station Hornsund, has a cool climate recalling Isfjord Radio and Bjørnøya.

Novaja Semlja extends ca. six degrees of latitude and the regional and local climatic gradients are considerable (Edlund 1928). The station Malyje Karmakuly has relatively high summer temperatures, but the bora winds contribute to a severe, cyclonally influenced climate.

The climatic character of Vardø, East Finnmark is oceanic and hemi-Arctic, and the surroundings are without forests, whereas Murmansk, Kola Peninsula is situated in a birch forested fjord district away from the immediate maritime influence, and enjoys a northern Boreal climate.

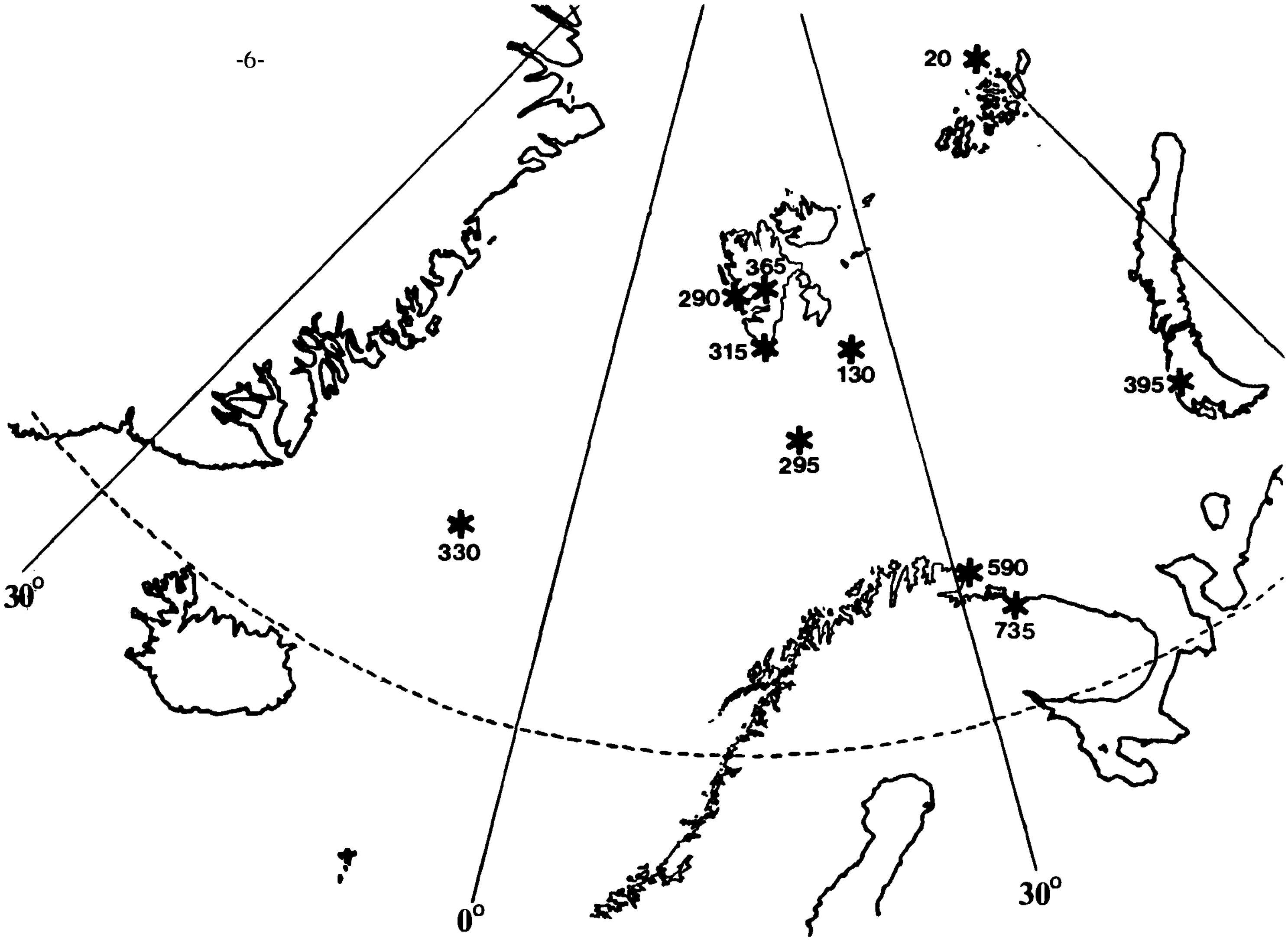


Fig. 1. Survey map of the North Atlantic Arctic sector, with location of some meteorological stations. Heat sums given as number of Degree-Days, July-August.

Table 1. Climatological parameters for some North Atlantic, Arctic stations (all below 50 m a.s.l.). Standard normals 1931-60, if not otherwise stated. Data after Steffensen (1969) and Müller (1982). Average wind chill and cooling power for June-August after Siple and Passel (1945) and Vinje (1962).

Station	N Lat. (°)	Monthly mean temperatures January	June	July	August	September	Heat sum DD-2	Wind chill	Cooling power
Ostrov Rudolfa	81.8	-20.0	-1.7	0.6	0.0	-5.0	20	875	30
Longyearbyen	78.2	-11.6	2.9	6.5	5.3	1.0	365	795	27
Isfjord Radio	78.1	- 9.2	1.8	4.9	4.4	1.3	290	835	30
Hornsund *	76.9	- 8.7	2.2	5.3	4.8	1.7	315	No record	
Hopen **	76.5	-12.3	-0.4	2.0	2.2	0.9	130	835	27
Bjørnøya	74.5	- 5.7	2.0	4.5	5.0	3.0	295	850	30
Malyje Karmakuly	72.4	-15.0	1.4	6.4	6.3	2.7	395	840	32
Jan Mayen	70.9	- 4.0	2.4	5.2	5.5	3.9	330	810	27
Vardø	70.4	- 4.6	6.2	9.3	9.8	6.8	590	665	22
Murmansk	69	- 9.9	8.9	12.8	10.9	6.4	735	575	20

* Based on Baranowski (1975)

** 1946-65

Table 2. Altitudinal records of some vascular species from Central Spitsbergen (Bünsow Land and Nordenskiöld Land); Bjørnøya, and the North Scandes, expressed as average number of Degree-Days, July-August (DD-2) at their extreme upper limits.

Species mapped and discussed in this contribution:	Central Spitsbergen Average DD-2	Central Spitsbergen Lowest DD-2	Bjørnøya	North Scandes Average DD-2	North Scandes Lowest DD-2	Note
Carex misandra	290	280	-	370	200 - 270	
Carex rufina	-	-	-	430	350	
Cassiope tetragona	230	160	-	300	210	
Luzula arctica	150	140	-	440	310	
Luzula wahlenbergii	340	340	-	390	290	
Poa abbreviata	150	85	-	-	-	
Ranunculus glacialis	-	-	-	220	40	Only SW Spitsbergen, lowland
Salix herbacea	-	195	195	240	140	"
Salix polaris	145	- 50	195	310	240	
Taraxacum cymbifolium	-	-	290	(460)		
Other, frequent or high ascending species, for comparison:						
Dryas octopetala	210	150	-	(300)		
Oxyria digyna	155	105	135	(285)		
Papaver dahlianum	15	- 75	215	(510)		P. radicatum: 180
Polygonum viviparum	195	75	235	(290)		
Saxifraga cernua	30	-135	120	(190)		

- : Absent from the area
( ): Based on a few extreme records, preliminary figure

Distribution patterns of some vascular plant species

10 species were mapped within the circumscribed area of the North Atlantic Arctic and adjoining parts of Fennoscandia, Iceland, and the Faeroes. Sources are quoted for each species except for records given previously (Engelskjøn 1986 a, b). An outline is provided of their horizontal and vertical ranges (Table 2, here transformed to heat sums at average upper limits), the latter limited to the North Scandes, Bjørnøya, and central fjord districts of Spitsbergen, whence some information is available (Hadač 1944; Rønning 1959; Sunding 1962, 1965, 1966; and unpublished records of the present author's from Reindalen in Nordenskiöld Land and the Gipsdalen-Tempelfjorden area in Bünsow Land). The recorded heat sums are based on DD-2=365 at Longyearbyen and a vertical gradient of 0.65^{o}/100 m.

The numbers (1-10) refer to the maps.

1. Carex misandra R. Br.

Greenland: Böcher 1938, Figs. 123, 142; Seidenfaden & Sørensen 1937, Fig. 57; Holmen 1957, pp. 105-106.
Spitsbergen: Rønning 1972, Map 32, supplemented by own observations in 1970 and 1985.
Novaja Semlja, Vaigatsj: Lynge 1923, Pl. 15:5; Tolmatsjev 1966a, Karta 47.

Tricentric in Fennoscandia and lacking on maritime North Atlantic islands as well as in eastern Svalbard and Semlja Frantsa Josifa, but extending to northernmost Greenland.

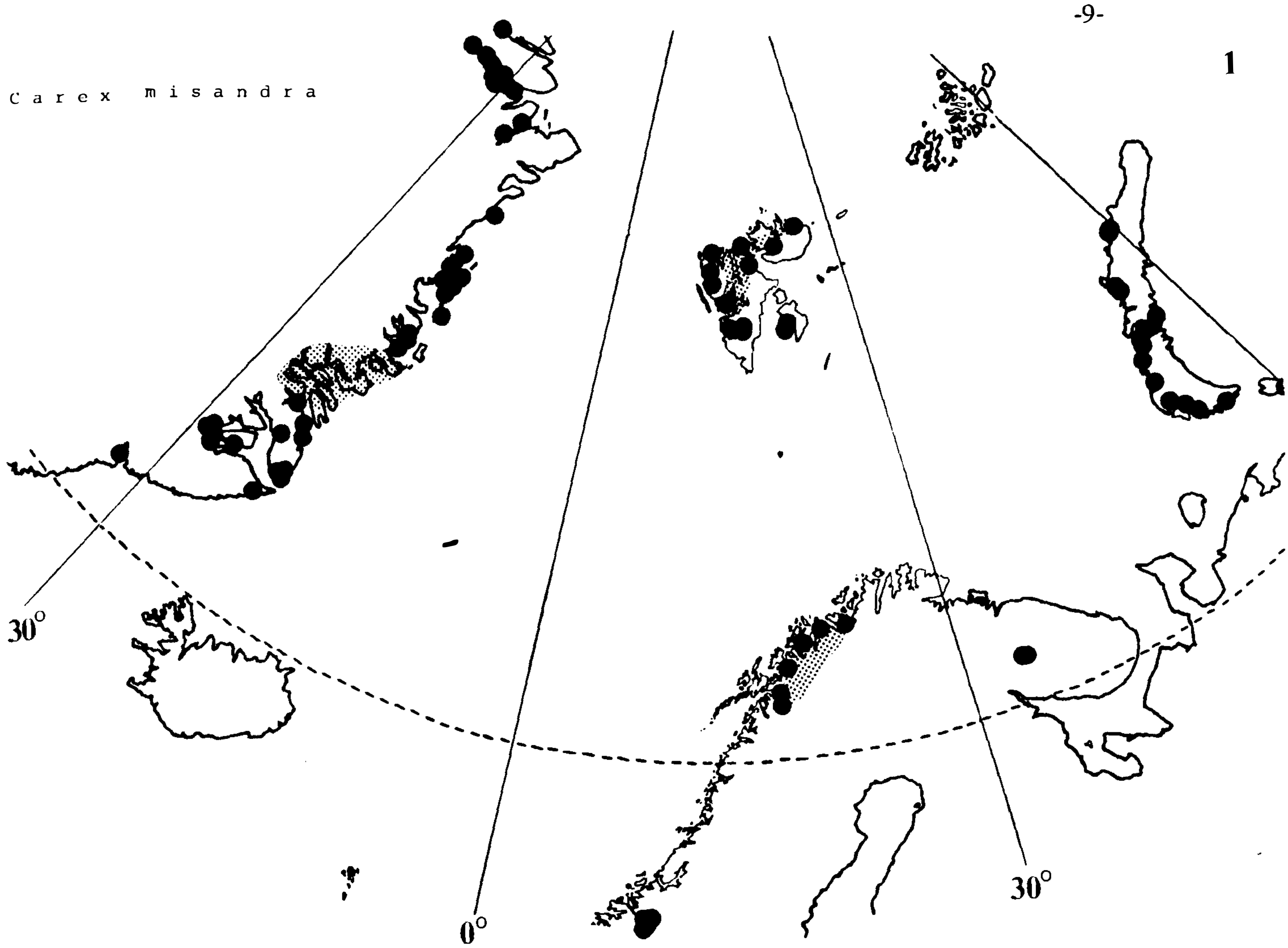
Altitudinal limits are moderate, averaging to DD-2=370 resp. 290 in the North Scandes and Spitsbergen.

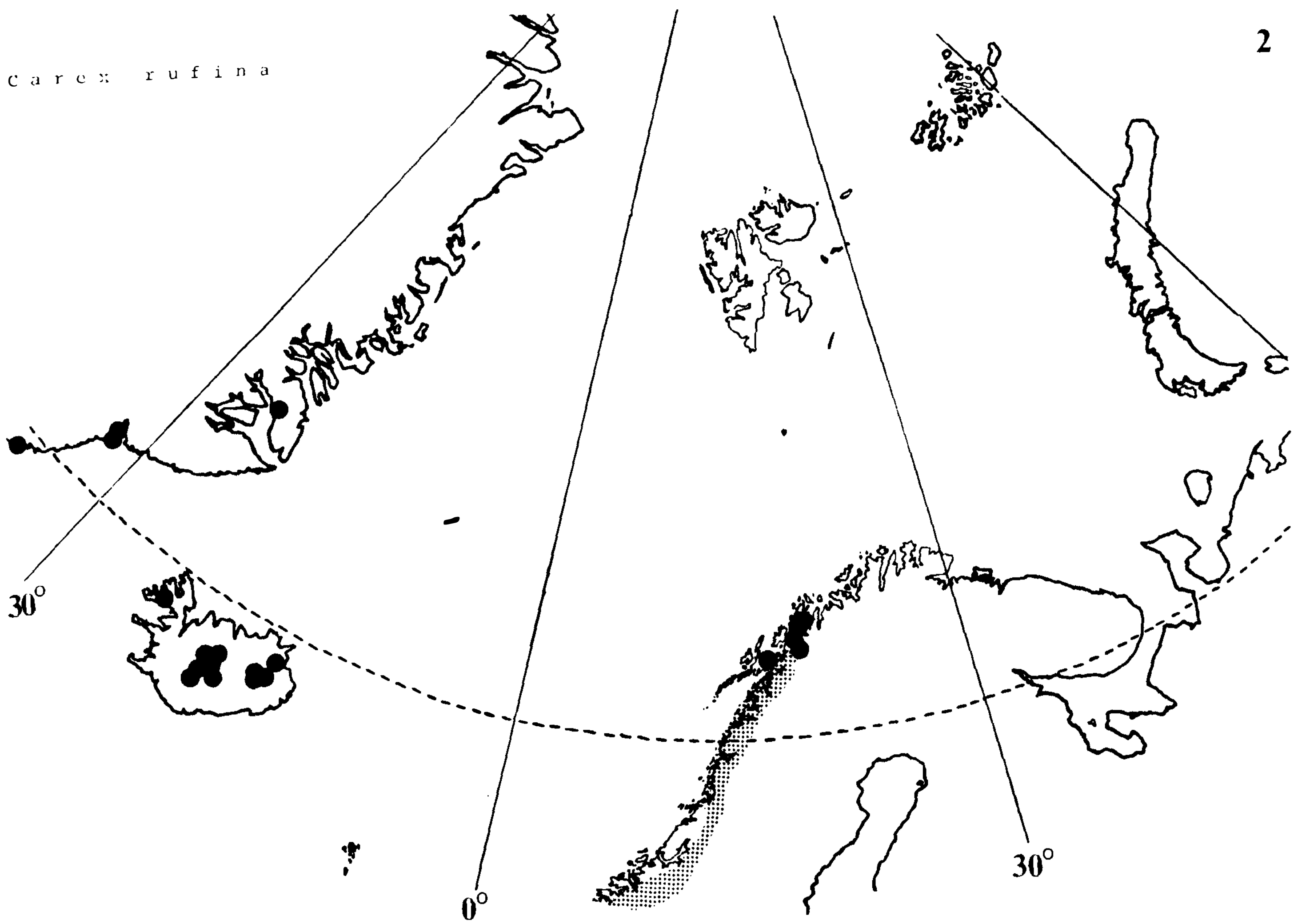
2. Carex rufina Drej.

Greenland: Böcher 1938, Fig. 125, 1956, p. 12.
Iceland: Grøntved 1942, Fig. 62; Óskarsson 1951, p. 13.

Transcending the Arctic Circle but not much north of 70^{o}, and concentrated in humid or coastal mountains, especially in Central Iceland and West Norway.

The North Scandinavian altitudinal limit is relatively low, but it should be kept in mind that this species is confined to sites with a snowmelt hydrology.


1
Carex misandra
30°
0°
30°


2
Carex rufina
30°
0°
30°

3. Cassiope tetragona (L.) D. Don

Greenland: Böcher 1933, Fig. 12, 1938, Figs. 85,86; Holmen 1957, Fig. 38; Fredskild 1966.
Spitsbergen: Nathorst 1883, p. 11; other literature up to Neilson 1970, Norwegian herbarium material, own investigations in 1970 and 1985 (see local map for Spitsbergen, Fig. 2).
Polar Urals - Pai-Khoi: Hultén 1955, p. 19.

Chiefly north of the Arctic Circle, with outposts at Angmagssalik, Southwest Greenland, in Central Kola, and in the Polar Urals. C. tetragona appears to be absent from Novaja Semlja and from extensive areas in southern and eastern Spitsbergen, particularly on the outer coast.

The species ascends only to moderate altitudes, marginal DD-2 being 300 in the North Scandes and 230 in Spitsbergen.

4. Luzula arctica Blytt

Greenland: Böcher 1952 a,Fig. 29; Holmen 1957, p. 135.
Spitsbergen: Rønning 1972, Map 14, supplemented by own investigations in 1970 and 1985.
Semlja Frantsa Josifa: Hanssen & Lid 1932, pp. 32-33; Tolmatsjev 1963, Karta 15.
Novaja Semlja, Vaigatsj and Kolgujev: Lynge 1923, Pl. 15:2; Tolmatsjev 1963, Karta 15.

South of the Arctic Circle the species occupies only a small area in Central South Norway. L. arctica is a frequent and conspicuous species in all Arctic lands north of ca. 70°, but is absent from maritime islands such as Jan Mayen and Bjørnøya. The species is apparently less common farthest north, e.g. on Semlja Frantsa Josifa.

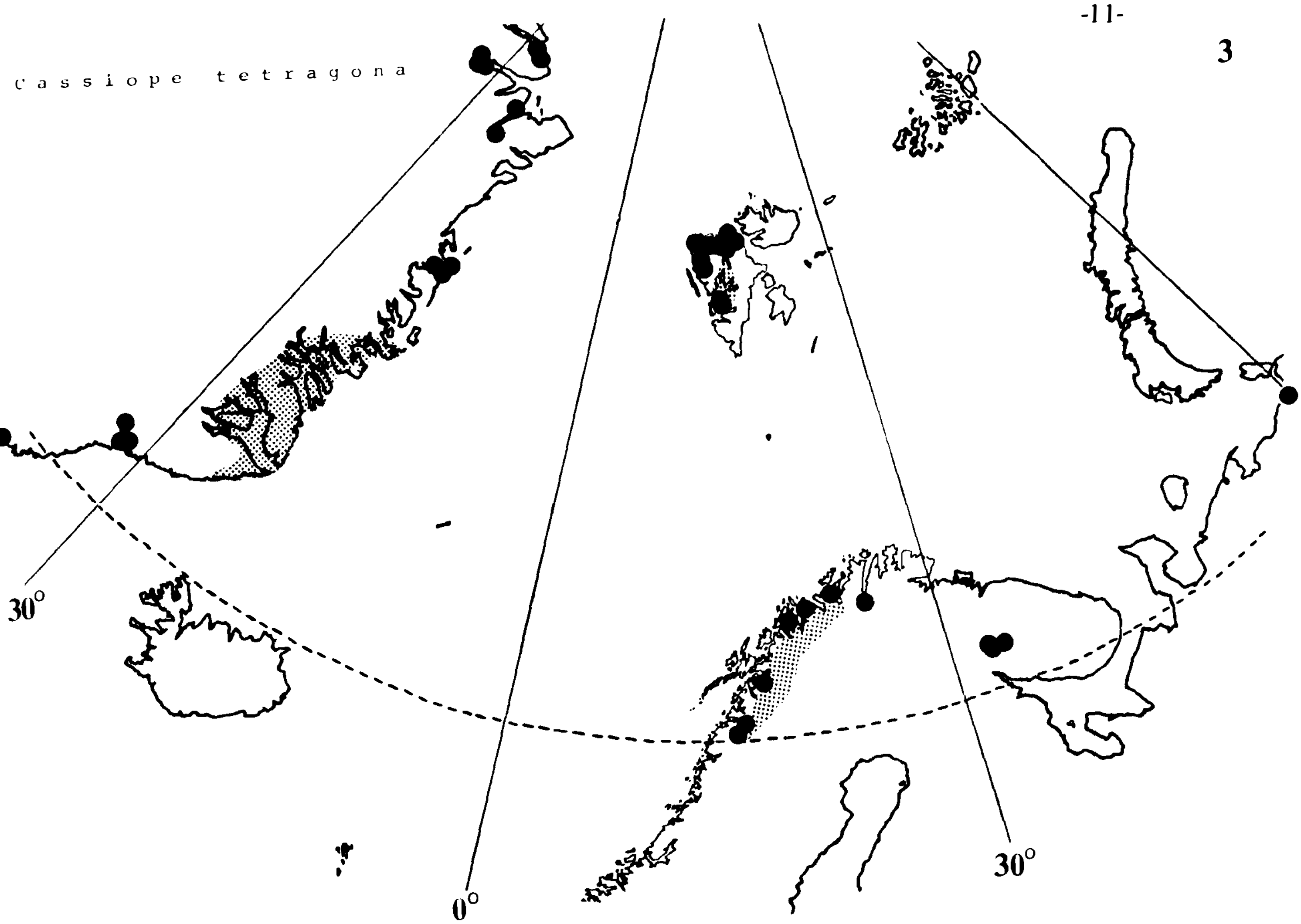
L. arctica ascends to moderate altitudes in the North Scandes but appears to be more hardy on Spitsbergen, showing DD-2=440 versus DD-2=150.

5. Luzula wahlenbergii Rupr.

Greenland: Holmen & Mathiesen 1953.
Spitsbergen: Rønning 1972, Map 13, supplemented by new finds by the present author in Berzeliusdalen and Reindalen (1970 and 1986).
Kanin - Malosemelskaja Tundra - Vaigatsj - Novaja Semlja: Lynge 1923, Pl. 15:2; Tolmatsjev 1963, Karta 9.

This is an eastern Arctic species which is very isolated in

3



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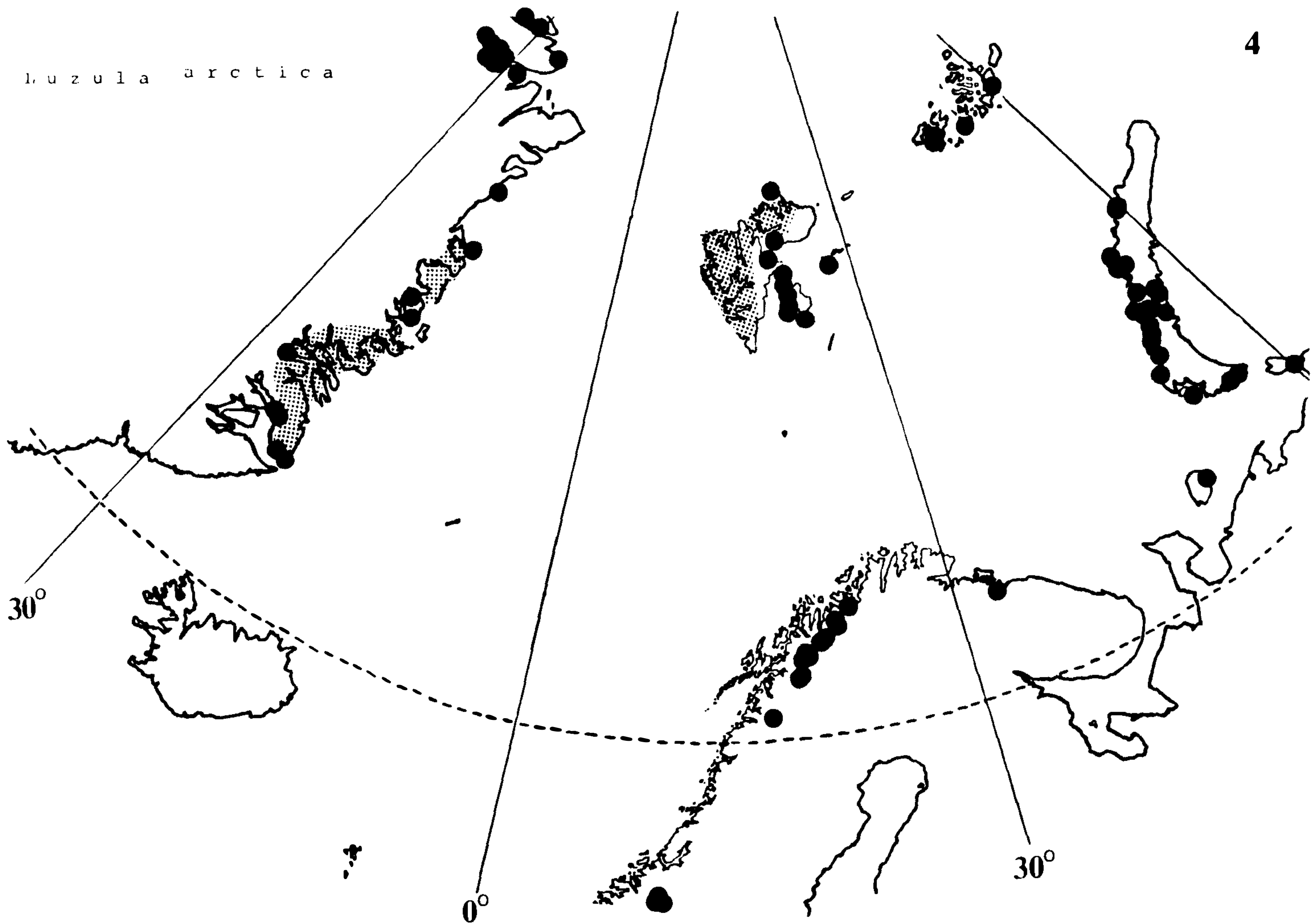


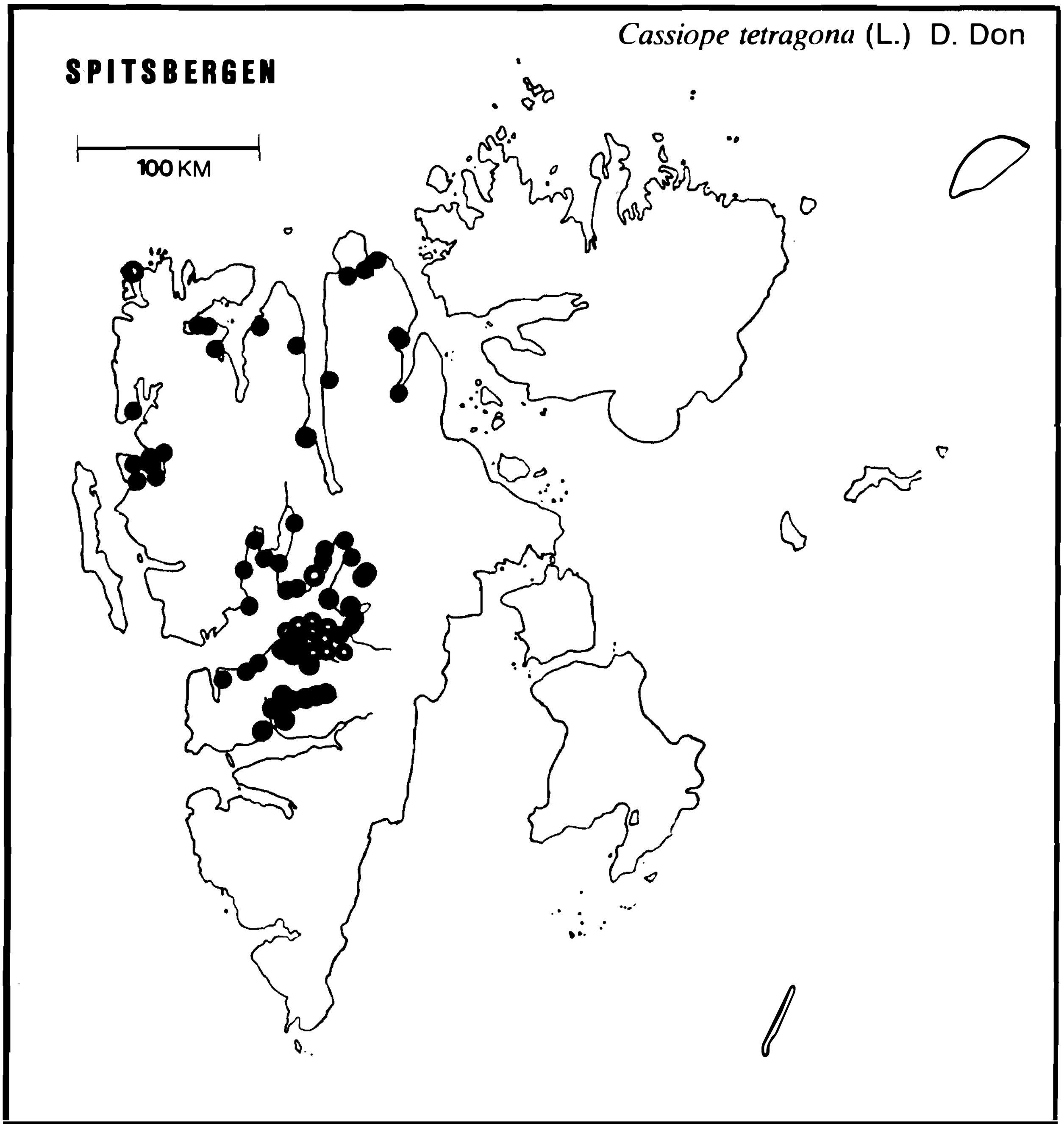
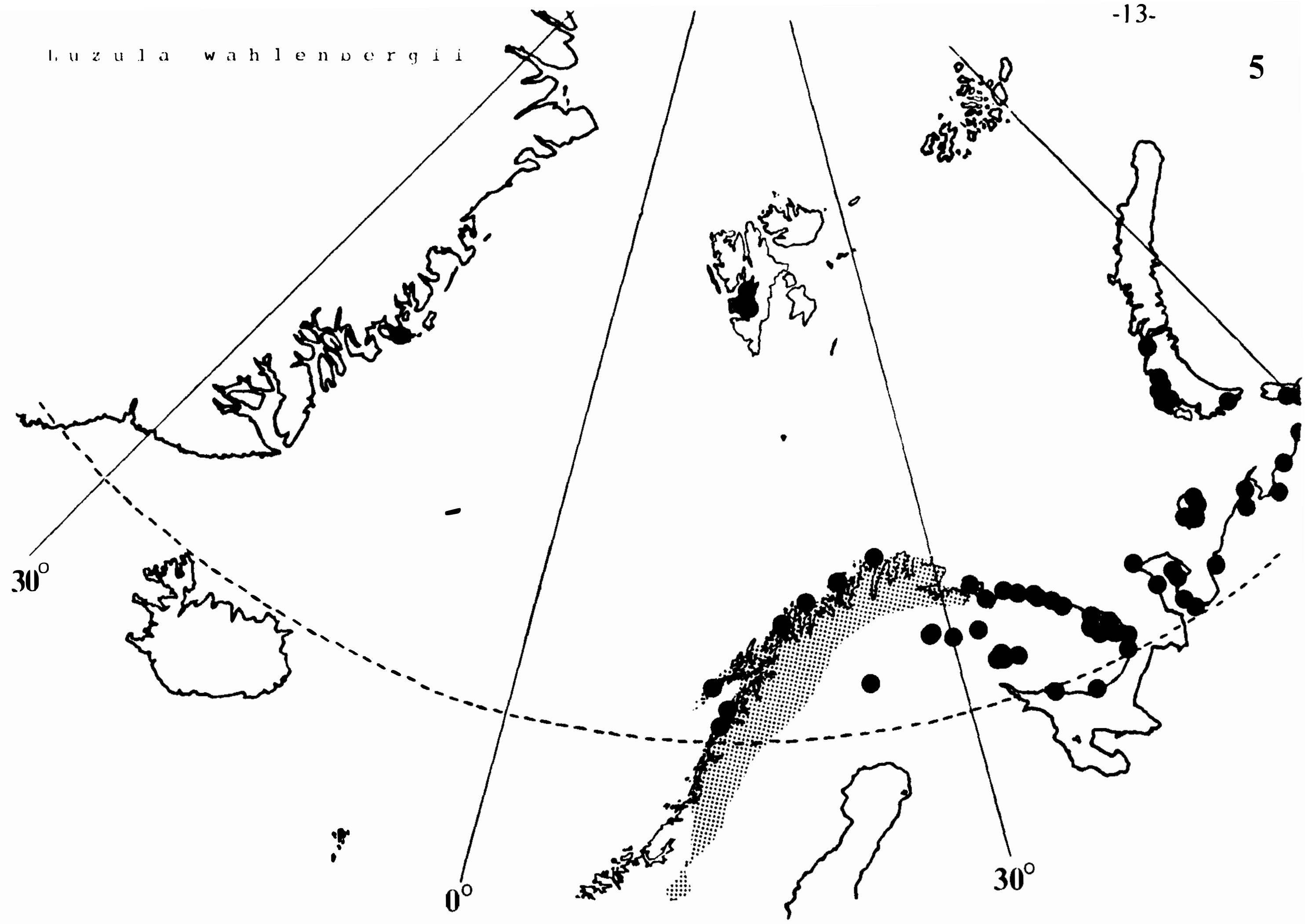
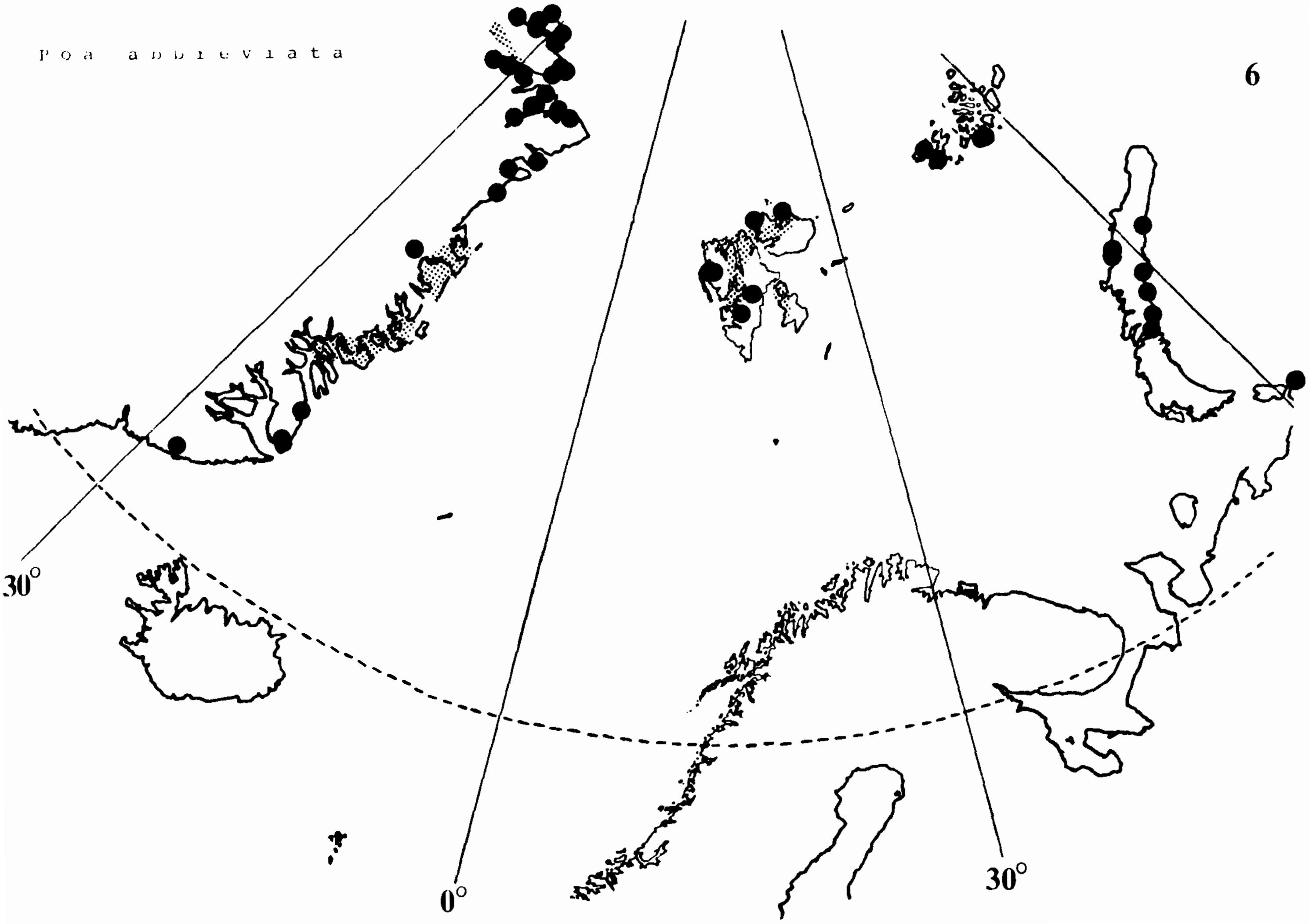


Fig. 2. Distribution of Cassiope tetragona in Spitsbergen.
Ring signature: specimen not seen.


Luzula wahlenbergii
5
30°
0°
30°


Poa abbreviata
6
30°
0°
30°

Greenland, but widespread in northern Eurasia southwards to mid-Scandinavian mountains. L. wahlenbergii is rather isolated in Central Spitsbergen and confined to the southern island of Novaja Semlja.

In Spitsbergen it is confined to wet mires at low elevation but may attain moderate altitudes in Scandinavia.

6. Poa abbreviata R. Br.

Greenland: Gelting 1934, Fig. 42; Holmen 1957, Fig. 36; Fredskild 1966.
Spitsbergen: Rønning 1972, Map 49; Hofmann 1968. Note that the Hornsund station is omitted because the specimen is a wrongly identified Colpodium vahlianum (Gåshamna 19 August 1960, O. Skifte TROM, O. I. Rønning det. 1969).
Semlja Frantsa Josifa: Hanssen & Lid 1932, p. 35; Tolmatsjev 1964, Karta 43.
Novaja Semlja - Pai-Khoi: Lynge 1923, Pl. 20:1; Tolmatsjev 1964, Karta 43.

This Arctic species is taken as representative of an element which does not occur in mainland Europe as far as is known, and which advances farthest north in Greenland. The present southern limit of P. abbreviata in Spitsbergen is on Edgeøya and on the northern shore of Van Mijenfjorden.

The vertical range of this species is considerable, ascending to 700 m a.s.l. in Wijdefjorden (O. A. Høeg, O).

7. Ranunculus glacialis L.

Greenland: Böcher 1938, Figs. 44-45; Seidenfaden & Sørensen 1937, Fig. 2; Halliday et al. 1974, p. 10.
Jan Mayen: Lid 1964, Map 32.
Iceland: Grøntved 1942, Fig. 91.
The Faeroes: Böcher 1937; Hansen 1966, p. 101.
Spitsbergen: Norwegian herbarium material, cf. also Neilson (1970, p. 34).

Widespread in East Greenland southwards to Angmagssalik, and frequent on maritime islands and coasts of the North Atlantic but not east of the Barents Sea, and confined to the southeastern coast of Spitsbergen, allegedly at low elevation.

Its ascension to high elevations in Scandinavia is a well-known feature of the high-alpine belt proper.

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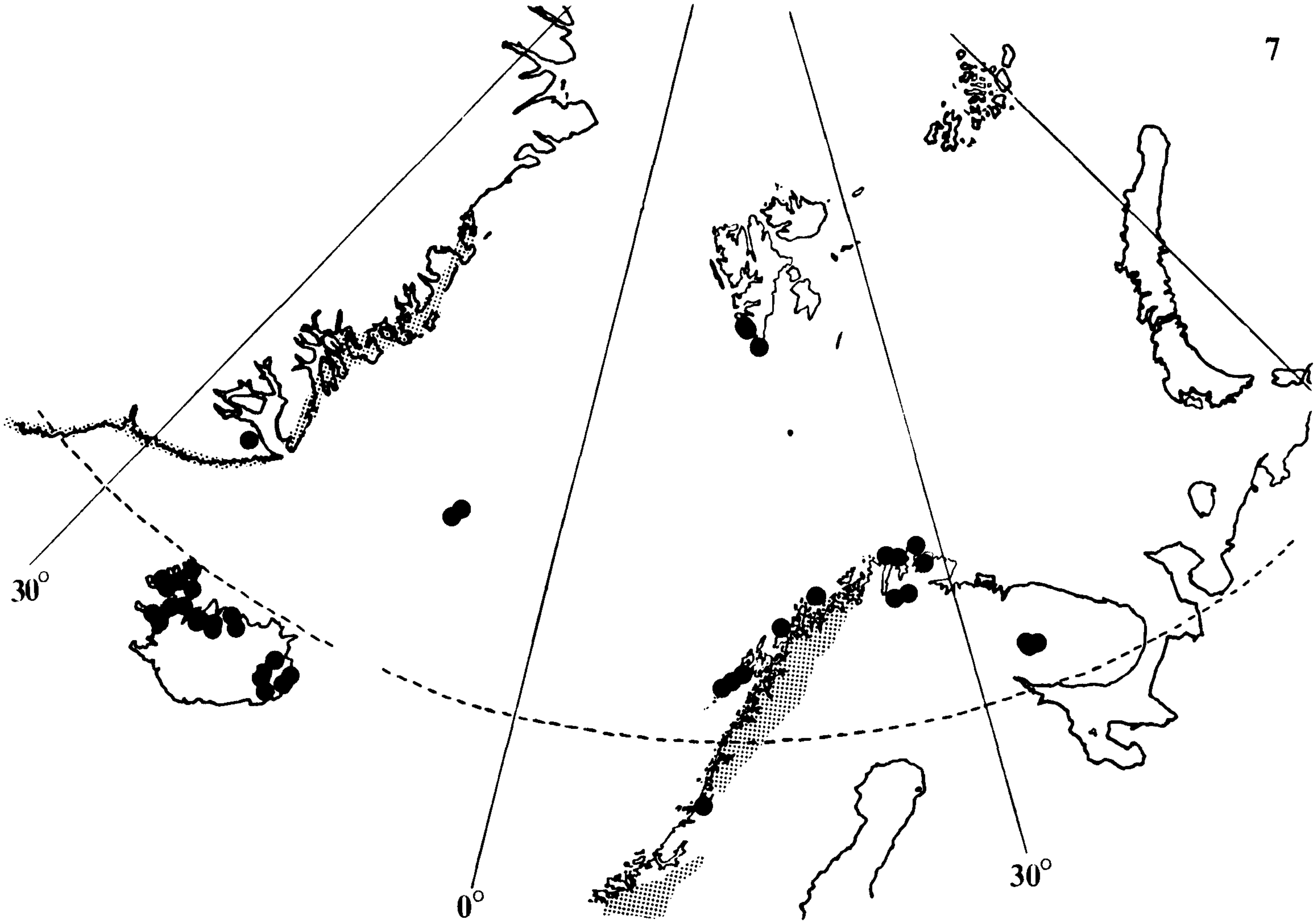
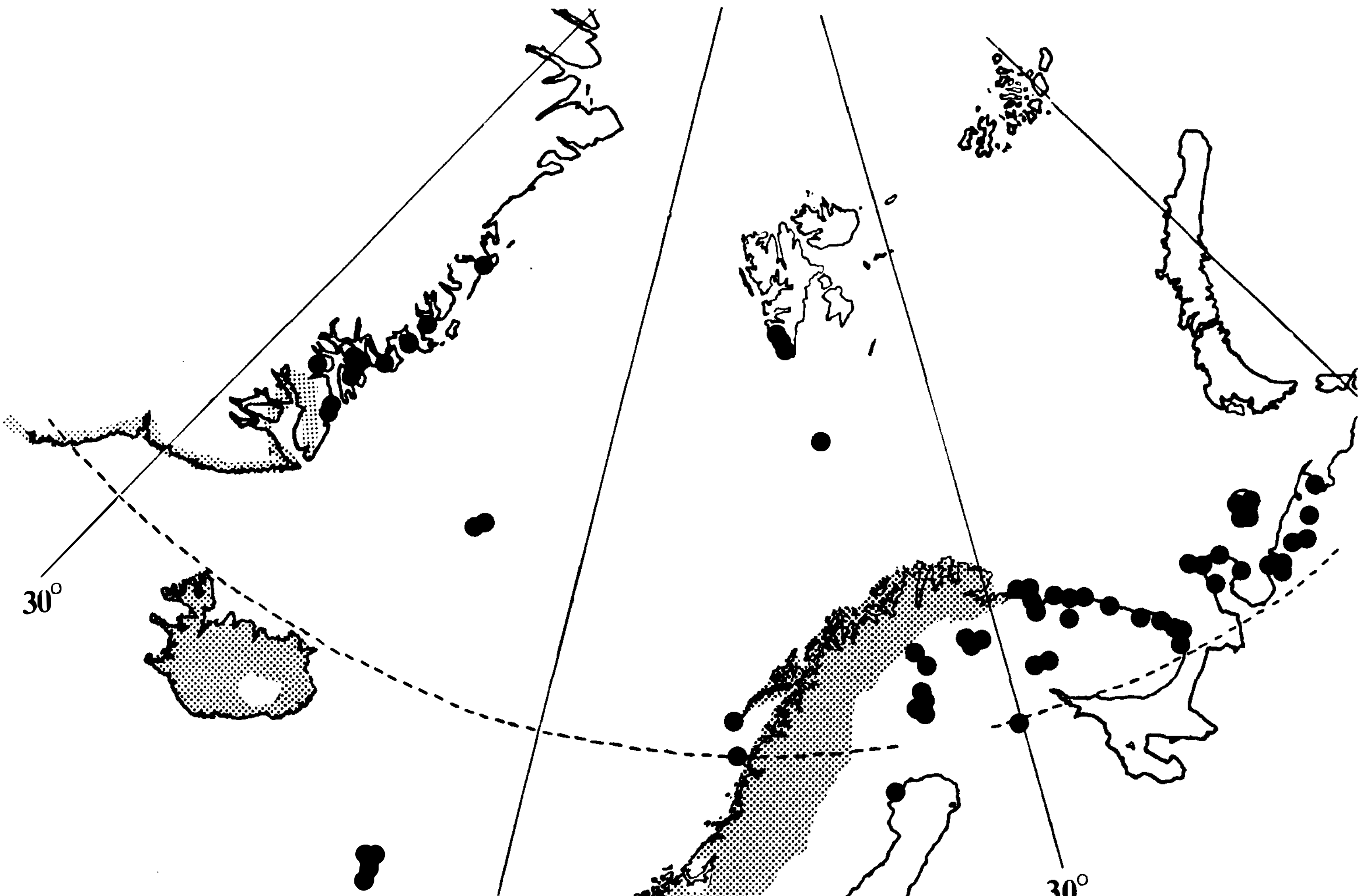




8. Salix herbacea L.

Greenland: Sørensen 1933, pp. 73-74; Böcher 1954, p. 111; Halliday et al. 1974, p. 11.
Jan Mayen: Lid 1964, Map 19.
Iceland: Grøntved 1942, p. 203.
The Faeroes: Böcher 1937; Hansen 1966, p. 105.
Spitsbergen: Revised material in Norwegian herbaria.
Kanin - Kolgujev - Malosemelskaja Tundra - Petsjorskaja Guba: Tolmatsjev 1966 b, Karta 6. Note that Tolmatsjev does not recognize records from Novaja Semlja and farther east entered by Hulten (1958, Map 24), nor does Lid (in Lynge 1923, pp. 16-22).

This species is widespread in East Greenland north to ca. 79°, but restricted to low ground on the southeast coast of Spitsbergen. S. herbacea is a characteristic species of maritime islands and coasts of the North Atlantic, and has not been confirmed to the east of Petsjora.

The vertical ranges in the North Scandes and on Bjørnøya coincide fairly well, and the species avoids the most extreme elevations.

9. Salix polaris Wg.

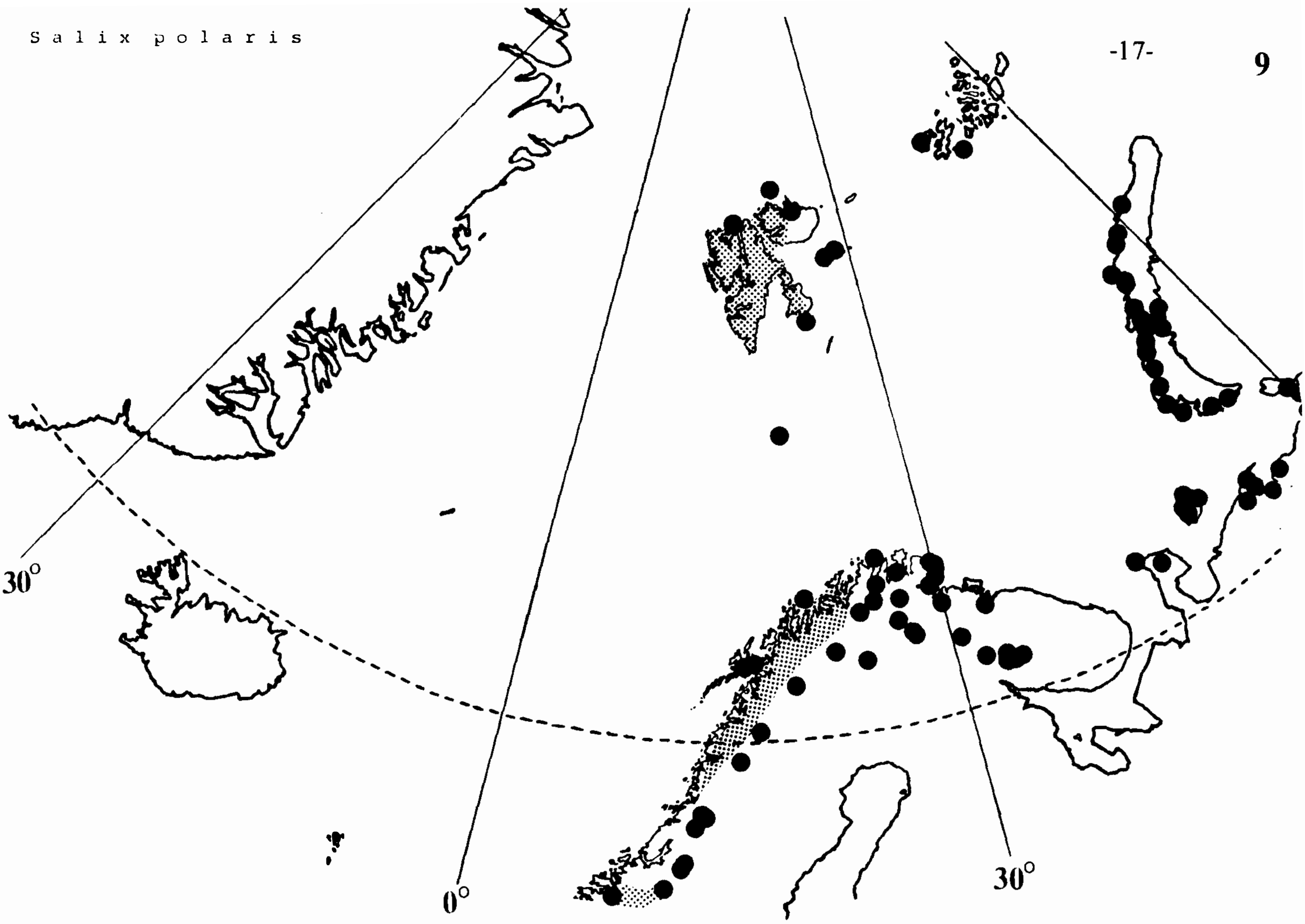
Spitsbergen: Revised material in Norwegian herbaria, cf. also Neilson (1968, p. 43, 1970, p. 48).
Semlja Frantsa Josifa: Hanssen & Lid 1932, pp. 31-32; Tolmatsjev 1966 b, Karta 7.
Novaja Semlja: Lid in Lynge 1923, p. 17; Tolmatsjev 1966 b, Karta 7
Kanin - Kolgujev - Vaigatsj - Polar Urals: Hultén 1955, p. 22; Tolmatsjev 1966 b, Karta 7.

The species has eastern Arctic connections and is entirely absent from Greenland, but is very frequent and physiognomic in the whole of Svalbard and Novaja Semlja, whereas it is rare farthest north, on Semlja Frantsa Josifa. S. polaris has its southern limit in the South Scandes.

The vertical range is considerable; to 1040 m a.s.l. in Central Spitsbergen. An increasing cold tolerance towards the north is indicated by Table 2.

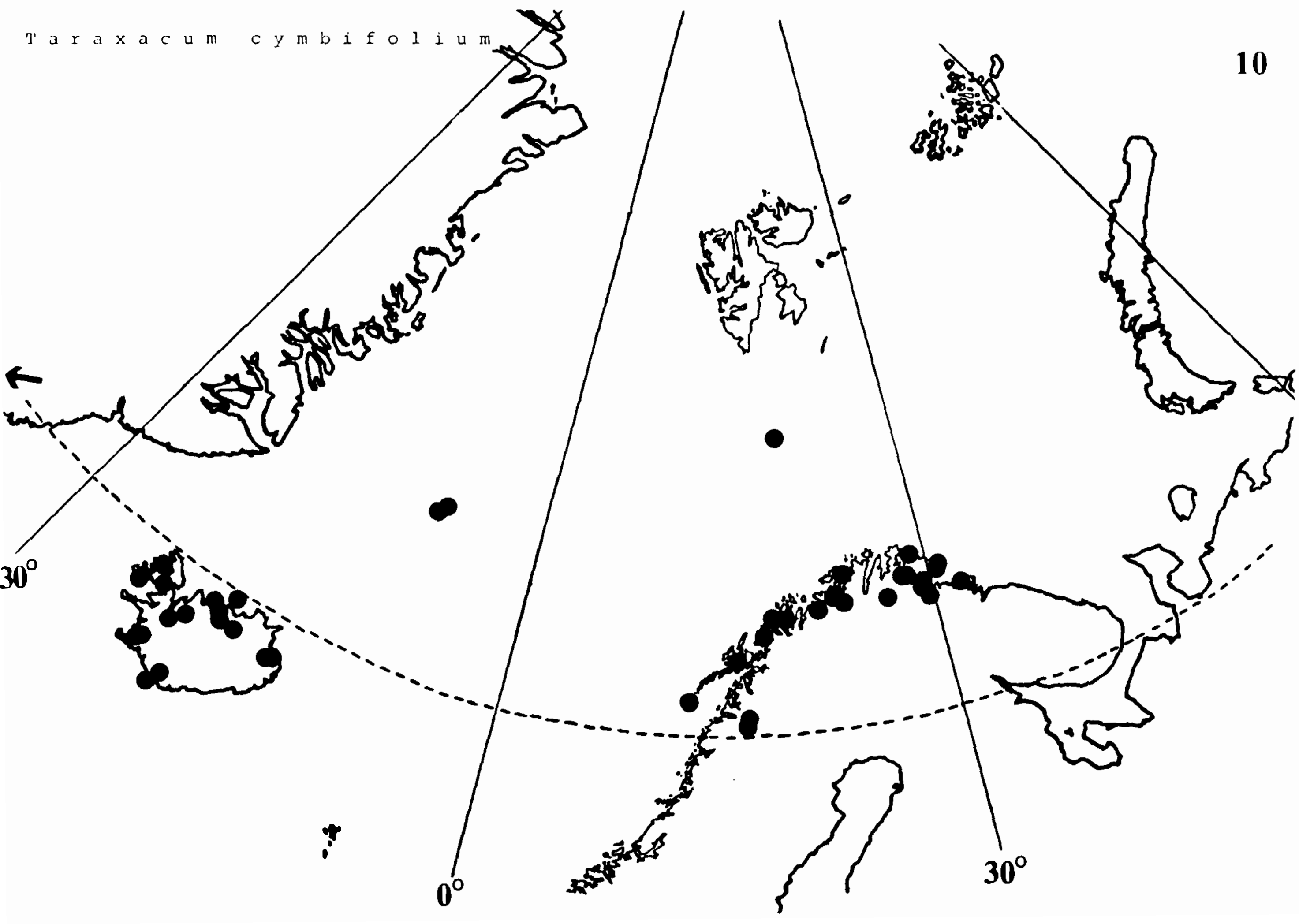
Salix polaris

9



Taraxacum cymbifolium

10



10. Taraxacum cymbifolium H. Lindb. ex Dt.

Greenland: Engelskjøn 1967, Gjærevoll & Ryvarden 1978.
Iceland: Christiansen 1942, Fig. 11.
North Scandinavia: Some new finds by the present author 1968-1985 (O, TROM).

This characteristic species of the Spectabilia section is most frequent in Iceland and Jan Mayen, and has outlying stations on Bjørnøya and in the Rybatsji Peninsula. One would expect T. cymbifolium to appear also in Southeast Greenland; which may depend on the taxonomy and nomenclature adopted.

The species does not enter great elevations but shows a certain preference for snow-beds.

* * *

THE SOUTH ATLANTIC ANTARCTIC, ESPECIALLY BOUVETØYA AND DRONNING MAUD LAND

Climates and their zonal change

Table 3 shows principal thermal parameters of nine stations on the stretch from the cool-temperate or sub-Antarctic Falkland Islands and South Georgia, southwards to continental Antarctic stations. Monthly standard normals are given of air temperatures, and heat sums are expressed as Degree-Days for December and January in continental stations (Fig. 3); for January and February in the maritime island stations. Average wind chill and cooling power are calculated for December to February (cf. Table 1).

The stations Halley Bay and the more southerly General Belgrano (Engelskjøn 1986 d, Tables 4,5) are situated in areas without exposed ground. Ice shelf stations such as these are climatically influenced by the strongly welded pack ice cover in the Weddell Sea. The generally cold, and moderately windy conditions, extend to Norway station (Vinje 1962). There are no coastal rock exposures on this stretch, but the relatively low mountains of Vestfjella seem to enjoy a local wet oasis climate (Lindsay 1972; Bratlien, personal communication).

The stations Novolazarevskaya, Syowa, and Molodezhnaya are located at low coastal exposures. Their local climates are seen to be considerably more favourable than the mentioned ice shelf stations, cf. MacNamara (1973). However, Novolazarevskaya at the Schirmacher Ponds Oasis, is rather windy although not comparable with the extreme katabatic wind conditions at Cape Denison, Wilkes Land (Walton 1984, pp. 10-11, Fig. 5).

The inland mountain climates are so little documented that a comparison will not be possible until results from the automatic station at Jutulsessen (Fig. 3, JU) become available.

There is no land in the mid-Atlantic between the coastal oases and Bouvetøya, ca. 16 degrees of latitude to the north. These regions are essentially different from a climatic and vegetational point of view (Engelskjøn 1986 c, d).

The meridional climatic change may only be inferred from observations at sea. Conditions along the west side of the Weddell

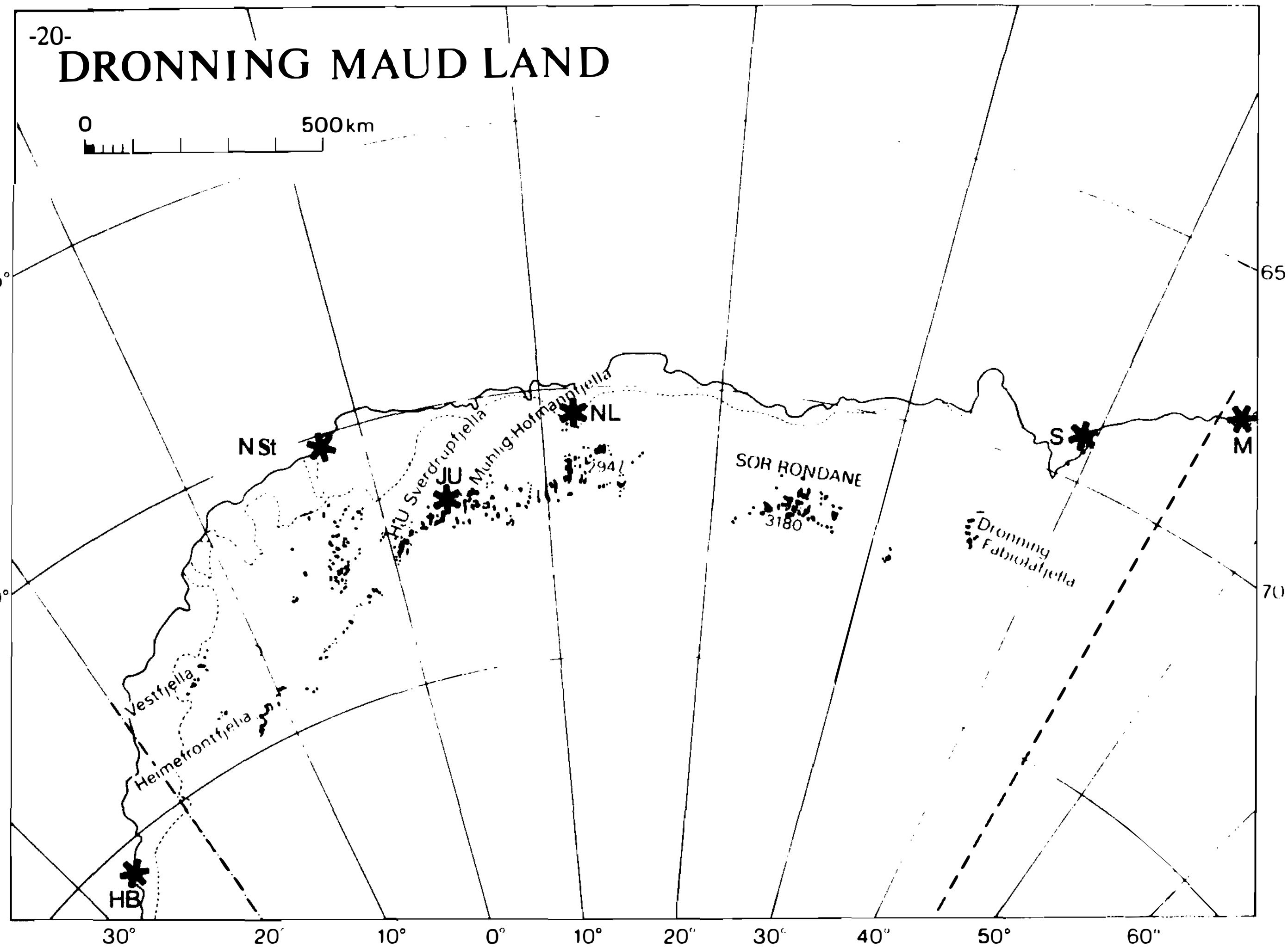


Fig. 3. Location of meteorological stations in Dronning Maud Land, Greater Antarctica, and adjoining areas. HB: Halley Bay, N St: Norway Station, JU: Jutulsessen in the Gjelsvikfjella mountains (operating from 1985, automatic station), NL: Novolazarevskaya, S: Syowa Station, M: Molodezhnaya.

Table 3. Climatological parameters for some South Atlantic stations (all below 90 m a.s.l.). Standard normals 1931-60, if not otherwise stated. Data after Müller (1982), Smith (1971), and MacNamara (1973). Definitions, cf. text, and Table 1.

S t a t i o n	S Lat. (°)	Monthly mean temperatures July	December	January	February	Heat sum DD-2	Wind chill	/ Cooling power
General Belgrano	78	-32.7	- 6.0	- 6.0	-13.2	- 370	1085	35
Norway Station	70.5	-26.1	- 5.2	- 4.4	- 8.9	- 300	1150	36
Novolazarevskaya	70.7	-17.9	- 0.8	- 1.2	- 3.9	- 60	1080	43
Syowa	69	-18.2	- 1.7	- 1.0	- 3.5	- 20	965	32
Molodezhnaya *	67.7	-19	- 1	- 1	- 4	- 60	1020	35
Orcadas	60.5	-10.6	- 0.6	0.2	0.4	15	890	30
Bouvetøya **	54.4	- 2.7	0.7	1.6	1.5	ca. 90	ca. 920	ca. 34
South Georgia ***	54.3	- 1.6	3.6	4.6	5.4	255	770	26
Stanley	51.7	1.9	8.1	9.5	8.9	545	No record	

* 1963-67
** 1977-81
*** 1944-64

Sea are strongly ice shelf influenced. The climatic gradient on the western side of the Antarctic Peninsula, in the Pacific sector, may be more instructive to show the transition from the continental to the maritime Antarctic, also from a biogeographic point of view (Longton 1967, Table 11).

South Georgia is an instance of a sub-Antarctic, maritime climate (Longton 1967, Fig. 17), whereas Stanley, Falkland Islands, exemplifies a cool temperate, South Atlantic climate.

Distribution patterns of some plant species

Six species, which are taxonomically fairly unambiguous, were mapped within the Antarctic, sub-Antarctic and southern cool temperate zones, with special emphasis on their occurrence in the Atlantic sector. Literature sources are quoted below the species headings. The numbers (11-16) refer to the maps of distribution.

Altitudinal limits so far known are presented in Table 4, expressed as heat sums at the highest recorded elevation.

11. Deschampsia antarctica Desv.

Skottsberg 1954, Greene 1964, 1970, Greene & Holtom 1971, Edwards 1972, 1974, Longton & Holdgate 1979, Smith 1982, Komarkova, Poncet & Poncet 1985.

The southernmost occurrence of this species, and of flowering plants in the Antarctic, is at Terra Firma Islands, 68° 42' S Lat. (Komarkova et al. 1985). There is an isolated station on Candlemas Island, South Sandwich Group (Longton & Holdgate 1979), but D. antarctica has not turned up on Bouvetøya although it extends eastwards to Îles Kerguelen and Heard Island (Holtom & Greene 1967, Fig. 59).

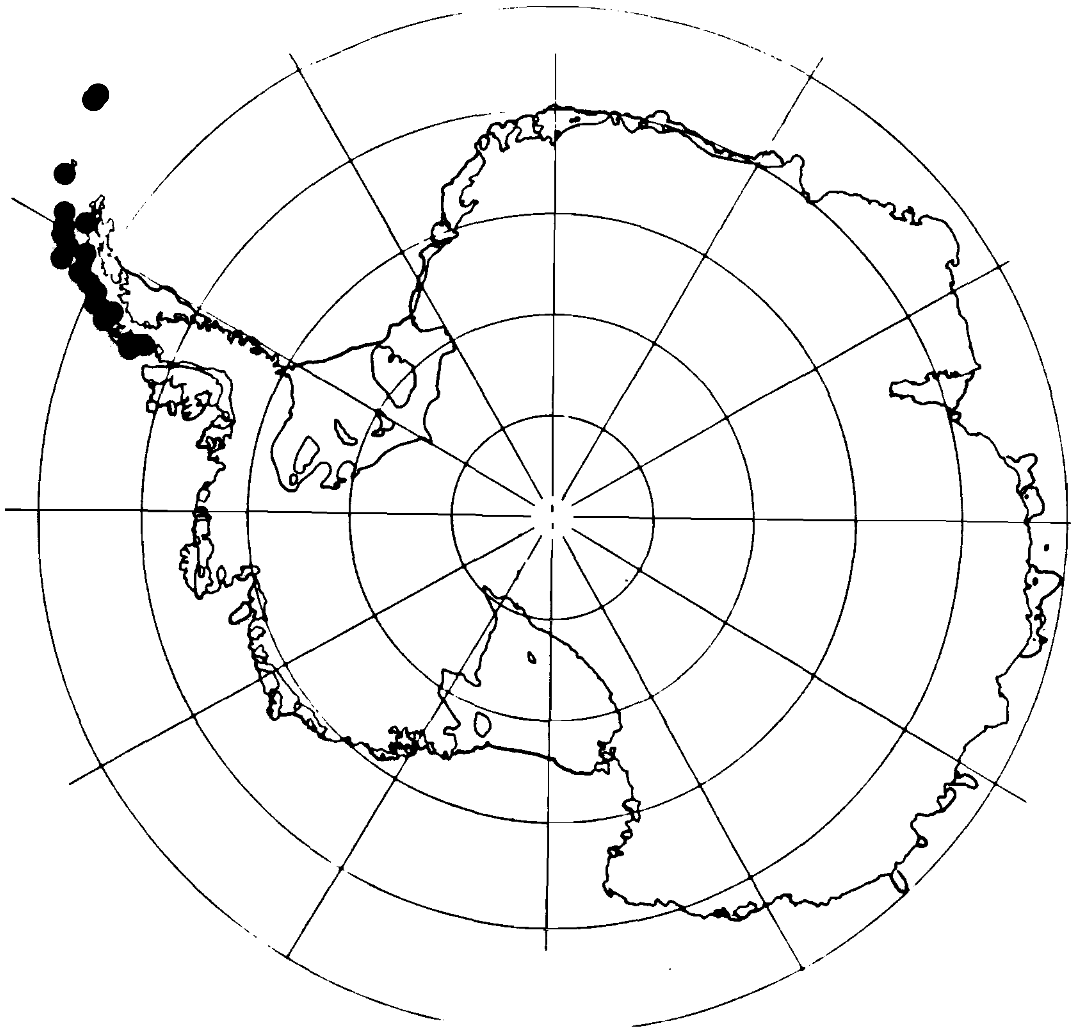
The highest elevations of this species are 275 m at Marguerite Bay (Smith 1982) and 180 m a.s.l. on Coronation Island (Edwards 1974), which correspond to heat sums (DD-2) lower than - 50.

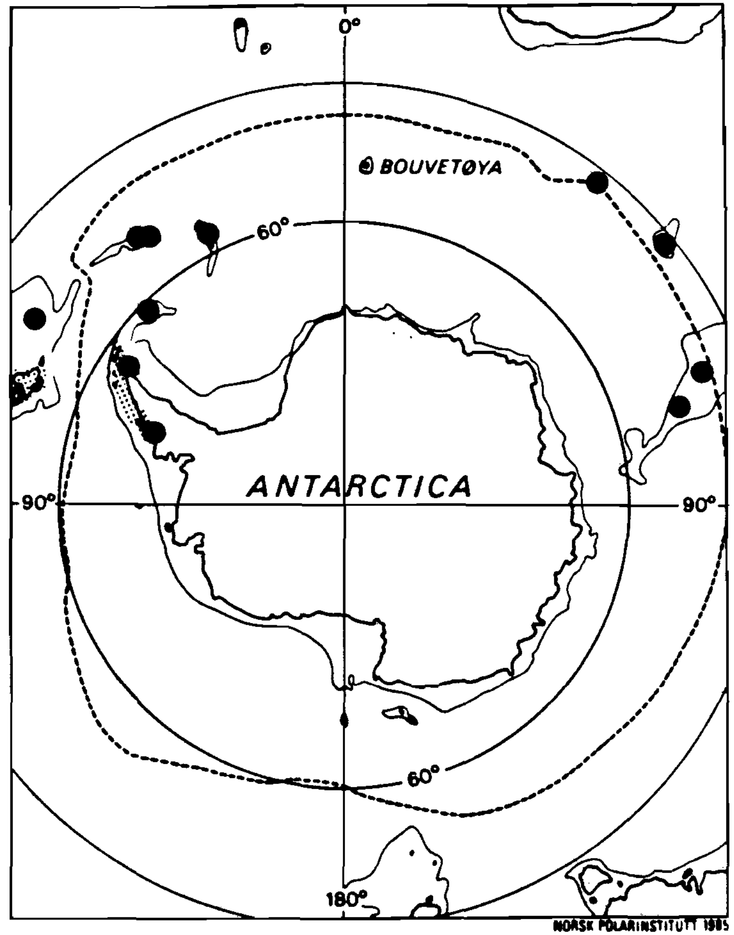
12. Pachyglossa dissitifolia Herzog & Grolle

Herzog & Grolle 1958, Grolle 1972, Schuster 1969, 1979, Smith 1972, Longton & Holdgate 1979, Bell & Blom 1986, Engelskjøn & Jørgensen 1986.

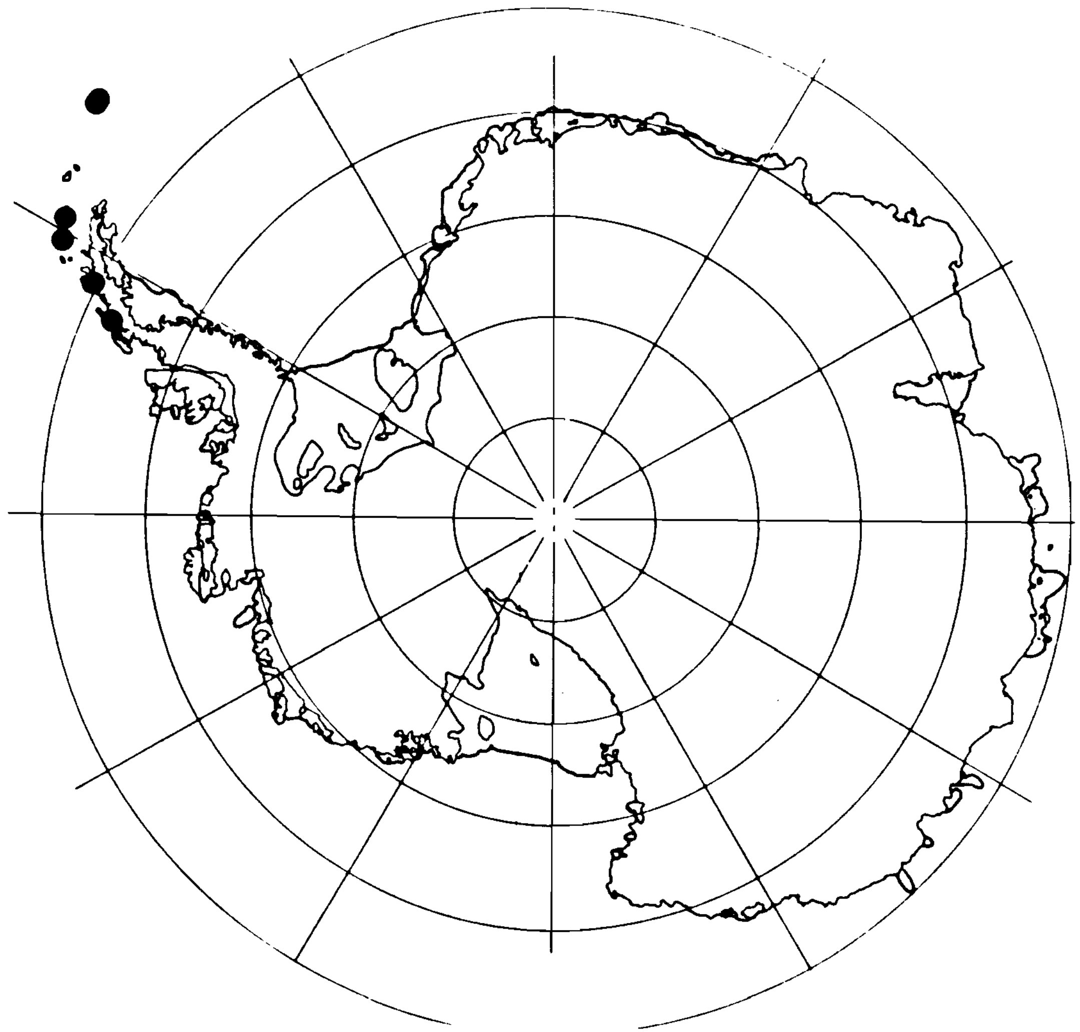
This hepatic species has not hitherto been recorded south of

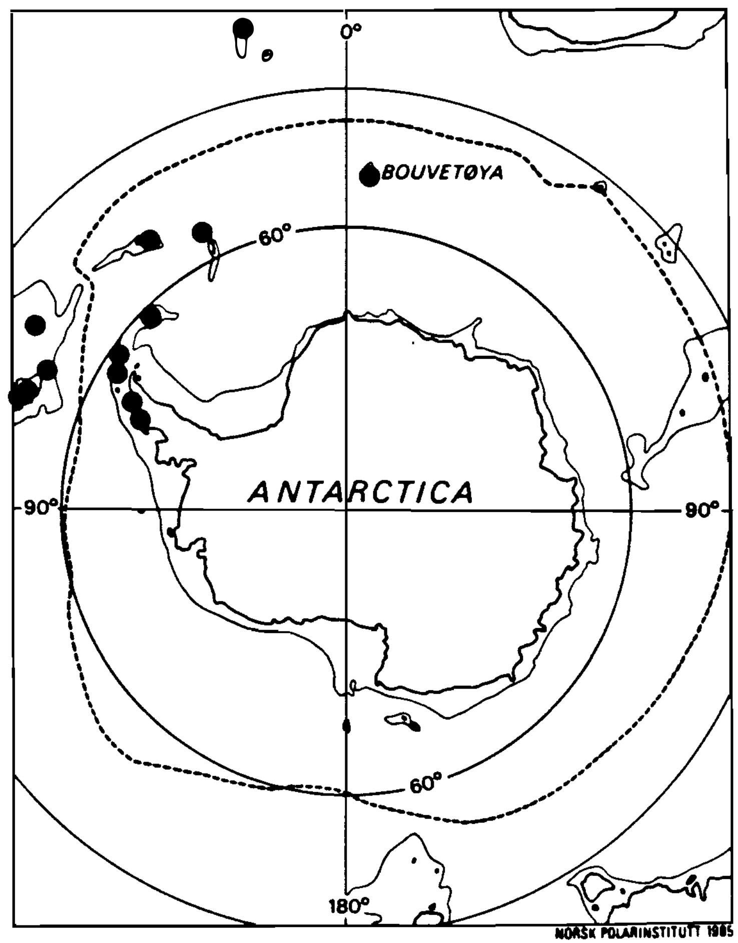
11. Deschampsia antarctica





12. Pachyglossa dissitifolia





the Antarctic Peninsula, but the distribution in Fuegia - Patagonia seems fairly extensive, and Pachyglossa extends eastwards to Bouvetøya and northwards to Tristan da Cunha.

Other hepatic species are recorded from the Antarctic Peninsula (Smith & Corner 1973, Schuster 1969, Map 24), but liverworts seem generally rare towards the south and are apparently absent from the continental Antarctic.

13. Sarconeurum glaciale (C. Muell.) Card. & Bryhn

Savitsj-Ljubitskaja & Smirnova 1961, 1969, Greene 1967, 1975, Greene et al. 1970, Pickard 1982, Seppelt 1984.

The distribution is circum-Antarctic but shows several lacunae such as in the coastal oases in eastern Dronning Maud Land, which have been explored by Japanese bryologists. Originally considered endemic to Antarctica, this species has been found as an arboreal epiphyte in southern Patagonia (Greene 1975).

In Dronning Maud Land Sarconeurum glaciale shows a preference for alkaline substratum, and does not attain as high elevations as Grimmia grisea; 1500 as against 1800 m a.s.l.

14. Usnea aurantiaco-atra (Jacq.) Bory

Huneck et al. 1984, Walker 1985, Jørgensen 1986.

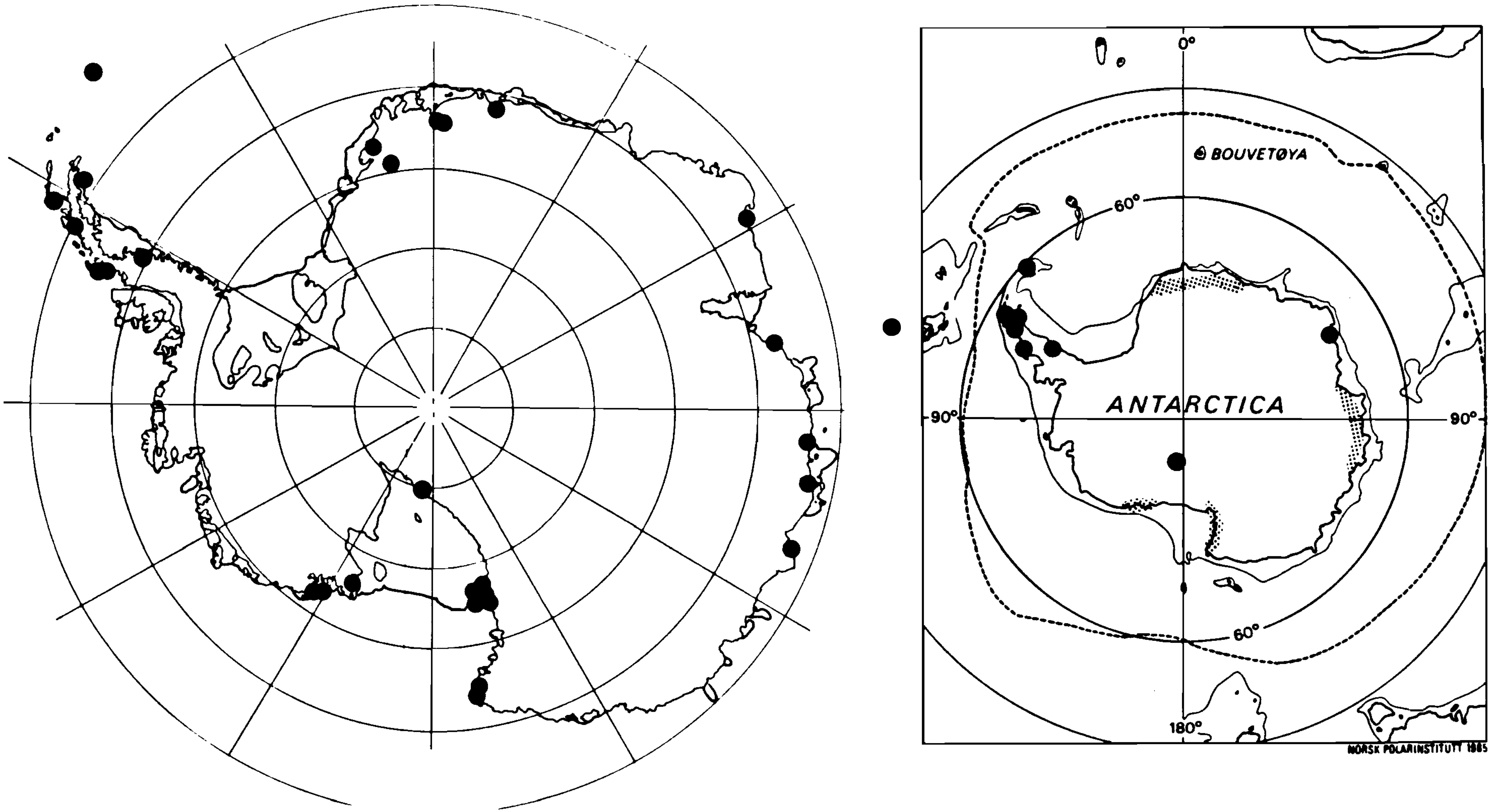
Distributed from Cabo de Hornos through Fuegia; throughout the maritime Antarctic but excluding the South Sandwich Islands, and attaining its eastern limit on Bouvetøya. It is very prominent in the plateau vegetation of various islands, but is definitely absent from continental Antarctica.

15. Usnea sphacelata R. Br. (=U. sulphurea (Koenig) Th. Fr.)

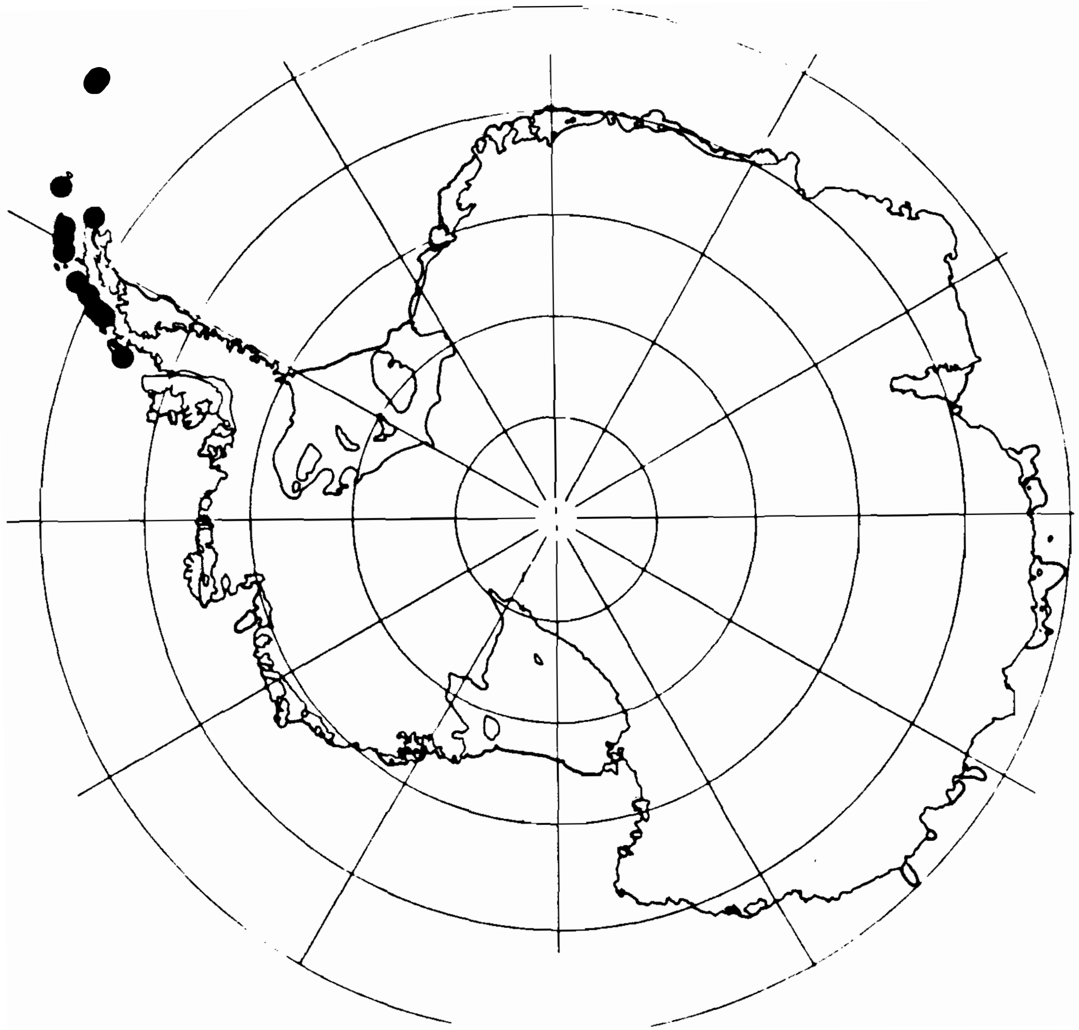
Lamb 1964, Kashiwadani 1970, Lindsay 1972, Øvstedal 1983 a, b, Huneck et al. 1984, Kappen 1985, Walker 1985.

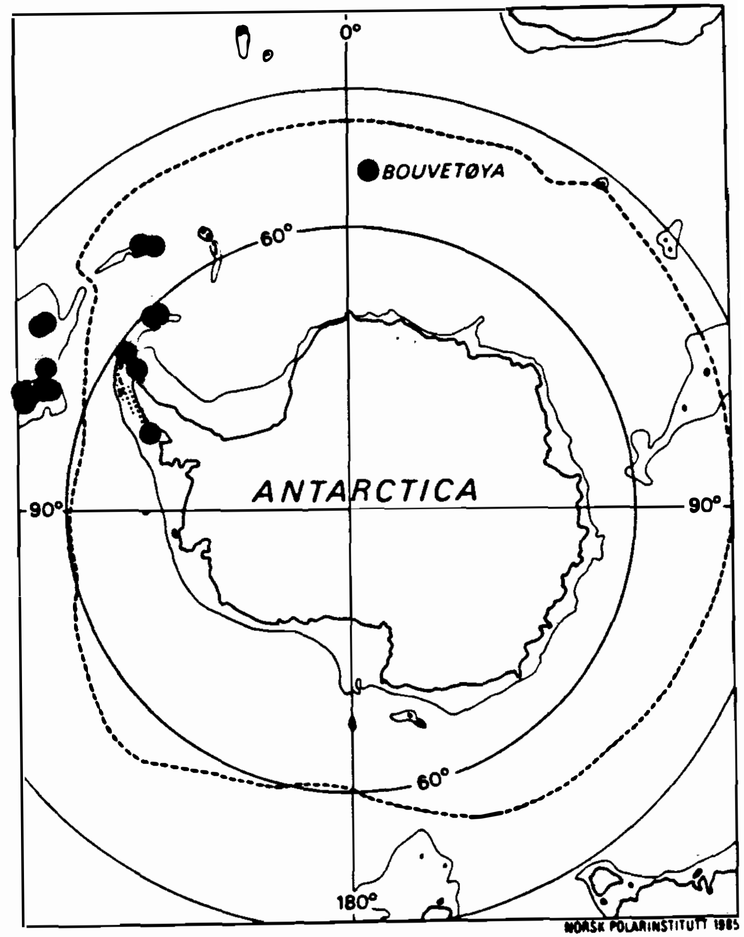
The distribution is circum-Antarctic, and, in world scale, bipolar (Lynge 1941). The species is unknown from the Scotia Ridge islands but seems ubiquitous on inland nunataks i.a. in Dronning Maud Land. However, it may be exacting as to ecological niches and does not surpass the 1900 m level.

13. Sarconeurum glaciale

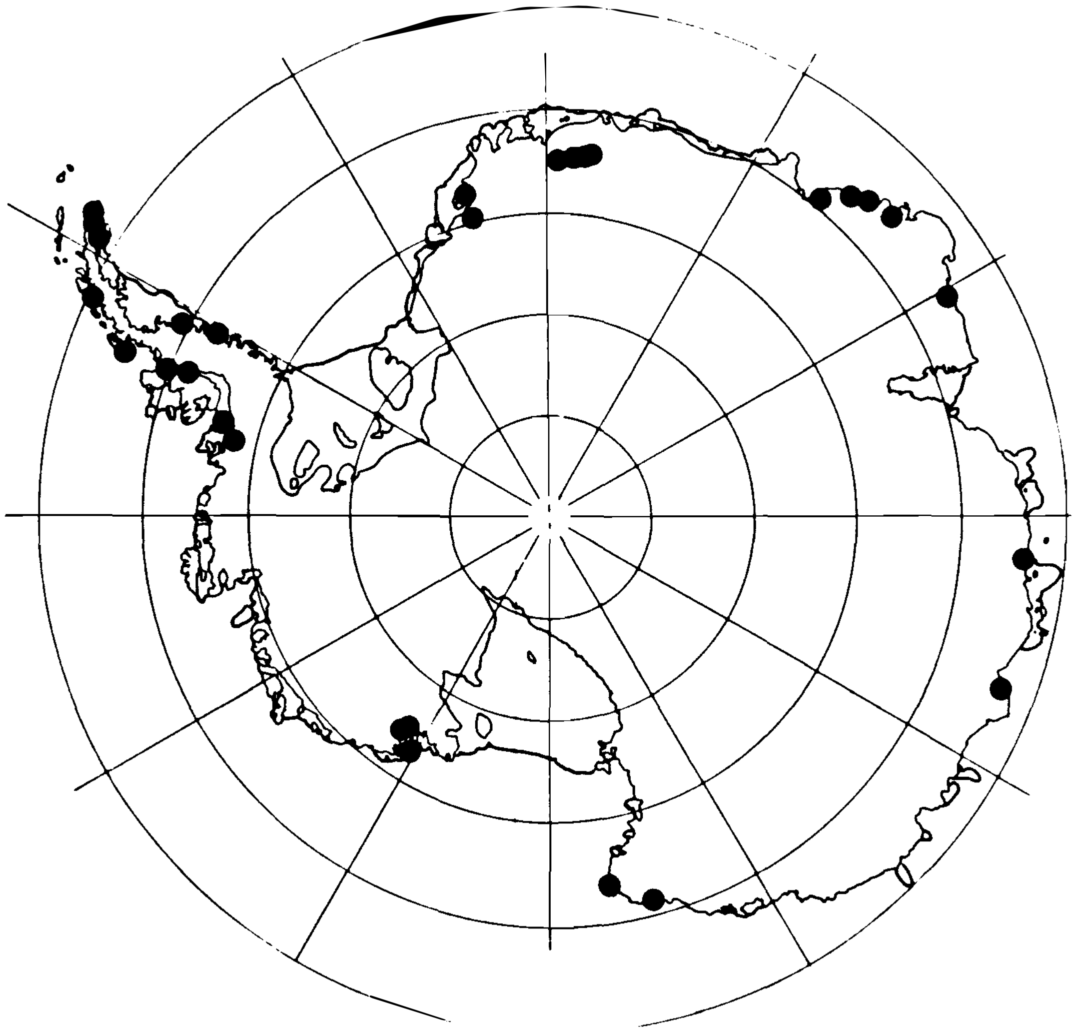


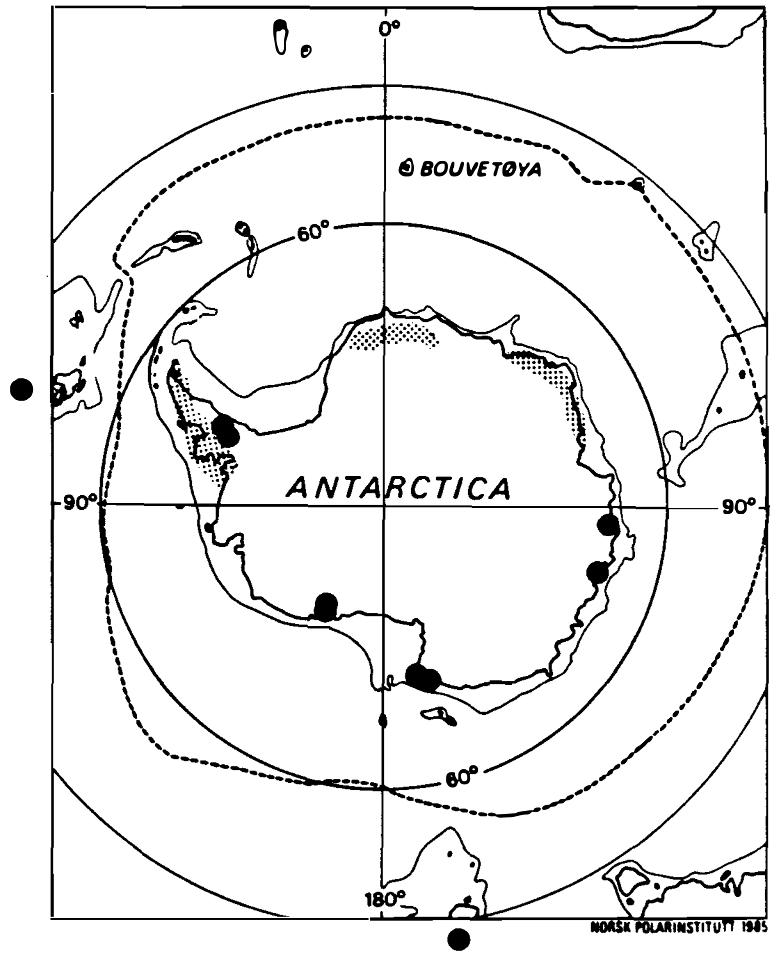
14. Usnea aurantiaco-atra
=Usnea fasciata

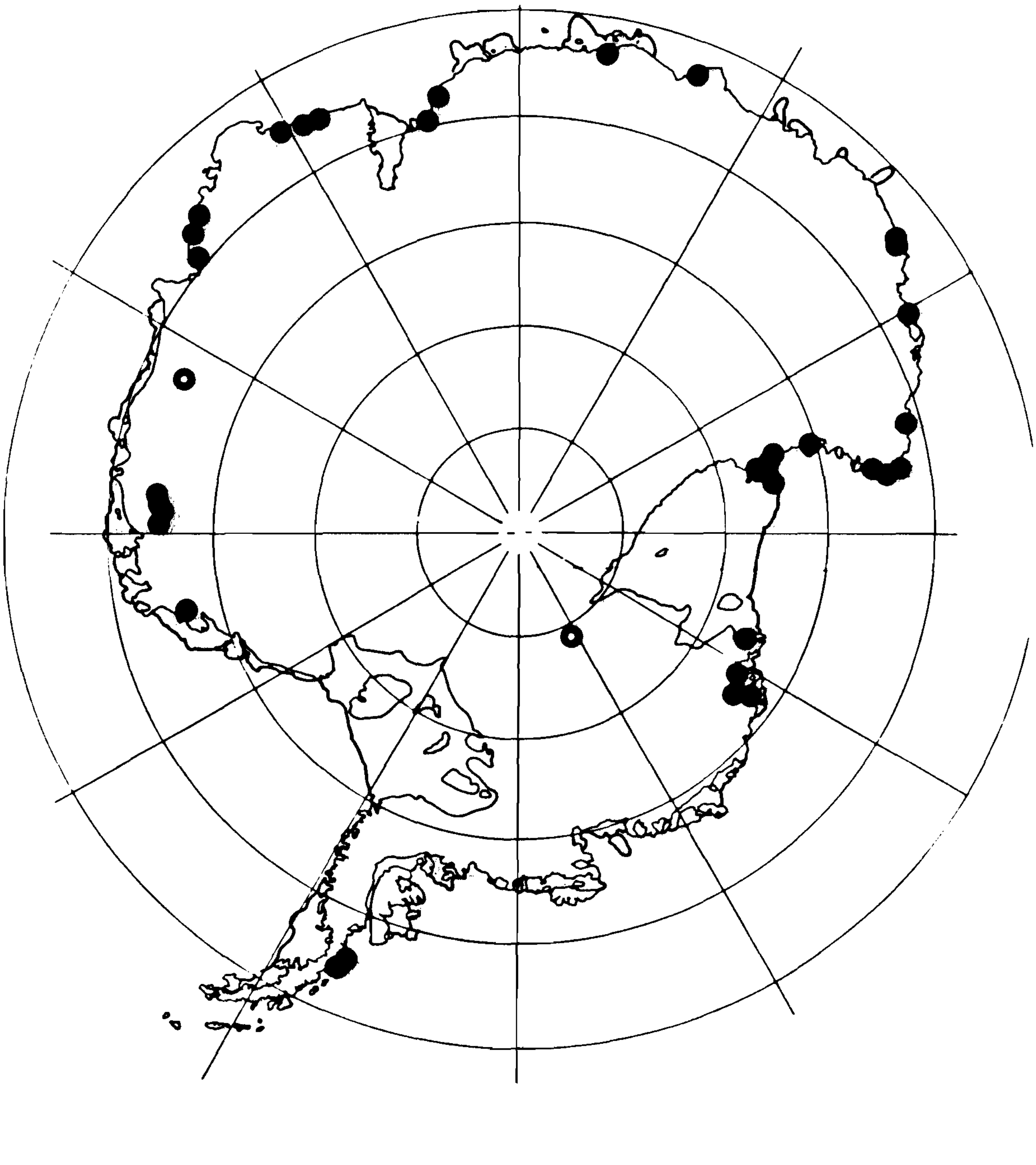




15. Usnea sphacelata
=Usnea sulphurea







16. Buellia frigida

16. Buellia frigida Darb.

Rudolph 1967, Lamb 1968, Golubkova et al. 1969, Kashiwadani 1970, Lindsay 1972, Filson 1974, 1975, Øvstedal 1983 a, b, Kappen 1985.

The distribution is circum-Antarctic and the species seems equally frequent on exposed rocks in coastal and inland nunatak areas. It seems to become less ubiquitous northwards on the Antarctic Peninsula.

B. frigida is among the lichen species attaining the highest elevations - 2450 m a.s.l. on Mt. Horten, Dronning Maud Land (Engelskjøn 1986 d), and the farthest south lichens recorded from the Horlick Mountains (Cameron et al. 1971) include a Buellia, tentatively identified as B. frigida.

* * * *

Table 4. Altitudinal records of some Antarctic, cryptogamic species from Dronning Maud Land and Bouvetøya, expressed as average number of Degree-Days, December-January resp. January-February (DD-2) at their extreme upper limits.

	Dronning Maud Land	Bouvetøya	Note
Pachyglossa dissitifolia	-	- 60	There are no liverworts in Dronning Maud Land
Sarconeurum glaciale	- 420	-	
Usnea aurantiaco-atra	-	- 60	
Usnea sphacelata	- 630	-	U. antarctica on Bouvetøya: - 70
Buellia frigida	- 840	-	

CONCLUSION

The interaction of ecological requirements and migrational events has led to the plant distributions of the present. Hence, grouping of the species of a local flora into geo-elements may be a risky undertaking for a variety of reasons, not least of method. In principle, there may be defined as many geoelements, migroelements, or ecoelements as there are species, or even more, if ecospecific differences are considered.

The 10 Arctic species mapped here show patterns of distribution which are different, in some cases complementary and non-overlapping (e.g. Poa abbreviata and Taraxacum cymbifolium). Among the possible contributing causes, their ecology and history of dispersal (Berg 1983, Dahl 1963) will not be considered at length, nor the role of soil chemistry. The latter is locally evident in the Arctic (Elvebakk 1982), less so in relation to more extensive areas which usually afford varied edaphic conditions.

Four categories of distribution may be identified relative to climates in the North Atlantic Arctic:

1. The northern Arctic category, represented by Poa abbreviata (Map 6). Such species are absent or rare south of 70° N Lat. Single stations on the European mainland appear to be extrazonal. Other instances of species showing a northern Arctic distribution are Braya purpurascens, Draba bellii, Draba subcapitata, Festuca hyperborea, Minuartia rossii, Papaver dahlianum, Poa hartzii, and Potentilla pulchella. Several of them advance to the northernmost end of Greenland, and especially Papaver dahlianum attains very high elevations with heat sums (DD-2) even below zero. This may be compensated by the thermal radiation increment as well by the dryness of the substratum. The species mentioned often occupy loess or lithosol deposits in seasonally semi-arid, inland valleys.

2. The mesic Arctic category, represented by Carex misandra (Map 1), Cassiope tetragona (Map 3, Fig. 2), Luzula arctica (Map 4), and Salix polaris (Map 9). These are widely distributed and vegetationally important species in the Arctic, but

are rare or absent in the maritime Arctic, notably Jan Mayen. In North Scandinavia and Kola the same species are concentrated to the interior and higher mountains.

Luzula arctica and Salix polaris have extensive distributions in Svalbard, Semlja Frantsa Josifa, and Novaja Semlja, and also show fairly low thermal demands. Carex misandra and Cassiope tetragona (Fig. 2) cease markedly towards the coast, to the northeast, and vertically. The absence of C. tetragona from Novaja Semlja is peculiar and worthy of consideration in relation to climate.

Other species which may be included in this category are Draba lactea, Hierochloë alpina (Fig. 4), Luzula arcuata ssp. confusa, Pedicularis hirsuta, Potentilla hyparctica, and Stellaria crassipes.

3. The maritime Arctic category, represented by Carex rufina (Map 2), Ranunculus glacialis (Map 7), Salix herbacea (Map 8), and Taraxacum cymbifolium (Map 10). These species are common on maritime islands and mountainous coasts fringing the North Atlantic, including the North Scandes. Only Ranunculus glacialis and Salix herbacea reach Spitsbergen, and none of those four species, Novaja Semlja. Their thermal demands range from moderate (Taraxacum cymbifolium) to very low (Ranunculus glacialis). A common property of these species is a preference of snowy or humid habitats.

Other species of a similar distribution and ecology are Alchemilla glomerulans, Cassiope hypnoides, Cerastium cerastoides, Draba crassifolia, Festuca vivipara var. hirsuta, Luzula arcuata ssp. arcuata, and Taraxacum croceum.

4. The hemi-Arctic category, represented by Luzula wahlenbergii (Map 5). This is an instance of species generally staying south of 74° N Lat., and which have relatively high thermal demands, judged from their altitudinal distributions. Hence the Central Spitsbergen occurrences of Luzula wahlenbergii appear to be extrazonal.

Other examples of species occurring extrazonally in parts of Svalbard are Betula nana (Fig. 5), Carex amblyorhyncha which belongs to the C. heleonastes complex (Fig. 6), Empetrum hermaphroditum, Hippuris vulgaris (on Bjørnøya), Kobresia simpiciuscula (Fig. 7), Petasites frigidus, Ranunculus

Fig. 4. Distribution of Hierochloë alpina in Spitsbergen. Supplemented after Rønning (1972). Ring signature: specimen not seen.

Fig. 5. Distribution of Betula nana in Spitsbergen. Based on Norwegian herbarium material; Nathorst (1883), Andersson (1910), Asplund (1918), Hadač (1944), and Lid (1967).

Fig. 6. Distribution of Carex amblyorhyncha in Spitsbergen. Based on previously known occurrences in Sassendalen (Seidenfaden & Sørensen 1937, p. 169; Böcher 1952 (CPH); Schweitzer 1966 (O, TROM)), and three newly discovered localities in Gipsdalen (Elven & Engelskjøn, 1985, O, TROM; Engelskjøn, 1985, O, TROM) and one at Kapp Thordsen (E. Dahl, 1984, personal communication). Ring signature: specimen not seen.

Fig. 7. Distribution of Kobresia simpliciuscula in Spitsbergen. Based on previously known occurrence in Billefjorden (Isachsen, 1925, O) and a newly discovered locality in Gipsdalen (Engelskjøn, 1985, O, TROM).

Fig. 8. Distribution of Ranunculus lapponicus in Spitsbergen. Based on Norwegian herbarium material; Nathorst (1883), Michelmore according to Dahl (1937), and Hadač (1944). Ring signature: specimen not seen.

Fig. 9. Distribution of Ranunculus pallasii in Spitsbergen. Based on Norwegian herbarium material, cf. also Engelskjøn, Kramer & Schweitzer (1972), and three newly discovered localities in middle Reindalen (Engelskjøn, 1985, O, TROM).

lapponicus (Fig. 8), Ranunculus pallasii (Fig. 9), Rubus chamaemorus, Salix glauca, and Vaccinium microphyllum.

The high number of species which are ubiquitous both in the Scandinavian Oroarctic and in the Arctic could not be treated here, but Table 2 includes some of them for comparison. It is seen that Dryas octopetala, Oxyria digyna, Polygonum viviparum, and Saxifraga cernua have vertical ranges showing the same trend in the North Scandes and Svalbard, when expressed as minimal heat sums. The tendency of lower heat demands on mountains of Central Spitsbergen may have several explanations. First, the heat sum of Longyearbyen, on which the calculations are based, may be not quite representative for the most continental parts of Spitsbergen, and the vertical temperature gradient may be less than 0.65^{o} / 100 m. Secondly, the Spitsbergen biotypes of several species may include some particularly hardy ones, compared to those of the North Scandes. Thirdly, the highest populations of vascular plants on Spitsbergen are situated on peaks which may protrude above the stratus for extended periods of the sunny polar summer, and surrounding glaciers and snowfields may contribute a substantial amount of reflected radiation.

Some conclusions of zonal subdivision may be drawn from this study.

The northern Arctic species belong to the broken-up vegetation encountered farthest north and inland in Spitsbergen (Elvebakk 1985, p. 282), Greenland (Holmen 1957, Fredskild 1966), and Ellesmere Land (Savile 1964). They may be adapted to a short, but sunny summer with semi-arid conditions after the snowmelt, and thus unable to persist in the maritime or southern Arctic.

The mesic Arctic species make up the zonal vegetation in the middle and northern Arctic tundra zones (Elvebakk 1985, p. 281) and show varying thermal demands. Cassiope tetragona is a remarkably selective species as regards regional and local climate (Summerhayes & Elton 1928, Holmen 1957, pp. 100-102). It seems to indicate a not too dry, continental Arctic climate, which is still in need of a better physical characterization. The Cassiope tetragona zone of Summerhayes & Elton is duly reflecting the sectional change of Spitsbergen vegetation,analogous to the North Scandes (Engelskjøn 1986 a), although Summerhayes & Elton (1928) and Eurola (1968, Fig. 10) outline the Spitsbergen distribution of Cassiope tetragona in a summary way only (cf. the present Fig. 2).

Salix polaris is a suitable vertical belt and zonal marker species (Dahl 1983). It is the last lignified species to remain with decreasing heat sum; its occurrences on Semlja Frantsa Josifa are restricted to the southern islands (Hanssen & Lid 1932), and S. polaris has not yet been recorded from Hopen. The species appears to cease at DD-2=ca. 100, which may be proposed as the limit of the most low-temperate Arctic zone still capable of supporting a few, other vascular plant species (cf. Elvebakk 1985, p. 232). I suggest the term 'desert' should be avoided for this zone, because conditions e.g. in northernmost Spitsbergen and Semlja Frantsa Josifa are not even semi-arid, according to current definitions (Neef 1970, pp. 518-519).

The maritime Arctic species are of various geographical connections, but a high proportion is amphi-Atlantic, all are absent or rare in North Greenland and Spitsbergen, and they prefer perinival or springy habitats. Accordingly, correlation between ambient air temperatures and distribution is problematic. The distribution of maritime Arctic species may be more successfully related to a prolonged autumnal season, such as on Jan Mayen, and to continuously humid conditions.

The overall distribution of these species shows northern limits in East Greenland, Bjørnøya, or the western coast of Spitsbergen, and they are widespread in the North Scandes including the Oceanic section of the mountains (Engelskjøn 1986 a).

The hemi-Arctic species occurring extrazonally in the lowland of Central Spitsbergen show an areal coincidence with DD-2 above 350. Their thermal demands may also be fulfilled in locally heated niches. For instance, the mire species Carex amblyorhyncha, Kobresia simpliciuscula, Luzula wahlenbergii, Ranunculus lapponicus, and Ranunculus pallasii grow at shallow, stagnant pools which are heated during the day up to 10-15 ^{o} (observations from Gipsdalen and Reindalen).

Hippuris vulgaris shows a similar performance on Bjørnøya. *Betula nana* and *Empetrum hermaphroditum* show a preference of well-drained, peaty or rocky slopes with an optimal sunward aspect (observations from Adventdalen and Reindalen).

The occurrences of such relatively heat-demanding species in the middle Arctic tundra zone (Elvebakk 1985, Fig. 3) is pertinent to the study of Holocene climatic oscillations in Spitsbergen, as suggested already by Nathorst (1883, pp. 64-65) and Andersson (1910, p. 411) ; see especially Zelikson (1971) and van der Knaap (1985) for traces i.a. of *Myriophyllum*.

Thermal relations of Antarctic plants

The Antarctic botanical zones show a generally more severe climate than in the Arctic with regard to low summer temperatures, high windspeed, and glacial impact. However, solar radiation attains the highest figures in the world owing to the clear air and the high elevations.

Most of the flora is cryptogamic, and the knowledge of its taxonomy, geographical distribution, and derivation, is still quite deficient.

Some conclusions of zonal and altitudinal division may be drawn from this study. The southern limit of vascular plant vegetation coincides with heat sums (DD-2) between 0 and -50, which corresponds to figures from the Arctic and from the high-alpine belt of the North Scandes. Exact figures cannot be given because of the varying impact of convective cooling and radiation.

In the maritime Antarctic a varied flora of liverworts, mosses, and all growth forms of lichens persists at a DD-2 of - 60, e.g. on Bouvetøya. However, the ground tends to be glacierized at elevations with lower heat sums, and this excludes plant life other than kryoseston, which is abundant on the firnfields of Bouvetøya.

The continental Antarctic zones are less prone to attract snow and ice on established exposures, due to less precipitation strong solar radiation and ensuing sublimation of the snow, and wind sweeping from a constant direction (MacNamara 1973).

These processes give rise to local, ice-free 'oases' or protruding nunataks, which may be dry and of an extreme polar desert nature, or wet, supporting a vegetation of mosses, lichens, algae, and cyanophyceans (Engelskjøn 1986 d).

In the continental Antarctic zone, the threshold value of moss vegetation of a slightly maritime character is DD= -100. Such vegetation, with Ceratodon purpureus and Bryum pseudotriquetrum, is encountered in the coastal oases of Dronning Maud Land (Matsuda 1968, Nakanishi 1977, Ochi 1979) and it seems related to the Ceratodon sp. - Bryum sp. - Pohlia association recorded in the maritime Antarctic (Gimingham & Smith 1970).

These species are absent from the Antarctic slope, the scarce moss vegetation of which consists of Grimmia spp. (G. grisea in Dronning Maud Land) and Sarconeurum glaciale. Limiting values for these species are DD-2= -600 and -400, respectively.

Various lichen, green algae, and cyanophycean communities persist higher and farther south on nunataks fringing the Polar plateau, with a diminishing species content and vegetative vigour. Prasiola, Usnea sphacelata, and Xanthoria elegans cease between DD-2= -500 and -700, whereas Acarospora chlorophana, Buellia frigida, Candelariella hallettensis, Lecanora expectans, Pseudephebe minuscula, Rhizoplaca melanophtalma, and Umbilicaria decussata persist between 2200 and 2450 m a.s.l., corresponding to a DD-2 of ca. -800 and lower.

The extreme upper limit of macroscopic plant life in Dronning Maud Land is ca. 2500 m a.s.l., and this vegetation consists only of a Lecidea sp. and epilithic cyanophycean/ chlorophycean mats. Calculation from various Antarctic areas (Engelskjøn 1986 d) suggests that the most hardy plants such as those quoted above may tolerate a DD-2 down to about - 1000, which is equivalent to a diurnal mean temperature of the ambient air of ca. -16^{o}, during December and January.

The term 'nunatak of the Antarctic type' has been used to describe conditions on high mountain peaks during the Vistulan glaciation on the northern hemisphere (Dahl 1946). This concept may need a qualification. It was calculated

(Engelskjøn 1986 a) that possible, higher nunataks in the North Scandes would possess a mainly non-vascular, cryptogamic vegetation during a glacial. However, the physiognomy and prevailing thermal and hydrological conditions of such a vegetation (at 65^{o} to 71^{o} N Lat.) would rather recall those of the maritime Antarctic of to-day, than nunataks of continental Antarctica. The latter are very far from affording conditions compatible with higher plant life. It may be recalled that the present summer temperature difference between the high-alpine belt of North Scandinavia and Antarctic mountains at corresponding southern latitude, and the same altitude, amounts to ca. 15 ^{o}C.

North Scandinavian nunatak climates could not possibly be severe enough to wipe out the species of bryophytes, lichens, green algae, and cyanophyceans which are now thriving in high-alpine habitats. The Antarctic experience tells that the cold-tolerant representatives of these cryptogamic groups have essentially greater tolerance of frigic conditions than vascular plant species.

* * * * *

ACKNOWLEDGEMENTS

The Botanical Garden and Museum, University of Oslo, has supported this study during the last two years' period by offering me working facilities on the grant D.70.49.085 of the Norwegian Research Council for Science and the Humanities. For recent floristic accessions from Spitsbergen, I thank my companions during the 1970 expedition: Professor H.-J. Schweitzer, Bonn and his party, as well as Mr. Arne Pedersen, Oslo, and during the 1985 expedition: Mr. Arve Elvebakk, Mr. Reidar Elven, Mr. Lasse Hodin, and Mr. Sigmund Spjelkavik, University of Tromsø, as well as Mr. Christian Brochmann, University of Oslo.
The Norwegian Governor of Svalbard, and the Norwegian Polar Research Institute, kindly contributed some logistic support on these expeditions.

R E F E R E N C E S

Aleksandrova, V. D. 1977. Struktura rastitelnykh gruppirovok polarnyj pustyni ostrova Semlja Aleksandry (Semlja Frantsa-Josifa).(The structure of plant associations of the polar deserts on the Aleksandra Land (Franz Joseph's Land). Pp. 26-36 in: Problemy ekologii, geobotaniki, botanitsjeskoj geografii i floristiki. Leningrad.

- 1980. The Arctic and the Antarctic: Their division into geobotanical areas (transl. D. Löve). Cambridge University Press. 237 pp.

Andersson, G. 1910. Die jetzige und fossile Quartärflora Spitzbergens als Zeugnis von Klimaänderungen. Pp. 409-417 In: Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit. Stockholm, Generalstabens Litografiska Anstalt.

Ando, H. 1979. Ecology of terrestrial plants in the Antarctic with particular reference to bryophytes. Pp. 81-103 in: Matsuda, T. & Hoshai, T. (eds.) Proceedings of the Symposium on Terrestrial Ecosystem in the Syowa Station area. Memoirs of National Institute of Polar Research, Special Issue, No. 11. Tokyo.

Asplund, E. 1918. Beiträge zur Kenntnis der Flora des Eisfjord-gebietes. Arkiv f. Bot. 15(14). 40 pp.

Baranowski, S. 1975. The climate of West Spitsbergen in the light of material obtained from Isfjord Radio and Hornsund. Acta Univ. Wratislaviensis 251, 21-34.

Bell, B. G. & Blom, H. H. 1986. Bryophytes of Bouvetøya. Norsk Polar-institutt Skrifter 185, - .

Berg, R. Y. 1983. Plant distribution as seen from plant dispersal. General principles and basic modes of plant dispersal. Sonderbd. naturwiss. Ver. Hamburg 7, 13-36.

Böcher, T. W. 1933. Phytogeographical studies of the Greenland flora, based upon investigations of the coast between Scoresby sound and Angmagssalik. Meddr. Grønland 104(3). 56 pp.

- 1937. Nogle Studier over Færøernes alpine Vegetation. Bot. Tidsskr. 44, 154-201.

- 1938. Biological distributional types in the flora of Greenland.

Meddr. Grønland 106(2). 331 pp.

- 1952 a. Contributions to the flora and plant geography of West Greenland. III. Meddr. Grønland 147(9). 85 pp.

- 1952 b. A study of the circumpolar Carex Heleonastes-amblyorhyncha complex. Acta Arctica 5. 32 pp., 1 pl. Societas Arctica Scandinavica, København.

- 1954. Oceanic and continental vegetational complexes in Southwest Greenland. Meddr. Grønland 148(1). 336 pp, 4 pl.

- 1956. Area-limits and isolation of plants in relation to the physiography of the southern part of Greenland. Meddr. Grønland 124(8). 40 pp.

Cameron, R. E., Lacy, G. H., Morelli, F. A. & Marsh, J. B. 1971. Farthest south soil microbial and ecological investigations. Antarctic J. of the US 6, 105-106.

Christiansen, M. P. 1942. The Taraxacum-flora of Iceland. Pp. 235-343 + 44 pl. in: Grøntved, J., Paulsen, O. & Sørensen, T. (eds.) The Botany of Iceland, 3/3(12).

Dahl, E. 1937. On the vascular plants of eastern Svalbard. Norsk Polarinstitutt Skrifter 75. 50 pp.

- 1946. On different types of unglaciated areas during the Ice Ages and their significance to phytogeography. New Phytologist 45, 225-242.

- 1963. Plant migrations across the North Atlantic Ocean and their importance for the palaeogeography of the region. Pp. 173-188 in: Löve, A. & D. (eds.) North Atlantic Biota and their History". Oxford, Pergamon Press.

- 1983. Skoggrenser og regioninndeling av arktisk-alpine områder. Kgl. Norske Vidensk. Selsk. Museet, Rapp., Bot. serie 1983(7), 60-75.

Edlund, O. 1928. Meteorologische und aerologische Beobachtungen der norwegischen Nowaja Semlja-Expedition im Sommer 1921. Rep. Sci. Res. Norwegian Exped. to Novaya Zemlya 1921,39. 55 pp.

Edwards, J. A. 1972. Studies in Colobanthus quitensis (Kunth) Bartl. and Deschampsia antarctica Desv.: V. Distribution, ecology and vegetative performance on Signy Island. British Antarct. Survey Bull. 28, 11-28.

- 1974. Studies in Colobanthus quietensis (Kunth) Bartl. and Deschampsia antarctica Desv.: VI. Reproductive performance on Signy Island. British Antarct. Survey Bull. 39, 67-86.

Elvebakk, A. 1982. Geological preferences among Svalbard plants. Inter-Nord 16, 11-31.

- 1985. Higher phytosociological syntaxa on Svalbard and their use in the subdivision of the Arctic. Nord. J. Bot. 5, 273-284.

Engelskjøn, T. 1967. Cyto-embryological studies in Arctic-alpine Taraxaca I. The Bear Island Taraxacum. Nytt Mag. Bot. 14, 125-137.

- 1981. Terrestrial vegetation of Bouvetøya. A preliminary account. Norsk Polarinstitutt Skrifter 175, 17-28.

- 1985. Botany of Gjelsvikfjella and Mühlig-Hofmannfjella, Dronning Maud Land - with some contributions from H. U. Sverdrupfjella and Vestfjella. Norsk Polarinstitutt Rapport No. 22, 43-54.

Engelskjøn, T. 1986 a. Patterns of distribution in the mountain flora of North Scandinavia. Sommerfeltia (submitted for publication).

- 1986 b. Eco-geographical relations of the Bjørnøya vascular flora, Svalbard. Norsk Polarinstitutt Skrifter (submitted for publication).

- 1986 c. Botany of Bouvetøya, South Atlantic Ocean. II. The terrestrial vegetation of Bouvetøya. Polar Research (submitted for publication).

- 1986 d. Botany of two Antarctic mountain ranges: Gjelsvikfjella and Mühlig-Hofmannfjella, Dronning Maud Land. I. General ecology and the development of the Antarctic cold desert cryptogam formation. Polar Research (submitted for publication).

- & Jørgensen, P. M. 1986. Phytogeographical relations of the Bouvetøya cryptogamic flora. Norsk Polarinstitutt Skrifter 185, - .

- , Kramer, K. & Schweitzer, H.-J. 1972. Zur flora des Van Mijenfjorden-Gebietes (Spitsbergen) und Hopens. Norsk Polarinstitutt Årbok 1970, 191-198.

Eurola, S. 1968. Über die Fjeldheidevegetation in den Gebieten von Isfjorden und Hornsund in Westspitzbergen. Aquilo, Ser. Bot. 7, 1-56.

Filson, R. B. 1974. Studies in Antarctic lichens II. Lichens from the Windmill Islands, Wilkes Land. Muelleria 3(1), 9-36.

- 1975. Studies in Antarctic lichens V: Lichenes Antarctici Exsiccati, Fascicle I, with additional notes on the taxonomy of each species. Muelleria 3(2), 146-158.

Fredskild, B. 1966. Contributions to the flora of Peary Land, North Greenland. Meddr. Grønland 178(2). 22 pp.

Gelting, P. 1934. Studies on the vascular plants of East Greenland between Franz Joseph Fjord and Dove Bay (Lat. 73°15' - 76°20' N). Meddr. Grønland 101(2). 340 pp, 4 pl.

Gimingham, C. H. & Smith, R. I. L. 1970. Bryophyte and lichen communities in the maritime Antarctic. Pp. 752-785 in: Holdgate, M. W. (ed.) Antarctic Ecology Vol. 2. Academic Press, London.

Gjærevoll, O. & Ryvarden, L. 1978. Botanical investigations on J. A. D. Jensens Nunatakker in Greenland. Kgl. Norske Vidensk. Selsk. Skrifter 1977(4). 40 pp.

Golubkova, N.S., Savitsj, V. P. & Simonov, I. M. 1969. Lichens of Western Enderby Land. Pp. 249-255 in: Collected Papers of Soviet Antarctic Expeditions (V. G. Averjanov ed.). Translation, Jerusalem.

Greene, S. W. 1964. The vascular flora of South Georgia. British Antarct. Survey Sci. Rep. 45. 58 pp.

- 1967. Bryophyte distribution. Pp. 11-13 in: Bushnell , V. C. (ed.) Antarctic Map Folio Series, Folio 5. American Geographic Society, New York.

- 1970. Studies in Colobanthus quitensis (Kunth) Bartl. and Deschampsia antarctica Desv.: I. Introduction. British Antarct. Survey Bull. 23.

- 1975. The Antarctic moss Sarconeurum glaciale (C. Muell.) Card. et Bryhn in southern South America. British Antarct. Survey Bull. 41/42, 187-191.

- , Greene, D. M., Brown , P. D. & Pacey, J. M. 1970. Antarctic moss flora: I. The genera Andreaea, Pohlia, Polytrichum, Psilopilum and Sarconeurum. British Antarct. Survey Sci. Rep. 64. 118 pp.

- & Holtom, A. 1971. Studies in Colobanthus quitensis (Kunth) Bartl. and Deschampsia antarctica Desv.: III. Distribution, habitats and performance in the Antarctic botanical zone. British Antarct. Survey Bull. 26, 1-29.

Grisebach, A. 1838. Ueber den Einfluss des Klimas auf die Begrenzung der natürlichen Floren. Linnaea 12, 159-200 (reprinted 1880 in: Gesammelte Abhandlungen und kleinere Schriften zur Pflanzengeographie pp. 1-29. Verlag von Wilhelm Engelmann, Leipzig).

Grolle, R. 1972. The hepatics of the South Sandwich Islands and South Georgia. British Antarct. Survey Bull. 28, 83-95.

Gröntved, J. 1942. The Pteridophyta and Spermatophyta of Iceland. The Botany of Iceland 4(1). 427 pp. Copenhagen.

Hadač, E. 1944. Die Gefässpflanzen des "Sassengebietes" Vestspitsbergen. Norsk Polarinstitutt Skrifter 87. 71 pp, 14 pl.

Halliday, G., Kliim-Nielsen, L. & Smart, I.H.M. 1974. Studies on the flora of the North Blosseville coast and on the hot springs of Greenland. Meddr. Grønland 199(2). 49 pp.

Hansen, K. 1966. Vascular plants in the Faeroes; horizontal and vertical distribution. Dansk botanisk arkiv 24(3). 141 pp.

Hanssen, O. & Lid, J. 1932. Flowering plants of Franz Josef Land collected on the Norwegian Scientific Expedition 1930. Norsk Polarinstitutt Skrifter 31. 42 pp.

Herzog, T. & Grolle, R. 1958. Was ist Pachyglossa? Rev. Bryol. Lichénol. N. S. 27, 147-165.

Hofmann, W. 1968. Geobotanische Untersuchungen in Südost-Spitzbergen 1960. Ergebn. der Stauferland-Expedition 1959/60 8. 83 pp. Franz Steiner Verlag, Wiesbaden.

Holmen, K. 1957. The vascular plants of PearyLand, North Greenland. Meddr. Grønland 124(9). 149 pp.

- & Mathiesen, H. 1953. Luzula wahlenbergii in Greenland. Botanisk Tidsskr. 49, 233-238.

Holtom, A. & Greene, S. W. 1967. The growth and reproduction of Antarctic flowering plants. Phil. Trans. Royal Soc. B 252, 323-337.

Hultén, E. 1955. The isolation of the Scandinavian mountain flora. Acta Soc. F. Fl. Fenn. 72(8). 22 pp.

- 1958. The amphi-Atlantic plants and their phytogeographical connections. Kgl. Svenska Vetensk.Akad. Handl. Ser. 4 7(1). 340 pp.

Huneck, S., Sainsbury, M., Rickard, T. M. & Lewis Smith, R. I. 1984. Ecological and chemical investigations of lichens from South Georgia and the maritime Antarctic. J. Hattori Bot. Lab. 56, 461-480.

Jørgensen, P. M. 1986. Macrolichens of Bouvetøya. Norsk Polarinstitutt Skrifter 185, - .

Kappen, L. 1985. Vegetation and ecology of ice-free areas of northern Victoria Land, Antarctica. 1. The lichen vegetation of Birthday Ridge and an inland mountain. Polar Biol. 4, 213-225.

Kashiwadani, H. 1970. Lichens of the Prince Olav Coast, Antarctica. Japanese Antarct. Res. Exped. Sci. Rep. Ser E 30. 21 pp, 3 pl.

Komarkova, V., Poncet, S. & Poncet, J. 1985. Two native Antarctic plants, Deschampsia antarctica and Colobanthus quitensis: a new southernmost locality and other localities in the Antarctic Peninsula area. Arct. Alp . Res. 17,401-416.

Lamb, I. M. 1964. Antarctic lichens: I. The genera Usnea, Ramalina, Himantormia, Alectoria, Cornicularia. British Antarct. Survey Sci. Rep. 38. 34 pp.

- 1968. Antarctic lichens: II. The genera Buellia and Rinodina. British Antarct. Survey Sci. Rep. 61. 129 pp.

Lid, J. 1964. The flora of Jan Mayen. Norsk Polarinstitutt Skrifter 130. 108 pp., 1 pl.

- 1967. Synedria of twenty vascular plants from Svalbard. Bot. Jahrbücher 86, 481-493.

Lindsay, D. C. 1972. Lichens from Vestfjella, Dronning Maud Land. Norsk Polarinstitutt Meddr. 101. 21 pp.

Longton, R. E. 1967. Vegetation in the maritime Antarctic. Phil. Trans. Royal Soc. B 252, 213-235.

- & Holdgate, M. W. 1979. The South Sandwich Islands. IV. Botany. British Antarct. Survey Sci. Rep. 94. 53 pp., 1 pl.

Lynge, B. 1923. Vascular plants from Novaya Zemlya. Rep. Sci. Res. Norwegian Exped. to Novaya Zemlya 1921, 13. 151 pp., 47 pl.

- 1941. On Neuropogon sulphureus (König) Elenk., a bipolar lichen. Skr. Norske Vidensk-Akad. i Oslo I. Mat.-Naturv. kl. 1940(1). 35 pp.

MacNamara, E. E. 1973. Macro- and microclimate of the Antarctic coastal oasis Molodezhnaya. Biuletyn Peryglacjalnyj 23, 201-236.

Matsuda, T. 1968. Ecological study of the moss community and microorganisms in the vicinity of Syowa Station, Antarctica. Japanese Antarct. Res. Exped. Sci. Rep. Ser E 29. 59 pp.

Müller, M. J. 1982. Selected climatic data for a global set of standard stations for vegetation science. W. Junk, Haag. 306 pp.

Nakanishi, S. 1977. Ecological studies of the moss and lichen communities in the ice-free areas near Syowa Station, Antarctica. Antarctic Rec. 59, 69-96.

Nathorst, A. G. 1883. Nya bidrag till kännedomen om Spetsbergens kärlväxter, och dess växtgeografiska förhållanden. Kgl. Svenska Vetensk.-Akad. Handl. 20(6). 88 pp.

Neef, E. (ed.) 1970. Das Gesicht der Erde. Brockhaus Nachschlagewerk Physische Geographie, Band 2. VEB F. A. Brockhaus Verlag, Leipzig. Pp. 505-908, 32 pl.

Neilson, A. H. 1968. Vascular plants from the northern part of Nordaustlandet, Svalbard. Norsk Polarinstitutt Skrifter 143. 62 pp.

- 1970. Vascular plants of Edgeøya, Svalbard. Norsk Polarinstitutt Skrifter 150. 71 pp.

Ochi, H. 1979. A taxonomic review of the genus Bryum, Musci in Antarctica. Pp. 70-80 in: Matsuda, T. & Hoshai, T. (eds.) Proceedings of the Symposium on Terrestrial Ecosystem in the Syowa Station area. Memoirs of National Institute of Polar Research, Special Issue, No. 11. Tokyo.

Óskarsson, I. 1951. Islenzkar starír. Náttúrufrædingurinn 1951(1), 1-21.

Pickard, J. 1982. Vegetation of the Vestfold Hills, Antarctica: a progress report. J. Hattori Bot. Lab. 52, 295-297.

Rudolph, E. D. 1967. Lichen distribution. Pp. 9-11 in: Bushnell, V. C. (ed.) Antarctic Map Folio Series, Folio 5. American Geographic Society, New York.

Rønning, O. I. 1959. Noen høydegrenser for planter på Spitsbergen. Blyttia 17-53-60.

- 1972. The distribution of the vascular cryptogams and monocotyledons in Svalbard. Kgl. Norske Vidensk. Selsk. Skrifter 24. 63 pp.

Savitsj-Ljubitskaja, L. I. & Smirnova, Z. N. 1961. On the modes of reproduction of Sarconeurum glaciale (Hook. f. & Wils.) Card. & Bryhn, an endemic moss of the Antarctic. Rev. Bryol. Lichénol. 30, 216-222.

- & - 1969. Mosses of East Antarctica. Pp. 484-487 in: Atlas Antarktiki 2. Hydrometeorological Publishing House. Leningrad.

Savile, D. B. O. 1964. General ecology and vascular plants of the Hazen Camp area. Arctic 17, 237-258.

Schuster, R. M. 1969. Problems of antipodal distribution in lower land plants. Taxon 18, 46-91.

- 1979. On the persistence and dispersal of transantarctic Hepaticae. Can. J. Bot. 57, 2179-2225.

Schweitzer, H.-J. 1966. Beiträge zur Flora Svalbards. Norsk Polarinstitutt Årbok 1964, 139-148.

Seidenfaden, G. & Sørensen, T. 1937. The vascular plants of Northeast Greenland from 74°30' to 79°00' N. lat. and a summary of all species found in East Greenland. Meddr. Grønland 101(4). 215 pp., 4 pl.

Seppelt, R. D. 1984. The bryoflora of the Vestfold Hills and Ingrid Christensen Coast, Antarctica. ANARE Res. Notes 20, 1-31.

Siple, P.A. & Passel, C. F. 1945. Measurement of dry atmospheric cooling in sub-freezing temperatures. U.S. Antarctic Service Expedition 1939-41. Proc. American Philos. Soc. 89, 177-199.

Skottsberg, C. 1954. Antarctic flowering plants. Svensk bot. Tidskr. 51, 330-338.

Smith, R. I. L. 1971. An outline of the Antarctic programme of the Bipolar Botanical Project. Pp. 50-71 in: Heal, O. W. (ed.) Proceedings IBP Tundra Biome working meeting on analyses of ecosystems, Kevo, Finland, September 1970.

- 1972. Vegetation of the South Orkney Islands with particular reference to Signy Island. British Antarct. Survey Sci. Rep. 68. 124 pp., 6 pl.

- 1982. Farthest south and highest occurrences of vascular plants in the Antarctic. Polar Rec. 21(131), 170-173.

- 1984. Terrestrial plant biology of the sub-Antarctic and Antarctic. pp. 61-162 in: Laws, R. M. (ed.) Antarctic Ecology I. Academic Press, London.

- & Corner, R. W. M. 1973. Vegetation of the Arthur Harbour-Argentine Islands reqion of the Antarctic Peninsula. British Antarct. Survey Bull. 33/34, 89-122.

Steffensen, E. 1969. The climate and its recent variations at the Norwegian arctic stations. Meteorol. Ann. 5(8), 217-349.

- 1982. The Climate at Norwegian Arctic stations. Klima 5. 44 pp.

Summerhayes, V. S. & Elton, C. S. 1928. Further contributions to the ecology of Spitsbergen. J. Ecol. 16, 193-268.

Sunding, P. 1962. Høydegrenser for høyere planter på Svalbard. Norsk Polarinstitutt Årbok 1960, 32-59.

- 1965. Plantefunn fra Vestspitsbergen sommeren 1963. Norsk Polarinstitutt Årbok 1963. 169-172.

- 1966. Plantefunn fra Vestspitsbergen sommeren 1964. Norsk Polarinstitutt Årbok 1964, 149-154.

Sørensen, T. 1933. The vascular plants of East Greenland from 71°00' to 73°30' N. Lat. Meddr. Grønland 101(3). 177 pp., 20 pl.

Tolmatsjev, A. I. 1963. Arktitsjeskaja flora SSSR. IV. Lemnaceae-Orchidaceae. Akademija Nauk SSSR, Leningrad. 95 pp.

- 1964. Arktitsjeskaja flora SSSR. II. Gramineae. Ibid. 273 pp.

- 1966 a. Arktitsjeskaja flora SSSR. III. Cyperaceae. Ibid. 174 pp.

- 1966 b. Arktitsjeskaja flora SSSR. V. Salicaceae - Portulacaceae. Ibid. 207 pp.

van der Knaap, W. O. 1985. Human influence on natural Arctic vegetation in the 17th Century and climatic change since A. D. 1600 in Northwest Spitsbergen: a paleobotanical study. Arct. Alp. Res. 17, 371-387.

Vinje, T. 1962. The cooling power in Antarctica. Norsk Polarinstitutt Årbok 1961, 7-22.

Walker, F. J. 1985. The lichen genus Usnea subgenus Neuropogon. Bull. British Museum (Natural History) Bot. Ser. 13(1). 130 pp.

Walton, D. W. H. 1984. The terrestrial environment. Pp. 1-60 in: Laws, R. M. (ed.) Antarctic Ecology I. Academic Press, London.

Zelikson, E. M. 1971. Palynological investigation of a Holocene peat deposit from Spitsbergen. Pp. 199-212 in: Neustadt, M. I. (ed.) Holocene Palynology. 3d International Palynological Conference, Novosibirsk, USSR, 1971. Moskva.

Øvstedal, D. O. 1983 a. Some lichens from H. U. Sverdrup Mountains, Dronning Maud Land, Antarctis. Nova Hedwigia 27, 683-690.

– 1983 b. Some lichens from Vestfjella. Dronning Maud Land, Antarctis. Cryptogamie, Bryol., Lichénol. 4, 217-226.