Afforestation experiments reflecting the treeline conditions in Southwest Greenland

SØREN ØDUM

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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.

Søren Ødum, Royal Veterinary & Agricultural University, Arboretum, DK-2970 Hørsholm, Denmark.

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

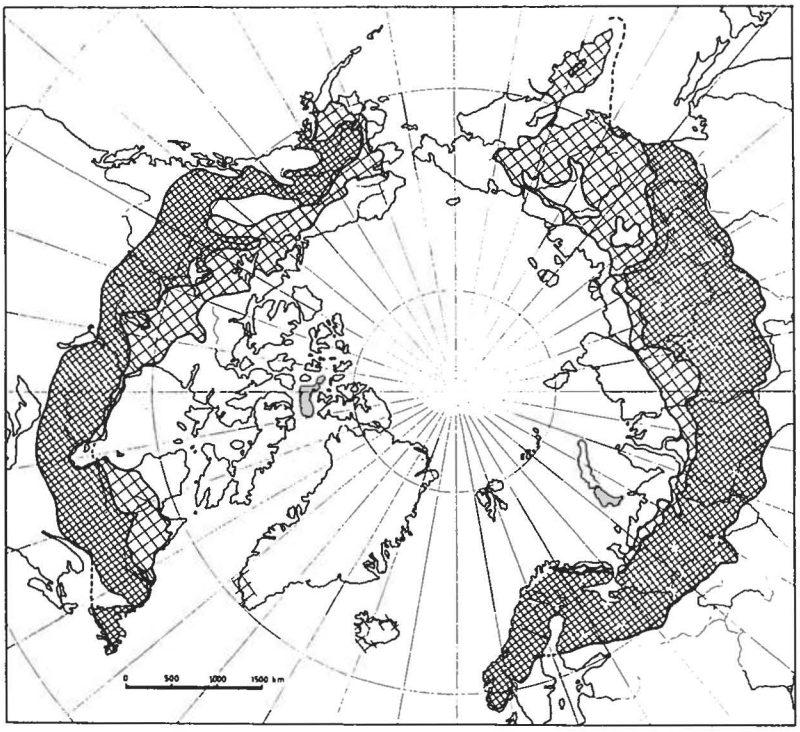


Fig. 1. The subarctic and northern boreal zones (Hustich 1966).

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

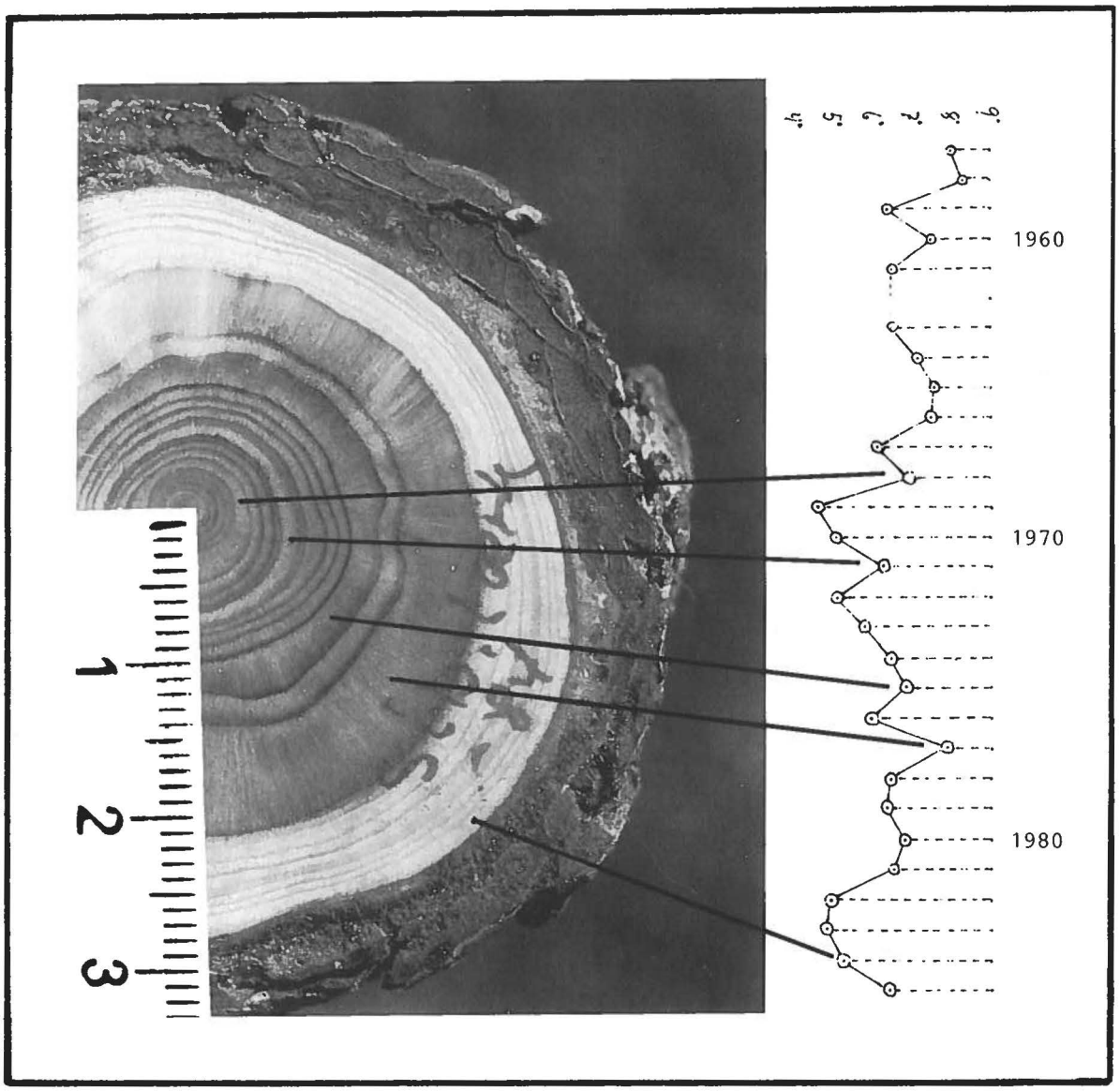


Fig. 2. A log of *Larix sibirica*, cut 1984 at Kugssuak, strongly reflects the width of the annual rings as a function of summer temperature. Mean temperature of the growing season (21 May to 20 Sept.) at Upernaviarssuk given in °C for 1957–1984. In Kugssuak the average temperatures are approx. 2°C higher. *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.

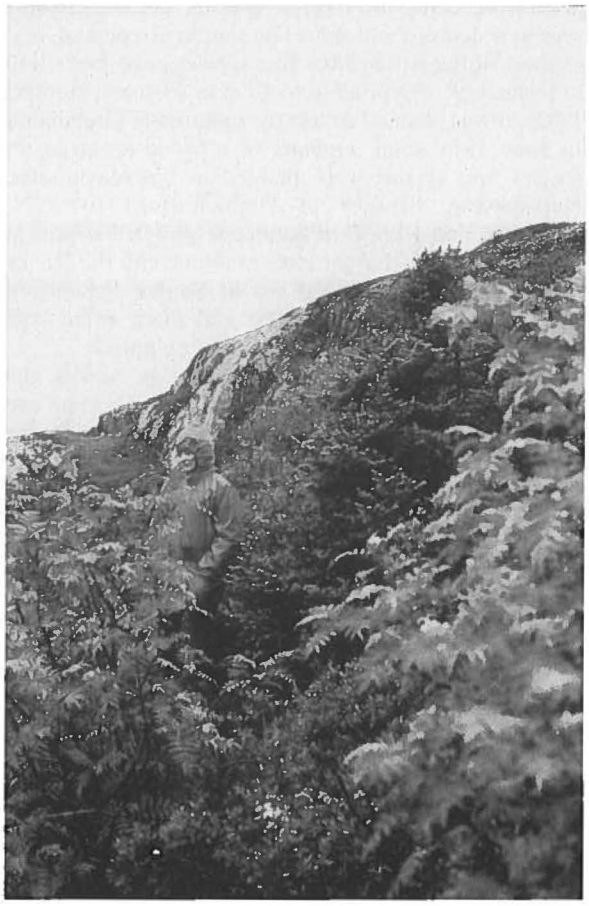


Fig. 4. Ivigtut. One of the specimens of *Abies balsamea*, transplanted from the coast of Labrador 1941 and not tending to grow above the *Sorbus*-scrub. S.Ø. phot. 1984.

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).

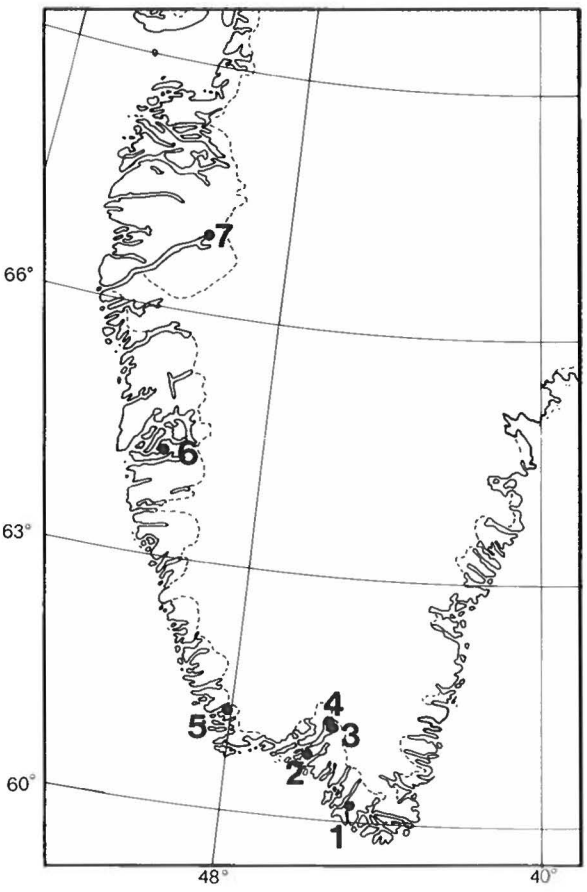


Fig. 5. The geographical position of the planting-localities mentioned. 1. Kugssuak at Tasermiut fiord, 2. Upernaviarssuk, 3. Narssarssuaq, 4. Qanagssiassat and "Rosenvinge's trees", 5. Ivigtut, 6. Qorqut, 7. Søndre Strømfjord.

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.

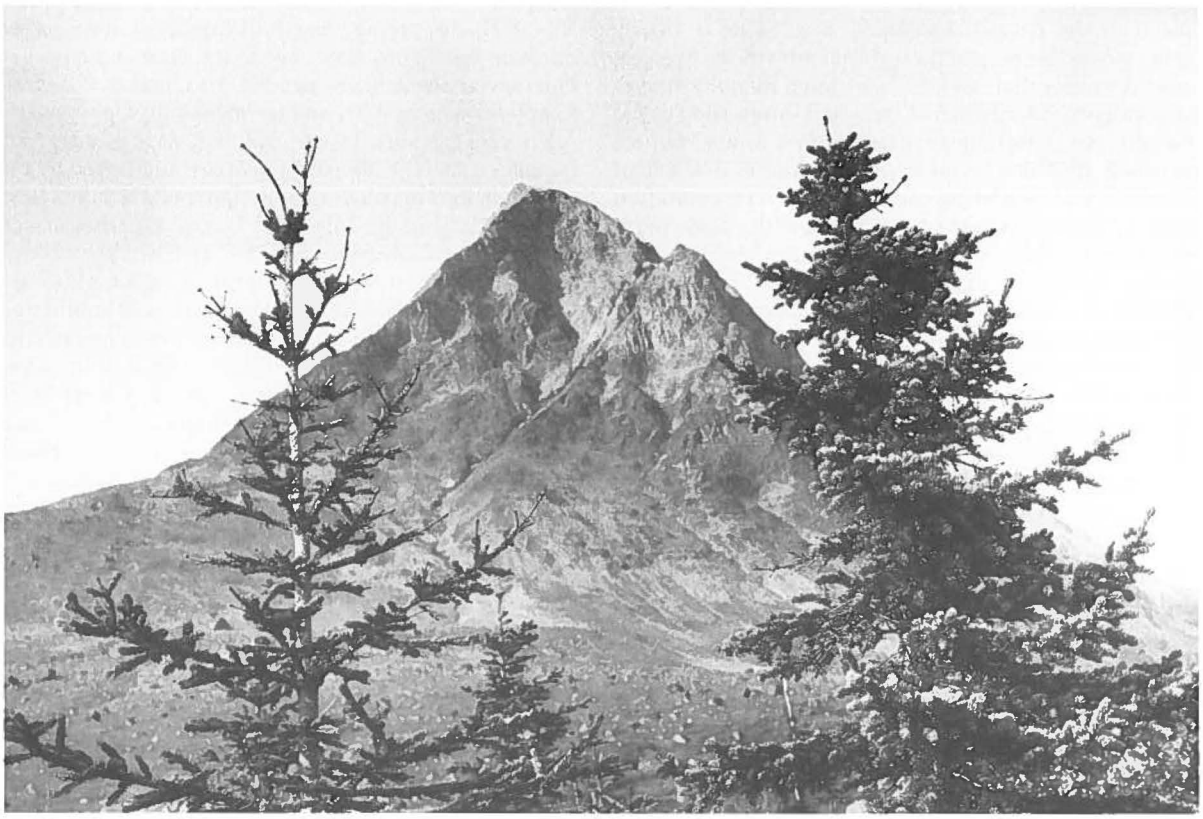


Fig. 7. Kugssuak. The selective effect of the cool "test-summers" 1982–84 on *Picea glauca* × *sitchensis*. S.Ø. phot. 1 Aug. 1984.

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.

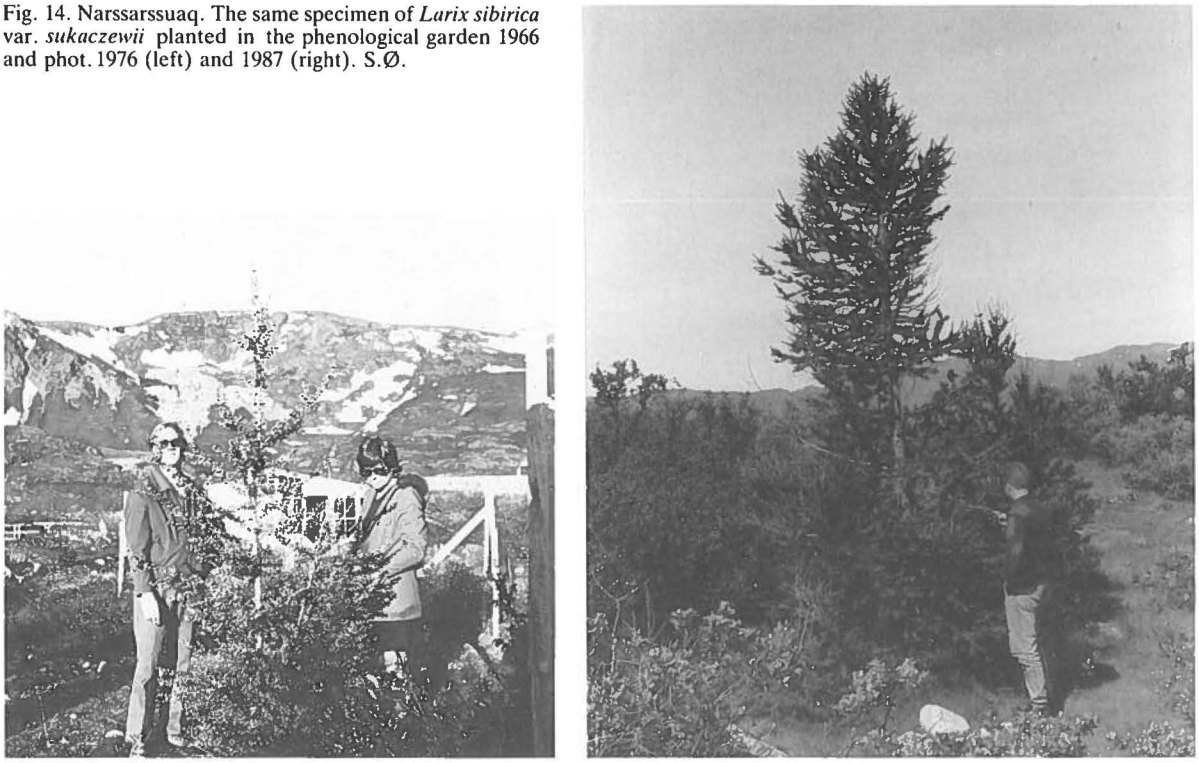
In Qanagssiassat and on nearby localities Bjerge tried quite a number of species during the 1950'es and 1960'es. Treeline-forming or high latitude species, which have failed to grow to bigger sizes, are e.g. *Abies sibirica* Ledeb., *Larix laricina* (Fairbanks, Alaska), *Picea mariana* (Goose Bay, Labrador),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

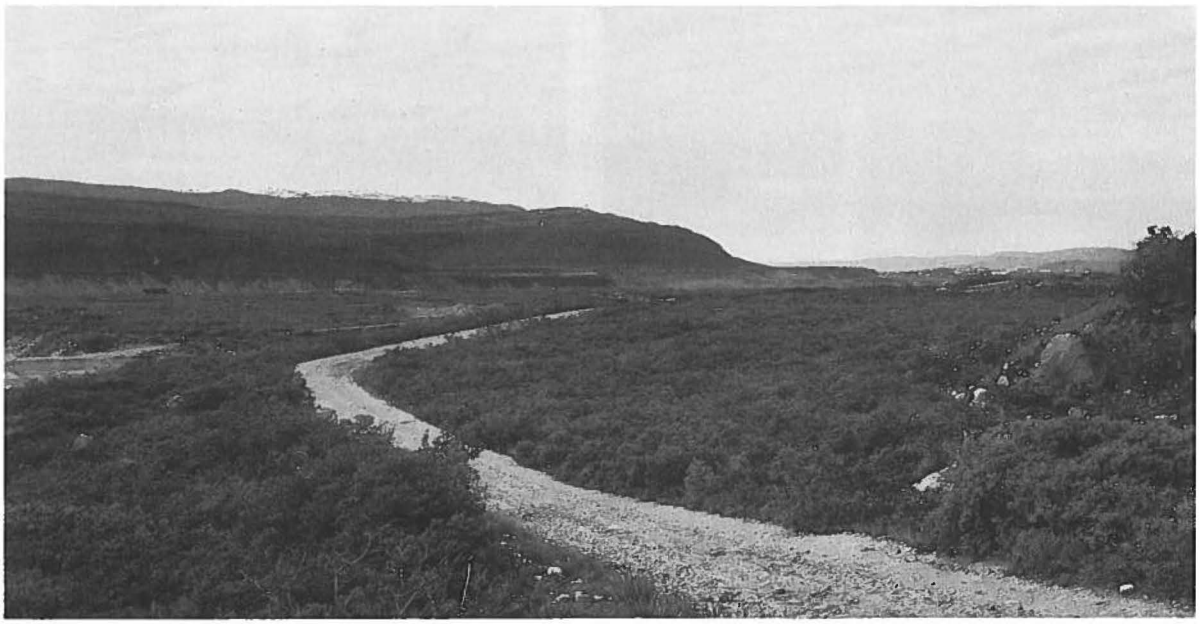

Fig. 22. View towards WSW in the valley 4 km E of Søndre Strømfjord airport. The outwash plains with scrub of *Salix glauca* and *Betula nana* were chosen for planting in 1976–79 (background left) and 1983ff (right). S.Ø. phot. August 1983.

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.

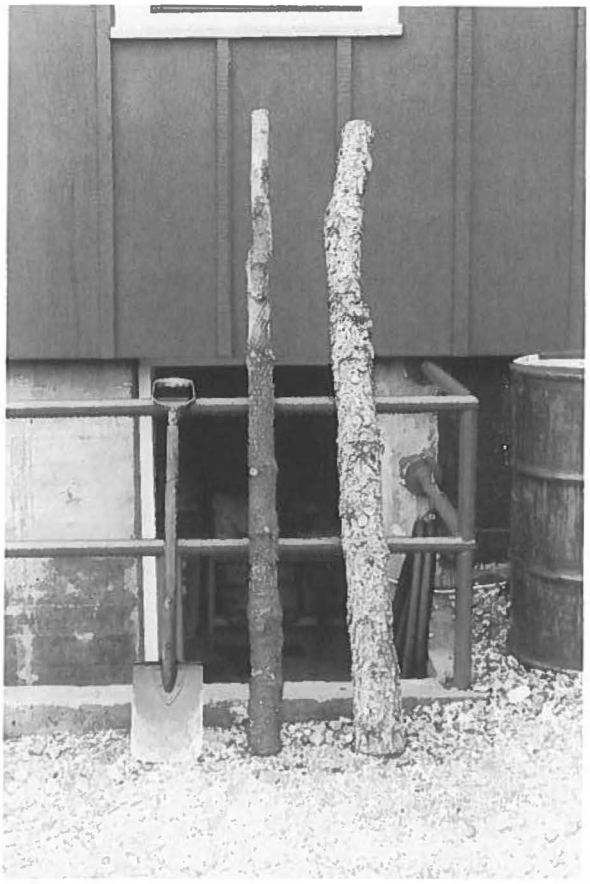

Fig. 24. Two 1.8 m logs from the SW Greenland plantations illustrating that timberline-conditions, and not just treeline-conditions might be considered. Left a *Picea glauca* × *sitchensis* (half of a forking tree) from Kugssuak, cut 30 cm above the ground: 10 years height-growth, 9.5 cm diam. at base 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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