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The Greenland Mountain birch zone, Southwest Greenland

edited by

B. Fredskild & S. Ødum

Bioscience
33 · 1990

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The Greenland Mountain birch zone, an introduction

BENT FREDSKILD and SØREN ØDUM

Fredskild, B. and Ødum, S. 1990. The Greenland Mountain birch zone, an introduction. – Meddr Grønland, Biosci. 33, 3–7 pp. Copenhagen 1990-9-28.

The immigration and present distribution of the Greenland "trees": *Alnus crispa* (Ait.) Pursh, *Betula pubescens* Ehrh. s.l. and *Sorbus groenlandica* (Schneid.) Löve & Löve is summarized. As a consequence of a very limited knowledge of the ecological conditions in this zone, the Nordic Subarctic Birch Project (SBP) organized a field trip to S Greenland in 1984 followed by a symposium in Copenhagen in 1988. The present volume of Meddr Grønland brings the results of these two events.

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Several papers, e.g. Rosenvinge (1896) and Böcher (1954, 1979) deal with the phytogeographical position of S Greenland, but not until recently a mapping of the vegetational zones of the area has been presented (Fig. 1, Feilberg 1984). Low forests of *Betula pubescens* with *Sorbus groenlandica* and *Salix glauca* are found in protected valleys in the interior, viz. in the subcontinental, subarctic, and in the suboceanic, low- or subarctic zone. The zonation, reflecting the strong climatic gradient from the cool, hyperoceanic outer coast to the subcontinental interior with fairly warm summers, is based on the distribution maps of 346 phanerogams (Feilberg

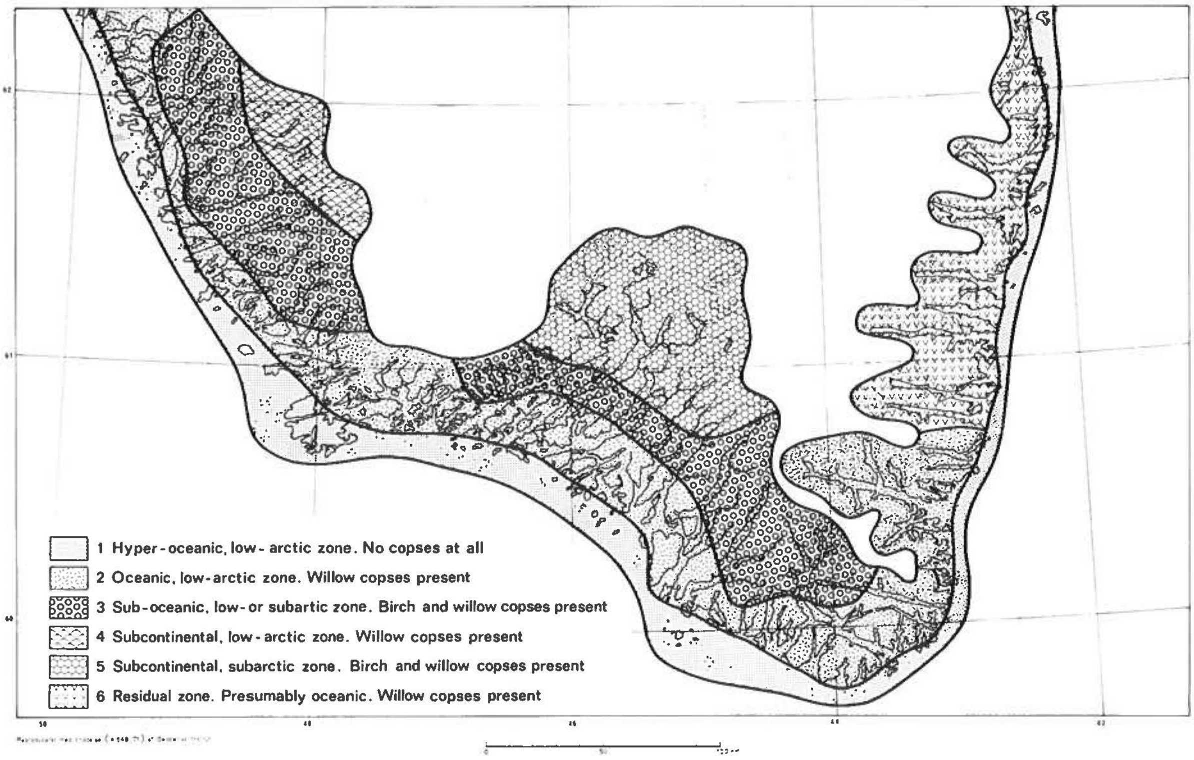

Fig. 1. South Greenland vegetational zones (after Feilberg 1984).

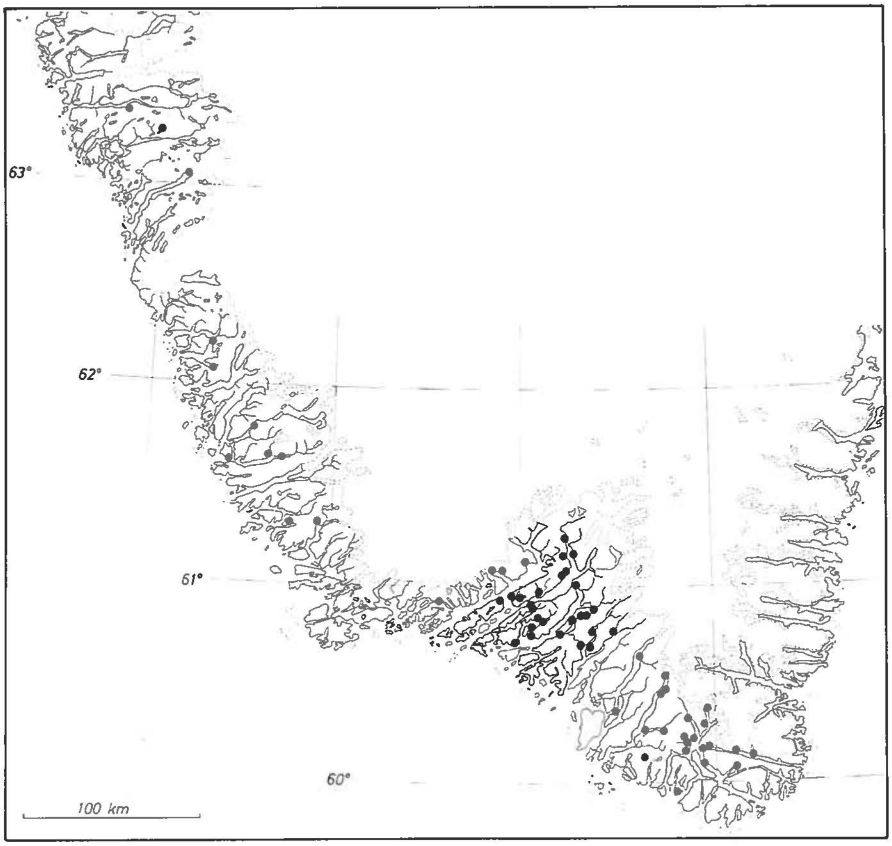

Fig. 2. The Greenland distribution of *Betula pubescens* Ehrh. s.l.

1984). The distribution maps of the three Greenland "trees": the European *Betula pubescens* (Fig. 2) and the American *Sorbus groenlandica* (Fig. 3) and *Alnus crispa* (Fig. 4) especially towards their N limit clearly reflect their preferring the interior with mean July temperature at ca. 10°C against ca. 6°C at the coast.

Alnus reached SW Greenland between 4000 and 3500 ^{14}C years B.P. (Fredskild 1983). Comparing its restricted area in Greenland with that in Canada, where it is a main component in the forest-line scrub zone, it seems odd that with one exception it is not found in S Greenland proper. Böcher (1979) explains this as a

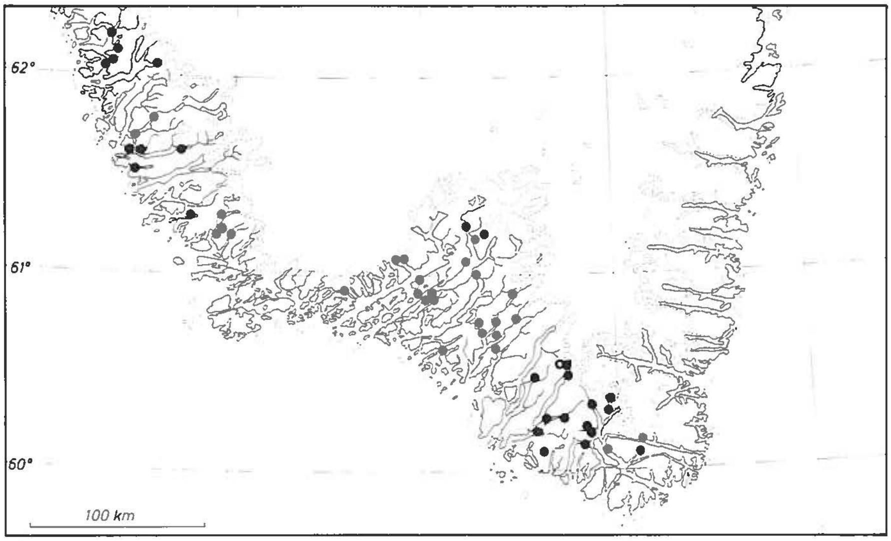

Fig. 3. The Greenland distribution of *Sorbus groenlandica* (Schneid.) Löve and Löve (after Feilberg 1984).

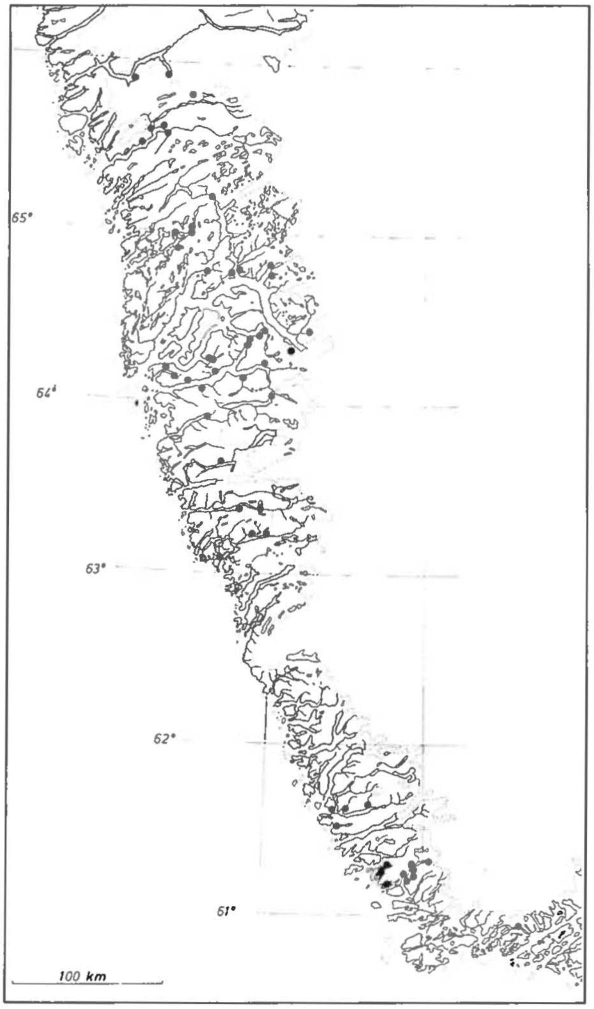

Fig. 4. The Greenland distribution of *Alnus crispa* (Ait.) Pursh.

result of too humid conditions in the south, cfr. the replacement of *Alnus crispa* by *A. sinuata* in the S Alaskan coastal mountains. However, compared with the conditions along the Labrador coast where *Alnus crispa* is growing, the climate in the interior S Greenland should not prevent its growing here, which thus may be caused by lack of dispersal. Difficulties in spreading may also explain the surprisingly big differences in immigration date of *Betula glandulosa* even to nearby localities in S Greenland. Thus, this species immigrated at the head of Tunugdliarfik, vis-à-vis Narssarssuaq, ca. 4400 B.P., while in Igaliko Fjord two fruits were found in a sample dated at 4710 ± 75 B.P. (K-5197), and in the Kap Farvel region its arrival, to three lakes, has been dated between 4000 and 3700 B.P. The only dating of *Betula pubescens* is at the first mentioned place, where it came ca. 3600–3400 B.P. Judging from the pollen size, the two species soon began crossing, resulting in plants with intermediate pollen size. Pollen of the entomophilous *Sorbus groenlandica* has only been found in one loc., viz. Drepanocladus Dam, a tiny pond at the head of a fjord behind Kap Farvel. Here, its pollen was frequent from the beginning of the sedimentation, ca. 2200 B.P., and to the beginning of the Norse era; however when this species immigrated cannot be told.

The Norse landnam in S Greenland, just before A.D. 1000, drastically changed the nature: grazing of sheep, goats, cattle and horses, tree cutting for fuel and timber, peeling of sods for house building, etc. reduced tree growth, broke the thin vegetation cover (Fredskild 1978, 1988) and caused soil erosion in those areas most exposed to the foehn winds (Jacobsen and Jakobsen 1986). However, after 4–5 centuries of utilization of the land, the Norsemen's gradually leaving the stage, resulted in recovery of the forest, at least locally. In recent centuries, the local population of man has been cutting birches for fuel (Fig. 5) mostly on slopes towards the fjords, by which it could be sailed to the settlements, leaving remote valleys less exploited (Oldendow 1935). In 1930, the most well-known forest clad valley, Qingua-dalen, was protected.

The introduction of sheep-breeding, at the beginning of this century, once again locally changed the vegetation severely, and whereas *Salix glauca* can stand biting

Fig. 5. Birch fuel and children (after Oldendow 1935).

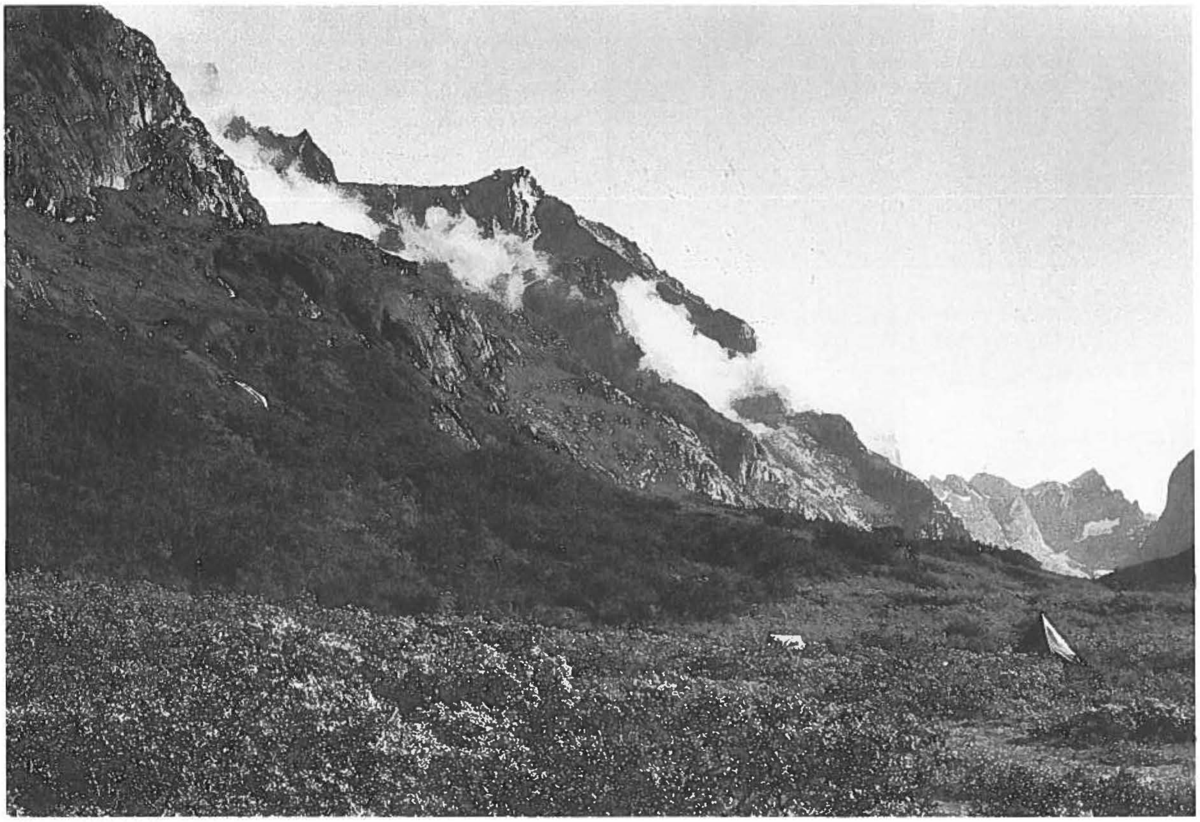

Fig. 6. Birch woodland (dark) and *Salix glauca* copse (foreground) on SE-facing slope in Qingua-dalen (S. Ødum phot.).

to a certain degree, no regrowth of *Betula pubescens* is found where even a few sheep are grazing. Luckily, some of the most vulnerable birch forest areas are now being protected by fencing.

The simultaneous interest in expansion of sheep-farming activities and awareness of the vulnerability of the ecosystem of the birch forest zone has, during the last decade, resulted in more comprehensive investigations (Thorsteinsson 1983, and twelve reports, published 1984–87 by the "Working party concerning environment and sheep-breeding in Greenland"). Only a few recent papers are, however, dealing with the Mountain birch proper and the birch forest (Kuivinen and Lawson 1982, Elkington and Jones 1974).

At The Treeline Symposium, held in Kevo and Abisko 1977 (Kallio and Sonesson 1979), it was evident that the SW Greenland birch forest zone and treeline conditions were less well-known, whereas numerous studies have been carried out along treeline in Fennoscandia, Iceland and in North America. At that symposium, the Nordic Subarctic Birch Project (SBP) was established, and members of the project decided to plan a workshop in Greenland in 1984 with the purpose of carrying out studies here, parallel to corresponding ones in Fennoscandia.

The fieldwork took place in Qingua-dalen (Fig. 6) and in Narssarssuaq during a three-week period in July-August and was supported by the Commission for Scientific Research in Greenland, The Experimental Station in Upernaviarssuk, and by Nordiske Forskersymposier. At a subsequent symposium, at the Botanical Institute, University of Copenhagen and the Arboretum in Hørsholm in June 1988, also supported by Nordiske Forskersymposier, results of the investigations were presented and discussed.

In the present book, these and related studies are published – as a kind of receipt for the economic and other kind of support from the said institutions and others, a help that is highly acknowledged.

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Mapping and monitoring of woodlands and scrub vegetation in Qingua-dalen, South Greenland

JON FEILBERG and STEN FOLVING

Feilberg, J. and Folving, S. 1990. Mapping and monitoring of woodlands and scrub vegetation in Qingua-dalen, South Greenland. – Meddr Grønland, Biosci. 33, 9–20 pp. Copenhagen 1990-9-28.

The vegetation in the S Greenland valley Qingua-dalen, containing the best developed, subarctic birch "forest" has been mapped by two different methods. The one combined the use of false infrared air photos with ground truthing, resulting in the map Fig. 5. Besides, a description of the woodland with analyses of the forest floor vegetation is given. The second method includes the use of data recorded by the Multi Spectral Scanner onboard the Landsat satellite. Finally advantages and disadvantages of the two methods are discussed.

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In 1984, the authors participated in the excursion to Qingua-dalen arranged by the Subarctic Birch Project. The area is poorly mapped, although being one of the best known woodland localities in the Julianehåb district, appearing as a subarctic oasis (Böcher 1979) – only slightly grazed by a few roaming sheeps and marked by visitors only to a very small degree.

The summer of 1984 was moreover used for field work as part of projects of the "Working party concerning environment and sheep-breeding in Greenland" (Arbejdsgruppen vedrørende Miljø og Fåreavl), Ministry of Greenland. One project concerned vegetational description (analyses of shoot density and degree of cover) and vegetation mapping (Feilberg 1985), the other concerned monitoring of potential pasture and its regional distribution (Folving 1984). The aims of the projects and their vegetation mapping were quite different, but as they both dealt with the nature of Qingua-dalen (vegetation types, landscape elements) there were obvious reasons for comparing the methods applied.

The area was revisited in 1985 in connection with a campaign to measure spectral reflection from various surface types in the Kugssuaq area and in 1986 in connection with the establishing of reference areas.

The investigation area

Qingua-dalen is situated in the southernmost part of Greenland (60°18′N, 44°30′W), 10 km east of Tasermiut (Fig. 1). It reaches from the east end of lake Tasersuaq (50 m a.s.l.) to a high mountain ridge about 12.5 km northeast. From the bottom of Qingua-dalen, a pass, 700 m a.s.l., leads southeast to the fiord Ilua. The valley is U-shaped with a bottom mainly consisting of glaciofluvial deposits. At several places rock outcrops are forming sort of thresholds, whereas moraines, consisting of concentrations of boulders, are rare, mostly to be found in the interior of the valley. Small crests of till may be found along the lower sides of the valley, and till may also be found in the screes, at most places covering part of the valley sides, especially the northwest-facing side. At several places there are landslides, and loose deposits are found as downwash from the rocks higher up. The luxuriance of the vegetation is decreasing towards the interior, and the area around the meltwater lake is dominated by fell-field. The surrounding high mountains, built up of gneiss and granite, are distinctly alpine, sheltering the valley. Wind-swept barrens are found only at the mouth of the valley, and small dunes can be seen along the shore of the lake. At several places levées are formed along the river which often becomes braided.

Climate

There are no weather records from the valley. The temperature is presumably the same as recorded at the stations in the inner fiords with mean temperature above 10°C during summer. The precipitation is probably influenced by the sheltering effect of the alpine

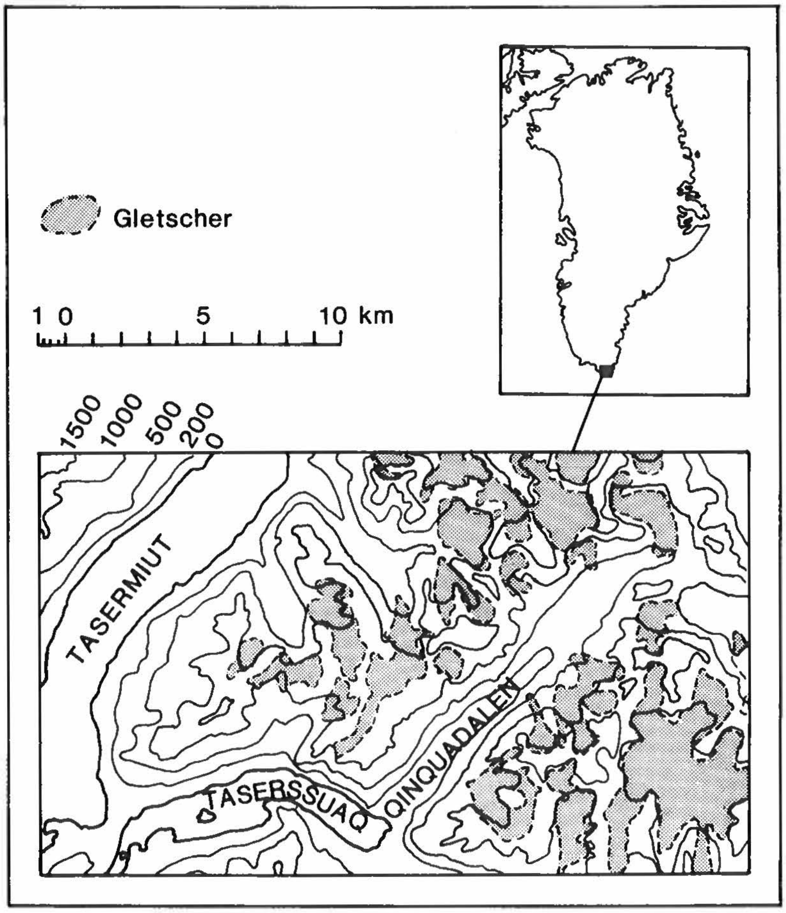


Fig. 1. Sketchmap of Qingua-dalen and the geographical location.

landscape and the specific location of the valley. However, judging from the vegetation, the total amount of precipitation may be greater than recorded at the inland stations farther to the north. The strongest wind is supposedly the foehn, probably never reaching extreme velocities due to the very well sheltered exposure of the valley. The fiord wind from the lake is the most frequent.

Fig. 2 shows hydroterm diagrams from four stations more to the north. The precipitation shelter in Qinguadalen is expected to be somewhat larger than in Narsaq and the continentality to be approximately the same as in Narssarssuaq (Folving 1984, Feilberg 1984).

Vegetation

The luxuriant woodland and scrub-vegetation in Qingua-dalen is unique for Greenland. Dwarf-shrub heaths are characterized by the frequent occurrence of *Ledum groenlandicum*. Common are also *Vaccinium uliginosum* ssp. *microphyllum, Betula glandulosa* and *Juniperus communis,* while *Empetrum nigrum* ssp. *hermaphroditum* and *Phyllodoce coerulea* are less frequent. Lichen heaths cover the well-drained plateaus, often rich in *Betula glandulosa* and *Nardus stricta.* Grassland slopes, here exclusively dominated by *Nardus stricta,* have a remarkably limited distribution compared to other parts of S Greenland. The otherwise typical grassland dominated by *Deschampsia flexuosa* or *Agrostis hyperborea* is not found. Only where snow persists for long periods there are grassland slopes. Fens are dominated by *Carex rostrata, Carex rariflora* and by luxuriant moss communities.

In the transition zone between the birch forest and the rocky sides there are small stripes with herb-slopes, rich in species and being especially remarkable for the luxuriant occurrence of *Streptopus amplexifolius.*

The riverbed is often densely covered with *Chamaenerion latifolium.*

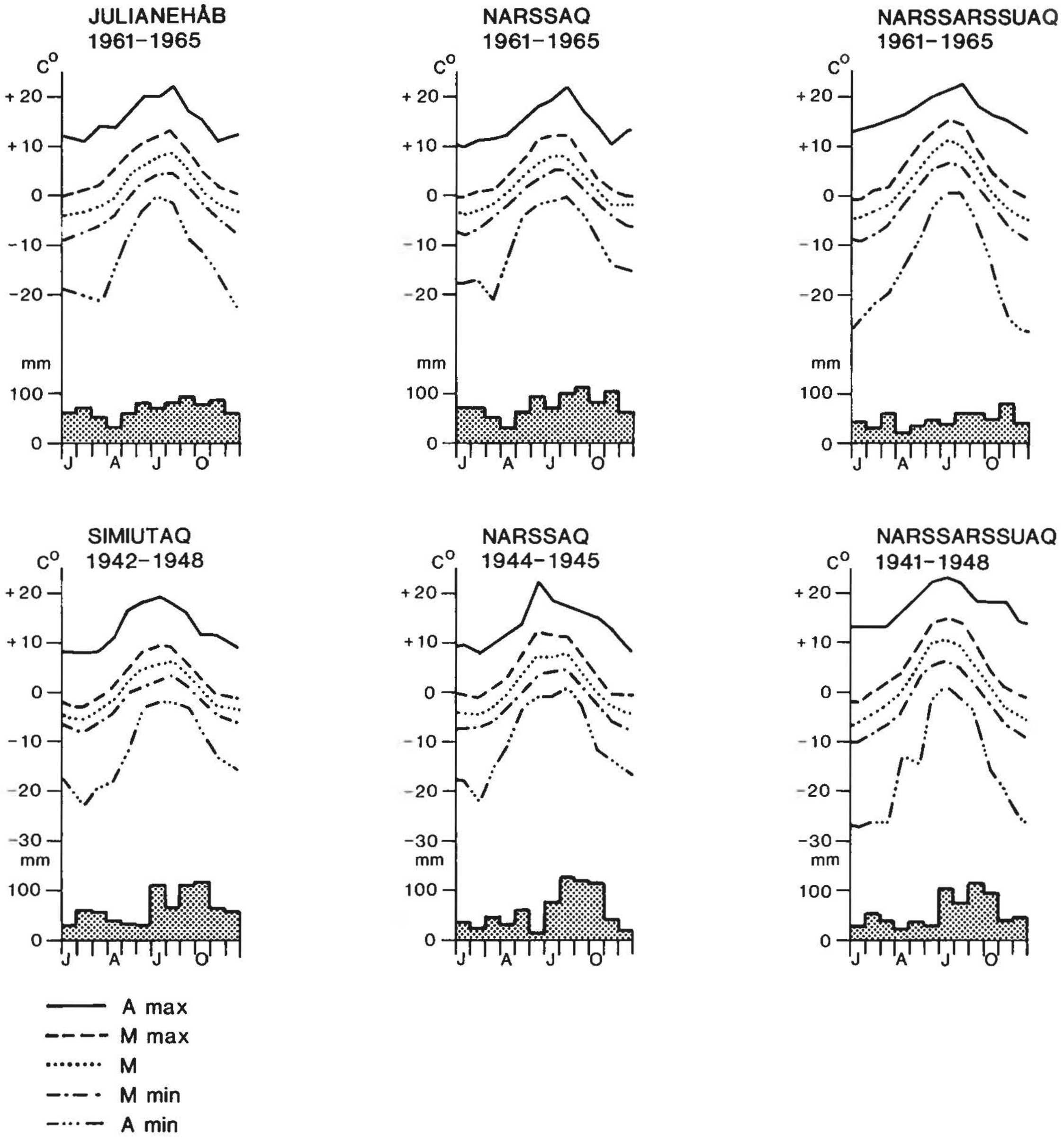


Fig. 2. Hydroterms from two periods from stations representing maritime (Julianehåb and Simiutaq), intermediate (Narssaq) and continental climates (Narssarssuaq).

History

The ruins from the Norse settlers (app. 1000–1400, Krogh 1982) indicate a rather effective exploitation of the woodlands in this period. After the disappearance of the settlers the whole area was left undisturbed for more than three centuries. With the new colonization there was a large need for fuel both for housekeeping and for production of whale oil. So all the accessible, forested areas in the fiords were felled – and to such a degree that in the 1930'es plans were made for replanting the area (Oldendow 1935). Draining was also started in order to further the tree growth, obviously without any effect. Today, the remaining forested area in Qingua-dalen is protected, and after all there is a reasonable hope for the survival of this unique scenery.

Methods

Analyses were made along lines of 20 m. Shoot density was measured for every metre, degree of cover for every fifth metre. For recording the shoot density a modified Raunkjær "circle stick" was used (Böcher 1975). However, instead of Böcher's values 1, 2 and 3, we prefer the values 10, 100 and 1000. The shoot density indexes of each species is the average of all 20 records. In most cases the index is giving an indication of the number of shoots per m^2.

For the determination of degree of cover we used a 0.9×0.9 m frame, divided in dm^2 by means of nylon thread. The measuring was made as follows: When placed on the vegetation, the plant species under each of the 100 points of intersection formed by wire and frame were registered by a thin, vertical steel stick. The degree of cover is the average of four recordings. Degree of cover of vegetations more than knee-high was not dealt with. All results are shown with one significant figure.

Description

The woodland is developed within the lower 7 km of the valley up to an altitude of app. 200 m (Fig. 3). The dominating tree is *Betula pubescens* ssp. *tortuosa* which is also forming the timber line in Scandinavia. It is polycormic and gnarled. The highest tree recorded was 10.25 m (Bjerge, pers. comm.), but there were many trees app. 9 m high. One tree had a trunk that was 14 m long, however, partly lying down. The average height is estimated to be approx. 6 m. The thickest trunk found was approx 40 cm in diameter at a height of one metre.

Sorbus groenlandica, the other tree-species of the valley, was frequently found on the northwest-facing slope but only in small stands. This tree is also polycormic, the trunks are, however, usually erect. The highest tree was approx. 5 m, the diameter of the trunk being 10 cm.

Salix glauca, elsewhere being distinctly shrub-like, sometimes attained dimensions similar to those of *Sorbus.* Due to the polycormic, gnarled *Betula* and the *Salix glauca* copse the woodland is almost impenetrable, and only in well-drained places open woodland-types with sedge-rich vegetation are found.

Four analyses were made on the woodland floor, three in 1984 an one in 1986. Only one vegetation-type was not dealt with: the moss-rich birch woodland which covers parts of the northwest-facing sites in the lower part of the valley.

Fig. 3.
Dense, mixed birch forest in Qingua-dalen.
(J. Feilberg phot.).

Results (Table 1)

The open birch woodland on drained soil (analysis 82) is rich in species although *Deschampsia flexuosa* is covering the greater part of the area.

The open birch woodland on semi-moist soil (analysis 84, Fig. 4) is rich in species as well, also with a great deal of dwarf-shrubs.

The last two types analysed (nos 209 and 83), are very dense birch woodland, consequently poorer in species, but they are much alike in composition of species.

Mapping

IR-airphotos

The airhotos used in this study were taken by the Geodetical Institute for "The Commission for Scientific Research in Greenland" at the request of mag. Ingvi Thorsteinsson. The photos were used without geometric rectification.

Method

Mapping was made by a combination of delineating the vegetation types on the airphotos and stereoscopic evaluation. The fairly small scale, app. 1:3.000, and the fact that the photos were taken in false colour, faciliated the interpretation very much. In fact it was in some places possible to identify single trees.

Field observations and photos, especially panoramic photos, taken from the valley sides, in many cases helped the interpretation.

Fig. 4. Open birch forest in Qingua-dalen, on SW facing slope. Max Hagman as scale (S. Ødum phot.).

Results

The map (Fig. 5) shows the distribution of plant communities. In some places the vegetation was so patchy, e.g. lichen heaths or willow copses mixed with birch woodland, that a combination of signatures was used.

The largest woodlands cover the south-east side of the river. Here the woodland is only interrupted by ravines or well-drained, wind-swept hills. Willow scrub and dwarf-shrub heath cover the remaining area of the valley side. Fens are mostly developed on the river plain.

The satellite image

The scene used was recorded on August 30, 1979. The data therefore represent the situation during the last part of the period of growth in a year with normal temperature variations, but with only half the normal precipitation (Folving 1984).

The data has been recorded by the Multispectral Scanner (MSS) onboard Landsat – from a height of appr. 900 km. The single picture elements, pixels, represents the average reflection from the ground within four spectral bands: 500–600, 600–700, 700–800 and 800–1100 nm- corresponding to green-, red- and nearinfrared light.

Method

The first step consists of a geometrical rectification of the data. The satellite image has been fitted to a standard 1:250.000 topographical map.

The original data from the multispectral scanner has

Table 1. Analyses of degree of cover (D) and shoot density index (S) in four Mountain birch woodlands in Qingua-dalen.

Analysis no:	*82*	*209*	*84*	*83*
Drainage condition:	Good	Medium	Medium	Poor
D = Degree of cover % (S) = Shoot density index (1–1000)	D(S)	D(S)	D(S)	D(S)
Shrubs				
Betula pubescens ssp. tortuosa	9(1)	6(50)	8(1)	2(1)
Sorbus groenlandica				+
Dwarfshrubs				
Empetrum nigrum ssp. hermaphroditum			2(50)	
Juniperus communis ssp. nana	5(9)		4(3)	
Ledum groenlandicum	+(1)	1(6)	20(20)	10(70)
Rubus saxatilis	5(20)			
Salix glauca	2(1)	9(3)	2(6)	5(3)
Vaccinium uliginosum ssp. microphyllum			2(1)	
Monocotyledones				
Agrostis hyperborea	1(1)	3(30)	5(100)	1(6)
Calamagrostis hyperborea			5(50)	
Calamagrostis langsdorfii		5(6)		6(6)
Carex atrata	+			
Carex bigelowii	5(60)	10(60)	+	20(30)
Carex macloviana	+			
Deschampsia flexuosa	40(600)	40(500)	20(300)	10(300)
Festuca rubra	3(50)		1(6)	
Listera cordata	+(5)		1(10)	1(50)
Luzula multiflora			+(2)	
Nardus stricta			+(1)	
Platanthera hyperborea			+	
Poa glauca/nemoralis	3(20)		+(2)	
Poa pratensis	3(70)	3(3)	2(10)	3(50)
Roegneria virescens	+(1)			
Streptopus amplexifolius				+
Dicotyledones & Pteridophyta				
Alchemilla filicaulis			+	
Angelica archangelica ssp. norvegica	1(70)	4(2)	7(3)	2(70)
Bartsia alpina			+	
Campanula gieseckiana	9(200)	1(50)	2(200)	
Cerastium alpinum	2(10)			
Cerastium fontanum ssp. scandicum	2(30)			
Chamaenerion angustifolium	1(5)		3(2)	
Coptis trifolia	+(50)		2(100)	+(1)
Equisetum arvense	1(70)	2(50)	1(1)	2(2)
Equisetum silvaticum		5(1)	7(5)	10(20)
Gymnocarpium dryopteris	10(60)		1(6)	
Hieracium lividorubens	1(1)		3(3)	
Lycopodium annotinum	+(3)		1(60)	2(20)
Polygonum viviparum			+	
Potentilla tridentata			1(1)	
Rhinanthus minor	+(6)	+(1)	+(1)	
Stellaria calycantha	+(1)	2(60)		7(100)
Taraxacum croceum			2(2)	
Thalictrum alpinum	5(80)	+(1)	2(30)	
Veronica fruticans	+(1)			
Mosses and lichens	2	7	2	13

been transformed into a vegetation index (Folving 1986) and has been transformed by a Principal Component Analysis (Davis 1973).

A. Vegetation index

The Normalized Vegetation Index (NDVI) is proportional to the amount of biomass and therefore expresses something about the luxuriance of the vegetation in the area. The index is calculated by dividing the difference between nearinfrared light and red light with their sum. The value of NDVI varies between 1 and −1. Normal healthy vegetation will absorb the red light and reflect most of the infrared light thus giving rize to positive NDVI values; the higher the value the higher the density or vigorousity of the vegetation. Non vegetated areas will normally have negative values. The division removes topographically induced variations in the reflection pattern because the irradiance variation caused by topographical variation is equal for the bands used in the calculation of NDVI. Figure 6 (below, curve A) shows the variation of the index along the profile 2 across the valley.

B. Principal component analysis

The single channels correlates two and two which means that they contain redundant information (Fig. 6). A principal component analysis will, among other things, compress the data: the first principal component carries 95% of the total variation, the second principal component carries a little more than 4% of the variation. It is easily seen that only the two first principal components are needed to express the variation of the original four datasets. At the same time the information are arranged in a very convenient way.

According to the principal component transformation used here the first principal component (Fig. 6, curve B) gives information on both the luxuriance of the vegetation and the topographical variation. The second principal component (Fig. 6, curve C) has been used because it is negatively correlated with the density of the vegetation, and especially because it can be used to eliminate dubious, partly snow covered areas.

C. Classifications

The first principal component, the vegetation index, and the second principal component has been rescaled and used to form a new data set.

The classification has been performed as an autoclassification, which means that the criteria has been purely statistical – i.e. not controlled by ground truth data.

In the first classification the whole data set was used including all areas without vegetation. The second classification, which has a better resolution (see below), has excluded all areas without vegetation, for instance snow and bare rock. The number of classes used is also different – in the first example 20 classes, in the second 25 classes have been used.

Fig. 5. Vegetation map of the outher part of the Qingua-dalen, based on field work and interpretation of airphotos.

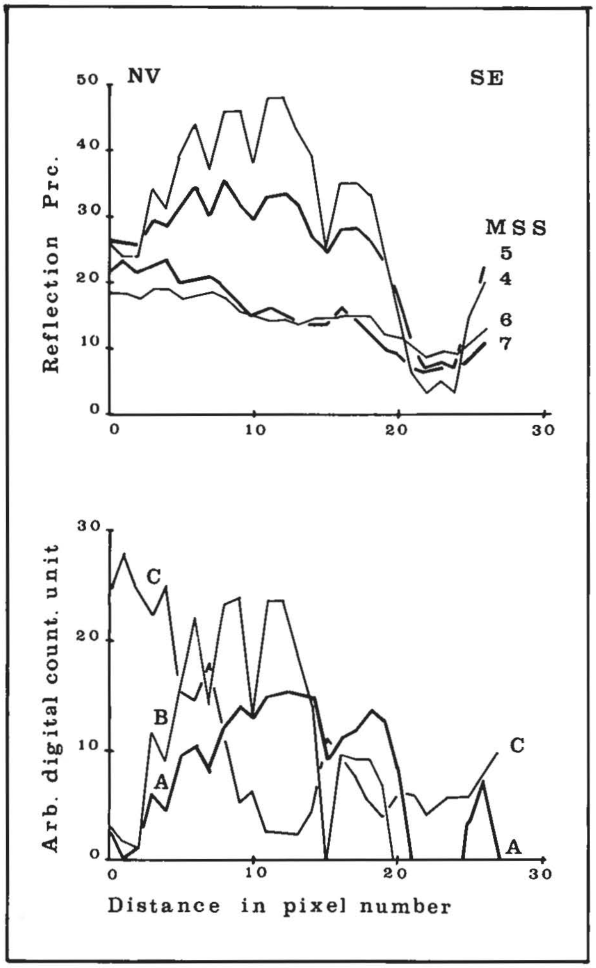


Fig. 6. The variation of the data along profile 2. Above the original data showing the strong, coupled correlation between the visible and the infrared bands.
Below: A = the vegetation index. B = the 1. principal component and C = the 2. principal component.

Results

The contents of the classes according to the first classification is given below – the color refers to the map (Fig. 7). Surface types without color indicated are not included in the map:

1 – rocks (with very little vegetation)	black
2 – mostly heath on level land	light green
3 – snow	
4 – rock	
5 – luxurious scrub etc. S-exposed	dark green
6 – rock	
7 – snow	
8 – S-exposed well vegetated slopes	green
9 – N-exposed very poorly vegetated slopes	red
10 – snow	
11 – water or deep shadow	
12 – luxuriant vegetation on N-facing slopes	yellow
13 – rock in shadow	
14 – snow	
15 – snow	
16 – fairly luxuriant vegetation on N-slope	pink
17 – snow	
18 – rock	
19 – fairly luxuriant vegetation on S-slope	dark greenish
20 – rocks	

The vegetation can be grouped in main types (Fig. 8). Class 5, 8 and 19 (open stars) represent the more luxurious types on the south exposed slopes. Class 9 and 16 (open triangles) represent the less luxuriant scrubs, heaths and grassy areas on north- and northwest facing slopes. The classes 2 and 12 (closed circles) are representative for the luxuriant north- and northwest facing vegetation types. Class number 1 (circle with closed star) is a characteristic transitional type almost without vegetation on south facing slopes.

Fig. 9 (right) shows the centroids of the classes relative to NDVI (x-axis) and first principal component (y-axis).

This preliminary classification gives a rather good impression of the general tendency of the variation in the vegetation of the area but does not allow documentation of a close connection to more well defined plant communities.

The second classification has been carried out in order to achieve a better resolution and a better connection to the dominant plant communities. Since the biomass production in comparative plant communities is directly connected with the solar irradiation, the separation of different exposures is most important.

Fig. 9 (left) shows the centroids of the classes corresponding to this classification in the same way as mentioned above.

The spatial variation of the classes can be seen on the map (Fig. 10). P. 1 show the area in "normal" false color presentation and gives the reason for the use of the rather large number of rock and snow classes which has to be used in order to separate unwanted areas from the vegetation covered land, which is shown as black on this map. P. 2 show the groups which are indicated by roman numerals on Fig. 9. Group I is red, II yellow, III dark green, and IV orange. These "colored areas" corresponds to the total vegetation covered area. All other surface types (incl. water) are shown in grey on this map.

Fig. 10, P. 3 show groups I and II in full resolution: 1 – red, 16 – dark green, 9 – olive, 20 – green, 5 – yellow, 13 – orange and 22 – brown. The other vegetation classes belong to the south- and southeast exposed slopes. All classes in group I belong to scrub-types and in rare cases to the luxurant grass/herbslopes. Group II show heath-types and more steppe-like types and transitional types between scrub and rock surfaces.

The area belonging to group I and II has been shown in black on Fig. 10, P. 4, where the rest of the vegetationclasses is colorcoded as follows: 23 – red, 3 – dark

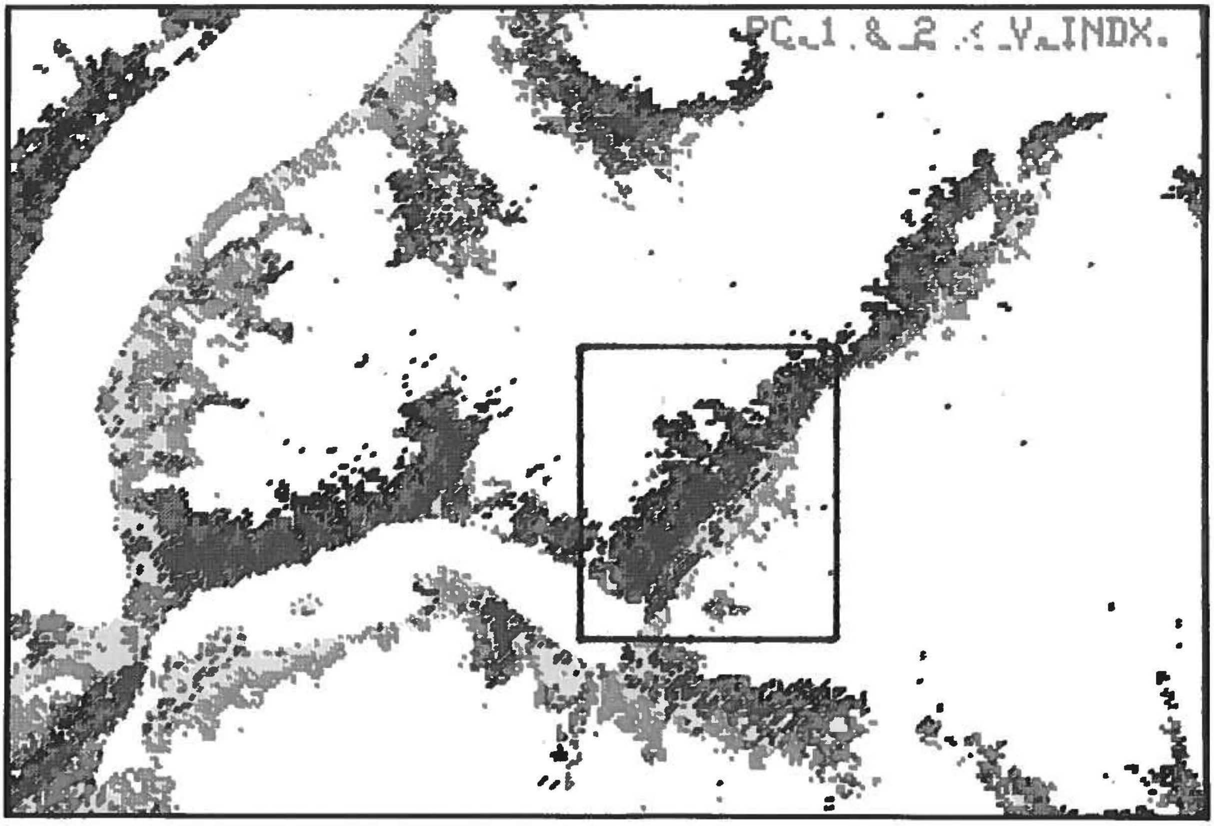
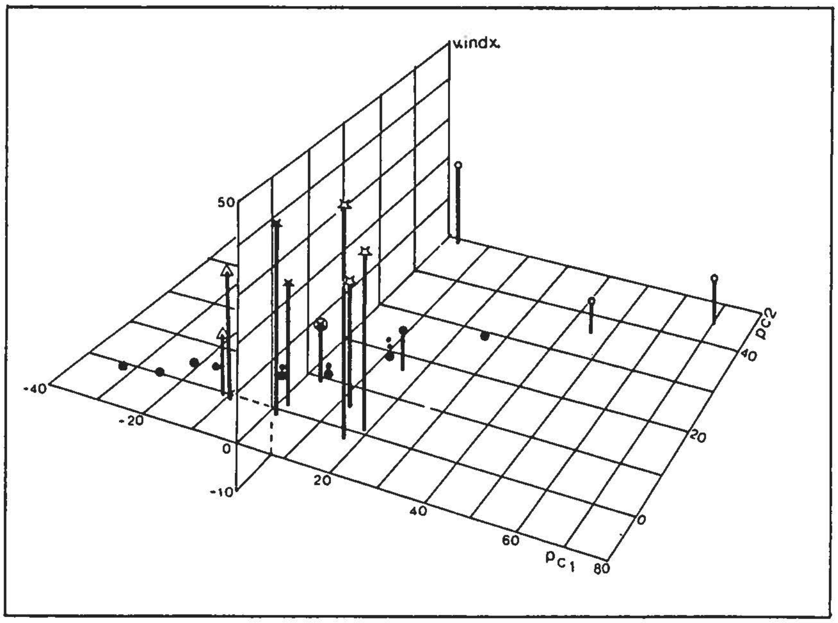


Fig. 7. The vegetated part of Qingua-dalen and its surroundings classified according to the main grouping of the vegetation covered area. Colours: see text p. 16.

Fig. 8. The relation between the centroids of the classes and the transformed data.



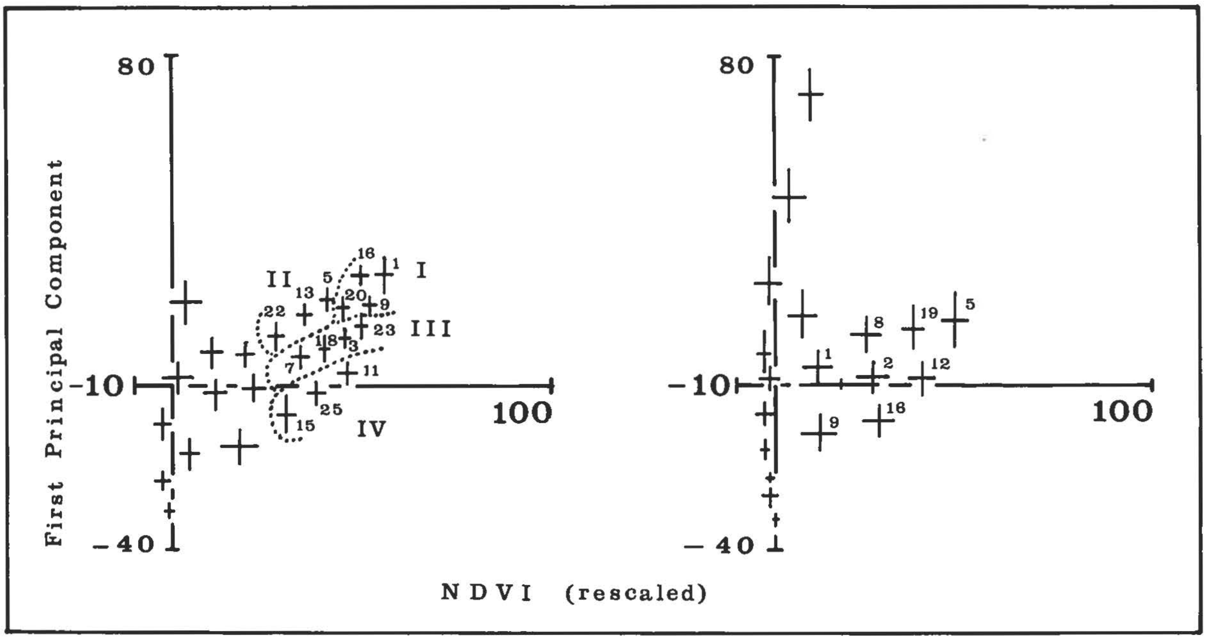


Fig. 9. Comparison of the two classifications. To the left the classification used to distinguish between the topografical location of the plant cover types, to the right the classification used to present the general distribution.

gren, 18 – olive, 7 – green, 11 – yellow, 25 – orange, and 15 – brown. The classes within group IV very clearly show the vegetation on north- and northwest facing slopes: 11 is luxurious scrub, 25 and 15 represents decreasing vigorousity, 15 contains grass, herbs and mosses on the rocky surface.

In group III the luxuriance decreases, from class 23 to class 7, and all types are found on level land or on very gently south sloping ground.

For practical reasons, the numbering of the two classifications are different, however, the position of the centroids (Fig. 9, left and right) are comparable.

Of course the results of the two classifications are very much alike. The first one was more directed toward a representation of the general luxuriance as expressed by the vegetation index, whereas the second divided the types along the first principal component (and to a lesser degree along the second principal component), thereby allowing a much better differentiation of the vegetation types because the exposure is considered.

Discussion

Of course, it cannot be expected that the very different methods presented here should give the same results, nor can it be expected that the cartographic results would show the surface types in identical ways. However, a comparison between Fig. 5 and Fig. 10, P. 3 clearly reveals the common features. On the other hand it is more difficult to compare the maps directly when the satellite data is split up in (too) many classes.

Our results should be seen as a result of two conditions: one is connected with the traditional mapping based on field reconnaissance and photo interpretation by which plant communities can be classified regardless of the degree of cover. The second condition is connected with the fact that the multispectral satellite borne scanner records a mean response from the surface, response i.a. the degree of cover of the vegetation, a factor which is very hard to decode by means of classifications and interpretations. The variation in height of the plants is also a crucial factor, since there is a direct connection between roughness and shadow of the surface.

By means of the traditional method the delineation can be carried out with great spatial accuracy, whereas the use of satellite images forces one to carry out the delineation solely on the raster based spectral reflectance, which very often means that the boundary between plant communities will appear as a group of more or less homogeneous pixels. This will often result in a failing possibility to compare the results visually as the boundaries will be represented as types build by the actual distribution of the plant communities within the pixels from the boundary. On the other hand when compiling from large scale to small scale in the traditional way one very often leave out the smaller areas of the specific plant community – the satellite data will give a better opportunity to take these smaller areas into consideration via the mechanism described above.

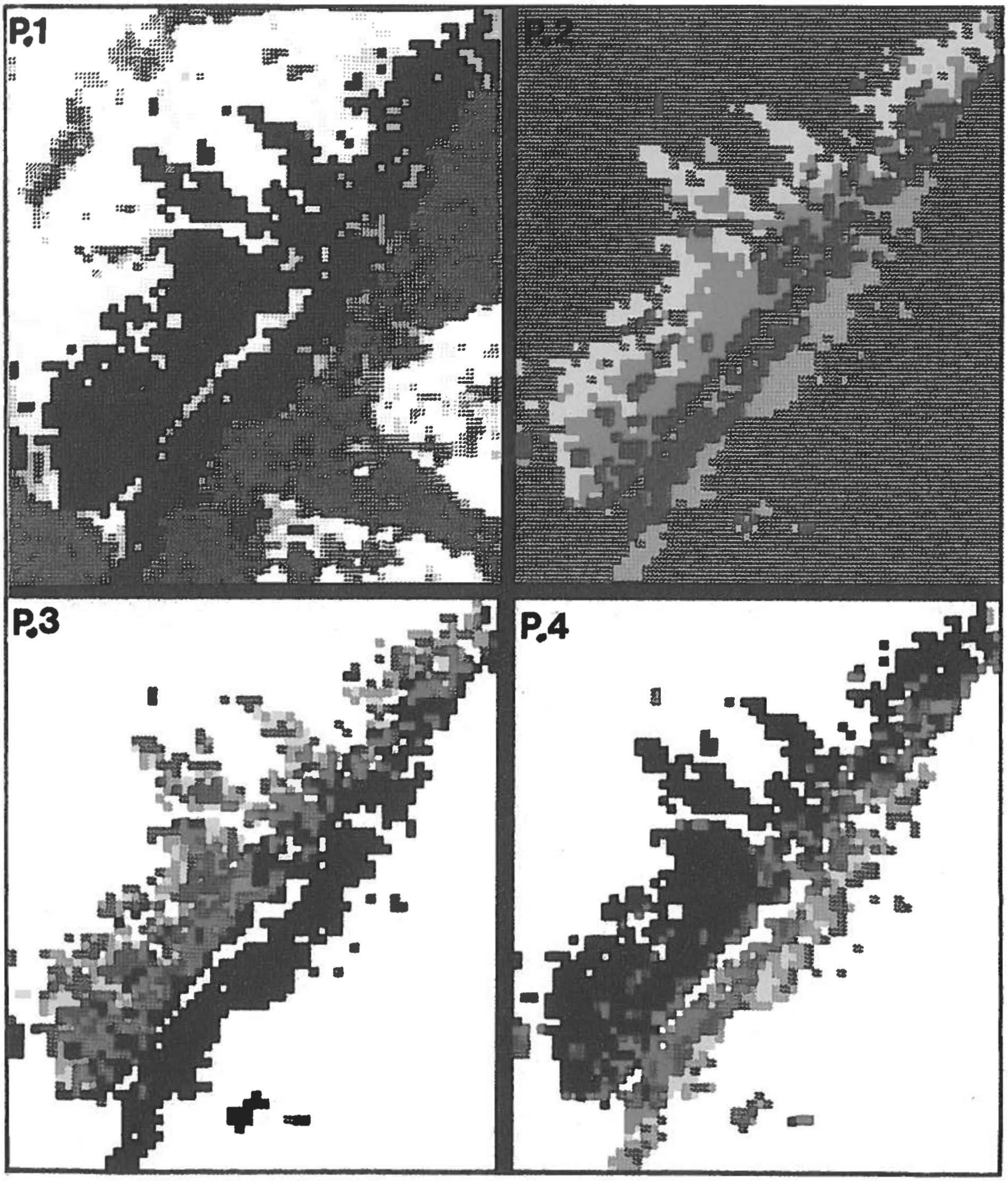


Fig. 10. The result of the classification when the topography is taken into consideration.

Thus, it can be concluded that in small scale mapping there will be very severe problems if one tries to replace traditional vegetation mapping by use of Landsat MSS-data. However, if a reasonably large scale mapping is wanted, classifications of various transformations of satellite data can be used – if the traditional map-appearance can be done without. This means that in the future more investigtions have to be carried out concerning the spectral reflection patterns from patchy surfaces in order to find a reasonable method (algorithm) with which to map the single plant cover types in a rational and fast way.

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Hybridization, introgression and taxonomy of the Mountain birch in SW Greenland compared with related results from Iceland and Finnish Lapland

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Sulkinoja, M. 1990. Hybridization, introgression and taxonomy of the Mountain birch in SW Greenland compared with related results from Iceland and Finnish Lapland. – Meddr Grønland, Biosci. 33, 21–29 pp. Copenhagen 1990-9-28.

Samples from birch populations were collected in Qingua-dalen and Narssarssuaq during the excursion of SBP (the Subarctic Birch Project) to SW Greenland 1984. In Qingua-dalen, where the environmental conditions are more favourable, the stems of the Mountain birch (*Betula pubescens* ssp. *tortuosa*) are taller and thicker and the leaf size is larger than in populations at Narssarssuaq. Intermediate forms – probably introgressions – between *B. pubescens* and *B. glandulosa* were found in both populations. According to cytological investigations of Qingua-dalen populations, the putative hybrids between *B. glandulosa* ($2n = 28$) and *B. pubescens* ($2n = 56$) were found to be triploids ($2n = 42$). Seeds collected from hybrids did not germinate but the germination of the Mountain birch was also extremely low in 1984. In the same year, *B. glandulosa* produced abundantly seeds with high germination percentage. Germination experiments with seeds collected in 1982 and 1985 indicated that under climatically favourable conditions Mountain birch produces viable seeds. Reproduction through vegetative means was found to be strong in all birch taxa.

Considerable differences have been found between the provenances of birches from SW Greenland and Finland in cultivation experiments carried out since 1976 in South and North Finland. The clones of *B. pubescens* and *B. glandulosa*, originating from Kangerdluarssuk, mature very late in autumn and the shoots above snow level were badly frostdamaged during the winter. This was particularly noticeable for *B. pubescens* in test fields in Lapland. The plants have survived, however, by means of re-suckering and started flowering at an early stage producing viable seeds. Probably no reproductive barriers between birches of the two geographically isolated areas, SW Greenland and Finland, have developed.

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The term "Mountain birch zone" has been used in phytogeography to describe the more or less uniform birch woodland extending from the northern part of the Kola Peninsula through the mountain region of Northwest Fennoscandia to Iceland and South Greenland. In this zone the birch often forms the horizontal and altitudinal tree line (e.g. Böcher 1979, Kallio et al. 1983, Hämet-Ahti 1987).

The taxonomic status of the Mountain birch has been disputed since Ledebour in 1849 described *B. tortuosa* from the Altai Mountains. The taxonomic history of this taxon and the use of the name *tortuosa* in this connection have been reviewed by Vaarama & Valanne (1973). The systematic rank given for the Mountain birch has varied. Some earlier authors have regarded it as a separate species (*B. tortuosa* Ledeb.), but many taxonomists now have included it in the very variable *B. pubescens* Ehrh. Böcher et al. (1968) have used the name *B. pubescens* Ehrh. coll. for the S Greenland birch, which "may be related eastwards to Scandinavian-Icelandic ssp. *tortuosa* (Ledeb.) C. K. Schneid., westwards to the North American ssp. *borealis* (Spach.) Löve & Löve". In many recent studies dealing with the arboreal birch in the subarctic zone of NW Europe and Greenland, authors have used the name *B. pubescens* Ehrh. ssp. *tortuosa* (Ledeb.) Nyman (e.g. Walters 1964, Feilberg 1984).

It should be mentioned, however that according to Orlova (1978, in Hämet-Ahti 1987) the Mountain birch, occurring in Northwest Europe and *B. tortuosa* in the Altai Mountains, are not of the same origin – an opinion shared by many authors. Orlova (1978) has given the name *B. czerepanovii* to the European taxon and Hämet-Ahti (1987) suggests that this name should be used at the subspecific level.

Besides the historical background of the nomenclature, further complications in the taxonomy of the Mountain birch are due to an adaptive evolution (clinal and ecotypic variation) caused by the varying environmental factors prevailing within its range and an occurrence of interspecific hybridization. This has been considered to be one of the evolutionary trends in many birch groups even at a species level (e.g. Walters 1968, concerning the origin of *B. pubescens*).

Concerning the Mountain birch zone, introgressive hybridization between the diploid (2n = 28) species, *B. nana* L., and the tetraploid (2n = 56) *B. pubescens* has been described from northern Fennoscandia (Vaarama & Valanne 1973, Sulkinoja 1981, Kallio et al. 1983) and from Iceland (Gröntved 1942, Elkington 1968). In South Greenland where the diploid species is *B. glandulosa* Michx., hybrids between this species and *B. pubescens* are frequently found (e.g. Jörgensen et al. 1957). On the basis of morphological characters, Elkington & Jones (1973) suggest that introgressive hybridization has taken place between the two species.

The present paper reports preliminary results from birch material originating from south-western Greenland. The aim of the study is to provide information on the role of introgressive hybridization in the evolution of Mountain birch in South Greenland compared with studies carried out in northern Fennoscandia. The study is a part of a joint Nordic research program "Subarctic Birch Project", SBP, subproject A: The morphological, genetic and physiological variability and evolution of the Mountain birch.

Study sites, materials and methods

Study areas in South Greenland, cultivation sites in Finland, and birch species and hybrids sampled are given in Table 1.

During the SBP excursion to South Greenland, 23.7.–7.8.1984, samples were collected in Qingua-dalen and at Narssarssuaq. Thirty trees of *B. pubescens* on each site were marked at random for investigation. The height and the stem diameter were measured. Measurements of six leaf characters commonly used in the taxonomic studies of *Betula* species (e.g. Gardiner & Jeffers 1962) were made of ten leaves per plant (Table 3). In Qingua a few individuals of *B. glandulosa* and putative hybrids between *B. glandulosa* and *B. pubescens* were included.

Collecting of seeds from labelled trees was carried out by P. Bjerge and I. Burkal in Quingua-dalen in Sept. 1984 and in Narssarssuaq in 1984 and 1985. Earlier collections by S. Ødum in 1982 from the two populations were also included. The germinability was tested at the University of Turku, Finland. Hundred seeds per plant on the surface of destilled water in Petri dishes were kept under 16-hours photoperiod in a greenhouse at 23 ± 2°C for two weeks.

For the vegetative propagation of birches basal parts of stems from a few individuals growing in Kangerdluarssuk (coll. 1976) and in Qingua-dalen (1984) were transplanted in the greenhouse of the University of Turku. Cuttings of the shoots, developed from the basal buds, were rooted in the nutrient medium using the method described by Valanne (1978). After rooting, the plants arisen from cuttings were planted for cultivation experiments and root tips were used for cytological studies. A Feulgen and Giemsa douple staining method developed by Puro and Nokkala (1977), with some modifications for hardwood trees (Hömmö & Särkilahti 1986), was used for determining chromosome numbers in root tips.

Table 1. Study sites in South Greenland (A) experimental fields in Finland (B) and birch species and hybrids sampled for investigation.

A. Populations in South Greenland.

Locality	Altitude m a.s.l.	Species	Individual No.	Year of coll.
1. Kangerdluarssuk 60°54'N, 45°40'W	50	*B. glandulosa*	G1	1976
		B. pubescens	G2	1976
2. Qingua-dalen 60°17'N, 44°32'W	30	*B. glandulosa*	Q71, Q91	1984
		B. pubescens	Q1–Q30	1984
		B. glandulosa × *pubescens*	Q90, Q100 Q900, Q9000	1984
60°17'N, 44°32'W	170	*B. pubescens*	Q200	1984
3. Narssarssuaq 61°10'N, 45°24'W	70	*B. pubescens*	N1–N30	1984

B. Experimental fields in Finland.

Locality	Latitude and longitude	Altitude m a.s.l.
1. Ruissalo, Turku, South Finland	60°37'N, 24°26'E	10
2. Pakatti, Kittilä, Finnish Lapland	67°40'N, 24°56'E	170
3. Kevo, Utsjoki, Finnish Lapland	69°46'N, 27°01'E	100

Fig. 1. A stand of *B. pubescens* in Qingua-dalen. In the middle tree no. Q4, height ca. 3.5 m.

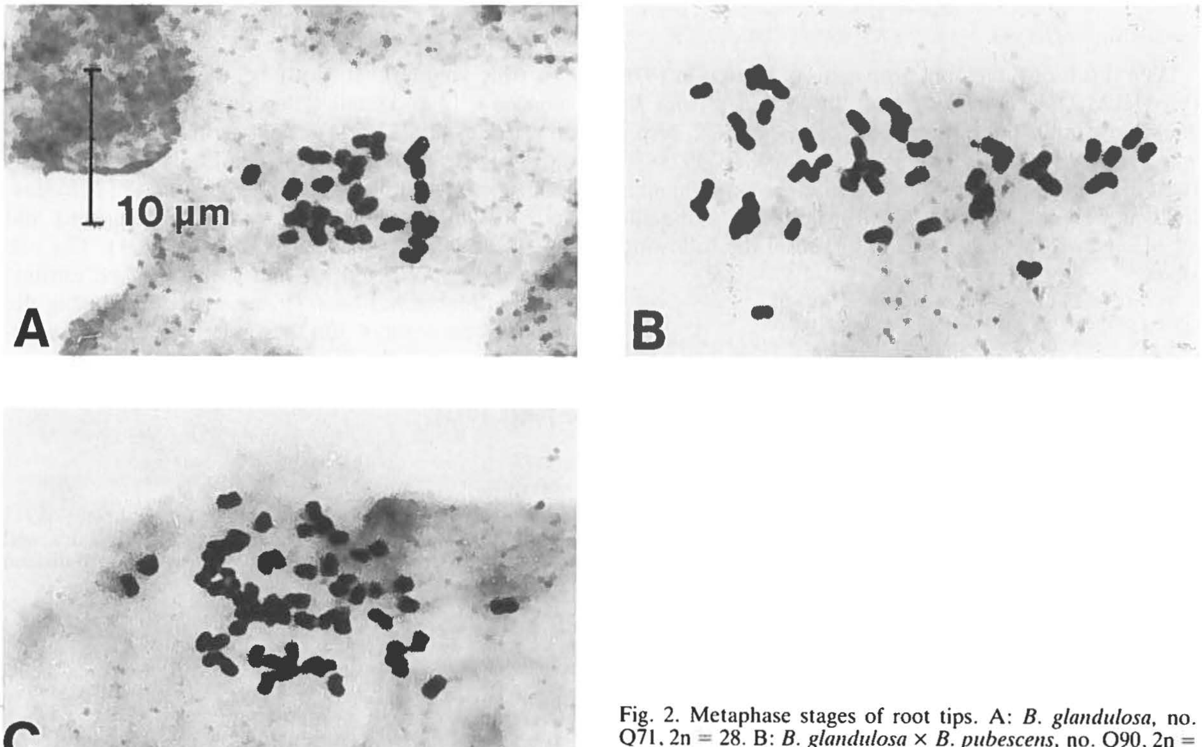

Fig. 2. Metaphase stages of root tips. A: *B. glandulosa*, no. Q71, $2n = 28$. B: *B. glandulosa* × *B. pubescens*, no. Q90, $2n = 42$. C: *B. pubescens*, no. Q10, $2n = 56$.

Fig. 3. A view from a stand of different birch taxa in Qingua-dalen. In the background tree no. Q9 of *B. pubescens*, height ca. 6.5 m (2n = 56); the hybrid clone no. Q900, height ca. 1.3 m (2n = 42) in the middle, both surrounded by a prostrate belt of *B. glandulosa*, height ca. 0.3 m (2n = 28).

As a result of the clonal propagation, started in 1976 (see Table 1), a clone of 6 and 20 seedlings from *B. glandulosa* no. G1 and from *B. pubescens* no. G2, resp., were grown in Turku, Finland. In the years 1978–80 these seedlings were transplanted in three experimental fields in Finland. Survival, growth, flowering and quality of seed of the clones was observed in the following years.

Results and discussion

External characters and chromosome numbers

The means of height and stem diameter of the trees of *B. pubescens* in Qingua-dalen and Narssarssuaq are shown in Table 2. The trees in Qingua-dalen were higher and thicker than those in Narssarssuaq. The highest trees measured in Narssarssuaq and Qingua-dalen were 4.0 m and 6.5 m, respectively. Trees are mostly polycormic, particularly in Narssarssuaq, forming a bush-like habit. The stems are sometimes lying almost horizontal and the maximum lengths of stems recorded in Qingua-dalen were 8 m. According to Feilberg (this volume), and others, the maximum height recorded is 12 m. Detailed description given by Elkington & Jones (1973, 1974) about scrub-woodland at the south-western corner of the bay at Eqaluit, Nordre Sermilik Fjord, resembles the birch population of Narssarssuaq. In Qingua-dalen birches are more vigorous and some tree-like individuals are present (Fig. 1). The valley has been protected for half a century but, earlier, human influence has been strong, especially during the time of Norse settlers. On the sheltered east- and west-facing slopes of the valley there are favourable habitats, protected by deep snow cover during winter (Elkington & Jones 1974).

Table 2. Mean height and stem diameter (at the height of 1.3 m) of *B. pubescens* in the populations of Qingua-dalen and Narssarssuaq. Differences tested by Student's test. Statistical significance indicated as in Table 3.

Populations	Height (m)			Stem diameter (cm)		
	mean	S.E.	n	mean	S.E.	n
Qingua-dalen	3.5	0.3	30	10.2	1.0	27
Narssarssuaq	2.5	0.1	30	4.9	0.5	27
	t = 3.3**			t = 4.5***		

Table 3. Analyses of leaf characters in different *Betula*-groups in Narssarssuaq and Qingua-dalen. Mean and standard error in each group are given. Number of plants in parenthesis. Difference tested by Student's test. * = p <0.05, ** = p <0.01 and *** = p <0.001.

Locality	Narssarssuaq		Qingua-dalen	
	B. pubescens	*B. pubescens*	*B. glandulosa*	*B. pubescens* × *glandulosa*
Leaf characters				
1 Blade length, mm	19.3±1.0 (17)	24.5±0.8 (19)	10.7±0.3 (2)	17.4± 2.3 (4)
B. pubescens	4.0***			
B. glandulosa	2.9**	5.3***		
B. pubescens × *glandulosa*	0.8	3.4**	2.0	
2 Blade width, mm	17.1±0.9	22.0±0.8	9.5±0.3	14.7± 0.8
B. pubescens	4.1***			
B. glandulosa	2.9**	4.9***		
B. pubescens × *glandulosa*	1.3	4.0***	4.5*	
3 Petiole length, mm	4.6±0.3	6.7±0.3	2.1±0.7	4.6± 0.8
B. pubescens	4.6***			
B. glandulosa	2.6*	4.6***		
B. pubescens × *glandulosa*	0.0	2.7*	2.0	
4 Basal angle, °	47.0±2.9	50.3±2.9	33.5±0.8	49.4±12.2
B. pubescens	0.8			
B. glandulosa	1.6	1.8		
B. pubescens × *glandulosa*	0.2	0.1	1.3	
5 Apical angle, °	61.5±1.6	56.7±1.2	68.1±1.6	58.6± 3.5
B. pubescens	2.4*			
B. glandulosa	1.4	2.9**		
B. pubescens × *glandulosa*	0.8	0.6	1.8	
6 Angle of axis and 2nd nerve, °	46.6±3.6	45.7±3.2	60.3±1.2	44.2± 6.0
B. pubescens	0.2			
B. glandulosa	1.3	1.4		
B. pubescens × *glandulosa*	0.3	0.2	1.8	

Results of the analysis of leaf characters are given in Table 3. A few individuals of pure *B. glandulosa* and its hybrids with *B. pubescens,* from which the chromosome number have been counted (Table 5; Fig 3), are included with *B. pubescens* for comparison. The number of these specimens is, however, not sufficient for statistical analysis.

The most distinctive differences between the groups were found in leaf size and in petiole length (characters 1–3). Differences in the means of angles (characters 4–6) were found only in *B. glandulosa* reflecting an obovate form of leaves. The pronounced differences found in leaf size and in petiole length between the populations from Qingua-dalen and Narssarssuaq may be partly due to the more favourable environmenral factors prevailing in Qingua-dalen. Leaf measurements of putative hybrids were made only on specimens collected in Qingua-dalen. The leaf size of hybrids was intermediate between *B. glandulosa* and *B. pubecens* in the same stand, but, compared with *B. pubescens* in the stand at Narssarssuaq, the leaves of hybrids were almost of the same size.

On the basis of the present study it is not possible to give any detailed description of the introgressive hybridisation between *B. glandulosa* and *B. pubescens* reported by Elkington & Jones (1973) from South Greenland, nor to what extent it has contributed to the evolution of Mountain birch in a particular population. The fact is, however, that intermediate types between *B. glandulosa* and *B. pubescens* are frequent in Qingua-dalen and Narssarssuaq. Although these individuals were avoided when marking the trees of *B. pubescens,* it

Table 4. Leaf analysis on Mountain birch in two SBP-sites in Finnish Lapland, Utsjoki, Kevo:
1. Foot of Jesnalvärri, 69°46′N, 27°00′E, 95 m a.s.l.
2. Top of Jesnalvärri, 69°46′N, 26°55′E, 280 m a.s.l.
Statistical significance indicated as in Table 3.

Leaf characters	Jesnalvärri				
	foot (n=30)		top (n=30)		
	mean	S.E.	mean	S.E.	t-value
Blade length, mm	32.2	0.6	31.6	0.6	0.7
Blade width, mm	28.3	0.5	26.9	0.7	1.7
Petiole length, mm	10.2	0.3	9.1	0.3	2.7**
Basal angle, °	51.2	2.1	46.8	2.2	1.4
Apical angle, °	51.3	0.8	50.8	1.0	0.4
Angle of axis and 2nd nerve, °	49.2	1.6	47.0	2.2	0.8

Table 5. Chromosome numbers in a few specimens sampled in Kangerdluarssuk (in 1976) and in Qingua-dalen (1984) (for localities and individual no., see Table 1).

Species	Individuals studied, No.	Chromosome number
B. glandulosa	G1, Q71, Q91	28
B. pubescens	G2, Q5, Q9, Q10, Q200	56
B. glandulosa × *pubescens*	Q90, Q100, Q900, Q9000	42

is possible that back-crosses to parent species, resembling *B. pubescens,* migh have been included.

According to earlier studies (Vaarama & Valanne 1973) and the studies carried out with leaf samples collected from two SBP-populations in Finnish Lapland (Table 4), the leaves of the Mountain birch from North Lapland are longer and broader compared to the values of the two *B. pubescens* provenances from South Greenland presented in Table 3. The significance of external characters including the morphology of leaves, the growth and habit of trees etc., can, however, be evaluated in more detail, after the plans of the Subarctic Birch Project designed to study the different populations and cultivated progenies of the Mountain birch have been accomplished.

The chromosome number of *B. glandulosa* ($2n = 28$) and *B. pubescens* ($2n = 56$; Table 5; Figs 2 and 3) correspond to the results reported from Greenland by Jörgensen et al. (1957). Earlier cytological studies of hybrid types are unknown to me. Specimens, in which the chromosome number were studied, were typical representatives of each group. Most likely all the intermediate individuals investigated are triploid F_1-hybrids ($2n = 42$) or near-by aneuploids, even if it is a well-known fact that an exact count of the chromosomes in *Betula* species is difficult. An exeption was individual no. Q200 sampled outside the study area in Qingua-dalen at an altitude of 170 m (see Table 1). This specimen, which had very small leaves and a semi-prostrate habit, resembling hybrid types, turned out to be tetraploid, $2n = 56$ (Table 5). Apparently this small shrub may be an example of an adaptive evolution of birch taking place in the extreme conditions prevailing on the tree line of the species. Similar forms described as a variety of the Mountain birch (var. *apressa,* Kallio & Mäkinen 1978) are found on the tree line of some mountains in Finnish Lapland.

Jörgensen et al. (1957), dealing with polymorphism in the Greenland birches, include *B. alpestris* Fr. in the hybrid complex. In their report from South Greenland Elkington & Jones (1973) have compared the *B. pubescens* population from England with the populations of birches from South Greenland. Based on morphological characters the authors suggest that introgressive hybridization between *B. glandulosa* and *B. pubescens* has affected the *B. pubescens* populations in South Greenland.

Many related descriptions of hybridization between the subsections *Nanae* and *Albae* of the genus *Betula* have been reviewed by Vaarama & Valanne (1973) and Kallio et al. (1983). Investigations on introgressive hybridization between the diploid species of *B. nana* and the tetraploid *B. pubescens* have been reported from Fennoscandia (Vaarama & Valanne 1973, Sulkinoja 1981, Kallio et al. 1983, Sulkinoja & Valanne 1987) and from Iceland (Elkington 1968).

In South Greenland the diploid representative of the *Nanae* subsection is *B. glandulosa.* The finding of triploid hybrids in the present study supports the interpretation presented by Elkington & Jones (1973), that introgression has taken place between *B. pubescens* and *B. glandulosa,* a species closely related to *B. nana.* Chromosome studies may, too, give cytological evidence for the mechanism by which introgression between species takes place in a birch population. In Finnish Lapland natural hybrids between *B. nana* and *B. pubescens* are triploids, but a few aneuploid and tetraploid individuals, probably backcrosses, have been found (Sulkinoja 1981).

Reproduction in nature

Many authors have stated that a vegetative reproduction is typical of birch in the mountain birch zone (cf. Elkington & Jones 1973 and 1974, Kallio et al. 1983). In the populations of Qingua-dalen and Narssarssuaq, shoots arising from basal buds of stems and from rooted branches of birches were frequent (Figs 4 and 5). Actually, the polycormic trees and shrubs are clones, in which the age of stems and branches varies. The age determined in one of the thickest stems (diam. 18 cm at base), from the polycormic tree no. Q9 in Qingua-dalen, was ca. 160 years old (Fig. 3). The decayed stems showed that, as a genotype, the tree was much older.

However, sexual reproduction takes place as well. The establishment of seedlings, however, under present conditions seems to be difficult, but some seedlings growing on open gravelly and sandy soil were found. Fertility of seed samples studied is shown in Table 6.

In the germinability of seeds collected in natural populations, both local and annual variation could be

Table 6. Germination tests on seeds collected in two natural populations (Qingua-dalen and Narssarssuaq). ^{m} = mixed seed sample. – = no germinative seeds, 0.0 = germination <0.05%, . . = not studied.

Species	Year	Germination %: mean ± S.E. Qingua-dalen	n	Narssarssuaq	n
B. pubescens	1982	–	12^{m}	44.5±5.0	16^{m}
B. pubescens	1984	0.1±0.1	16	0.0±0.0	27
B. pubescens	1985	. .		19.2±2.4	16
B. glandulosa	1984	72.0	1	. .	
B. glandulosa × *pubescens*	1984	–	3	. .	

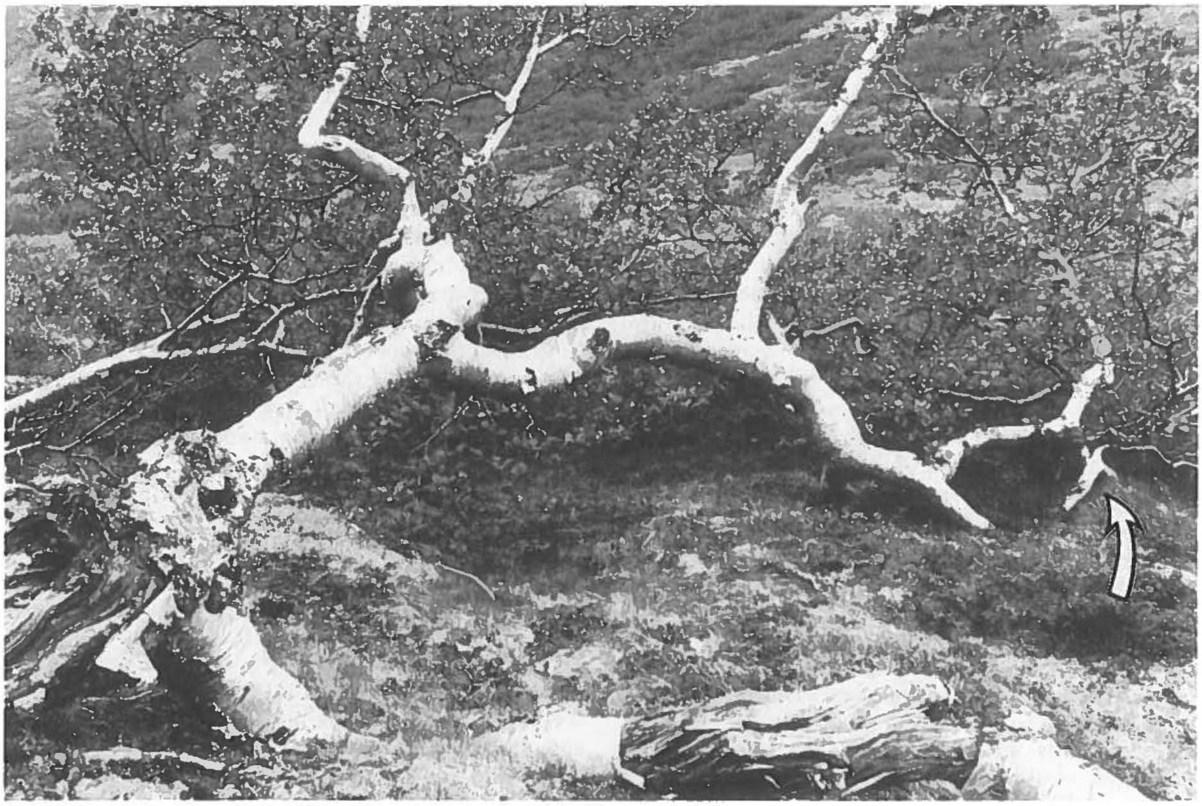

Fig. 4. A fallen tree in Qingua-dalen with rooted branch seen on the right side of the picture (arrow).

found (Table 6). In 1984, only few germinating seeds were found in *B. pubescens*, whereas in *B. glandulosa* the germination percentage was high. In the same year an abundant production of fruiting catkins was found in many bushes of *B. glandulosa*, while seed yield in *B. pubescens* was very poor. No evidence, however, of the fertility of hybrid specimens was provided by germination tests. This may be partly due to a low number of individuals studied and partly due to a poor seed year at Qingua-dalen in 1984.

In North Lapland (Sulkinoja & Valanne 1980, Sulkinoja 1981), a lower germination rate compared with the parent species is characteristic for natural hybrids between *B. nana* and *B. pubecens*, but in favourable seed years some of them produce viable seed. In the cultivated progenies of natural hybrids the chromosome number of different individuals varies from the triploid to the pentaploid level (2n = 70), including introgressants with aneuploid and tetraploid numbers. In the "families" grown from open pollinated seed of *B. nana* from northern Lapland, spontaneous hybrids are common. In experimental crosses, carried out between *B. nana* and *B. pubescens*, the crossability has been more successful when *B. nana* has been used as the female parent. Clausen (1970), in his studies of interspecific crossability in the genus *Betula*, found that *B. nana* as well as *B. glandulosa* as a female parent can be crossed with *B. pubescens* with good success while the reciprocal cross is highly incompatible.

F_1 progenies, grown from seed of experimental crosses, have been confirmed to be triploid and when

Fig. 5. Rooted branch (cf. Fig 4).

cultivated they grow well. In F_2 offsprings, as well as in those of natural hybrids, hybrid weakness and variation of morphological characters caused by an unbalanced chromosome set, have been found. However, a small number of F_3 seedlings have been able to grow from seeds of a tetraploid F_2 individual (Sulkinoja unpubl.).

Some authors (e.g. Löve & Löve 1956, considering the origin of *B. pubescens* in Iceland) have doubted the significance of introgressive hybridization owing to the sterility found in a triploid plant resulting from a cross between diploid and tetraploid species. Reports of a successful hybridization and introgression between two diploidbirch species, *B. glandulosa* × *nana* (Clausen 1970), *B. glandulosa* × *pendula* (Inki & Valanne 1979), and *B. pendula* × *nana* (Sulkinoja 1981), have been desribed. The main part of studies concerning the crossability between the three diploid species and *B. pubescens* have been carried out outside the range of Mountain birch. Hagman (1971) in his studies on the crossability between *B. pendula* and *B. pubescens,* has shown that a strong incompatibility exists between the two species, but an increased compatibility is found in some birch individuals in northern Lapland confirming the well-known fact that hybrids between birch species *(B. nana, B. pendula, B. pubescens)* are much more frequently occuring in Lapland than, e.g. in South Finland. Evidently, the environment in the subarctic region of Northwest Europe has favoured hybridization and gene flow between *B. nana* and *B. pubescens* giving rise to the evolution of the Mountain birch.

Cultivation experiments

The clones planted in field tests in Finland 1978–79 have shown distinct difficulties in adaptation to local environment, particularly in Lapland. *B. glandulosa* (G1), which has a prostrate habit, has survived better even in Lapland, where it, however, seems to be too late in the fall. The importance of a provenance could clearly be seen in the clone of *B. pubescens* (G2). The upper parts of stems and branches have died and it has survived by the means of a pronounced capacity to produce new shoots. Ten years after planting, the height of the living branches of the clone varied in Lapland and in South Finland 20–30 cm and 60–100 cm, respectively. Even in Ruissalo, South Finland, which is situated almost at the same latitude as Kangerdluarssuk (see Table 1), the trees were badly damaged during winter. A thin layer of snow, commonly recorded at the Southwest coast of Finland, may be insufficient to protect these birches, but probably also other environmental factors are involved, e.g. the more continental climate of southern Finland compared to S Greenland.

In spite of difficulties in adaptation to local environment the clones have produced seeds in many years. Seed production began in 1978 when the clones were two years old from the starting of propagation. The yield and quality of seed varied annually as in local birch species. As in nature, the seed production of *B. glandulosa* was more abundant than that of *B. pubescens.*

The highest and lowest germination percentages found in sample tests in different years are given in Table 7. In order to test the crossability between the clones and the local birches and to prevent self pollination, the clones were emasculated in some of the years (indicated by an + in Table 7). The results indicate that the two South Greenland species easily cross with birches in Finland, where the genus *Betula* is represented by two diploid (2n = 28) species, *B. nana* and *B. pendula,* and by the tetraploid *B. pubescens* (2n = 56). *B. pendula* does not occur in Utsjoki, and thus – at least in North Lapland – the clones must have been pollinated by *B. nana* or *B. pubescens.* Self-pollination within the clones has not been studied, but birch species are generally strongly self-incompatible, as has been shown by e.g. Hagman (1971). For further investigations, seedlings of the clones have been planted in experimental fields in Lapland during the years 1984–87.

An earlier experiment, started in South Finland, has proved marked differences between a parent clone and its F_1 progeny from the same field site. In 1979 a F_1 "family" was grown from open pollinated seeds of the clone G2 growing in Ruissalo, South Finland. In 1981 seedlings were planted in field test in Ruissalo. At the age of nine years (1987) the height of trees was 4.5 m ± 0.2 (n = 27). Compared with the parent clone (height 0.6–1 m) in the same field the growth of trees was much better. Crooked stems and branches, which are characteristic for the clone, were still found in this F_1 family, but damage caused by frost was not observed.

Evidently a clone, representative of one genotype only, can not show the whole range of variation likely to be found in a population. Therefore, cultivation of a seed population has been started in Lapland in 1983 from seeds collected from 16 trees at Narssarssuaq in 1982. It is too early to draw any far-reaching conclusions as to the thriving of this birch provenance but the external and phenological characters of seedlings resemble those found in the clone of *B. pubecens* G2. It may be stated that early flowering, which is also characteristic for the clone G2 and its F_1 "families", has been

Table 7. Germinability of clones in sample tests in the years 1978–87 in experimental fields of Finland. + = emasculated clones. – = no germinative seeds, 0.0 = germination <0.05%, . . = not studied.

Species/ Clone No.	Highest/lowest germination %: mean ± S.E. South Finland Turku Ruissalo	Finnish Lapland Kittilä Pakatti	Utsjoki Kevo
B. glandulosa	12.0±1.6+	66.8±1.6+	53.8±1.9+
G1	9.8±1.5	4.3±0.5	. .
B. pubescens	55.0±1.0	64.3±3.4+	20.0
G2	18.5±2.1	. .	. .
	35.8±3.8+	. .	. .

found in many three year seedlings when cultivated in the field site in Kittilä. Lappish Mountain birches begin flowering generally at an older age but early flowering, and abundant seed production, was found in the Icelandic "families" of *B. pubescens,* which have been cultivated in all field sites in Finland since the year 1979. Icelandic birches are quite well adapted to the environment at Ruissalo, South Finland, but in Lapland they seem to be too late and many trees are badly damaged by frost.

Further investigations on Greenlandic birch material, planted in test fields, will be included in the birch research program carried out in Kevo Research Institute since 1970, and in the Subarctic Birch Project (SBP). Besides studies in natural population, these programs include comparative studies of different birch provenances originating from the range of Mountain birch when cultivated in different test fields.

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On stomatal behavior in the Greenland Mountain birch

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Kauhanen, H. 1990. On stomatal behavior in the Greenland Mountain birch. – Meddr Grønland, Biosci. 33, 31–33 pp. Copenhagen 1990-9-28.

The study was conducted to determine response of birch stomata to evaporative demand and plant internal water status. The experiment was undertaken in Qingua-dalen at a site with microtopographical variation. Comparisons were made between trees from a dry hill and from a moist river bank, respectively.

Under natural "stress" conditions, with high air temperature and low humidity, birches in both habitats did not exhibit any significant stomatal response to evaporative demand or low xylem-water potential. Under artificial stress two different patterns appeared. Dry habitat birches closed their stomata abruptly with decreasing xylem-water potential, while stomatal closure in moist habitat trees was gradual.

Key words: Greenland, Mountain birch, Qingua-dalen, stomatal closure, xylem-water potential.

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Much attention has been given to the effects of water stress on stomatal behaviour. Numerous studies have shown that plant water deficit is an important factor controlling stomatal aperture. Low water potential caused by drying out of the soil or high evaporative demand sooner or later result in stomatal closure (e.g. Davies and Kozlowski 1977). There is good evidence that stomata of many species are sensitive to ambient humidity (Schulze and Kuppers 1979). Even rapid changes in atmospheric humidity may cause alterations in stomatal aperture (Fanjul and Stones 1982).

Relationships between stomatal closure and plant water potential vary among species from different habitats (Quraishi and Kramer 1970, Davies and Kozlowski 1977). Measurements on Mountain birch in northern Fennoscandia (Kauhanen, unpubl.) give some indication that this relationship may vary within a single species as well.

The climate of Greenland is characterized by such extremes as hyperoceanity and continental dryness (Böcher 1979, Ødum 1979). Thus, beside harsh temperature conditions, humidity and wind may be important environmental factors determining growth and survival of birch trees.

This paper describes stomatal behaviour in Mountain birch in Greenland. The special objective of the study is to determine response of birch stomata to evaporative demand and internal water status.

Methods

The study was carried out in Qingua-dalen, South Greenland, during the Subarctic Birch Forest Ecosystem Workshop in late July and early August of 1984. Main features of the research area are described elsewhere (Kuivinen and Lawson 1982, Ødum 1984).

Two sites were selected at the head of Qingua-dalen, a dry site on a terrace of outwash deposits and a moist site on the river bank. The sites were 200 meters apart, about one kilometer NE of the outlet of the river in lake Tasersuaq.

All measurements were made in the field during dry days. Threshold xylem-water potential values for stomatal closure were determined on one tree at each site. Decrease of xylem-water potential was induced by cutting twigs. Response of stomata was monitored on two trees per site.

Xylem-water potential was measured by pressure chamber technique (Scholander et al. 1965) and stomatal resistance by means of diffusion porometer (Turner and Parlange 1970). Five to six separate leaves and branches were sampled on each tree. Air temperature was monitored by using EireLec thermometer and K-type thermocouples.

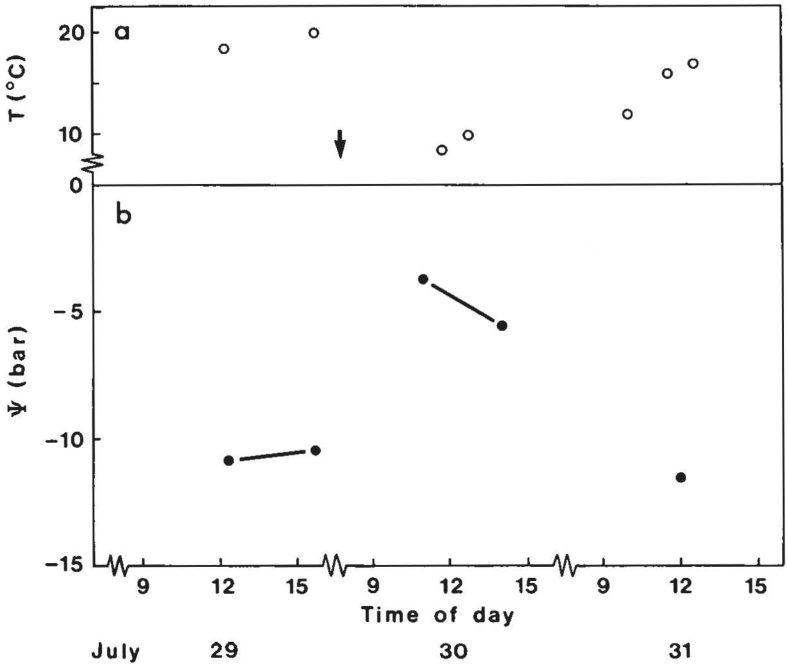

Fig. 1. Range of air temperature (a) circles and xylem-water potenial (b) for Greenlandic birch at the dry site of Qingua-dalen. Occurrence of rain is shown by the arrow.

Results

Daytime values of xylem-water potential ranged from −3.1 to −11.8 bars depending on precipitation and temperature. July 29th was the warmest day of the visit to Qingua-dalen. A maximum temparature of 23°C was measured that day. Midday water potential value for dry habitat birches (Fig. 1) was −10.8 bars. Next day, after nightly rain, it rose above −4 bars but fell back to −11.5 bars one day later when sun was shining again.

Birches from both sites showed low stomatal resistance when measured before and after the rainy day (Table 1). Xylem-water potential values in the former case were slightly higher than those in the latter.

Determination of treshold water potential values for stomatal closure showed two different patterns (Fig. 2). Stomata of dry habitat birches began to close at a low water potential of −25 bars and the closure was abrupt, while trees from moist site closed their stomata gradually when water potential fell below −20 bars.

Table 1. Relative stomatal resistance (rs) and xylem-water potential (Ψ) in Greenlandic birch at two different sites, measured in sunny weather before and after a rainy day. The rs values are given with one standard error.

	July 29		July 31	
	rs (s)	Ψ (bar)	rs (s)	Ψ (bar)
Dry site	13.41±.95	−10.8	14.18±.92	−11.5
Moist site	13.71±.50	−10.2	11.70±.90	−10.3

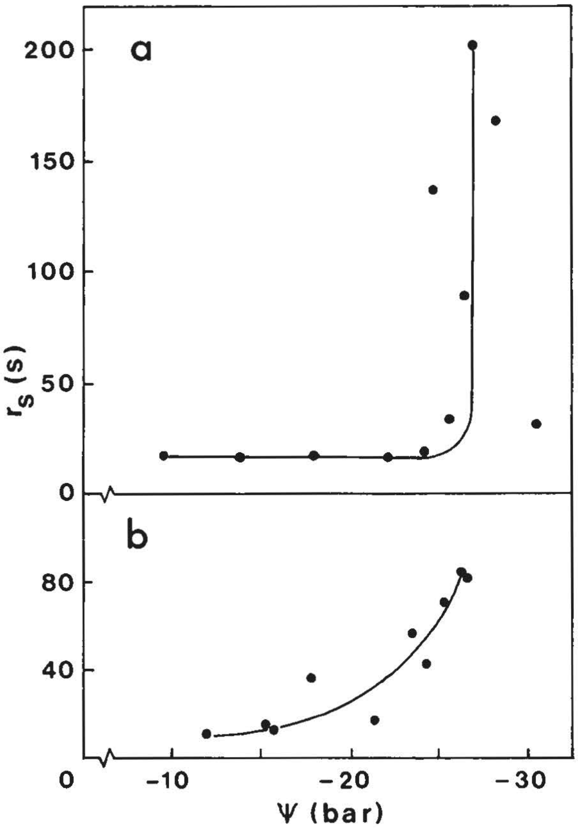

Fig. 2. Relationship between relative stomatal resistance (rs) and xylem-water potential (Ψ) in Greenlandic birch under artificial desiccation. (a) Dry site, (b) moist site. Points are individual observations.

Discussion

Stomatal closure during the middle of the day has been reported for many species of forest trees (Kramer and Kozlowski 1979). This phenomenon has been observed in Mountain birch also in northern Sweden (Kauhanen 1986). However, Greenlandic birches did not show any sign of midday stomatal closure despite the "stress" type weather. Because data of air humidity are lacking the role of evaporative demand remains rather obscure.

Osonubi and Davies (1980) have shown in birch seedlings that a direct response of stomata to a change in vapor pressure deficit acts as a stress-avoidance mechanism. The results of this study indicate that Greenlandic birches did not have any need of stomatal adjustment; even dry habitat trees were able to keep their stomata open throughout the day. It is conceivable that, despite the high temperature, evaporative demand in Qingua-dalen was not high enough to result in stomatal adjustment.

Threshold water potential for stomatal closure varies widely between species (e.g. Federer 1977) and probably between growth stages and sites (Ritchie and Hinckley 1975). This work has shown that the form of the stomatal resistance-water potential curve may vary within a species. The curvilinear type for moist habitat trees versus the threshold curve for dry habitat trees may indicate that the former ones are more drought-avoiding than the latter ones.

Federer (1977) measured a threshold value of −15 bars for mature birch under natural conditions, whereas birch seedlings grown in greenhouse showed a value of −14 bars (Osonubi and Davies 1980). The critical value for Greenlandic birch was much lower (−25 bars, cf. Fig. 2a). It is likely that the difference is partly a procedural artifact.

There is some experimental evidence that artificial desiccation results in lower xylem-water potential values than natural desiccation (West and Gaff 1971). Therefore further measurements on Greenlandic birch are needed.

This study has indicated that internal water status of Greenlandic birches was not affected by decreasing water potential or increasing evaporative demand. A likely explanation is that, even on sunny summer days, air humidity is high enough for the stomata to remain open throughout the day. Probably the role of summer water stress in the case of Greenlandic birch is negligible.

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Altitudinal and within-crown distribution of insect grazing on Mountain birch (Betula pubescens coll.) in SW Greenland and NW Norway

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Tenow, O. 1990. Altitudinal and within-crown distribution of insect grazing on Mountain birch (*Betula pubescens* coll.) in SW Greenland and NW Norway. – Meddr Grønland, Biosci. 33, 35–42 pp. Copenhagen 1990-9-28.

The distribution of grazing on birch leaves over different altitudes and levels above the ground was studied on valley slopes at three Greenland localities with different degree of oceanity, and compared with three Norwegian localities previously studied. In the Greenland valleys, grazing was concentrated to the lower half of the slopes and to the near-ground foliage, except at the most continental locality where it extended up into the crowns of the tree-sized birches. In the Norwegian valleys, grazing comprised most of the forest-clad slope and the whole crown of the birch trees. In Norway, the grazing insects were *Epirrita autumnata* and *Operophthera brumata* (Lep., Geometridae), their larvae being in outbreak numbers, in Greenland the larvae had left the foliage and therefore remained unidentified. They were in non-outbreak numbers. The importance of these differences for the results is discussed, as well as the effect of climate on grazing and the effect of grazing on growth of birches.

Key words: Mountain birch, *Salix glauca,* Greenland, Fennoscandia, *Operophthera* spp., *Epirrita autumnata,* grazing, outbreaks, zonation.

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The Mountain birch (*Betula pubescens* Ehrh. coll.) forest region is a northern maritime phenomenon which occurs in Fennoscandia, Iceland, northern Ural and, as a westernmost outpost, in south-western Greenland (Hämet-Ahti 1963; Böcher 1979; Ødum 1979). The insect fauna of circumpolar northern birches, including those of Greenland, has been inventoried and compared by Koponen (1978, 1983). In the Mountain birch forests of Fennoscandia, the geometrids *Epirrita (Oporinia) autumnata* (Bkh.) and *Operophthera* spp. are the most important leaf-eating insects. Thus, larvae of *O. brumata* and *O. fagata* severely defoliate birch forests along the Norwegian coast, while larvae of *E. autumnata* defoliate Mountain birch forests in a more easterly position in the Fennoscandian mountain chain. The outbreaks of these three species are synchronous and recur at intervals of about 9–10 years (Tenow 1972). The outbreaks of *E. autumnata* and *O. brumata* greatly affect the growth and survival of the Mountain birch (e.g. Nuorteva 1963; Kallio & Lehtonen 1973, Vaarama & Valanne 1973; Sonesson & Hoogesteger 1983). In Greenland, one candidate for a similar importance in the birch forest ecosystem could be the Bruce spanworm, *O. bruceata* (Hulst.), a relative and nearctic vicarian of *O. brumata,* known to graze birch and willow severely in North America and Greenland (Koponen 1978; Sippell et al. 1975). In Greenland, the dominant herbivorous insect group on birch is leaf-chewing lepidopterous larvae which made up 67% of the specimens sampled by Koponen (Koponen 1978). Beside *O. bruceata,* larvae of the two tortricid moths *Acleris caryosphena* (Meyr.) and *Eucosma indecorana* (Zett.) were of importance.

A few previous studies have focused on the altitudinal zonation of insect herbivores in the Mountain birch forest and then exclusively in Fennoscandia, centering on differences between species, foremost *E. autumnata* and *O. brumata* (Tenow 1965, 1972; Hågvar 1972, 1976). Bogacheva (1984) mapped within-crown occurrence of insects on birch in forest tundra.

The Greenland part of the present study was performed in 1984. The aim was to compare the distribution of leaf-eating insects on valley slopes with that in the Fennoscandian mountain chain. Fennoscandian data were gathered during the 1962–68 outbreak of *E. autumnata* and *Operophthera* spp. They were obtained from both the southern and northern parts of the mountain chain (cf. Tenow 1965, 1972). From a climatic-phytogeographic point-of-view (Tuhkanen 1984), SW Greenland is similar only to northern Scandinavia. For a comparison, therefore, only data from the northern part is used here.

Investigation localities

The vegetation of SW Greenland is zoned across a steep climatic gradient from hyperoceanity at the sea to continentality at the inland ice-cap. The outer hyperoceanic and oceanic zones lack birch growth in any form. Inland of these oceanic zones, three localities were studied in 1984 (Fig. 1 A, B):

1. Kangerdluarssuk, at Lakseelv, (60°53'N, 45°50'W), close to Narsaq within the suboceanic northern boreal zone (sensu Tuhkanen 1984) but with a strong oceanic influence. The slopes are covered mainly with scattered, dense *B. pubescens* and *Salix glauca* L. shrubs, mostly less than 1.5 m in height, interspersed with some prostrate *Juniperus communis* L. Some of the birches may be intermediate with *B. glandulosa* Michx. Studies were performed on July 22–24 at two sites on the northern side of the Lakseelv valley, one on a west-facing slope at the fiord head near the GGU (Greenland Geological Survey) camp site where the birch "tree" line is at about 75 m a s.l., and the other on a southeast-facing slope 1 km up the valley, with the valley floor at 30 m and the "tree" line at about 100 m. The herbivorous insect fauna of Kangerdluarssuk was studied by Koponen during an outbreak of *O. bruceata* on *B. pubescens* and *S. glauca* in 1976 (Koponen 1978).

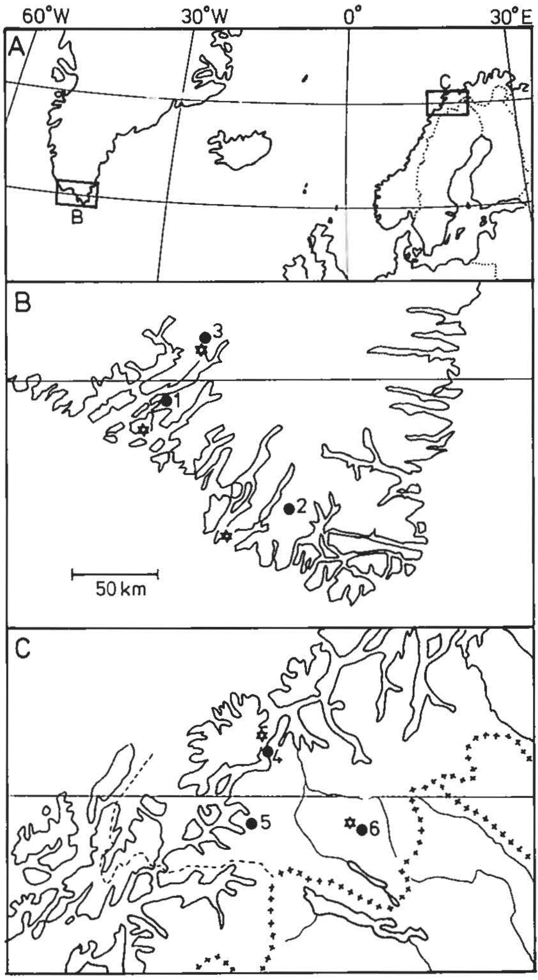

Fig. 1. Maps of investigation localities (●) with nearby weather stations (☆). A: General overview of investigation regions. B: SW Greenland with 1) Kangerdluarssuk (weather station: Qaqortoq/Julianehåb), 2) Qingua-dalen (Nanortalik), 3) Hospital Valley (Narssarssuaq). C: NW Norway with 4) Trollvika (weather station: Gibostad), 5) Engmo, 6) Frihetsli (Dividalen).

2. Qingua-dalen, (60°16'N, 44°30'W), in the same climatic/vegetational zone as Kangerdluarssuk but in a sheltered situation 10 km SE of Tasermiut fiord. Here, stands of polycormic *B. pubescens* trees have a luxuriant growth with heights and stand densities approaching those of Scandinavian birch forests. The tallest trees near the valley bottom are 6–8 m in height and even reach 12 m (Rosenvinge 1898; Oldendow 1935; Kuivinen & Lawson 1982). Between the birch stands are vast areas of dense *S. glauca* thickets. Specimens of *Sorbus groenlandica* (Schneid.) and *J. communis* occur scattered in the birch stands. On July 28 – August 2, insect grazing was studied on the slope of both sides of the valley about 1 km upstream of the valley river outlet into Lake Taserssuaq (23 m). Here the valley bottom is at 25 m a s.l. and the "forest" line at about 275 m and 180 m on the northwest and the southeast side of the valley, respectively. A detailed description of the lower part of the valley is given by Oldendow (1935).

3. Hospital Valley, (61°16'N, 44°30'W), within the subcontinental northern boreal zone. The study site is situated 6 km northeast of Narssarssuaq Airport, on a slope exposed to the north. Dense thickets of *B. pubescens* and *S. glauca* extend on the slope with sparse trees, 3–4 m in height in sheltered positions. The valley floor and the "forest" line are situated at app. 40 m and 170 m a s.l., respectively. The study was performed on July 17–18 and July 20.

Comparisons are made with the spatial distribution of insect grazing at three localities in the county of Troms, NW Norway, at about the same distance from the sea as in Greenland (Fig. 1 A, C) and with about the same length of growing season (120–160 days and about 120 days, respectively, with a mean daily, or monthly, temperature above +5°C, according to Tuhkanen 1984).

4. Trollvika (69°15'N, 18°00'E), 3 km north of Finnsnes Commune and situated within the suboceanic sector of the northern boreal zone (Tuhkanen 1984). The meadow *B. pubescens* forest, mainly of monocormic birches 10–18 m in height and interspersed with *Sorbus aucuparia* L., *Salix* sp. and *J. communis* specimens, extends from sea level up to about 320 m. The study, performed on July 4, 1965, was complemented on June 25, 1966.

5. Engmo (68°43′N, 18°05′E), in the Salangdalen on the east-facing slope of the fjell Trosen is in the suboceanic middle boreal zone (Tuhkanen 1984). The forest is a rich heath *B. pubescens* forest with monocormic trees, 5–15 m in height, extending from the valley floor at about 110 m up to about 420 m a s.l. At lower levels, small *Pinus sylvestris* L. stands occur. The study was made on June 28–29, 1964 and completed on June 27–28, 1965.

6. Frihetsli (68°46′N, 19°43′E) on the west-facing slope of the fjell Anaskåla in the Dividalen valley. This site is in the middle boreal zone but under a more continental influence than the two previous localities (Tuhkanen 1984). The *B. pubescens* forest extends from the Divielva river at 200 m a s.l. up to about 560 m. It is a heath forest of polycormic and monocormic birches, 6–10 m in height, including *P. sylvestris* trees at lower altitudes. The study was performed on July 1 1964.

In Fig. 2, mean monthly temperatre curves are given for weather stations which are close to some of the investigation localities (Fig. 1 B, C). The temperature data for Narssarssuaq should be representative of the nearby Hospital Valley, and the oceanic Qaqortoq/Julianehåb is somewhat more extreme than Kangerdluarssuk. The Norwegian Gibostad and Dividalen are good representatives of Trollvika and Frihetsli, respectively. Weather stations that are representative of Qingua-dalen and Engmo are lacking. The exposed oceanic Nanortalik, 40 km WSW of Qingua-dalen, shows the extremes of the outer coast.

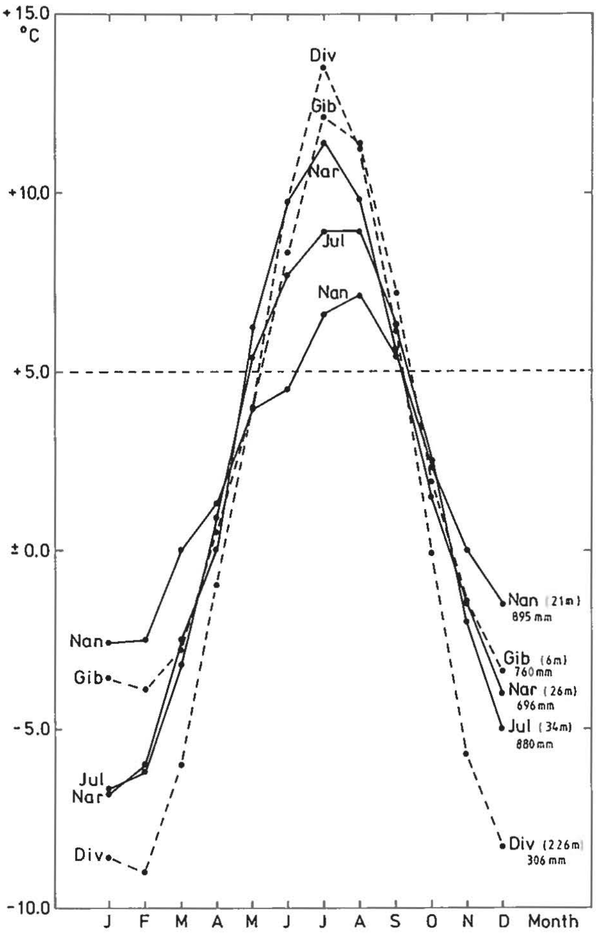

Fig. 2. Mean monthly temperature curves for topical Greenlandic and Norwegian weather stations, according to Sestoft (1970), Lufttemperaturen i Norge 1861–1955. I. Middelverdier, Oslo 1957, and Nedbøren i Norge 1895–1943. I. Middelverdier og maksima, Oslo 1949. SW Greenland: Jul = Qaqortoq/Julianehåb, Nan = Nanortalik, Nar = Narssarssuaq. NW Norway: Gib = Gibostad, Div = Dividalen. Figures within parenthesis after name = altitude above sea level; figures below name = average annual precipitation. Horizontal, dashed line at +5°C marks lower temperature limit for the growing season, according to Tuhkanen (1984). Position of weather stations, see Fig. 1.

Materials and methods

At each investigation locality, the occurrence of leaf-eating insects was quantified at 2–4 stations at different altitude levels from the valley floor to altitudes near the forest line. At each station 10 birches were sampled, except in Norway in 1964 when only 6 birches were used. In the valley of Qingua-dalen, the sampling plots, laid out parallel with the slope, were 100 × 100 steps in size. The trees to be sampled were identified by using the sides of the plot as a grid for randomly selected coordinates and by taking the tree closest to each of the ten pairs of coordinates, paced out on the plot. All other plots were 50 × 50 m, sometimes modified according to the topography. The sampled trees were selected by "random walk" and pointed out blindly from a distance to prevent a subjective choice. Neither selection is truly random. However, they are erratic in relation to the distribution of larvae and consumption, and should not bias a comparison among sites. At some exceptionally steep plots (Trollvika) and in birch forest outliers (Kangerdluarssuk and Hospital Valley) all accessible and available trees of the plot had to be sampled to get n = 10. On the Greenland plots, but not on the Norwegian ones, 10 *S. glauca* bushes were selected for sampling, viz., the one closest to each of the selected birches.

Generally, birches of the NW Norway localities were taller than those of the Greenland localities and while the polycormic Greenland birches formed thickets with much of the leaves near the ground, the mainly monocormic NW Norwegian birches carried their foliage well lifted up from the ground. On the Norwegian plots, one twig (on average with 50–70 leaf-carrying shoots) per tree was taken from the lower half of the crown at 2–3 m above the ground, by climbing the tree with a ladder. On the Greenland plots, with their low birches and willows, one twig per tree or bush was taken from the middle part of the crown, reached by hand 1.5–2.0 m above the ground. In addition, at the Qingua-dalen sites, each selected birch and willow was also sampled for one twig within 0.5 m from the ground.

Each sampling unit was kept apart, either treated on the spot (Greenland) or put into a transparent plastic bag and transported to a separate handling place. The investigation in Norway was made during the on-going 1964–66 outbreak and the number of shoots and larvae of different species was counted per twig and the counts transformed to the number of larvae per 100 shoots. In addition, the representativeness of the estimates for different altitudinal zones of a site was checked from merely visual evaluation of the damage inflicted to the foliage at return visits later in the summer. In Greenland, the spring and summer of 1984 were extremely early and warm, and all leaf-eating larvae had already terminated their feeding and had left the foliage prior to the investigation. Thus, no counting of larvae was possible. As a substitute, the leaves of 100 shoots per twig were examined for gnawing marks and the number of grazed shoots per 100 shoots was recorded. Neither was it possible to identify the insect species causing the damage.

The altitude above sea level of the valley floor, forest line and sampling plots was determined from current topographical maps (Greenland 1:250 000 and 1:100 000; Norway 1:50 000) and with a pocket altimeter (Lambrecht Höhenmesser 1304).

Data were not transformed for normality. The (2 × s.e.) bars of average values in Figs. 3–5 below therefore more likely correspond to a confidence interval of 80–90% than to one of 95% (cf. Axelsson et al. 1975). Data were tested for significant differences with appropriate non-parametric statistical methods (Zar 1984). The following are used: K-W test = Kruskal-Wallis test, W test = Wilcoxon paired-sample test, and M-W test = Mann-Whitney test.

Results

Greenland

At the main investigation locality, Qingua-dalen, insect grazing on tree-sized birches (Fig. 3 A) was concentrated to the lower part of the slope ($p < 0.01$, K-W test) and to low levels above the ground ($p < 0.01$, W test), on both sides of the valley. The highest frequency of gnawn shoots, 34%, was on the northwest side of the valley (southeast-facing slope) closest to the valley floor. Near the "forest" line, 250 m a s.l. on the northwest side and 175 m on the southeast side, the frequency of gnawn shoots was less than 10%. Similarly, in the upper part of the crowns, at 1.5–2 m above the ground, the grazing frequency was less than 10% and this was the case at all investigated altitudes. This difference in grazing as a function of altitude reappeared in *S. glauca* (Fig. 3 B, northwest side: $p < 0.01$, K-W test), as well as

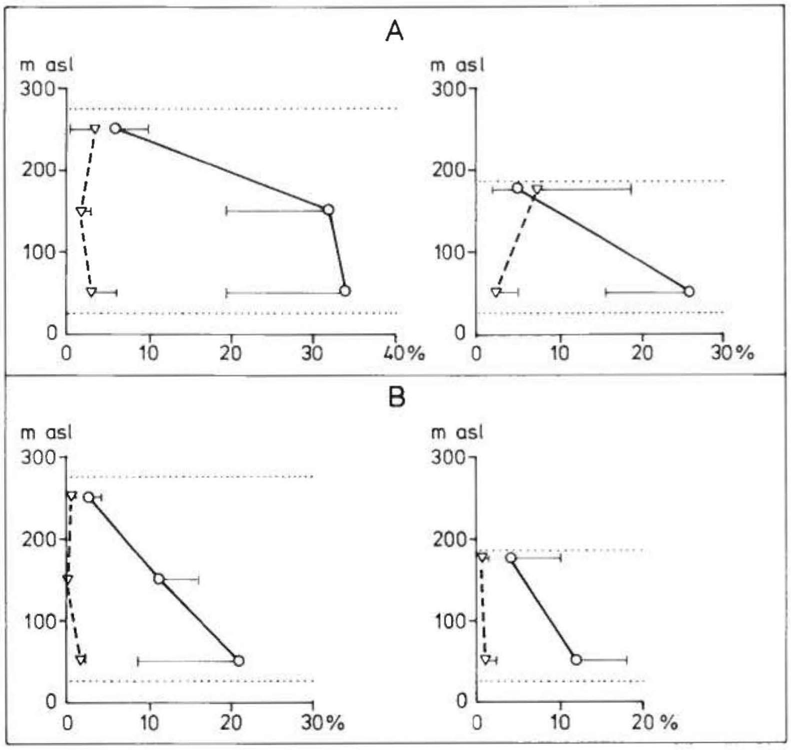

Fig. 3. Percentage of grazed shoots at 0.5 m (circles) and 1.5–2.0 m (triangles) above the ground at different altitudes above sea level (a s.l.) in Qingua-dalen. A: *Betula pubescens* on NW side (left diagram) and SE side (right) of valley. B: *Salix glauca* on NW side (left) and SE side (right) of valley. Altitudes of valley floor and upper limit of *B. pubescens* stands are indicated by dotted lines. Horizontal bars = 2 × s.e.

the difference in grazing as a function of height above the ground (northwest side: $p < 0.005$, southeast side: $p < 0.05$, W tests), in spite of the willow shrubs being only about half the height of the birches.

At the two subsidiary localities, with either a lack of tree-sized birches (Kangerdluarssuk), or a clumped occurrence of birch trees (Hospital Valley, upper slope), no separation was made between "low" (below 0.5 m above the ground) and "high" insect grazing (at 1.5–2 m above the ground).

At Kangerdluarssuk, the height of the birches (*Betula* spp.) was low, 0.2–0.8 m near the head of the fiord and 0.2–1.5 m about 1 km up the valley, the birches attaining the higher values in sheltered positions near rocks and stones. Consequently, the grazing occurred mainly within 0.5 m above the ground.

The grazing frequency on birch (Fig. 4 A) was highest at the outer study profile and at the lowest altitude (25%), although the difference between altitudes within the profile was not significant. Grazing was lower on *S. glauca* than on *Betula* (inner profile: $p < 0.05$, outer profile: $p < 0.001$, M-W tests), i.e. less than 5% (Fig. 4 A).

In Hospital Valley, which is the only investigated inland locality, the grazing frequency at 2 m above the ground on the 3–4 m high *B. pubescens* trees (Fig. 4 B) was highest in the lower half of the slope, ($p < 0.001$, K-W test), apparently with a maximum 50 m above the valley floor, however not significantly different from the grazing intensity at the lowest situated station. Insect grazing was generally lower on *B. glandulosa* and *S. glauca* shrubs (0.5–2 m in height), than on *B. pubescens* ($p < 0.01$, M-W tests) although data are lacking for the lowermost station (Fig. 4 B).

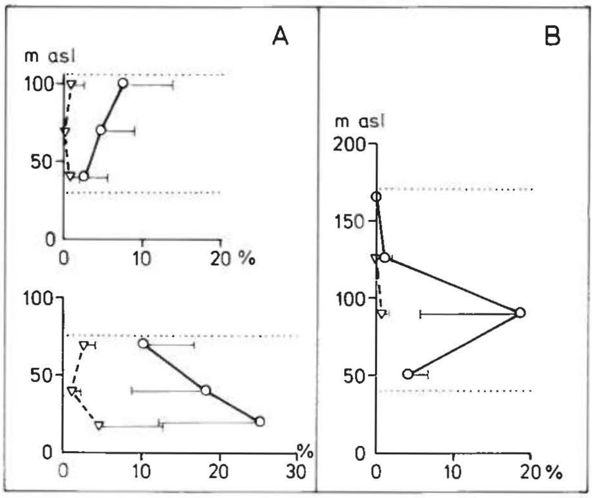

Fig. 4. Percentage of grazed shoots of *Betula pubescens* (circles) and *Salix glauca* (triangles) at different altitudes above sea level (a s.l.). A: Kangerdluarssuk, inner part (upper diagram) and outer part (lower) of the Lakseelv valley. B: Hospital Valley. Altitudes of valley floor and upper limit of *B. pubescens* stands are indicated by dotted lines. Horizontal bars = 2 × s.e.

Norway

In Norway, the insects still occurred on foliage when the field work was performed. Two of the localities were studied in two years. For the first year, counts of the most important grazers, *O. brumata* and *E. autumnata*, are reported separately, for the second year they are pooled.

At Trollvika, which is the most seaward investigation site, grazing obviously was high over most of the slope, as judged from the larval counts (Fig. 5 A). In 1965, the birch forest was brown-eaten from sea level up to about 100 m a s.l. In 1966 the larval population was still high up to the forest line, but declining compared to the preceding year (Fig. 5 A).

At Engmo, grazing in 1964 (Fig. 5 B) was high at both the upper and the middle altitudes of the slope and significantly lower near the valley floor ($p < 0.05$, K-W test). The forest became brown-eaten only in a middle, horizontal zone. This damage pattern was recorded at a

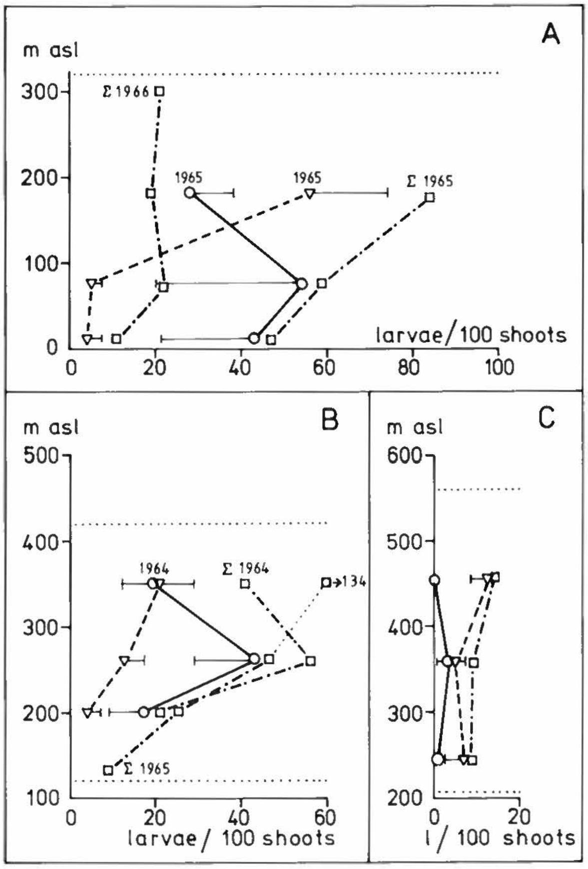

Fig. 5. Abundance of larvae of *Operophthera brumata* (circles) and *Epirrita autumnata* (triangles), separately, and summed up (squares) on *Betula pubescens* at different altitudes above sea level (a s.l.). A: Trollvika 1965, with addition data from 1966. B: Engmo 1964, with addition data from 1965. C: Frihetsli 1964. Altitudes of valley floor and upper limit of *B. pubescens* forests are indicated by dotted lines. Horizontal bars = 2 × s.e.

visit later in the season when grazing had ceased, on August 10 1964. The outbreak culminated in 1965 with very large numbers of larvae at the highest station (Fig. 5 B). On a return visit on August 12 1965, it was observed that the brown-eaten zone this summer had shifted up-slope, now extending vertically from about 325 m a s.l. to near the forest line.

In contrast to the situation at the two former localities, the population at Frihetsli had not reached outbreak numbers in 1964 (Fig. 5 C). There were no obvious differences in total larval numbers along the slope. A return visit in 1982 revealed the occurrence of many dead birch trees in the upper half of the slope, killed by an outbreak, probably in the middle of the 1960's. The birch forest became severely defoliated in the upper part of the slopes on the eastern side of the river also in the 1940's and on the western side in 1955 (Tenow 1972).

At Trollvika, *E. autumnata* larvae dominated in number in the upper half of the slope ($p < 0.01$, W test) in 1965 and *O. brumata* in the lower half ($p < 0.01$) (Fig. 5 A).

The same trend was seen in 1964 at Engmo (Fig. 5 B), where *E. autumnata* larvae increased significantly in number up-slope ($p < 0.01$, K-W test), however, without being more abundant than *O. brumata* at the uppermost station. The abundance of *O. brumata* larvae was higher at the intermediate station than at the lower station ($p < 0.05$, K-W test), and the larvae were more abundant than the larvae of *E. autumnata* ($p < 0.05$, W test).

Also at Frihetsli, in 1964, the abundance of *E. autumnata* increased with altitude, however, without the increase being significant (Fig. 5 C). Like at Engmo, the occurrence of *O. brumata* larvae peaked at the intermediate altitude station ($p < 0.05$, K-W test).

Discussion

In both regions insect outbreaks have been documented on Mountain birch (Tenow 1972; Koponen 1978). In addition, in 1987 and 1988, after the performance of the present study, outbreaks of *O. bruceata* occurred in SW Greenland, e.g. at Kangerdluarssuk (P. Bjerge pers. comm.; H. Bohse pers. comm. and larval sample).

The results of present investigations are in accordance with previous studies of altitudinal distributions of different insect grazers in Fennoscandia, where outbreaks of *E. autumnata* mainly occur in the upper parts of the forest-clad valley slopes of the Fennoscandian mountain chain, while outbreaks of *O. brumata* centre in the middle or the lower parts, at least during the initial phase of an outbreak (Tenow 1965, 1972; Hågvar 1972).

The altitudinal distribution of outbreak species may change considerably from the initial and the peak years to the last year of an outbreak, when the original distribution becomes distorted by the effects of virus disease and parasitism on the larval populations, and starvation of the larvae (Tenow 1972). Thus, when comparing the altitudinal zonation of leaf-eating insects, the different conditions prevailing during the study , i.e. an outbreak situation with identified insect species in northern Norway and a near endemic population situation with unidentified species in Greenland, call for caution when interpreting data. However, in Greenland and during the first year of study at the Norwegian localities, the populations were either in the initial or peak phase of a culmination with healthy individuals still essentially unaffected by density dependent factors. A comparison is therefore considered justified. The fact that the two regions were studied during separate time periods and where grazing was evaluated from the percentage grazed shoots and the abundance of larvae, respectively, is assumed not to interfere with large basic similarities or differences.

Furthermore, by comparing SW Greenland localities (Lat. 61°N) with localities in similar climatic-phytogeographical subzones in northern Norway (Lat. 69°N) instead of sites on the same latitude in southern Norway (cf. Fig. 1 A), some effects on distribution of very different vegetational and faunal composition should be reduced.

In Greenland, grazing was mainly at low altitudes of the slopes, either near the sea level as at the two suboceanic localities Kangerdluarssuk and Qingua-dalen, or with a maximum some fifty meters above the valley floor, as in Hospital Valley, the inland-most, subcontinental locality. In contrast, in all Norwegian profiles the grazing was frequent at most altitudes, mainly by *E. autumnata* at the upper levels of the slope and by *O. brumata* at the lower levels.

This difference may simply be due to the absence in SW Greenland of an adapted occupant of the upper parts of the birch zone, like *E. autumnata* (cf. Downes 1988). However, there is one potential leaf-chewing insect, the tortricid *A. caryosphena*, which Koponen found up to the limit of birch, both at Kangerdluarssuk and Narssarssuaq. This species also occurred in Hospital Valley and the inner part of the Lakseelv valley at Kangerdluarssuk (Koponen 1978).

On the other hand, if grazing by *E. autumnata* in Fennoscandia is disregarded, there are large similarities in the grazing patterns of the two regions. This applies at least in the first year of an *O. brumata* outbreak. Thus, grazing by *O. brumata* was mainly at a low altitude on the slope profiles, in the same way as found for the total grazing at the Greenland localities, either close to sea level at Trollvika, the coastal, suboceanic locality, or with a maximum some hundred meters above the valley floor at Engmo and the more continental Frihetsli farthest from the coast.

It is unknown which species caused the grazing observed in Greenland. Outbreak numbers of *O. bruceata* occurred at Kangerdluarssuk in 1976 (Koponen 1978) and 1987–88 (H. Bohse pers. comm.). On the same occasion *O. bruceata* also occurred at Narsaq and Narssarssuaq but in fewer numbers (Koponen 1978; H. Bohse pers. comm.). Thus, it is reasonable to assume that *O. bruceata* was an important component in the leaf-eating guild in 1984, at least at the suboceanic localities.

The newly hatched larvae of *O. brumata* and *O. bruceata* enter and attack opening buds of their hosts (Briggs 1975; Brown 1962) and an early bud burst is considered decisive for the success of *O. brumata* on fruit-trees (Holliday 1977). Bioclimate, and hence the phenology of bud burst and leafing-out, changes systematically up-slope along valley sides. Commonly, on an inland valley slope, the middle zone ("the thermal belt", cf. Geiger 1961) has the warmest climate and, consequently, the earliest flushing of leaves. In the Fennoscandian mountain chain, *O. brumata* outbreaks tend to start within these belts of early leafing (Tenow 1972). A dependence of *O. bruceata* on a similar phenological relationship may partly explain similarities in the form of grazing profiles in SW Greenland and the abundance profiles of *O. brumata* in northern Norway.

Differences in life conditions are perhaps better illustrated by the different distributions above-ground of grazing. At the two suboceanic Greenland localities, grazing on both willow and birch was almost entirely confined to foliage near the ground. At Kangerdluarssuk, this restriction may primarily have been imposed by the mostly low growth of birch and willow. However, it is interesting to note that during the outbreak at Kangerdluarssuk in 1976, with complete defoliation of the low birch shrubbery, the tallest *B. pubescens* formations were in good condition and carried very few herbivores (Koponen 1978). This does not exclude the possibility that starving larvae may sometimes climb trees and to some degree extend grazing upwards. Similarly, in Qingua-dalen, grazing near the ground prevailed in spite of the fact that tree-high birches and tall willow stands dominated along much of the slope profiles. Thus, obviously some factor(s) other than foliage height restricted the vertical extent of grazing. In northern Norway no such restriction was observed; trees were defoliated from the base to the very top of the crowns.

Larvae of *O. bruceata* are more mobile and more easily dislodged from the foliage than those of *O. brumata* (Eidt & Embree 1968). Where both species occur in the same region, as in parts of North America, it has been observed that in forests infested with *O. bruceata*, understory plants are often most heavily defoliated while the wind-exposed portions of the tallest trees may be untouched. On the other hand, in forests infested by *O. brumata*, the understory vegetation is relatively untouched, even when the overstory is completely defoliated (Eidt & Embree 1968). Thus, the different vertical extent of grazing in Greenland may have arisen from influences of the different insect species composition, in the same way as discussed for differences in the altitudinal extent of total grazing (see above).

However, a direct effect of a more severe and special climate in Greenland can not be ruled out as a contributing cause. The concentration of larvae of *A. caryosphena* on near-ground foliage, especially on leaves close to stones, was ascribed by Koponen (1978) to the warm microclimate in this habitat as contrasted with the conditions at some distance from the ground. The severity of climate is further illustrated by its effect on birch growth. From Fig. 2 it is seen that Narssarssuaq, the most continental of the topical Greenland weather stations, has a summer temperature, a length of growing season and an annual precipitation which is rather similar to that of the most seaward of the two Norwegian weather stations, Gibostad. In spite of this similarity, Narssarssuaq and the nearby Hospital Valley have only smaller, scattered stands of birch trees at a lower altitude, while Trollvika, close to Gibostad, has a luxuriant, continuous meadow birch forest up to more than 300 m a s.l. Qaqortoq/Julianehåb and Nanortalik lack birch growth due to their exposed oceanic positions (Böcher 1979).

In SW Greenland, hence, birch forests are near their limit of maintenance productivity (Elkington & Jones 1974), the depression of growth to shrubbery or its complete exclusion in coastal areas being caused by too low summer temperatures, too many days with strong winds, and by fog coming in frequently from a sea cooled by drifting ice even in summer (Böcher 1979). In winter, occasional very strong and often long-lasting, warm and dry foehns, blowing from the inland icecap, may desiccate buds and twigs of trees (cf. Ødum 1979).

Reasonably, these special climatic features will affect the insect fauna of birch and willow as well. Thus, candidate factors, acting on one or several life stages irrespective of species, and causing a peculiar, »crouching« form of grazing at the suboceanic localities in Greenland, are windy weather and a chilled air which warms up and keeps warm only in sheltered positions near the ground (cf. Hansen 1973). This assumption is supported by the finding at Hospital Valley, farthest from the sea, that grazing extended up into the crowns in the same way as at the Norwegian localities.

In conclusion, grazing in SW Greenland seems to be mainly in the lower half of the valley slopes, while in Fennoscandia it extends over most of the birch-clad slope. Furthermore, in climatically exposed sites, grazing is concentrated to near-ground foliage, while in Fennoscandia it extends over most of the birch crowns. Only at protected inland localities does it have a similar vertical extent in Greenland.

Hypothetically, then, growth of tree-sized birches in SW Greenland should be significantly affected by outbreaks of leaf-eating insects only at lower altitudes on the slopes at inland sites, while the Mountain birch forest in Fennoscandia is affected over most of its altitudinal and horizontal extent.

Acknowledgements

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Afforestation experiments reflecting the treeline conditions in Southwest Greenland

SØREN ØDUM

Ødum, S. 1990. Afforestation experiments reflecting the treeline conditions in Southwest Greenland. – Meddr Grønland, Biosci. 33, 43–61 pp. Copenhagen 1990-9-28.

Scrub of *Betula pubescens*, *Alnus crispa*, and particularly *Sorbus groenlandica* indicate potential conifer-treeline conditions in SW Greenland. Experimental tree-planting elucidates the phytogeographical position of the region, especially when using plant material of well known origin.

The history of early introductions and experiments leading to afforestation-attempts 1953ff is surveyed. *Pinus sylvestris, Larix sibirica, Picea glauca*, and *Picea glauca* × *sitchensis* have grown to 4–6 m at interior fiords between 60°N and 61°N. Recent introductions of high latitude and high altitude origins of *Picea glauca, Abies lasiocarpa*, and *Pinus contorta* from Alaska and Yukon have resulted in obviously better adaptable plant material.

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The phytogeographical position of SW Greenland is not easily defined. In the interior fiords climatic conditions, such as length of growing season, mean temperatures, and degree-days, are comparable to polar and alpine conifer-treeline environments on the neighbouring continents (Mikola 1962, Payette & Gagnon 1979, Sarvas 1970, Sestoft 1970, Tukhanen 1984, Viereck & van Cleve 1984, Ødum 1979). Equivalent or slightly warmer conditions prevail in the valleys and the coastal lowlands of Iceland, where successfully growing and even reproducing plantations of a broad spectrum of introduced conifers are to be seen (Bjarnason 1967, Bløndal 1982, 1987).

The nearest coniferous forests and treelines are situated approx. 1000 km WSW of S Greenland at 55°–58°N in northern Labrador. Here *Picea mariana* (Mill.) B.S.P. is the northernmost species along with *P. glauca* (Moench) Voss, and *Larix laricina* (Du Roy) K. Koch (Payette 1983). Elliott-Fisk (1983) found the present treeline being relic west of Hudson Bay and advancing northward in Labrador, but is not discussing the disjunct Greenlandic subarctic scrub-forest.

The absence of native conifers (except for *Juniperus*) in Greenland, Iceland, the Faroe Islands and coastal NW Europe, as mapped and discussed by e.g. Hustich (1966, 1979), leaves an impression that the North Atlantic lowlands with present or past scrub-forest of *Betula pubescens* are more "arctic" than indicated by their climatic conditions and, in e.g. SW Greenland, additionally by their subarctic and boreal floraelements (Böcher 1949, 1979, Feilberg 1985). The rather naked look of the interior valleys of SW Greenland is probably to a much higher extent than generally considered a result of past and present activities by man and husbandry (Oldendow 1935, Fredskild 1981, 1988, Jacobsen 1987).

The scrub-forest of *Betula pubescens, Sorbus groenlandica*, and *Alnus crispa* in the interior fiord-landscapes south of the Arctic Circle may indicate a potential conifer treeline. Especially so on W-exposed slopes, where the most luxuriant stands are found (distribution maps, Fredskild and Ødum, this volume). *Sorbus groenlandica* is closely related to *Sorbus decora* (Sarg.) Schneid., or might be considered a geographical ssp. or var. of this species. *S. decora* is confined to the northern boreal forest zone of Labrador (Hustich 1947) and further south. In White Mts., New Hampshire, *S. americana* Marsh. occurs just below the treeline of *Abies balsamea* (L.) Mill. and *Picea mariana* (Leak & Graber 1974, and own obs.). In Greenland *Sorbus* is clearly more demanding than *Betula* and *Alnus*, having a scattered occurrence in the birch woodland and being most common on the warmest slopes. It flowers early enough (mid July) to mature seed in the warmest summers only.

The *Sorbus* species in Alaska, *S. scopulina* Greene and *S. sitchensis* Roem., have neither spread to the spruce forests in Brooks Range (north of the Arctic Circle) nor to altitudes above treeline in the coastal mountains in the South (Viereck & Little 1972, and own obs.). In Iceland and Scandinavia *Sorbus aucuparia* L. is rather common in the mountain birch woodland, mainly on favourable exposures at lower altitudes. It

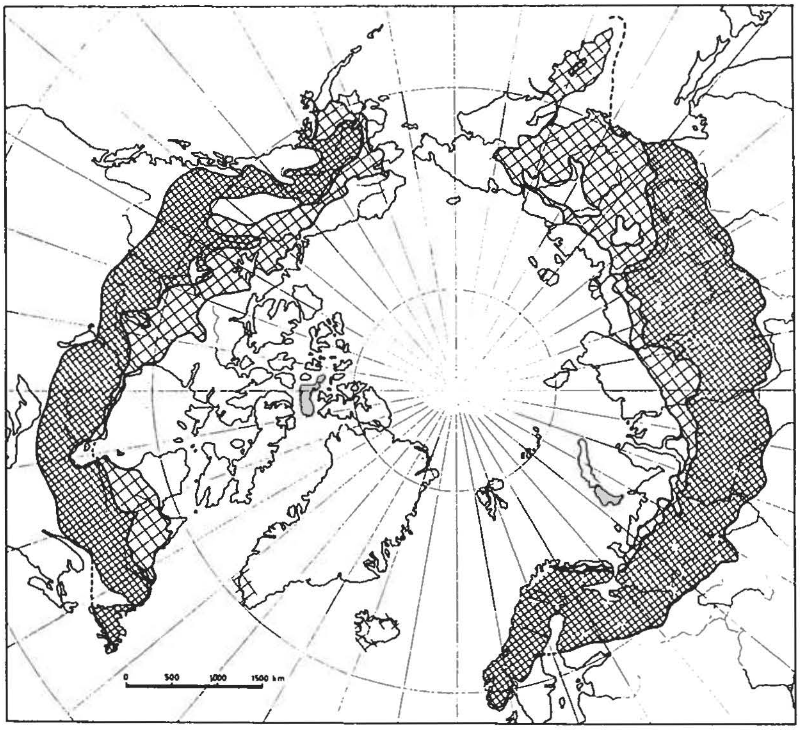

Fig. 1. The subarctic and northern boreal zones (Hustich 1966).

reaches almost the treeline on Varanger Peninsula, N Norway, and occurs on adjacent coasts.

In Scandinavia *Betula pubescens* is found at higher altitudes and latitudes than *Pinus sylvestris* and *Picea abies* (L.) Karst., in the Scandes with a vertical difference varying from approx. 50 to 200 m (Hustich 1966, Kullman 1979, 1981). In Alaska, *Alnus crispa* and *Populus balsamifera* L., are found on the N-slopes of Brooks Range, extending further north than the white spruce forest *(Picea glauca)*, as well as beyond the limit of conifers towards the Bering Sea (Viereck & Little 1972). Here the dynamics of *Alnus*-populations, e.g. the degeneration of very old stands of polycorm individuals and the generative regeneration of new stands on exposed soil (Wilson & al. 1984), resemble those of the mountain birch woods in SW-Greenland. Similar observations are recorded in northern Labrador by Gilbert & Payette (1982). In White Mts., New Hampshire, *Alnus crispa* forms a scrub-forest above the treeline of conifers (own obs.). In the coastal mountains of southern Alaska the closely related *Alnus sinuata* (Reg.) Rydb. occurs at higher altitudes, as well as further west on Kodiak Island and Alaska Peninsula, than the spruce forest (Viereck & Little 1972, and own obs.), being a pioneer on landslides and fresh moraines.

Hence the presence of *Betula pubescens* and *Alnus crispa* in Greenland is not a too convincing indication of a potential conifer treeline. However, the approx. 200 m vertical span of *Betula pubescens* on the most favourable exposures, its locally obtained tree-size, and the scattered *Sorbus* scrubs, suggest its probability.

Cool summers limiting tree-growth

Inadequate summer warmth is the generally accepted main factor preventing the growth of tree species to higher than 5 m (def. of treeline, Payette 1983) in arctic and alpine environments. Close to or at treeline a cool summer will result in badly maturing annual growth and subsequent damage or cutback due to frost, desiccating winds (in Greenland foehns from the icecap), mechanical damage from drifting snow, or other "classical" injuries. Series of cool summers will normally increase damages dramatically.

A spell of very cool summers occured in SW Greenland in 1982–84. Mean temperatures, recorded by Poul Bjerge at Upernaviarssuk Experimental Station, E of Julianehåb (Fig. 2), for the growing season (May 21–Sept. 20) were 1.5°C below the average for a 28-year period. As a response, the flowering of *Sorbus* was delayed till mid and late August. 1984 was the coldest year recorded within the period. Injured or dead tops or whole branch systems were observed among native birch trees 1984 and 1985.

As some of the introduced trees may expose a promising establishment and growth during years with "normal" or warm summers, the selective effect of cool "test-summers" is indeed welcome prior to an evaluation of the plantations. It can establish guidelines for a search for more adaptable origins and genotypes of species already planted, and perhaps additional species.

In the following survey of the preliminary results of experimental planting, the response of species and origins to these cool test-summers is given special attention.

Early introductions of seed and plants

The first known sowings or plantings were those carried out by the Herrnhut missionaries in Lichtenau between Julianehåb and Nanortalik. They probably sowed *Picea abies* (origin of seed unknown) at the fiord around 1846, and there are records from 1898 to 1923 about spruces having grown here to 1–3 m and about the collecting of Christmas-trees and spruce twigs for decoration (Bak 1981, Jørgensen 1949, Olsen 1929, Oldendow 1935, Rosenvinge 1896). No conifers have been observed in this fiord-landscape in recent decades.

Rosenvinge (1896), who investigated one of the above mentioned spruces taken to Denmark by N. Hartz, initiated the sowing of *Pinus sylvestris* and *Picea abies* 1892 at Igaliko and at the head of Tunugdliarfik fiord N of Narssarssuaq. The seed, originating from northernmost Norway (Oldendow 1935), resulted in

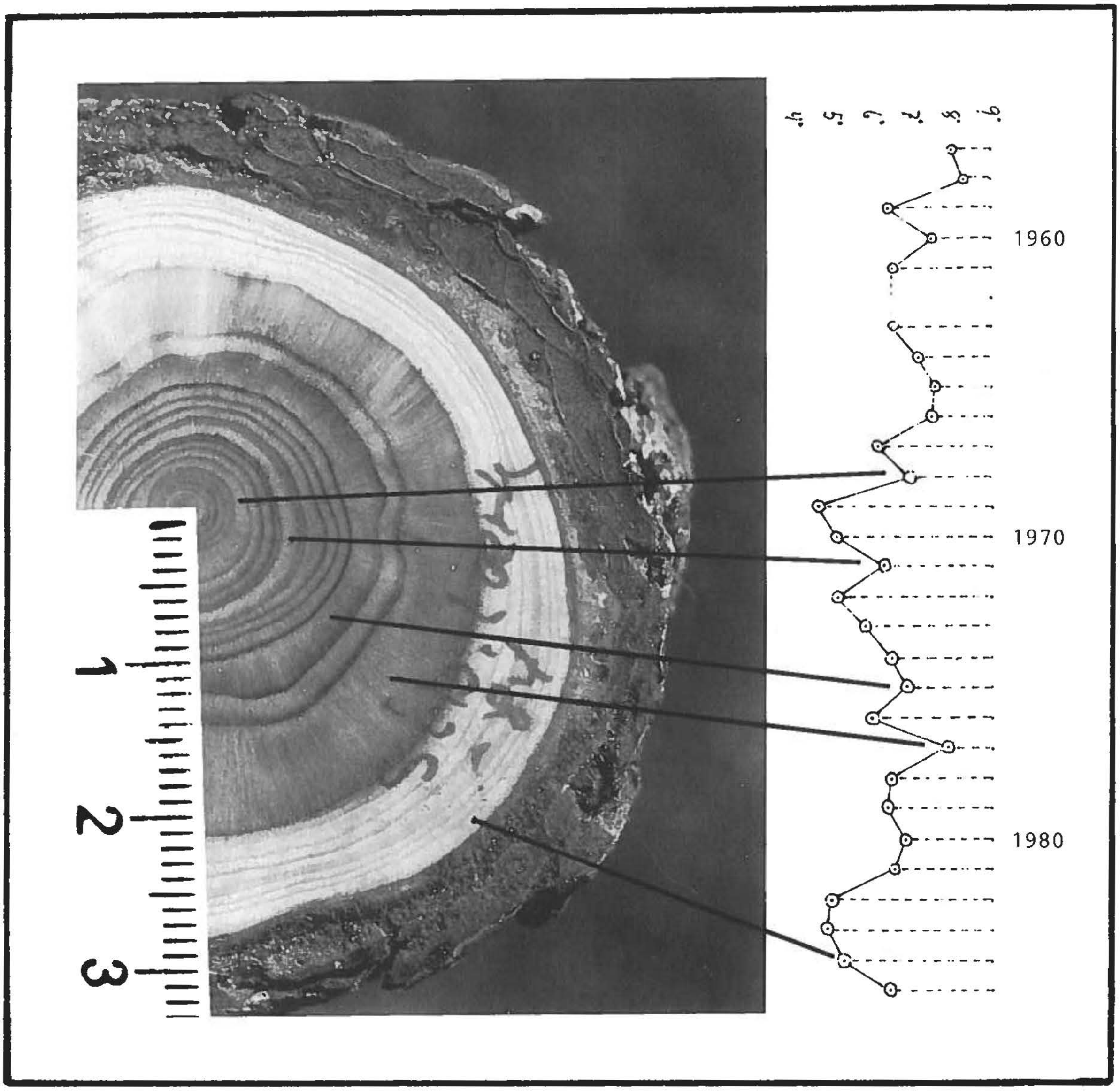

Fig. 2. A log of *Larix sibirica*, cut 1984 at Kugssuak, strongly reflects the width of the annual rings as a function of summer temperature. Mean temperature of the growing season (21 May to 20 Sept.) at Upernaviarssuk given in °C for 1957–1984. In Kugssuak the average temperatures are approx. 2°C higher. *Larix sibirica* in Greenland would be a superb indicator of any natural or artificial global heating. Bjerge del. and S.Ø. phot. 1986.

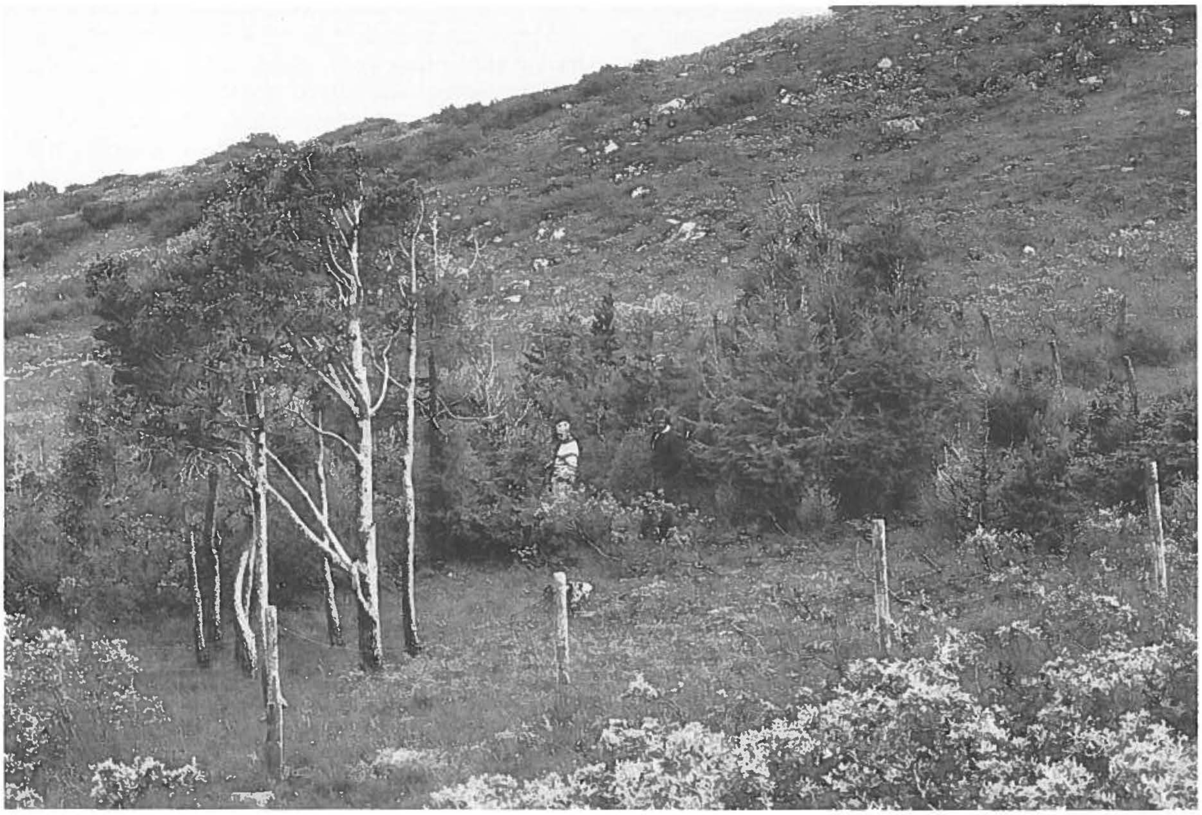

Fig. 3. Qanagssiassat. To the left the remaining "Rosenvinge's trees" with flagged crowns due to the effect of the foehn winds. To the right some *Pinus contorta*, *Larix sibirica*, a.o., planted 1953ff. Compared with photos in Oldendow (1935) it is evident how rapidly the slopes have been denuded due to the effect of sheep grazing. S.Ø. phot. 1983.

groups of small trees of which the only one remaining appears on dated photos, e.g. in Nielsen & Ødum (1981) and Oldendow (1935). Jørgensen (1949) measured 8 pines and 3 spruces of 3.5 m in height with an estimated production of 3 m^3/ha. At present remain 6 pines and 1 spruce, the tallest pine being 5 m.

K. N. Christensen of the Agricultural Station in Julianehåb, corresponded in 1929–30 with C. Syrach-Larsen, the initiator of the Arboretum in Hørsholm and its director 1937–68, about cooperation in finding and introducing material of trees and shrubs adaptable to Greenland conditions (archives at the Arboretum and Upernaviarssuk). This resulted in the sending of seed and plants of a number of species and origins, e.g. *Picea glauca* from Quebec, *Picea sitchensis* (Bong.) Carr. from Queen Charlotte Isl. and the Alaskan coast, *P. engelmannii* (Parry) Engelm. from British Columbia, *Larix gmelinii* (Rupr.) Litv., and *Pinus cembra* L. In 1932 K. N. Christensen replies that all plants sent had died, and that seed of *Picea abies* from Finland and *Picea glauca* from Canada had germinated only 10%, with the seedlings looking miserable. He states that he has lost faith in any afforestation attempts due to the bad ripening of new growth. Whether the *Picea glauca* seed referred to include a sample of seed of Mackenzie R. Delta origin (Inuvik, 70°N), which A. E. Porsild sent to Greenland a few years earlier (Olsen 1929) is not unveiled.

The only remaining tree originating from this period may be a *Picea abies* in Qingua-dalen, where K. N. Christensen on the initiative of M. P. Porsild (letter to Oldendow 1931) during 1933–34 investigated and ditched the lower part of the valley (archives at Upernaviarssuk, and Oldendow 1935). Several cutbacks are evident in this spruce, sheltered by birches. In 1984 it was measured 2.1 m, and in 1987 2.4 m with stem diam. at base: 27 cm, at 30 cm: 12 cm, and at 40 cm (after forking) up to 6 cm.

In 1937–38 C. Syrach-Larsen and Eric Hultén corresponded on the subject. As a result Eric Hultén sent seed of *Picea sitchensis* from Prince William Sound, Alaska. Prior to World War II state forest supervisor K. Kierkegaard, Palsgaard, applied for a travel to Greenland to plant forests (letters to Grønlands Styrelse (Oldendow), Statsskovdirektoratet, and Hedeselskabet). The plans were encouraged by S. C. E. Flensborg, director of Hedeselskabet and initiator of plantations established in Iceland and on the Faroe Isles. Flensborg also planned to ship plants to Greenland (archives at Upernaviarssuk). However, the war stopped this project.

It should also be mentioned that some conifers were planted early in this century at the small town of the kryolite-mine in Ivigtut (61°12'N, 48°10'W) by people emplyoed at the mine. Several small *Pinus sylvestris* (1 m) and maybe *P. mugo* were observed later (Porsild 1945, Pedersen 1972). A few *Picea glauca* and *Abies balsamea* (Fig. 4), not tending to grow much higher than 3 m, remain of conifer-seedlings dug up 1941 by navigator R. Bang-Christensen on "Julius Thomsen" when calling at Battle Harbour, Labrador, 53°N, and planted in Ivigtut (Böcher 1977).

Larger-scale planting since 1953

In 1947 C. A. Jørgensen, botanist and professor of genetics at the Royal Veterinary & Agricultural University visited W Greenland and caught interest in more comprehensive afforestation. He turned to Syrach-Larsen at the Arboretum and C. H. Bornebusch, the director of the State Forest Res. Inst., to outline a project, which was approved by Grønlands Styrelse.

Jørgensen and Bornebusch carried out a planning-tour in 1948, visiting Rosenvinge's trees, and estimated the productivity of the birchwoods to 2–4 m^3/ha. They choose, among other sites, the W-facing slopes of Qanagssiassat next to Rosenvinge's trees for future planting. Bornebusch and Jørgensen were convinced about the possibilities, provided the "right species of birch and conifers from the coldest localities in Canada, Alaska, N Europe and Siberia could be obtained, and provided the localities chosen for plantations were sheltered from the foehns (W-exposures)" (Jørgensen 1949, and Arboretum archives). Hence a search for seed and the production of plants was started, a work in which the Arboretum and the State Forest Nursery in Humlebæk took responsibility. Seed was mainly obtained from forest research institutions, particularly in the Nordic countries and Canada.

As a result Jørgensen sailed to Greenland in May 1953 with 20.000 plants and with a team of five foresters, P. Chr. Nielsen (the Arboretum), F. Dalskov, B. Christiansen, O. Thorsen, and P. Bjerge. Most plants were planted at Qanagssiassat (1 ha) and Upernaviarssuk (¼ ha). They had suffered somewhat from transportation and too early growth, and it was decided to produce future plants in Greenland. After settling permanently in Upernaviarssuk 1956, Bjerge has been running the nursery of the station and conducting the planting-work. A major project 1959–61 was his planting of 20.000 locally produced plants in two plantations (3–4 ha) at Kugssuak, Tasermiut fiord, 10 km from the Qingua-dalen (Bjerge 1959, Bjerge & Ødum 1987). Material has been added to these main plantations, and the spectrum of species and origins has been enlarged, not least due to supplies from the State Forestry of Iceland.

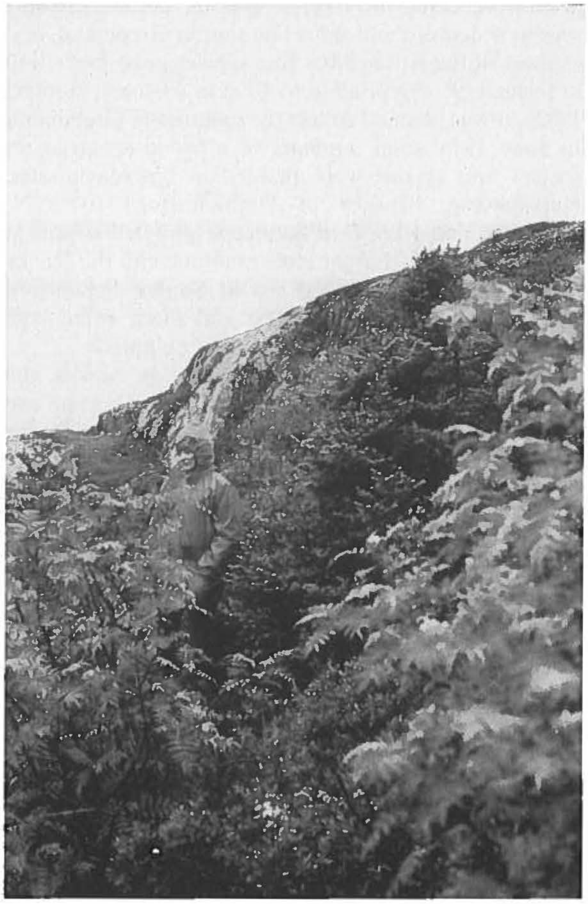

Fig. 4. Ivigtut. One of the specimens of *Abies balsamea*, transplanted from the coast of Labrador 1941 and not tending to grow above the *Sorbus*-scrub. S.Ø. phot. 1984.

Recent introductions from the Rocky Mountains and the Alaskan-Yukon region

In 1971 a seed-collecting expedition was made in the central Rocky Mts. in USA (Feilberg & Ødum 1972). The main purpose was to collect *Pinus contorta* Loud. var. *latifolia* S. Wats., *Picea engelmannii* (Parry) Engelm., and *Abies lasiocarpa* (Hook.) Nutt. for provenance trials for IUFRO (International Union of Forest Research Organization) as well as for arboretum purposes. Other species were collected as well. The three conifer species together with *Populus tremuloides* Michx. are forming the uppermost forest zone of the region with *Picea engelmannii* and, northernmost, *Abies* *lasiocarpa,* being the treeline species. As the growing season is delayed and short like that in Greenland, and as most of the Rocky Mts. tree species grow fairly well in Iceland (*P. engelmannii* to 10 m in 40 years, Bløndal 1982), it was planned to test the material in Greenland. In June 1976 small numbers of a broad spectrum of species and origins were planted in Upernaviarssuk, Narssarssuaq, Qorqut at Godthåbsfjord (64°15'N, 50°55'W), and 4 km E of Søndre Strømfjord airport at the Arctic Circle. Larger scale planting with the Rocky Mts. material was carried out at Søndre Strømfjord 1977–79. Some *Pinus sylvestris* and *Picea abies* from northernmost Fennoscandia were also planted.

In 1981 a collecting tour was made in Alaska and western Yukon with the purpose of getting seed and plants, where possible from close to or at treelines, for trials in Greenland and the Faroe Islands (Ødum 1981). Due to the long intervals between good seed-years at the treelines, it was decided to collect a few hundred small plants from most of the 20 localities, ranging from 61°N to 67°N (Arctic Village, 740 m alt., Brooks Range, N-limit of *Picea glauca*). Hypothetically the seedlings established at treeline represent a screening of the hardier genotypes of the populations (Ødum 1985). The majority of 4.000 plants dug up were *Picea glauca* (10 origins), while *P. g.* × *P. sitchensis, P. mariana, Abies lasiocarpa, Larix laricina, Populus tremuloides,* and *P. balsamifera* were obtained from fewer localities. *Abies lasiocarpa* was collected at its northernmost locality (Keno Hill, Yukon, 63°57'N, 1100 m alt.).

This material and 2.880 potted saplings of *Pinus contorta* var. *latifolia* from 12 localities (59°–63°28'N) in Yukon and northernmost Brit. Col. (seed collected by G. Skaret, Mosjøen, and plants provided by J. Dietrichson, NISK, Norway) was together with additional material planted at Kugssuak (not the *Pinus contorta*), Narssarssuaq, Qorqut, and Søndre Strømfjord 1982–83. According to Chritchfield (1985) this morphologically well defined Yukon-race of *Pinus contorta* may have achieved its hardiness and adaptation to northern latitudes on isolated outposts during the last glaciation. For decades this pine has been an object of provenance trials in the Nordic countries, and it is widely planted for wood production particularly in the northern Sweden and Finland (Lindgren & Lindgren 1985).

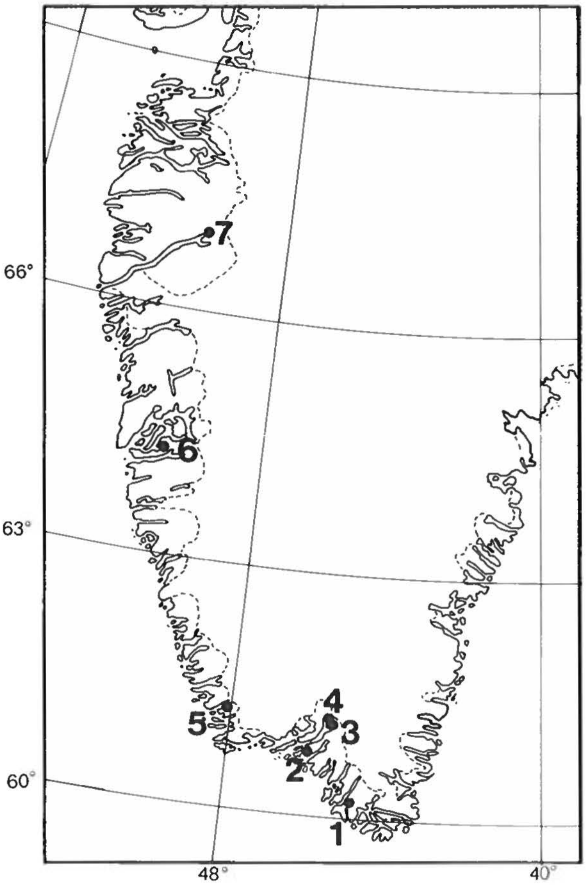

Fig. 5. The geographical position of the planting-localities mentioned. 1. Kugssuak at Tasermiut fiord, 2. Upernaviarssuk, 3. Narssarssuaq, 4. Qanagssiassat and "Rosenvinge's trees". 5. Ivigtut, 6. Qorqut, 7. Søndre Strømfjord.

Development of species and origins in the various plantations and discussion of results

Not surprisingly all specimens of trees introduced prior to 1950 obviously have disappeared, except for Rosenvinge's trees from northernmost Norway and the Ivigtut trees from the Labrador coast. Besides originating from northern latitudes and/or summer cool climates, these few introductions were sowed or planted directly at favourable sites in scrub-forest of *Betula* and *Sorbus*. The spruces sowed or planted at Lichtenau fiord did obviously survive for many years due to similar favourable conditions, but being of a probably too southern and/or low altitudinal origin they have very unlikely grown above the scrub. They may have developed like the spruce in Qingua-dalen. The cool summers of the outer coasts prevent the maturing of annual growth during most years. As most of the sowing and planting carried out in the thirties by K. N. Christensen took place in Julianehåb, the seedlings and plants were predestined to perish sooner or later, independent of origin. Only artificial shelter, increasing the temp. near the ground together with means of protection during the winter, have in some gardens resulted in survival and moderate development of individual specimens of the later introduced *Larix sibirica, Picea engelmannii, P. glauca,* and *Abies lasiocarpa* (Bjerge & Ødum 1987).

According to Feilberg (1984) Upernaviarssuk is situated in the oceanic low-arctic zone. This is clearly reflected by the possibilities of tree growth. P. Bjerge's records reveal that out of a very large number of species, origins and cultivars of trees and shrubs tried in the nursery, many were dead after the first winter. Others perished after one or more years, often as a result of severe winters following cool summers. The plantation next to the nursery clearly shows how the same plant material, now developing to tree-size in the subcontinental zones, is krummholz-like and dramatically thinned or cut back after the "test-summers". 30-year old *Picea glauca* × *sitchensis* (Kenai) and *Pinus sylvestris* (N-Norway) are currently less than 1 m in height, while a few *Larix sibirica* reach 2 m (Fig. 6). In the sheltered nursery with somewhat higher temperatures near the ground, the plant material with mature annual shoots and buds and without severe winter-damages will in general be worthwhile transplanting to the plantations at the inner fiords. The conifers having grown to same size in the plantation, the nursery, or the garden at Upernaviarssuk expose a reduced and delayed annual growth, shorter needles, and a formation and development of less lateral buds and twigs on apical shoots, when compared to similar material in Narssarssuaq and Kugssuak. On e.g. *Pinus contorta* (Alaska coast 55°–58°N) the average length of topshoots and needles on three specimens were during the "test-summers" in Upernaviarssuk 6.0 cm (needles 3.1), and in Narssarssuaq 9.6 (needles 4.7), and in 1985–86 in Upernaviarssuk 6.6 cm (needles 3.3 cm), while in Narssarssuaq 15.6 (needles 5.1). The climatic gradient is illustrated by the minimum and maximum temperatures on a calm, clear day by the end of July 1986 being: Upernaviarssuk 3.5°C and 11°C, Narssarssuaq 5°C and 20.5°C.

In Kugssuak at Tasermiut fiord the plantations are situated within the phytogeographical zone considered by Feilberg (1984) to be suboceanic, low- to subarctic. The sandy W-facing moraine slopes in most of the plantation-area are well drained with scattered low scrubs of *Salix glauca*. *Nardus stricta* is common. A few *Betula pubescens* indicate that this locality with easy access from the coast may have been clad with scrub-forest of birch. The species and origins planted here 1959–61 are *Larix sibirica* (Krasnojarsk, 56°N, 90°E, 750 m, and Haskasska, approx. 54°N, 90°E), *Picea glauca* (Knik River, N of Anchorage, 61°30′N, low alt.), *Picea glauca* × *sitchensis* (Kenai Peninsula, approx. 60°N, low alt.), and smaller groups of *Picea glauca* (Moonbeam, Ontario, 49°20′N, 82°W, and Allan Isl., French River, Sask.,

Fig. 6. Upernaviarssuk. The development of this plantation with *Larix sibirica* (back), *Pinus sylvestris*, *Picea glauca*, and *Picea glauca* × *sitchensis* (front) from 1953–60 illustrates its situation as being beyond a potential treeline. S.Ø. phot. 7 July 1987.

Fig. 7. Kugssuak. The selective effect of the cool "test-summers" 1982–84 on *Picea glauca* × *sitchensis*. S.Ø. phot. 1 Aug. 1984.

52°N, 106°W), and *Larix sibirica* (seed from Finland). When planted, each stand of *Picea* was mixed with one source of *Larix*.

Due to attack by a Larch-cancer (*Potebniamyces coniferarum* (Hahn) Smerlier, cf. Roll-Hansen & Roll-Hansen (1971)), more than 80% of the *Larix*-trees were killed 1980–85. In an area with originally 2.400 trees only 130 (5.4%) survived. In Iceland, Bløndal (1982) observed that serious attacks similarly coincided with spells of cool summers. In 1987 the remaining trees were up to 4–5 m in height (1982 3–4 m). The different provenances have not yet exposed marked variation in growth rate and other qualities, and cut-back of annual growth following the cool "test-summers" has not been observed.

In the same area were originally planted 1.000 *Picea glauca* × *sitchensis* of which 788 (78.8%) remained in 1987. The average height of 20 trees, randomly sampled, was in 1987 2.8 m (1.9–4.1 m) with an average of topshoots 1985 12.6 m (5–21 cm), 1986 20.4 cm (10–28 cm), and 1987 (growth not finished 14 July) 15.5 cm (8–25 cm). In 1982 the average height of the same trees were 2.1 m (1.1–3.0 m). The "test-summers" 1982–84 damaged 1–3 years growth on many trees, particularly on the more *P. sitchensis*-like individuals of the hybrid-swarm, while the more *P. glauca*-like were less harmed or without damages (Fig. 7–8). The damages were not correlated to height. Out of 38 trees 9 were unharmed (23.6%), 10 (26.4%) with damaged annual shoots, and 19 (50%) with damages of the last 2–3 years growth. In 1987 almost all damaged trees had recovered with new leaders erecting from upper lateral branches.

The *Picea glauca*-stands (Knik River) grow a little slower and finish their annual growth a little earlier. In the best growing stand (Fig.9) the average height of 20 trees were in 1987 2.6 m (1.8–3.4 m) with topshoots 1985 14.6 cm (7–25 cm), 1986 19.5 cm (12–27 cm), and 1987 16.9 cm (10–25 cm). After the "test-summers" out of 40 trees the 13 (32.5%) were unharmed, 19 (47.5%) with damaged annual shoots, and 8 (20%) with damaged 2 years growth. The two Canadian, more southern *Picea glauca* origins have developed less well and are more regularly damaged. The Knik River origin of *Picea glauca* came through the "test-summers" in a generally better condition than *P. glauca* × *sitchensis*, starting off faster in 1985–86. The gap in average height between them is diminishing.

A few spruces, killed by *Armillaria mellea* s.l., were felled or dug up for study of growth. From the photos in Böcher (1977) it is evident that the spruces, 15 years after they were planted, only recently had grown above the low willow-scrub. Accordingly the annual incre-

Fig. 8. Kugssuak. A moderately growing and hardy *Picea glauca* × *sitchensis*, 2.5 m high, *P. glauca*-like. Behind a less resistant, faster growing, 4 m high, *P. sitchensis*-like tree. The fallen tree has been killed by *Armillaria*. S.Ø. phot. 14 July 1987.

ment, as evident from stumps of felled trees, is extremely low the first 10–15 years. A dug up tree showed a vigorous secondary lateral root-system, the development of which appear to be simultaneous with the rapidly increasing height-growth of the tree (Fig. 11). In the thickest root (4.6 cm diam.) 11 annual rings were counted, while the stem at 10 cm above ground had grown from 1 cm to 7 cm in diameter the last 12 years. The root had grown 70 cm in 5 years.

Among the best developing species and origins planted at Kugssuak 1982–84, the following are the most promising: Coastal *Pinus contorta* (Haines and Skagway, both Alaska) and *P. contorta* var. *latifolia* (Stewart Crossing, Yukon, Fig. 12), *Picea glauca* (several origins from southern Alaska, see Fig. 13), and *Abies lasiocarpa* (Yukon and Wyoming). In spite of the cool "test-summers" they all established well with increased annual growth and without any damages.

In the nearby Qingua-dalen three young specimens of *Betula pubescens* were studied for comparison of growth. They measured 79, 108, and 123 cm with average of annual topshoots 1985: 8.3 cm (with 4–6 cm cut-backs), 1986: 11 cm, and 1987: 4 cm. Their diameter at base varies between 1.6 and 2.1 cm, with 15 annual rings. Hence the conifers are much more productive.

Narssarssuaq and the head of Tunugdliarfik fiord (with Rosenvinge's trees and the Qanagssiassat-plantation) are situated in the subcontinental-subarctic zone (Feilberg 1984), and the meteorological station at Narssarssuaq has recorded the longest and warmest summers of SW Greenland with 9.8°C as the average temp. for June-August, and with the average temp. for July-August above 10°C. In the Qanagssiassat-plantation, next to the 90-year old Rosenvinge's trees, the best devel-

Fig. 9. Kugssuak. Poul Bjerge in his 1960-plantation of *Picea glauca* (up to 3.4 m high trees) and *Larix sibirica* (to 4.5 m). S.Ø. phot. 15 July 1987.

Fig. 10. The northern plantation at Kugssuak. (Compare with fig. 6). The person shown with an arrow stands at the trees in Fig. 9. S.Ø. phot. 15 July 1987.

Fig. 11. Kugssuak. Dug up *Picea glauca* × *sitchensis* (killed by *Armillaria*) showing the superficial main roots which started developing approx. 10 years after the tree was planted. S.Ø. phot. 1987.

oped trees of *Larix sibirica* have grown to approx. the same size in 30 years (5.5 m heigh and 18 cm diam.), and in the "phenological garden" (Sestoft 1970) in Narssarssuaq, a *Larix sibirica* Ledeb. var. *sukaczewii* N. V. Dylis from 58°50'N, 60°07'E (central Ural Mts.) has grown to a similar size in 20 years (Fig. 14). The *Larix* trees are forming cones almost every year, in 1987 with some filled seeds. Selfsowing has, however, not yet been observed. The relatively slow growth of Rosenvinge's trees is obviously a result of their very northern origin (photoperiodic growth control). Later plantings of high latitude origins of *Pinus sylvestris* from Fennoscandia planted in Qanagssiassat 1953ff and in Narssarssuaq 1984ff grow similarly slowly and have not been frost damaged. During the "test-summers" the needles on Rosenvinge's trees were shorter than normal (1–2 cm) and were damaged by frost or foehns in 1984 (reddish appearence of tree-crowns) but the twigs and buds remained unharmed.

In Qanagssiassat and on nearby localities Bjerge tried quite a number of species during the 1950'es and 1960'es. Treeline-forming or high latitude species, which have failed to grow to bigger sizes, are e.g. *Abies sibirica* Ledeb., *Larix laricina* (Fairbanks, Alaska), *Picea mariana* (Goose Bay, Labrador), *Picea abies* (northern Sweden and Norway), *Picea sitchensis* (Pr. William Sound, Alaska).

The first introduced *Pinus contorta* originated from seed from Klosterheden Plantation (dept. 617) in Denmark. They were planted during the 1960'es, grew very fast but were repeatedly frost damaged, especially on lateral growth. The material is of a too southern and

Fig. 12. Kugssuak. *Pinus contorta* from Skagway (left), planted 1982, and *P. c.* var. *latifolia* from Stewart Crossing, Yukon (right), planted 1984. Obs. the earlier cessation of grovth in *P. c.* var. *latifolia*. S.Ø. phot. 14 July 1987.

Fig. 13. Kugssuak. *Picea glauca* from the low altitude Knik River (left) and from the tree-line at Broad Pass (right) both N. of Anchorage, Alaska. The slight difference in latitude between the two origins (61°30'N and 63°15'N) and maybe the selective pressure among seedlings at the treeline cause an earlier ripening of shoots and buds in the Broad Pass origin. S.Ø. phot. 14 July 1987.

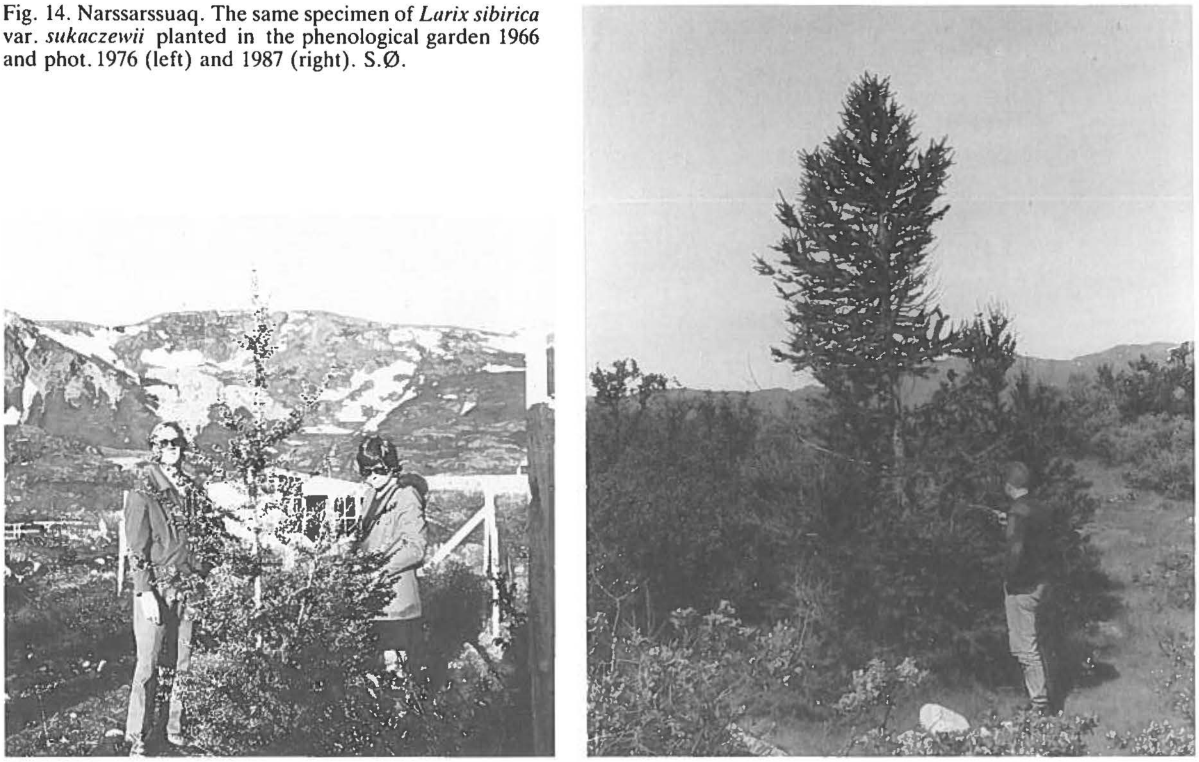

Fig. 14. Narssarssuaq. The same specimen of *Larix sibirica* var. *sukaczewii* planted in the phenological garden 1966 and phot. 1976 (left) and 1987 (right). S.Ø.

coastal origin. Later introductions of material of Alaska coast origin approved to be more hardy, but the plants exposed some damages on shoots and needles during the cool "test-summers", probably due to delayed growth and ripening. The *Pinus contorta* var. *latifolia* plants from the 1976-planting in Narssarssuaq had in 1987 grown to 50–110 cm with 5–13 cm topshoots. They start growing late like *Pinus contorta* from Alaska, but stop the prolongation of shoots earlier and were not damaged during the cool summers. The *Pinus contorta*-material from Yukon and northern Brit. Col. is much better adapted and hardier (Fig. 15), starting growth and ripening shoots earlier and with increasing length of tops (in 1988 up to 25 cm). There has not yet been observed any variation in hardiness among the various origins.

Among the plants from 1976 it is interesting to notice that *Picea glauca* from as far south as Black Hills, North Dakota, has grown fairly well (Fig. 16) with 10–20 cm topshoots 1986–87. *Picea engelmannii* (Fig. 17) and *Abies lasiocarpa* from the Rocky Mts. are hardy but grow very slowly with 5–10 cm topshoots. (The hardiness of *Abies lasiocarpa* and *Picea engelmannii* in trials at treeline in northern Sweden is dealt with by Remröd et al. 1976). Hardy and slow-growing is also *Pinus cembra* L. ssp. *sibirica* Loud. with 5–15 cm topshoots (Fig. 18). These three species are in general slow starters and may speed up after some years. A *Picea pungens* from Vernal, Utah, has grown to 55 cm with 8 cm undamaged topshoots.

All the Alaska-Yukon material, which was planted in openings in scrub and scrub-forest of *Salix glauca* and *Betula pubescens* on SW-exposures 1982–84, is in general hardy and performing well. Best adapted are *Picea glauca*-origins from treeline localities in central and southern Alaska. One of the best origins (Broad Pass) had topshoots to 10 cm in 1986, 15 cm in 1987, and 20 cm in 1988. The prolongation of topshoots does normally finish during the first week of July, and the ripening of annual growth takes place before August (Fig. 19). The northernmost origins of *Picea glauca* (e.g. from Brooks Range, 68°N) stop their growth much too early due to daylength control, but are, of course, totally hardy. *Abies lasiocarpa* from Yukon has a promising, but slow start.

It is too early to evaluate in further details all the species and origins planted in Narssarssuaq during the latest years (several thousand plants). It is, however, worth mentioning, that among the species and origins of *Larix* tested so far, *L. sibirica* var. *sukaczewii* is superior. Graftings of 10 clones of *Larix sibirica* and *L. s.* var. *sukaczewii* from Finland, carried out June 1983 by K. Næss-Schmidt, the Arboretum, show that even hardier and better adapted genotypes might be found (Fig. 20). The clones were selected in Finland by Max Hagman, Finn. Forest Res. Inst. Among origins of *Pinus*

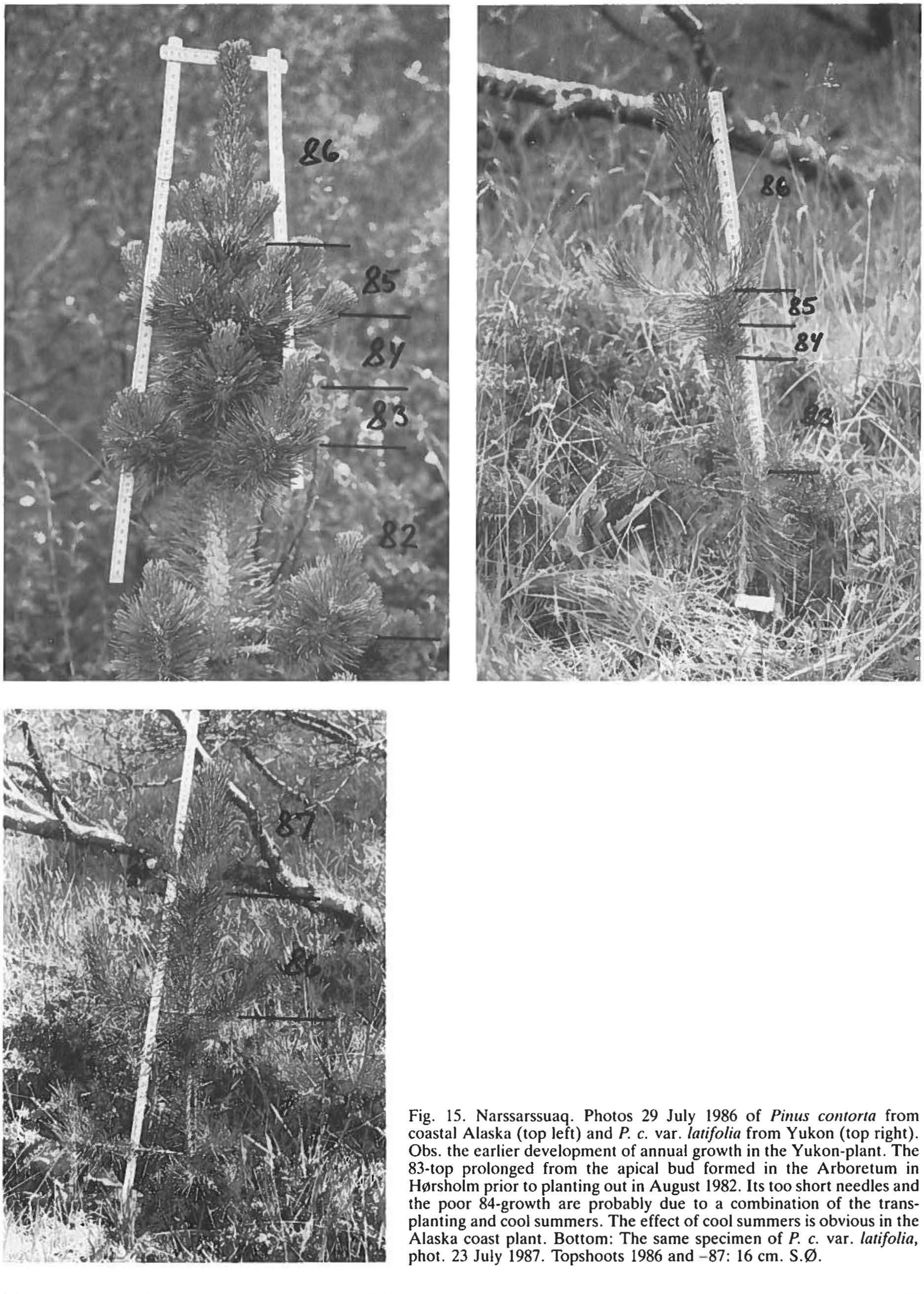

Fig. 15. Narssarssuaq. Photos 29 July 1986 of *Pinus contorta* from coastal Alaska (top left) and *P. c.* var. *latifolia* from Yukon (top right). Obs. the earlier development of annual growth in the Yukon-plant. The 83-top prolonged from the apical bud formed in the Arboretum in Hørsholm prior to planting out in August 1982. Its too short needles and the poor 84-growth are probably due to a combination of the transplanting and cool summers. The effect of cool summers is obvious in the Alaska coast plant. Bottom: The same specimen of *P. c.* var. *latifolia*, phot. 23 July 1987. Topshoots 1986 and –87: 16 cm. S.Ø.

Fig. 16. *Picea glauca* from Black Hills, Dakota, growing surprisingly well in Narssarssuaq. The annual growth is, however, developing and ripening too late. Here, 4 July 1987, the topshoot of this 80 cm plant was 12 cm, and 2 weeks later it had prolonged to 19 cm (compare with fig. 19). S.Ø.

Fig. 17. Narssarssuaq. *Picea engelmannii* from Jackson, Wyoming slowly growing with 5 cm annual topshoots 1985 and –86. S.Ø. phot. 25 July 1986.

sylvestris, which have been planted recently, treeline origins dug up in the Hardanger mountains, 60°N, S Norway, are obviously better adapted than Rosenvinge's trees and other very northern origins. They may also benefit from their original *mykorrhiza* (Fig. 21).

Among recent plantings in Ivigtut, a remarkable 5 m high (1984) *Populus trichocarpa* Hook. can be seen. It was transplanted here from the nursery in Upernaviarssuk in the 1970'es, and the material might have come from Iceland, where a number of clones from southern Alaska are growing well. In Upernaviarssuk all older material of *Populus* died during the "test-summers". In the phenological garden in Grønnedal nearby *Larix sibirica* var. *sukaczewii* of the same seed-source as in Narssarssuaq has grown to only 1–2 m due to exposure to cool fiord-winds.

At Qorqut, Godthåbsfjord, the climate is suboceanic and the growing season shorter than in Narssarssuaq. In the 1960'es were planted a row of *Larix sibirica, Picea glauca,* and *P. glauca* × *sitchensis* (same material as planted at Upernaviarssuk and Kugssuak). No trees have grown higher than 1.5 m, and they have repeatedly been cut back by frost or desiccation. A planted *Sorbus groenlandica* is 25 cm high with 1–2 cm annual shoots. Of the 1976-planting of Rocky Mts.-material remain only a few *Pinus contorta, Picea engelmannii* and *Abies lasiocarpa,* all slow-growing, and only a *Abies lasiocarpa* from Montana (35 cm high, 4 cm topshoots) is undamaged. Most of the material from Alaska-Yukon and Fennoscandia planted in 1983 was alive in 1986 except for a few too southern or too oceanic origins. However, only high elevation origins of *Picea glauca* from central and northern Alaska and *Abies lasiocarpa* from Yukon had adapted well with good colour of the needles and increasing height-growth. The *Pinus contorta*-material from Yukon and northern Brit. Col. was generally improving, but not as convincing as in Narssarssuaq. *Betula pubescens* from Tunugdliarfik fiord and from Kiruna, N Sweden, had been planted for comparison. The plants of Greenland-origin had died, whereas the plants from Swedish Lapland all grew well with 10–20 cm undamaged topshoots. Among other broad-

Fig. 18. Narssarssuaq. *Pinus cembra* var. *sibirica*, planted as seedling 1976, measuring 84 cm 1987 with a fat 14.5 cm topshoot. S.Ø. phot. 4 July 1987.

Fig. 19. Narssarssuaq. *Picea glauca* from Broad Pass, Alaska, dug up as sapling 1981, transplanted to here from the Arboretum nursery 19 August 1982, and phot. 4 July 1987. The 13 cm topshoot is in the early stage of ripening. The 1986 topshoot was 8 cm.

leaved species tested *Populus tremuloides* and *P. balsamifera* from near treeline in central Alaska had adapted well.

At Søndre Strømfjord the climate is continental and the growing season very short (approx. 10 June to 20 August). Of the large number of origins and plants from the Rocky Mts. and additional material from Fennoscandia and Siberia planted in 1976–79, remain very few specimens of *Picea glauca* (Fig. 23), *P. engelmannii*, and *Abies lasiocarpa* from the northern Rocky Mts., *Pinus sylvestris* and *Picea abies* from northernmost Finland, *Pinus cembra* and *Larix sibirica* from USSR, and a single *Pinus contorta* from Yukon. They either grow extremely slow or are repeatedly cut back. Of the 1983-planting of Alaska-Yukon material, only tree-line origins from 64°N and northward are performing well with increasing height growth and undamaged annual shoots: *Picea glauca* (Fig. 23), *Abies lasiocarpa*, *Populus balsamifera*, and *P. tremuloides*.

Conclusions

In the subcontinental-suboceanic SW Greenland from Tasermiut fiord to the Narssarssuaq region, the results of the afforestation experiments indicate that favourable exposures are well below a potential coniferous treeline, and maybe even a timberline (Figs 9, 10, 14, 24). The preliminary results of the recent introductions indicate that the best adaptable species and origins for SW Greenland conditions might be obtained from NW North America, especially from treeline populations in Alaska and Yukon. Treeline-origins from approx. 64°N and higher latitudes in Alaska-Yukon may push the potential treeline northward to Godthåbsfjord or even to Søndre Strømfjord. The fluctuating weather conditions and the spectrum of adaptable origins of exotic tree species confirm that the treeline conditions in SW Greenland have more in common with alpine treelines than with the polar treeline of the lowlands in central and eastern N America and Asia.

Fig. 20. A grafting of *Larix sibirica* var. *sukaczewii*, clone P. 40, Raviola, Finland, on a top of a seed-plant of the same sp. and var. in Narssarssuaq. Grafted June 1983, phot. 23 July 1987. The shoots are fatter and the foliage darker. S.Ø.

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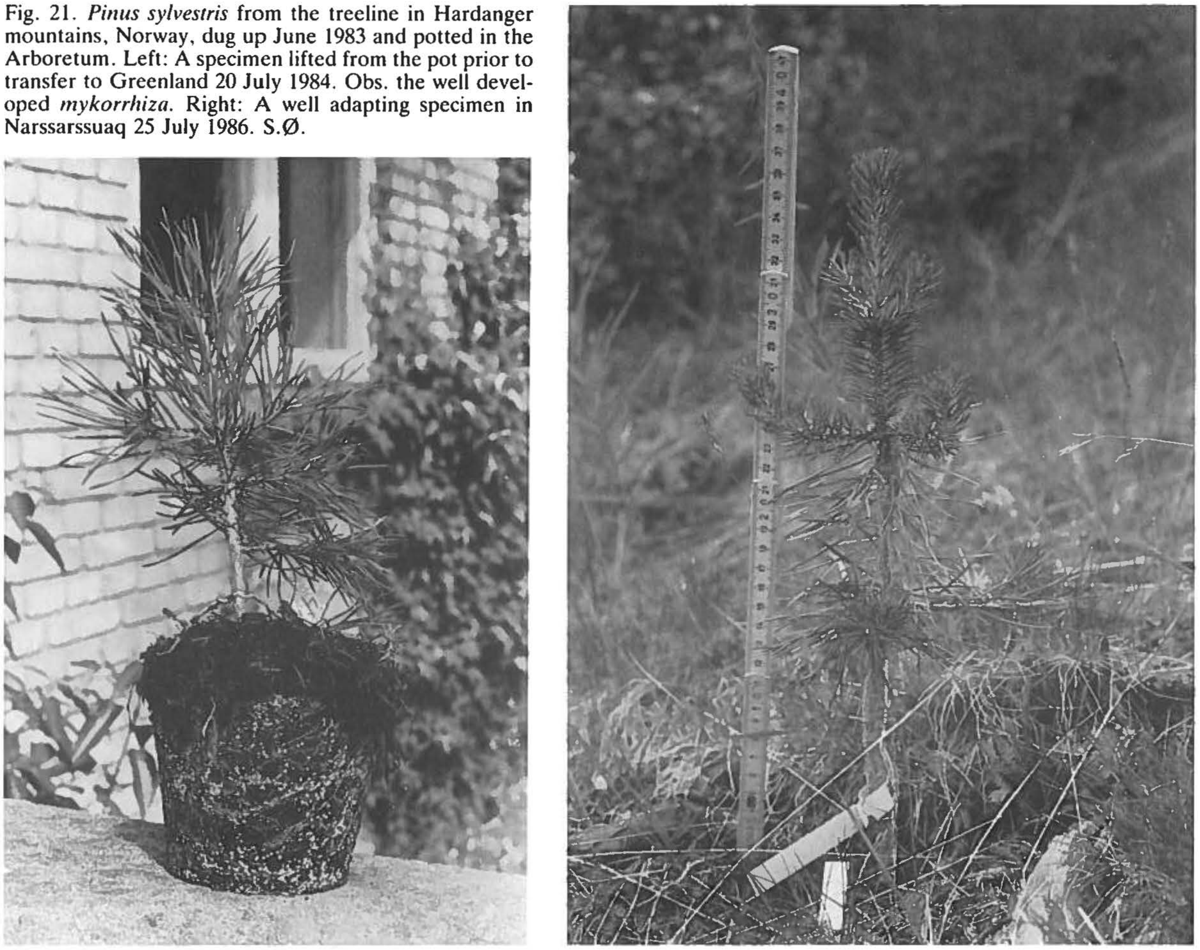

Fig. 21. *Pinus sylvestris* from the treeline in Hardanger mountains, Norway, dug up June 1983 and potted in the Arboretum. Left: A specimen lifted from the pot prior to transfer to Greenland 20 July 1984. Obs. the well developed *mykorrhiza*. Right: A well adapting specimen in Narssarssuaq 25 July 1986. S.Ø.

Fig. 22. View towards WSW in the valley 4 km E of Søndre Strømfjord airport. The outwash plains with scrub of *Salix glauca* and *Betula nana* were chosen for planting in 1976–79 (background left) and 1983ff (right). S.Ø. phot. August 1983.

Fig. 23. Adaptability of three origins of *Picea glauca* at Søndre Strømfjord. Top from Highwood Summit in the northern Rocky Mts., Alberta, planted 1979 and phot. August 1983. Bottom left a specimen dug up at treeline on the Yukon Plateau (Boundary W of Dawson City, 64°N, 1000 m alt.), and bottom right a specimen dug up in Brooks Range, Alaska (68°07'N, 740 m alt.), both planted August 1983 and phot. 5 August 1986. S.Ø.

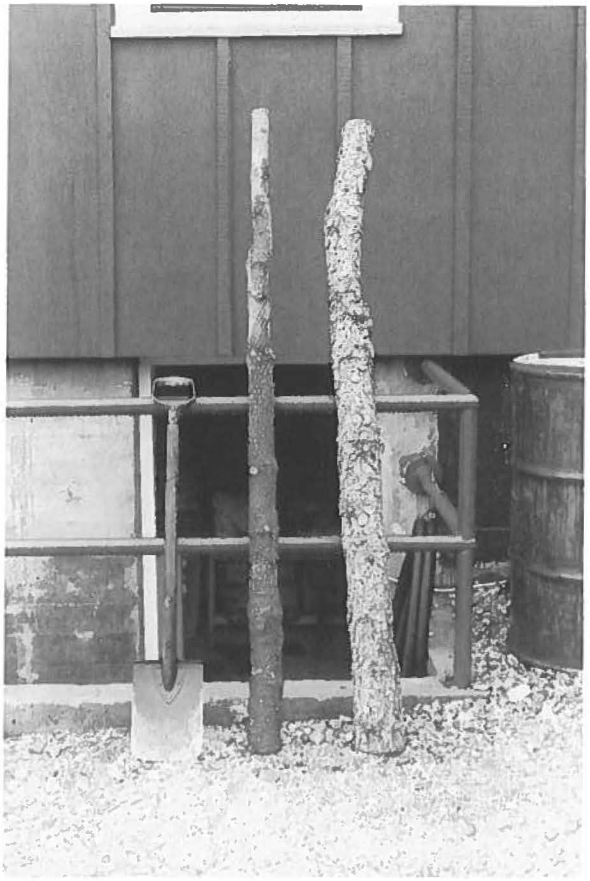

Fig. 24. Two 1.8 m logs from the SW Greenland plantations illustrating that timberline-conditions, and not just treeline-conditions might be considered. Left a *Picea glauca* × *sitchensis* (half of a forking tree) from Kugssuak, cut 30 cm above the ground: 10 years height-growth, 9.5 cm diam. at base and 4 cm at top (here 7 annual rings). Right a *Larix sibirica* from Qanagssiassat (9 years height-growth), diam. at base 13 cm (24 annual rings) and 8 cm at top (15 annual rings). S.Ø. phot. 1987.

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Nutrient ecology, vegetation and biomass of two South-Greenlandic birch forest sites

EUROLA, S., LAINE, K. and WIELGOLASKI, F. E.

Eurola, S., Laine, K. and Wielgolaski, F. E. 1990. Nutrient ecology, vegetation and biomass of two South-Greenlandic birch forest sites. – Meddr Grønland, Biosci. 33, 63–75 pp. Copenhagen 1990-9-28.

Two semi-dry birch forest sites were studied in Narssarssuaq (hemiarctic, subcontinental) and in Qingua-dalen (hemiarctic, suboceanic). The height of the scrub is only 1.3–2.8 m. A heavy podsolic soil prevails with thick moss-litter-humus and iron-rich horizons. The biomass of litter and dead material is high (1595 g/m^2). *Deschampsia flexuosa* prevails in the field layer. Twenty site types were distinguished in the vegetation transect across the Qingua-dalen. Mesic and moist types are dominant on the north exposed slope without any vertical differences which are more clear on the opposite side of the valley. The Ca content in the soil is high, particularly at Narssarssuaq (5–10 times higher than for K and Mg). The somewhat increased Na content in the humus layer at Narssarssuaq may be caused by minerals in the sea spray at this site which is relatively close to the fjord. Loss on ignition and total N in the humus layer are approx. low at both sites, probably because of considerable mixing with the mineral soil. Both the Ca and the N content in the plants are higher at Narssarssuaq than in those from Qingua-dalen, and are, generally, also higher than on oligotrophic subalpine/subarctic (northern oroboreal) birch forest sites of Fennoscandia. The high Na content in the sea spray at Narssarssuaq is reflected in a high content of Na in the birch bark and in *Cladina* lichens. "Total" sums of sugars (glucose+fructose+sucrose) in all parts of birch determined were higher in Qingua-dalen than at Narssarssuaq except in older twigs and roots. Starch contents, generally, show the same tendency, due to higher temperature (south exposed slope) and higher net assimilation. There were no differences in the contents of "total" carbohydrate (total sugar + starch) in other species between the two study sites.

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Our study group of the internordic Subarctic Birch Project (SBP) studied July 23 – August 6, 1984 nutrient ecology and vegetation of birch scrubs at Narssarssuaq (appr. 61°10'N, 45°28'W) and in Qingua-dalen east of Tasermiut Fjord (60°17'N, 44°33'W). In both areas birch scrubs are growing up to 150 m a.s.l., and willow copses 250 m a.s.l. in the hemiarctic zone. The humidity climate at Narssarssuaq is subcontinental (annual precipitation 698 mm, temperature of June-august 9.8°C), in Qingua-dalen suboceanic (Feilberg 1984, Fig. 5).

Two semi-dry birch scrub sites were selected for sampling (Fig. 1). At Narssarssuaq the site is situated on a hill side close to the fjord on a low (15–20 m) ridge appr. 30 m a.s.l., in Qingua-dalen near to the valley bottom on a slope (exposition 160° at the angle of 10 degrees) appr. 50 m a.s.l. Three birches were taken for study via a systematic probability sampling with distances of 10 m between the trees. The vegetation analyses, biomass collections, and soil profile analyses were made at the distance of 2 m from the sample trees from which were collected buds, catkins, leaves, one-year shoots, <0.5 cm older twigs, thicker twigs, roots, outer and inner bark, and stem wood for mineral nutrients (total N, total P, Ca, Mg, Na and K) and carbohydrate (glucose, fructose, sucrose and starch) analyses. Mineral elements were extracted from ashed material by a concentrated HCl-HNO$_3$ mixture and analysed by emission (K, Na) and absorption (Ca, Mg) in an atomic absorption spectrophotometer and by spectrophotometer (P). Total N was analysed by a semi-micro Kjeldahl technique. Carbohydrate contents (starch and the soluble sugars: glucose, fructose and sucrose) were analyzed by an enzymatic method, described in detail by Beutler et al. (1978). The same carbohydrates and mineral nutrients were determined in *Deschampsia flexuosa, Pleurozium schreberi,* and *Cladina* coll., and also *Empetrum* at two sites in Qingua-dalen. The mineral elements are also determined in the soil. A vegetation transect across the Qingua-dalen was analysed. Comparisons are made with the results from Hardangervidda, South Norway (60°N, 7°30'E, 780 m a.s.l.), Kilpisjärvi (69°N, 20°50'E, 500–600 m a.s.l.), and Kevo (70°N, 27°E, 130 m a.s.l.), North Finland (Sonesson et al. 1975).

The nomenclature of the vascular plants is in accordance with Feilberg (1984), the bryophytes with Koponen et al. (1977), and the lichens with Santesson (1984).

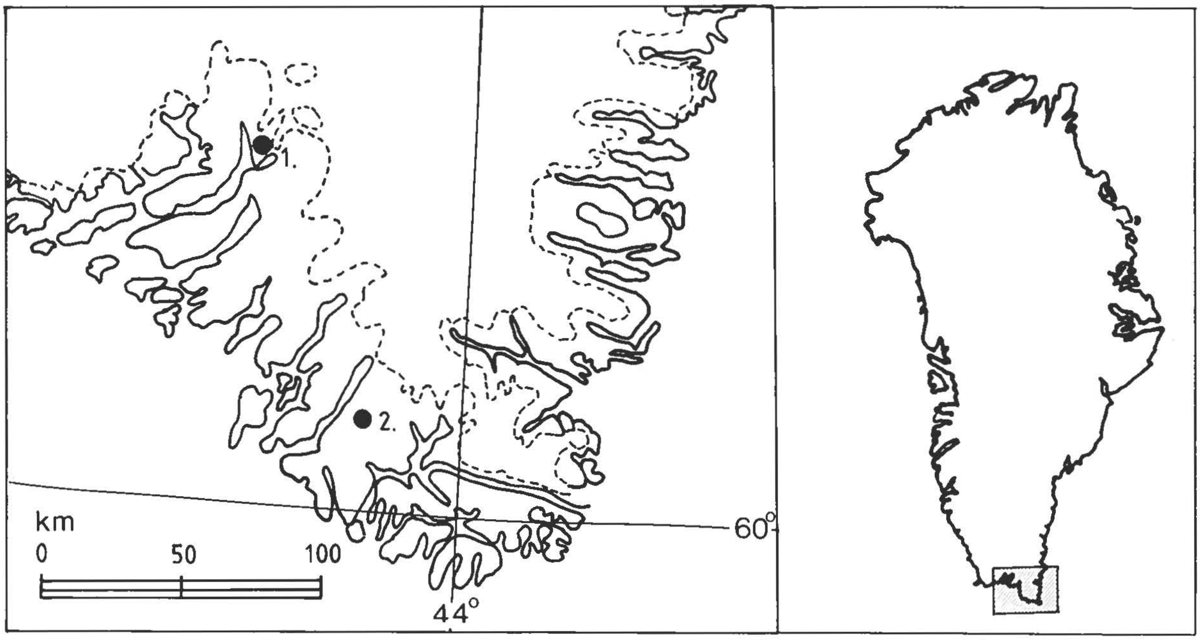


Fig. 1. The study area in Greenland. 1 = Narssarssuaq, 2 = Quingua-dalen.

Results and discussion

Soil

The sample plots at both Qingua-dalen and Narssarssuaq sites are relatively dry in spite of a thick litter-humus layer (Table 1), on an average for both sites 12 cm, higher than at Hardangervidda, subalpine southern Norway (4 cm), and in northern Finland, at Kevo (9 cm; Hinneri et al. 1975) and at Kilpisjärvi (3–8 cm; Seppo Eurola, pers. comm.).

In Qingua-dalen the strongest eluviated A_2 horizon is observed in the upper part of the valley (plot 4), which also has the thickest litter-humus layer as seen in Table 1. This may indicate a higher precipitation just in front of the mighty mountains than further down in the valley. In spite of the thick humus layer and the strong podzolization at this site, the accumulation of precipitated humus is rather weak in the B-horizon. This is due to the good drainage in the coarse, sandy mineral soil with most of the grains (about 80%) in the 2–0.2 mm fraction. However, the loss on ignition in the B-horizon at plot 4 is higher (9.5%) than the average in that horizon of all plots in Qingua-dalen (8%), and especially at Narssarssuaq (3.8%) (Table 6). This may be the cause of the B-horizon of the plot 4, which may be called an iron-humus podzol, being more brownish than at the other plots. Here the B-horizons are light yellow and are true iron-rich podzols, as also observed in subalpine and subarctic birch forests of Fennoscandia (Hinneri et al. 1975). Although the thickness of the eluviated A_2-horizon varies much between the Greenlandic plots, it seems, generally, thicker than in the birch forest studied in the relatively continental Kevo, northern Finland (4 cm), but thinner than in the oceanic, subalpine southern Norwegian birch forest (13 cm) (Hinneri et al. 1975).

Table 1. Soil profiles from Qingua-dalen (4 sample plots) and Narssarssuaq (3 sample plots). Depth of each layer in cm. normal subsoil may be found deeper in the profile. Question mark means iron-rich horizon deeper than about 30 cm. Eluviated A_2 horizon are not always observed.

		Qingua-dalen				Narssarssuaq		
Study plot	(no.)	1	2	3	4	1	2	3
Litter	A_{00}	5	1	2	6	5	3	4
Humus	A_{0-1}	10	9	7	12	5	8	8
Leached	A_2	9	2	3	17	–	10	–
Iron-rich	B	?	25	35	20	23	24	27

Sample plots

In average the height of birches in Greenland ranges between 2 and 5 metres (Feilberg 1984). The average height of the birches studied were only 1.5 (Narssarssuaq) and 2.4 metres (Qingua-dalen). Some trees in the herb-rich scrub measured in Qingua-dalen were 8 m high and 16 cm thick. Most of the trees are polycormic (Table 2). Especially in Qingua-dalen the main stems are often lying wave-like with many erect, stem-like

Table 2. Vegetation of the sample (1 m^2) in Qingua-dalen and at Narssarssuaq. Nrs. 1–3 are percentage cover analyses, P. A. is a percentage of point (stick) analysis with distances of 20 cm (The point area <1 cm^2). x = growing in the neighbourhood of the sample plot.

	Qingua-dalen				Narssarssuaq			
Study plot (No.)	1	2	3	P.A.	1	2	3	P.A.
Betula pubescens:								
The thickest branch (cm) at the base	10	15	12	7	6	11		
The thickest branch 1.3 m	8	13	12	3	4	8		
Number of branches at the base (ø >2 cm)	9	5	2	18	7	11		
The highest branch (m)	3	3.2	3.5	2.6	2	2.3		
Average height (m)	2.7	1.6	2.8	1.3	1.3	2		
Age in years	75	95	87					
Betula pubescens				67				98
B. glandulosa × *pubescens*					*60*		*40*	
B. glandulosa								2
Juniperus communis	10	5	15	17				2
Salix glauca		×				2		10
Angelica archangelica		1						
Anthoxanthum odoratum							30	1
Campanula gieseckiana	+	5	×	8				
Chamaenerion angustifolium		2	+					
Deschampsia flexuosa	70	80	30	81	20	50	20	62
Festuca rubra		×						
Hieracium sp.	×	×	×	2			1	
Lycopodium annotinum		×	×					
Poa pratensis		×		3	+			
Potentilla tridentata	×							
Dicranum majus	+		+					
D. scoparium	×			2				2
Hylocomium splendens	+	1						
Pleurozium schreberi	×	1	+	13	60	10	70	40
Polytrichum juniperinum								2
Ptilidium ciliare		+		1				
Tortula ruralis	+							
Cetraria islandica	+	×	×	2	1	1	5	2
Cladonia cornuta	×					+		
C. deformis + *sulphurina*	×	×	×	1				
C. fimbriata	×			1		+		
C. gracilis coll.	×		×	1	1			4
C. mitis	×		×		0,5	2	3	14
C. rangiferina	×	×	×					12
C. squamosa			×	1				
Peltigera aphthosa		×					2	14
Litter	15	30	80	85	20	80	10	46

branches. *Deschampsia flexuosa* dominates in the field layer (Table 2) with an average percentage cover of 60 in Qingua-dalen, 30 at Narssarssuaq (81 and 62% respectively in the point analyses). At Narssarssuaq the moss (average 33%) and lichen cover are greater than in Qingua-dalen (see especially the point analysis values in Table 2). In spite of this both sample plots belong to the *Agrostis borealis – Anthoxanthum odoratum* subsp. *alpinum* type with scrub and low forest vegetation after Böcher (1954). It is vicarious to the suboceanic *Empetrum* and to the subcontinental *Empetrum-Myrtillus* types (Hämet-Ahti 1963) of Northern Fennoscandia. Richness of dwarf shrubs is typical to the Fennoscandian types.

Biomass

The biomass analyses from the Qingua-dalen (Table 3 and Fig. 2) show the abundance of litter + dead material as a result of a low decomposition rate. Compared to the amount of biomass in Fennoscandian subalpine birch forests the biomass of the field layer in Qingua-dalen is much lower, whereas the weight of litter + dead material is 3–10 times higher. The biomass of the bottom layer is also higher in Qingua-dalen. *Deschampsia flexuosa* makes 98% of the field layer biomass; the corresponding value of this grass is in Hardangervidda approx. 8%, in Kilpisjärvi 6%, and in Kevo only 0.3%. According to these biomass data conditions seems to be

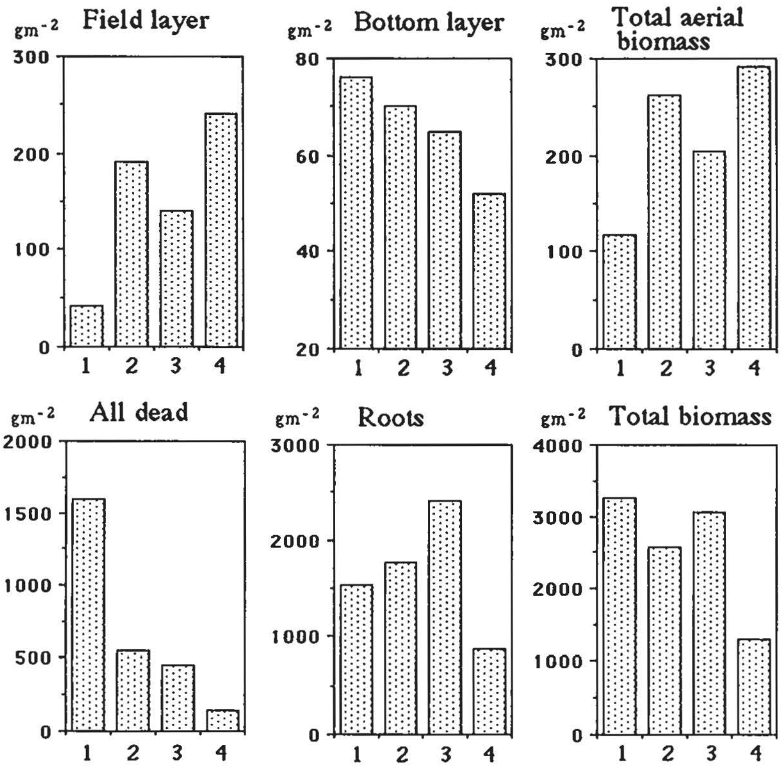


Fig. 2. Biomass (dry weight, g/m^2) of the birch forests excl. above-ground trees and shrubs in Qingua-dalen, Greenland (nr. 1; suboceanic), Hardangervidda, Norway (nr. 2, relatively oceanic), Kilpisjärvi, Finland (nr. 3; suboceanic; mean of 7 forest types), and Kevo, Finland (nr. 4; subcontinental) after Östbye et al. 1975 and Kjellvik & Kärenlampi 1975 (nrs. 2 and 4), Kallio 1975 (nr. 4), and Kyllönen 1988 and Eurola et al. 1982 (nr. 3).

more oceanic in the Greenlandic sites than in the Fennoscandian ones.

Vegetation transect

The vegetation transect gives an overview of the vegetation incl. the birch scrubs in Qingua-dalen. There was no time for exact vegetation analyses, only for notes about the most important species. Thus the vegetation was grouped into 19 types (Table 4, see also table 5) and the species of these types, in turn, into six clusters, namely 1) fjeld, 2) dry to mesic scrub/copse, 3) herb-rich vegetation, 4) ubiquitous on mineral soil, 5) mire/seepage, and 6) ubiquitous on all sites.

Comparisons of the types in Table 4 with the vegetation classifications of Böcher (1954), Knapp (1964) and Daniels (1982) are approximately as follows:

0. Rocky area (see Table 5).

1. Block field. – Böcher: 47, Table 5: 4–6, *Veronica fruticans – Sedum annuum* type; Knapp: 119, Tab. 7, *Rhacomitrium lanuginosum* – Gesellschaft.

2. Wind exposed heath. – Böcher: 149–154, Table 15 *Dryas* and *Rhododendron* sociations of the *Rhododendron – Pedicularis lanata* type; Knapp: 99– 104, Tab. 1: H. Zwergstrauch-Heiden; Daniels: 50–60, Ass. Carici – Dryadetum integrifoliae.

3. Lichen-rich heath. – As nr. 2.

4. Talus slope. – Böcher: 46–53 *Thymus drucei* sociation of the *Veronica fruticans – Sedum annuum* type.

5. South exposed heath. – Böcher: 46–53, scrub-like vegetation associated with the *Veronica fruticans – Sedum annuum* type; Daniels: 57, Carici – Dryadetum integrifoliae subass. thymetosum drucei.

6. South exposed birch scrub. – As nr. 5, intermediates between nrs 5 and 7.

7. Dry birch scrub. – Böcher: 64, scrub or low forest vegetation associated with the *Agrostis borealis – Anthoxanthum alpinum* type, its *Deschampsia flexuosa* sociation.

8. Semi-dry birch scrub. – As nr. 7.

9. Semi-dry willow copse. – As nr. 7, perhaps near to the *Angelica – Stellaria longipes* type of Böcher: 89–94.

10. Moss-rich, mesic willow copse. – Böcher: 103, scrubs associated with the *Phyllodoce coerulea – Lycopodium alpinum* type; Knapp: 112, Tab. 4, Weiden-Gebüsche mit Zwergstrauchern; Daniels: 37–43, Ass. Phyllodoco – Salicetum callicarpaeae.

11. Mesic birch scrub. – As nr. 10.

12. Herb-rich birch scrub. – Böcher: 70–76, *Betula pubescens* scrub of scrub or low wood vegetation connected with the *Streptopus – Lastrea* type.

13. Herb-rich willow copse. – Böcher, the same vegetation type as in nr. 12, but its *Salix glauca callicarpaea* scrub; Knapp: 113, Table 5, Kraut-reiche Weiden-Gebüsche; Daniels: 31, Lactucion alpinae generally taken.

Table 3. Biomass of the birch scrub in Qingua-dalen. The mean values (d.w.g.) are calculated on a square meter basis, while the other figures are on a sample plot basis (50 × 50 cm for vascular plants, 25 × 25 cm for mosses, lichens, litter + dead plants, and 10 × 10 cm for humus and roots).

Sample plot	1	2	3	Mean
Juniperus	–	34.50	–	46.00
Deschampsia	4.86	11.40	13.48	39.64
Hieracium	–	0.51	–	0.68
Campanula	–	0.10	0.07	0.24
Mosses	7.15	0.11	2.19	50.40
Lichens	4.65	–	0.07	25.12
Litter + dead plants	48.20	113.38	137.56	1595.36
Humus	6.14	11.71	–	595.00
Roots	4.39	26.29	15.52	1540.00

Table 5. Percentage cover of the vegetation types in the transect across Qingua-dalen.

	%		%
Rocky area	6	Moss-rich willow copse	14
Block field	6	Mesic birch scrub	4
Wind exposed heath	2	Herb-rich birch scrub	4
Lichen-rich heath	10	Herb-rich willow copse	6
Talus	7	Willow copse on gravel	3
South exposed heath	1	Open gravel	3
South exposed scrub	2	Birch-willow mire	1
Dry birch scrub	11	Open bog	2
Semi-dry birch scrub	4	Open fen	3
Semi-dry willow copse	10	Seepage	1

14. Willow copse on alluvial gravel.

15. Open alluvial gravel.

16. Birch- and willow-rich mire. – Böcher: 102 *Vaccinium uliginosum – Betula glandulosa rotundifolia* sociation rich in *Sphagnum*; Daniels: 25, Ass. Sphagno – Salicetum callicarpaeae.

17. Open bog. – Böcher, as nr. 16; Daniels: 23 *Vaccinium microphyllum – Carex rariflora – Sphagnum fuscum* community.

18. Open fen. – Böcher: 103–108, *Scirpus austriacus* type; Knapp: 123, acidiphile Seggen-Moorgesellschaften; Daniels: 70–71, Table 23, *Paludella squarrosa Carex rariflora* sociation.

19. Seepage site. – Daniels. 70–71, Table 23, *Calliergon sarmentosum* communities.

Based on transect data (Fig. 3 a and b) it can be concluded that:

1) At the SSE facing side the driest types are situated in the upper part, the mesic and herb-rich ones in the lower part of the slope. This succession is generally lacking on the NW slope.

2) Generally taken, on mineral soil the height of *Betula pubescens*, *B. glandulosa*, *Salix glauca* and *Sorbus groenlandica* increases downslope.

3) The birch scrub limit (forest limit) is situated lower at the northern exposition (appr. 100 m a.s.l. N, 150 m S); willow copses begin to disappear over 200 m a.s.l. on both slopes.

4) Together dry and semi-dry birch scrubs are common (15% of all types in the transect, 70% of the scrub types).

5) *Sorbus groenlandica* grows only on the north exposed slope.

Chemical soil and plant analyses

The soil "total" sum of bases, in which the measured amounts of K, Ca, Mg and Na are added, is higher at Narssarssuaq than in Qingua-dalen in the humus and iron rich layers (A_{0-1} and B horizons, Table 6), mostly due to higher content of Ca, at least in two of the Narssarssuaq plots. The content of this element is 5–10 times higher than for K and Mg at Narssarssuaq, while only twice as high in Qingua-dalen. In a relatively rich alpine meadow at Hardangervidda, southern Norway, Ca dominated even more. In oligotrophic birch forests both in that area and in northern Finland, however, the content in the humus layers was again only twice as high as for Mg and only slightly higher than for K, while the amount of these elements often exceeded that of Ca in the B-horizon (Hinneri et al. 1975). The comparison between the two Greenlandic birch forest sites suggests that the rocks generally are rather calcium-rich at Narssarssuaq, while relatively calcium-poor in Qingua-dalen. The low sum of bases in the alluviated A_2 layer at Narssarssuaq is due to strong leaching of all elements. However, analyses from one sample plot only is carried out for this layer at Narssarssuaq as it was missing in the other sample plots at that site. Generally, the contents of Na and Mg are highest in the humus layer at Narssarssuaq, while differences between the sites are small in the other layers, maybe somewhat higher in Qingua-dalen than at Narssarssuaq, both for Na, Mg and K. The increased amounts in the humus layer at Narssarssuaq are probably caused by spray from the fjord, which the sample plots at this site are relatively well exposed to because of the nearness to the fjord.

The loss on ignition is surprisingly low in the humus layer at all sample plots (Table 6). The highest value (23.3%) is observed at plot 4 in the upper part of Qingua-dalen, causing a somewhat higher average compared to Narssarssuaq. This means that most of the humus layer is mixed up with mineral soil (A_1), and is not a really true raw humus (A_0), which may have a loss on ignition at about 80% (Hinneri et al., op.cit.). This indicates relatively good nutrient conditions at least at Narssarssuaq, in spite of a strong cryptogam cover, to some degree also reflected in the vegetation. The mixing of inorganic matter in the humus layer may be explained by the many dust storms caused by the heavy foehns down the valleys. The loss on ignition is low for all plots in the eluviated A_2-horizon, but somewhat higher in the B-horizon in analyses from Qingua-dalen

Table 4. Some floristic data of the vegetation types in Qingua-dalen (see text).

1.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Racomitrium lanuginosum	×																		
Cetraria islandica	×	×																	
Cladonia cornuta	×	×																	
Rhytidium rugosum	×	×																	
Umbilicaria sp.	×	×																	
Alectoria nigricans		×																	
Cladonia bellidiflora		×																	
Ochrolechia frigida		×																	
Polytrichum piliferum		×																	
Thamnolia vermicularis		×																	
Alectoria ochroleuca		×	×																
Cetraria cucullata		×	×																
Sphaerophorus globosus		×	×																
Betula glandulosa × pubescens		×	×																
Rhododendron lapponicum		×	×					×											
Juncus trifidus		×	×										×						
Solorina crocea		×	×										×						
Cetraria ericetorum	×	×	×					×											
Diapensia lapponica			×																
Hierochloë alpina			×																
Loiseleuria procumbens			×																
Bryum sp.			×																
Trisetum triflorum			×												×				
Cladonia mitis	×	×	×		×	×				×									
Cladonia rangiferina	×	×	×			×				×									
Cetraria nivalis	×	×	×	×															
Luzula spicata	×	×	×	×									×						
Woodsia ilvensis	×			×															
Saxifraga cespitosa	×			×						×									
Draba incana			×	×															
Potentilla tridentata			×	×									×						
Cladonia fimbriata				×															
Cladonia pyxidata				×															
Phyllodoce coerulea				×									×						
Thymus praecox				×		×													
Viscaria alpina				×	×		×												
Silene acaulis				×									×						
2.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Agrostis tenuis					×														
Cladonia deformis						×													
Nardus stricta						×													
Cladonia gracilis						×				×									
Dicranum scoparium							×												
Draba aurea							×												
Pleurozium schreberi							×	×	×	×	×								
Eriophorum angustifolium									×										
Cardamine pratensis									×										
Carex canescens									×										
Cerastium fontanum									×										
Rhinanthus minor ssp. *groenlandicus*			×						×	×	×	×							
Poa pratensis				×					×	×	×	×							
Rhytidiadelphus squarrosus									×	×	×	×							
Angelica archangelica									×	×	×	×				×			
Thalictrum alpinum									×	×		×							×
Sanionia uncinata									×	×		×	×	×					
Equisetum arvense									×	×		×	×			×	×		
Peltigera aphtosa						×				×	×								
Ledum palustre ssp. *decumbens*								×		×	×	×	×			×	×	×	
Dicranum majus										×	×	×							
Climacium dendroides										×		×							
Peltigera canina										×		×							
Gymnocarpium dryopteris										×	×	×	×						
Lycopodium dubium										×	×	×	×			×			
Hieracium groenlandicum											×	×							
Stellaria calycantha									×		×	×				×			
Bartsia alpina									×		×		×						×
Barbilophozia sp.											×								
Coptis trifoliata											×	×	×						

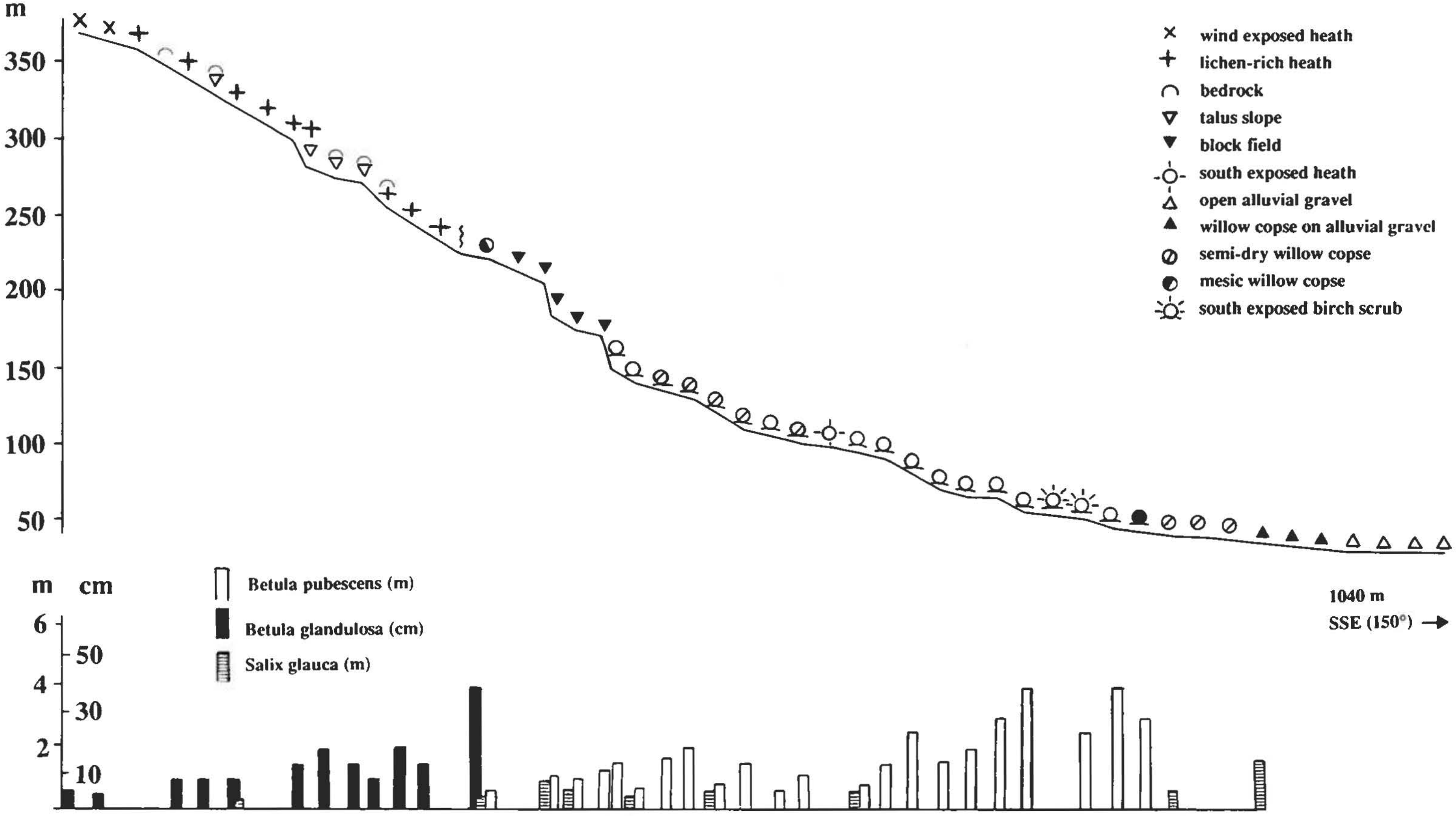
Listera cordata											×	×				×			
Sorbus groenlandica											×		×			×			
Taraxacum spp.						×						×	×						
Platanthera hyperborea										×		×	×						
Lycopodium clavatum												×							
Marchantia polymorpha												×							
Streptopus amplexifolius												×	×						
Alchemilla alpina												×	×			×			
Pseudobryum cinclidioides												×				×			

3.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Festuca rubra			×										×		×				
Agrostis mertensii			×						×				×	×	×				
Luzula multiflora				×									×	×					
Carex macloviana													×						
Gnaphalium norvegicum													×						
Huperzia selago													×						
Poa alpina													×						
Phegopteris connectilis													×						
Calamagrostis langsdorffii												×		×		×			
Juncus filiformis														×					
Juncus arcticus														×					
Racomitrium canescens				×									×		×				
Chamaenerion latifolium													×		×				
Carex atrata															×				
Deschampsia alpina															×				

4.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Cerastium alpinum	×		×				×			×					×				
Deschampsia flexuosa	×		×	×	×	×	×	×		×	×	×			×				
Chamaenerion angustifolium			×		×	×	×			×	×	×							
Hieracium sp.	×		×			×	×			×			×						
Poa glauca	×		×	×	×		×		×	×		×	×		×				
Alchemilla alpina	×		×							×	×	×	×		×				×
Campanula gieseckiana	×		×	×	×	×	×	×		×		×	×	×					×
Juniperus communis	×		×	×		×	×	×		×			×						×
Polygonum viviparum				×					×			×	×						×

5.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Sphagnum fimbriatum																×			
Sphagnum teres																×			
Sphagnum warnstorfii																×			
Equisetum sylvaticum																×	×		
Sphagnum angustifolium																	×		
Sphagnum fuscum																	×		
Sphagnum russowii																	×		
Vaccinium oxycoccos ssp. *microphyllum*																	×		
Aulacomnium palustre																	×	×	
Carex rariflora																		×	
Cinclidium arcticum																		×	
Paludella squarrosa																		×	
Polytrichum swartzii																		×	
Salix arctophila																		×	
Aulacomnium turgidum																		×	×
Scirpus cespitosus																		×	×
Carex capillaris																			×
Carex scirpoidea																			×
Dicranum undulatum																			×
Kiaeria sp.																			×
Oncophorus virens																			×
Orthothecium chryseum																			×
Pinguicula vulgaris																			×
Calliergon sarmentosum																			×
Calliergon trifarium																			×

6.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Betula glandulosa		×	×	×					×	×							×	×	×
Betula pubescens	×					×	×	×		×	×	×				×	×	×	
Empetrum hermaphroditum			×	×				×		×	×		×				×	×	×
Hylocomium splendens	×						×	×	×	×	×					×			×
Vaccinium uliginosum		×	×	×				×	×	×			×					×	


m
350
300
250
200
150
100
50
× wind exposed heath
+ lichen-rich heath
∩ bedrock
▽ talus slope
▼ block field
south exposed heath
△ open alluvial gravel
▲ willow copse on alluvial gravel
⊘ semi-dry willow copse
◐ mesic willow copse
south exposed birch scrub
1040 m
SSE (150°) →
m
cm
6
4
2
50
30
10
Betula pubescens (m)
Betula glandulosa (cm)
Salix glauca (m)

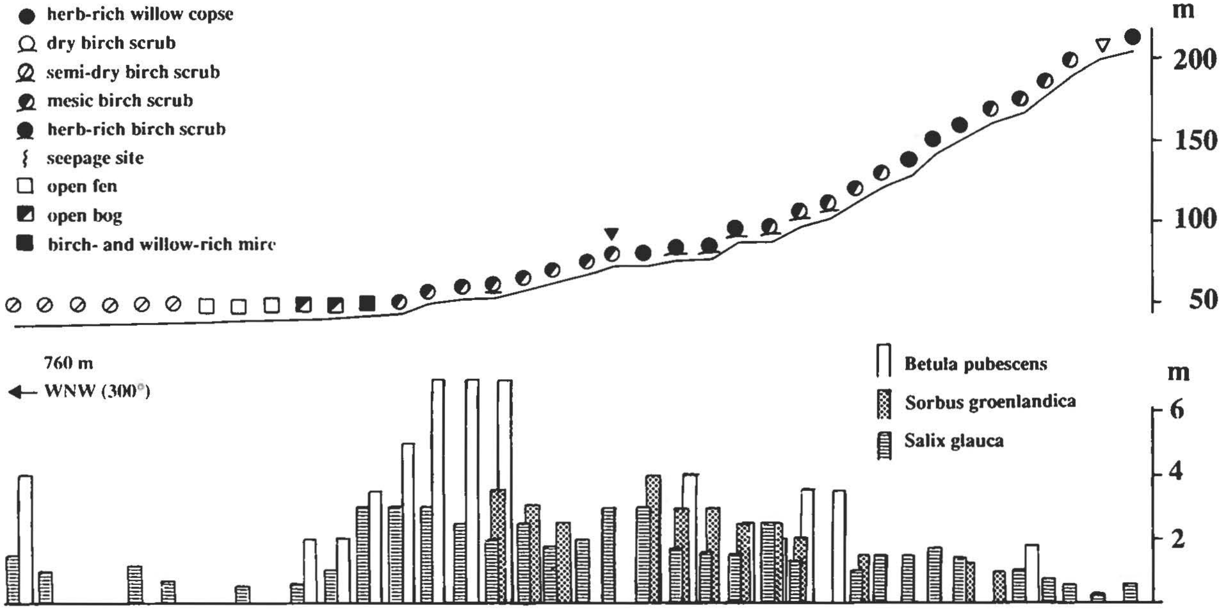


Fig. 3. Vegetation transect across Qingua-dalen. The distance between the study site is 20 m. 3a. The SSE facing valley side (length 1040 m). 3b. The WNW facing side (760 m).

than from Narssarssuaq due to more humus washed down to the deeper layers.

"Total" N normally reflects directly the amount of organic material in the soil. This is the main reason for the generally low N contents observed at all plots in Greenland. However, compared to loss on ignition the N content may even be lower in the mineral layers at some of the Greenland plots than found in other birch forest studies, reflected for instance by 0.12% "total" N in the B-layer in plots from Qingua-dalen compared to a loss on ignition at 8% (Table 6), while in the B-layer at a subalpine birch forest at Hardangervidda, southern Norway, a "total" N of 0.44% is found compared to a loss on ignition at 6.5% (Hinneri et al., op. cit.). By using the regression equation in that paper (tot. C $= -0.17 + 0.53 x$ loss on ignition) on the Greenland material a C/N ratio of 25.9 is calculated as an average for the humus layers in the Qingua-dalen and 22.5 for the same layer at Narssarssuaq. These ratios are fairly high, yet somewhat lower than corresponding ratios in the birch forest humus layers at Hardangervidda (Norway, 28.6) and Kevo (Finland, 36.1). A high C/N ratio means that the availability of N to plants is poor, but based on the calculations it might be a little better in the humus layer of the Greenland sites than of the Fennoscandian sites.

A thicker humus layer and consequently a higher loss on ignition in Qingua-dalen may be the reason for the higher total weight down to 35 cm (Table 7). In the discussion on the sum of bases it is mentioned that two plots at Narssarssuaq show relatively high Ca percentages both in the humus and the B-horizons. This is reflected also in a higher Ca content on a weight basis at Narssarssuaq. Although the Na weight is approximately the same at both sites as total sum down to 35 cm, a detailed study on the various layers again shows higher Na weight in the humus layer at Narssarssuaq (26.7 gm^{-2}) than in Qingua-dalen (12.5 gm^{-2}) in spite of thinner humus layers at the first site reflecting the supposed sea spray Na accumulation in the upper soil layers.

The Narssarssuaq soils down to 35 cm (Table 7) contain nearly 1.5 times as much Ca on a weight basis as a Norwegian subalpine birch forest soil down to the same depth, while the weight of total minerals of N, P, K and Mg are 3–5 times higher in the Norwegian soil than in the Greenland ones (Wielgolaski et al. 1975). This indicates the importance of Ca for the release of most nutrients in the soil to make them available to the plants, as the vegetation data presented do not suggest particularly poor ecosystems for plant growth at the Greenland sites. Also the Norwegian chemical soil analyses showed that the only element that increased in so-called nutrient rich soil was Ca (Wielgolaski et al. op. cit., Table 4).

The ash content in most of the various parts of birch from Greenland (Table 8) is generally of the same order as for the same parts of similar phenological stages in subalpine and subarctic birch from Fennoscandia, harvested in early August (Wielgolaski et al., op. cit.). However, the contents particularly in leaf buds, annual shoots and roots seem to be significantly higher in Greenland, especially of Ca, but significantly of N as well. Generally, the Ca and N contens are highest in nearly all birch parts from Narssarssuaq (Table 8). The high Ca content in the Narssarssuaq plant reflects the often high Ca percentage both in the humus and the iron-rich layers at this site. The high N content in the birches at Narssarssuaq, however, does not reflect the amount of total N in the soil, but rather the lower C/N ratio in the humus at Narssarssuaq. In most parts of birch K and Mg percentages are highest at Narssarssuaq. However, this is not the case for K in leaf buds and annual shoots and for Mg in leaf buds. One reason for those discrepancies may be that the phenological development had gone further in the probably warmer Qingua-dalen. K is one of the elements which is most

Table 6. Total sum of bases (sum K, Ca, Mg and Na), loss on ignition, and total N (all in % of dry weight). Average for the same plots in Qingua-dalen (Qin, 4 plots) and at Narssarssuaq (Nar, 3 plots) in the various soil layers. In all plots average of 3 replicates. – = not determinated.

	"Total" sum bases		Loss on ignition		"Total" nitrogen	
	Qin	Nar	Qin	Nar	Qin	Nar
Humus A_{0-1}	0.62	0.99	17.9	15.6	0.36	0.36
Leached A_2	0.58	0.22	3.1	3.7	0.06	0.04
Iron-rich B	0.69	1.36	8.0	3.8	0.12	0.06
"Sub"-soil B–C	0.74	–	4.3	–	0.08	–

Table 7. Amount of minerals (total) in kg m^{-2} in the upper 35 cm, average for the sample plots Qingua-dalen (4 plots) and Narssarssuaq (3 plots), respectively, calculated for each horizon, but summed. Average of 3 replicates of each plot.

	Soil weight	N	P	K	Ca	Mg	Na
Qingua-dalen	220.6	0.37	0.20	0.23	0.95	0.29	0.05
Narssarssuaq	228.0	0.24	0.22	0.23	1.84	0.27	0.06

Table 8. Total "macronutrients" and ash (% of dry weight) in various plant parts of *Betula pubescens* in late July at two sites in southwestern Greenland, Qingua-dalen (Qin, average of 4 sample plots) and Narssarssuaq (Nar, average of 3 plots), in most plots 3 replicates.

	Ash		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sodium	
	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Catkins	2.6	2.5	1.49	1.85	0.26	0.21	0.55	0.60	0.38	0.20	0.13	0.13	0.46	0.47
Leaf buds	4.3	4.0	2.12	2.40	0.34	0.26	0.65	0.48	0.70	0.98	0.24	0.19	0.10	0.11
Leaves	4.7	3.5	2.13	2.25	0.31	0.24	0.18	0.62	0.55	0.92	0.17	0.28	0.10	0.11
Annual shoots	2.9	3.0	1.60	1.65	0.24	0.22	0.95	0.46	0.40	0.68	0.14	0.21	0.30	0.15
Older twigs	1.5	1.2	0.39	0.54	0.08	0.06	0.21	0.33	0.18	0.27	0.06	0.07	0.10	0.08
Roots	2.9	3.2	0.39	0.47	0.10	0.06	0.17	0.43	0.35	0.44	0.08	0.09	0.12	0.11
Inner bark	2.7	2.0	0.58	0.58	0.06	0.05	0.22	0.46	0.60	0.68	0.05	0.21	0.12	0.17
Outer bark	0.6	0.8	0.35	0.36	0.03	0.02	0.13	0.13	0.10	0.19	0.02	0.03	0.06	0.18
Wood	0.4	0.4	0.15	0.14	0.02	0.01	0.04	0.18	0.10	0.10	0.03	0.03	0.07	0.11

easily transported in plants. It is reduced in leaves throughout the season (and is low in birch leaves analysed from Qingua-dalen compared to those from Narssarssuaq), but may be accumulated in newly formed young material as leaf buds and new shoots. The high content of Na in annual birch shoots in Qingua-dalen may be explained the same way. However, the Na content in outer birch bark exposed to the sea spray is higher at Narssarssuaq.

The ash content of the other plant species analysed from Greenland (Table 9) show the same tendencies as birch when compared with figures from Fennoscandia (Wielgolaski et al., op. cit.). The extremely high ash content of non-green *Pleurozium*, however, must be caused by inclusion of some soil particles. The specific minerals analysed show less clear tendencies than the birch parts. The amount of K in green *Deschampsia* and *Pleurozium* is lower at both sites in Greenland than in the same parts of these species from Fennoscandian birch forests. Similar tendencies are observed for Ca and Mg, as well as for total N in *Cladina*. Only for Na the highest figures are measured in the Greenlandic understorey plants. As mentioned this may be caused by the closer vicinity to the fjord at the Narssarssuaq sites. If so, the Na content should be higher at Narssarssuaq for these species as for most parts of birch. This is the case for *Cladina*, but not for *Deschampsia* and *Pleurozium* (Table 9), which is difficult to explain. Again, probably this is caused by the difference in phenological development between plants from the two Greenlandic sites. The phosphorus content is generally higher in plants from Qingua-dalen, both for the understorey plants and for the birch parts. This is true although there are no clear tendencies between the total phosphorus content in soil from the two Greenlandic sites. As for the parts of birch the Ca content of the understorey plants is generally highest at Narssarssuaq. On the other hand, there are no clear differencies in those plants between the sites for the elements K, Mg and total N in contrast to the birches.

Evergreen plants normally show low contents of most mineral nutrients. This general rule is particularly true for lichens, but also for mosses and evergreen shrubs compared to deciduous woody plants and to herbaceous phanerogams (Wielgolaski et al., op. cit.). Most evergreen plants may survive with a low metabolism and a low uptake of nutrients from the soil, which mean that they often grow on a poor soil. In Greenland the low mineral content in evergreens is clear when comparing on one hand the contents of different elements in *Cladina*, in green *Pleurozium* and in shoots of *Empetrum* (which show low, but still somewhat higher figures than

Table 9. Total macronutrients and ash (% of dry weight) in some understorey plants in Qingua-dalen (Qin, average of 4 plots) and Narssarssuaq (Nar, average of 3 plots). – = not determined.

	Ash		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sodium	
	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Cladina	1.7	3.7	0.32	0.30	0.07	0.06	0.09	0.28	0.08	0.15	0.04	0.04	0.08	0.17
Pleurozium														
Green	3.9	7.8	0.78	0.70	0.17	0.12	0.12	0.11	0.33	0.27	0.12	0.07	0.13	0.07
Non-green	7.4	22.0	0.58	0.54	0.10	0.08	0.72	0.41	0.57	0.60	0.12	0.12	0.23	0.13
Deschampsia														
Green	5.6	4.7	1.53	1.19	0.24	0.20	0.85	0.99	0.20	0.30	0.09	0.10	0.17	0.11
Non-green	3.5	5.4	0.69	0.80	0.17	0.11	0.46	0.33	0.12	0.16	0.04	0.05	0.24	0.16
Empetrum														
Fruits	2.3	–	0.25	–	0.11	–	0.50	–	0.14	–	0.07	–	0.38	–
Annual shoots	2.9	–	0.65	–	0.15	–	0.72	–	0.58	–	0.15	–	0.29	–
Earlier green	2.5	–	0.32	–	0.08	–	0.52	–	0.53	–	0.13	–	0.13	–
Non-green	1.3	–	0.34	–	0.06	–	0.27	–	0.25	–	0.10	–	0.11	–

Table 10. Glucose, fructose, sucrose and starch content (% of dry weight, average ± S.E.) in various plant parts of *Betula pubescens* in Qingua-dalen (Qin) and Narssarssuaq (Nar). n = number of replicates, . . = value about zero.

		Glucose		Fructose		Sucrose		Starch	
	n	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Catkins	4	4.94±0.96	3.59±0.34	1.81±0.37	2.04±0.15	0.06±0.06	0.45±0.11	0.15±0.05	0.76±0.30
Leaf buds	1	1.46	1.14	1.26	0.78	2.87	0.03	0.20	0.87
Leaves	4	3.87±0.22	3.45±0.20	2.78±0.09	1.68±0.88	0.18±0.08	0.18±0.02	2.36±0.41	0.42±0.01
Annual shoots	5	1.91±0.32	2.20±0.16	1.53±0.25	1.35±0.27	0.16±0.14	. .	1.14±0.58	0.21±0.15
Older twigs	4	1.33±0.24	1.45±0.09	0.75±0.12	0.80±0.03	0.10±0.10	0.44±0.02	1.08±0.35	0.29±0.04
Roots	4	1.11±0.09	1.09±0.05	0.72±0.21	0.67±0.02	0.01±0.01	0.40±0.05	3.97±0.57	2.93±0.47
Inner bark	4	2.04±0.43	1.38±0.04	1.14±0.25	1.07±0.14	. .	0.01±0.01	1.62±0.26	1.63±0.59
Outer bark	3	0.20±0.02	0.12±0.02	0.01±0.01	. .	. .	. .	0.22±0.09	0.11±0.06
Wood	3	0.06±0.05	0.04±0.02	0.10±0.02	0.08±0.02	0.57±0.05	0.48±0.07	0.97±0.21	0.79±0.10

the cryptogams) with on the other hand the higher content in green *Deschampsia* and in leaves and shoots of birch. This is particularly clear for total N. However, none of the plants analysed chemically from Greenland are eutrophic species. Such would probably have even higher percentages of most of the nutrients studied.

Glucose, fructose, sucrose and starch content (% of dry weight) in various part of birch are presented in Table 10. In most parts glucose is present in greater amounts than fructose and sucrose. Highest values of glucose and fructose were found in catkins and leaves, of starch in leaves and roots, and of sucrose in leaf buds. Contents of these compounds are highest in annual than in older shoots and high in inner than in outer bark. Wood of birch contains more sucrose and starch than other organic compounds studied here.

"Total" sums of sugars (glucose+fructose+sucrose) in all parts of birch determined here were highest in Qingua-dalen except in older twigs and roots. Starch contents, generally, showed the same tendency. Glucose content in catkins and inner bark of birch seems to be markedly high in Qingua-dalen. "Total" sum of carbohydrates (glucose + fructose + sucrose + starch) in various parts of birch are highest in Qingua-dalen, probably due to high temperature (more favourable exposure) and net assimilation, which is indicated also by better growth rate (biomass) of birches (see table 2). This is in accordance to results found by Mooney and Billings (1965) and Skre et al. (1975). However, the soil moisture and the soil nutrient levels may affect the total sugar content, causing a higher content in plants from nutrient rich sites than from poorer ones (Skre et al. 1975).

Among the species studied here *Cladina* showed the lowest values of glucose, fructose and sucrose (Table 11). Starch content in *Cladina* was two to three times higher than in *Pleurozium* and *Deschampsia*. Generally, green parts of plants had highest contents of glucose, fructose, sucrose and starch. However, two exceptions were found. Non-green leaves of *Deschampsia* contained more starch than green leaves and those of *Empetrum* more sucrose. Berries of *Empetrum* had high values of glucose and fructose, but standard errors were high because of only two replicates. High variations might depend on different stages of ripening of berries. Sucrose contents in green parts of *Pleurozium* were high at both study sites. "Total" sum of sugars in *Cladina* from Narssarssuaq is about 30% higher than in samples from Qingua-dalen. However, the contents of starch showed a converse pattern, and therefore the total amount of carbohydrates did not differ between the sites. Nor did the content of some other organic compounds differ.

The present study, however incomplete it is, shows some of the relationships between the birch wood ecosystems of Greenland and similar ones in Fennoscandia. In most cases the similarities are clear, although some discrepancies are also found.

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Table 11. Glucose, fructose, sucrose and starch content (% of dry weight, average ± S.E.) in some understorey plants in Quingua-dalen (Qin) and Narssarssuaq (Nar). n = number of replicates, – = not determined.

		Glucose		Fructose		Sucrose		Starch	
	n	Qin	Nar	Qin	Nar	Qin	Nar	Qin	Nar
Cladina	3	0.12±0.04	0.21±0.03	0.04±0.03	0.09±0.04	0.10±0.01	0.08±0.03	0.05±0.06	0.41±0.09
Pleurozium									
Green	3	0.64±0.08	0.58±0.04	0.58±0.09	0.47±0.06	4.96±0.70	5.15±0.36	0.21±0.21	0.21±0.11
Non-green	3	0.55±0.06	0.60±0.07	0.46±0.07	0.46±0.08	1.21±0.34	2.41±0.70	0.19±0.10	0.29±0.03
Deschampsia									
Green	2	0.73±0.29	0.63[1]	0.66±0.19	0.80[1]	1.43±0.02	4.30[1]	0.06±0.04	0.17[1]
Non-green	2	0.56±0.03	0.69[1]	0.65±0.07	0.52[1]	0.72±0.02	0.49[1]	0.13±0.06	0.26[1]
Empetrum									
Fruits	2	5.38±4.61	–	3.63±3.76	–	0.63±0.62	–	0.18±0.12	–
Green	2	1.12±0.40	–	0.71±0.54	–	0.20±0.01	–	1.66±0.20	–
Non-green	2	0.31±0.04	–	0.13±0.08	–	0.63±0.03	–	1.03±0.19	–

1. Only one replicate.

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Larger fungi associated with *Betula pubescens* in Greenland

STEEN A. ELBORNE and HENNING KNUDSEN

Elborne, S. A. and H. Knudsen, 1990. Larger fungi associated with *Betula pubescens* in Greenland. Meddr Grønland, Biosci. 33, 77–80 pp. Copenhagen 1990-9-28.

A list of 102 larger fungi mainly associated with *Betula pubescens* in Greenland is given.

Species from most of the major taxonomic groups of larger fungi are represented. The species have been classified into a number of broad mycogeographical types. It is concluded that the fungi associated with *B. pubescens* in the subarctic part of southern Greenland constitute a fairly large group of which 4/5 of the species are mainly distributed in temperate areas and 1/5 in subarctic or arctic areas.

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Due to the absence of *Betula pubescens* in Lange's (1948, 1955, 1957) primary area of investigation, only a few species associated with this tree are listed in his flora from the west coast of Greenland.

During expeditions (Elborne in 1981, Knudsen in 1983, 1984) to southern Greenland however, it became obvious that there were a large number of fungi associated with this tree. The collections are now being revised with the purpose of writing a, flora of Greenlandic basidiomycetes.

The various species of which several are new to Greenland will be described in more detail in papers preceding this flora. These papers are e.g. "Aphyllophorales of Greenland" by J. H. Petersen & K. Hauerslev (in press) and "Myxomycetes of Greenland" by H. F. Gøtzsche (in press) in which a large number of species associated only with *B. pubescens* in Greenland are mentioned.

As a result of the symposium on the Mountain birch (*Betula pubescens* Ehrh. var. *tortuosa* (Ledeb.) Nyman) in Greenland we hereby present a preliminary paper whichs draws attention to the large number of species from different taxonomic groups associated with this tree. Some of the species are also associated with the other two Greenlandic *Betulas*, *B. glandulosa* and *B. nana* and occasionally with *Alnus crispa* and *Salix glauca*, but the species included here were found at least once with *B. pubescens*.

Fig. 1. *Entoloma melenosmum* from the type-locality. It seems to have a preference for very rotten stumps of *B. pubescens*. Photo: H. Knudsen.

Table 1.

Saprobionts and parasites on trunks and branches	*Betula pubescens*	*Betula nana/ glandulosa*	*Alnus crispa*	*Salix* spp.	Distribution
Ascocoryne cylichnium	R				T>S
Scutellinia scutellata	O				T>S
*Taphrina betulina****	R				TS
*Taphrina carnea Johans.****	R	C			SA>T
Exidia repanda	C	O			S>bT
Tremella foliacea	O				T>S
Tremella mesenterica	O				T>S
Bjerkandera adusta	R				T>S
Ceriporia reticulata	C		O		TS
Cerrena unicolor	O				TS
Chondrostereum purpureum	C				TS
Clavariadelphus fistulosus	O			O	TS
Corticium erikssonii	O				TS
Cristinia helvetica	R				T>S
Cytidia salicina	R		C		S>AbT
Hymenochaete cinnamomea	O		O	O	TS
Hymenochaete tabacina	O		O	C	TS
Hyphoderma praetermissum	R		R		T>S
Hyphoderma radula	C			C	TS
Hyphoderma setigerum	C		O	C	TS
Hyphodontia arguta (Fr.) J. Erikss.	R				T>S
Hyphodontia aspera (Fr.) J. Erikss.	R				TS
Hypochnicium sphaerosporum	R				T>S
*Inonotus obliquus****	C				TS
*Inonotus radiatus****	C		C		TS
Junghuhnia separabilima	R		O		TS
Lentinellus omphalodes	O			C	S>TA
Peniophora incarnata	C			C	T>S
Peniophora laurentii	O			O	S>bTA
Phanerochaete sordida	O			O	TS
*Phellinus lundellii****	C		C		S>bT
Polyporus brumalis	O				T>S
Polyporus varius	O		O	C	TSA
Radulomyces confluens (Fr.) M. P. Chr.	C				TS
Scopuloides hydnoides (Cooke & Massee) Hjortst. & Ryv.	O		O	O	TS
Sistotrema brinkmannii	R		C		T>S
Sistotremastrum niveocremeum	O			O	T>S
*Stereum rugosum****	C		O	R	T>SA
Subulicystidium longisporum	R		R		TS
Tomentella ruttneri	R				T>S ?
Tomentellastrum fuscocinereum	R				?
Trechispora farinacea	C		O	C	TS
Trechispora microspora	R		R		TS
Trechispora mollusca	R				T>S
Trechispora praefocata	R				T>S
Trechispora subsphaerospora	R				T>S
Tubulicrinis calothrix	R				bT>S
Tubulicrinis gracillimus (Rog. & Jacks.) Cunn.	C		C	C	S>T
Tyromyces chioneus	C				TS
Vararia investiens	O				bTS ?
*Armillaria lutea Gill.****	R				T>S
Hohenbuehelia fluxilis (Fr.) Orton	R			O	T>S
Kuehneromyces mutabilis	O			O	T>S
Mycena galericulata	C				TS
Mycena rubromarginata	C	R		C	TS
Panellus ringens	C				S>bT
Panellus serotinus	O				T>S
Pluteus atricapillus	O	R	R		T>S
Pluteus romellii	O				T>S
Simocybe rubi	R				T>S
Lycoperdon pyriforme	O				T>S

Table 1. Saprobionts and parasites on trunks and branches. C = common; O = occasional; R = rare; A = arctic; S = subarctic; T = temperate; b = boreal; >= more common in the area before this sign than in the area mentioned after the sign; *** = parasite; ? = information insufficient.

Material and methods

All the material of the mentioned species is deposited at the Botanical Museum, University of Copenhagen (C).

The names of species and authors for the agarics follow Moser (1983), for the *Aphyllophorales, Heterobasidiomycetes* and *Gasteromycetes* Jülich (1984) and for the *Ascomycetes* Cannon, Hawksworth and Sherwood-Pike (1985). If not the authors are mentioned.

All major groups of higher fungi were represented in the final list. However, a number of genera are still so poorly known that it was impossible to include species from these genera except for a few well-known species. These genera are: *Cortinarius, Inocybe, Hebeloma, Galerina, Clitocybe, Psathyrella,* and to some degree *Russula* and *Lactarius*. Likewise the association with *B. pubescens* may prove to be of a secondary character for some of the species.

Discussion and conclusions

As seen in the tables above a large number of macrofungi are associated with *Betula pubescens*. The aim of this paper is to demonstrate the presence of a large subarctic fungal element associated with *B. pubescens* in Greenland. Since the distribution of *B. pubescens* is almost congruent with the subarctic part of Greenland (Feilberg 1984), we therefore chose investigating the fungi associated with this host. However, it should be noted that in Greenland there are other subarctic fungi neither associated with *B. pubescens* nor with any other tree.

Among the mycorrhizal symbionts, the following have been found either exclusively or predominantly with *B. pubescens*: *Cortinarius violaceus, Lactarius lapponicus, L. necator, L. trivialis, L. utilis, L. vietus, Russula aurantiaca, R. gracillima* and *Tricholoma atrosquamosum*. Except for the single species of *Tricholoma*, *Betula* and conifers are the usual hosts for these fungi in NW Europe.

Several mycorrhizal symbionts e.g. *Leccinum versipelle, Russula aeruginea, R. velenovskyi, R. depallens, Tricholoma album* and *T. fulvum* which are commonly found with *B. pubescens* in northern Europe (Ryman & Holmåsen 1984) even at latitudes north of the subarctic area in Greenland have so far not been found in Greenland.

Saprobionts on trunks are the largest group of fungi restricted to the subarctic zone in Greenland. *Exidia repanda* is probably the only species which can be considered as obligatory for *B. pubescens*. *Betula* is the only host in Greenland for *Inonotus obliquus, Cerrena unicolor, Phellinus lundellii* and *Panellus ringens*. It is the main host in the northern part of their area of distribution, but in the southern part there are other hosts as well. *Ascocoryne cylichnium, Bjerkandera adusta, Chondrostereum purpureum, Inonotus radiatus, Polyporus brumalis, Tyromyces chioneus, Armillaria lutea, Kuehneromyces mutabilis, Mycena galericulata, Panellus serotinus, Pluteus atricapillus, P. romellii* and *Lycoperdon pyriforme* are all common species on trunks and stumps of various hosts in northern Europe.

A number of species otherwise commonly found at high latitudes in Scandinavia and Canada have not yet been found in Greenland: *Fomes fomentarius, Phellinus nigricans, P. laevigatus, Piptoporus betulinus, Daedaleopsis septentrionalis, Lenzites betulina, Trametes pubescens, Pycnoporus cinnabarinus, Trametes zonatella, Pleurotus* spp. and *Hypoxylon multiforme*. It is yet to be learned whether these species can be found in the few other protected valleys in southern Greenland, or whether they are absent simply because they have been unable to colonize Greenland from their present distribution area in Iceland, Scandinavia and Canada.

The change of hosts which often occurs in fungi between the northern and southern area of their distribution is also seen in some of the species mentioned here.

Table 2.

Saprobionts on litter (fallen twigs and leaves)	*Betula pubescens*	*Betula nana/ glandulosa*	*Alnus crispa*	*Salix* spp.	Distribution
Agaricus semotus	O	O			TSA
Calocybe naucoria	O				bTS ?
Collybia obscura	O	C			S>bT
Entoloma melenosmum Noord.	C				S
Entoloma olidum Noord.	O	C			S
Entoloma sericeonitens (Orton) Noord.	R				T>S ?
Entoloma subarcticum Noord.	C			C	S
Entoloma vernum	R			R	bTS>T
Hemimycena mauretanica	R			R	T>S ?
Lepiota clypeolaria	R	?		?	T>S
Marasmius epiphyllus	R			C	TS
Mycena abramsii	O		O	C	TS
Mycena hiemalis	R			C	TS
Mycenella margaritispora	R				T>S

Table 2. Saprobionts on litter (fallen twigs and leaves). Abbreviations, see Table 1.

Table 3.

Mycorrhizal symbionts	*Betula pubescens*	*Betula nana/ glandulosa*	*Alnus crispa*	*Salix* spp.	Distribution
Thelephora terrestris	O			O	T>S
Amanita arctica Bas, Knud. & Borg.	O	O		O	SA
Amanita battarrae Boud.	O	O			T>S
Amanita groenlandica Bas ex Knu. & B.	O	C		C	SA
Amanita mortenii Knud. & Borgen	O	O			S
Amanita muscaria	R				T>S
Amanita nivalis Grev.	O	C		C	SA
Boletus subtomentosus Fr.	C	O			T>S
Cortinarius cinnamomeus (L.: Fr.) Fr.	O	O			T>S
Cortinarius croceus (Schff.) Bi. & Gu.	O	O		O	TSA
Cortinarius huronensis Ammi. & Smith	R			R	SA
Cortinarius raphanoides	C				TS
Cortinarius violaceus	R				T>S
Inocybe flocculosa	R				T>S ?
Laccaria bicolor	O				TS
Lactarius glyciosmus	C	C		C	TSA
Lactarius lapponicus	O				S
Lactarius necator	R				T>S
Lactarius pubescens	C	C		O	TSA
Lactarius repraesentaneus	O	O			T>SA
Lactarius rufus	O	O			T>SA
Lactarius theiogalus	O	O			T>S
Lactarius trivialis	R				bT>S
Lactarius utilis (Weinm.) Fr.	R				bT>S
Lactarius vietus	O				T>S
Leccinum atrostipitatum Smi. & Thie.	C	O			T>S
Paxillus involutus	C	C			TS
Rozites caperatus	O	O			TS
Russula aurantiaca	R				bTS
Russula claroflava Grove	C	C			TS
Russula nitida	C				TS>A
Tricholoma atrosquamosum	R				T>S

Table 3. Mycorrhizal symbionts. Abbreviations, see Table 1.

Laccaria bicolor, Lactarius rufus and *Russula consobrina* are usually associated with conifers, but in Greenland they grow with *B. pubescens, B. glandulosa* and *B. nana*. The only native conifer, *Juniperus communis,* does not form ectomycorrhiza. Among the saprobionts growing on litter and debris the only species restricted to the occurrence of *B. pubescens* is *Entoloma melenosmum*. This species was described from southern Greenland where it occurs with *B. pubescens* and often around rotten stumps.

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