ON THE FOREST-TUNDRA AND THE NORTHERN TREE-LINES

A preliminary synthesis

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I. TERMINOLOGY

The concepts forest-line or forest-limit, timber-line or tree-line are all somewhat vague and difficult to define, cf. Brockman-Jerosch (1919), H 1952 and others. For this reason, it has not always been easy to plot them accurately on a map. In the sense employed, for instance, by North American writers, the frequently used expression "timber-line" may, thus, mean the northern limit of commercially profitable forest utilization, the polar or altitudinal limit of forest or the tree-line in general.

But, "when is a tree a tree?" According to Brockman-Jerosch (1919) 5 metres should be the minimum height for a "tree", whereas Heikinheimo (1921), for the vast northern birch forests, proposes 2 metres. Where cartographic accuracy is needed the concept tree-line is too vague an expression. On the other hand, particularly at the polar limit of the forests, the capacity of a tree seedling or a young tree to reach above the snow cover is the crucial point, of course. Thus, when a tree seedling reaches above the snow and grows into a 2 or 5 metres high tree, this fact tells us something concrete, at least about the local climate, the existence of wind shelter, etc.

The same vagueness marks the concept "forest-line. How many trees are needed on one acre before we can talk of a forest, or how many logs make a forest? This simple question is crucial for the paleocologist, cf. Martin (1959, p. 221), but it is also of importance for the evaluation of the concepts used here. Hermes (1955, p. 2) defines a forest in the following words: "Unter Wald verstehen wir eine Verzweigung von 'Stamm'-Bäumen mit Kronenbildung von mindestens 3—5 m Höhe. But immediately after this the concept is widened considerably: "in der Nähe des polaren Grenzbereichs werden aber schon gute mannhhohe Baumgesellschaften als Wald angesprochen."

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We can hardly operate with just one forest or tree-line, because in very few places, in a planted conifer forest in Iceland or near a glacier in Alaska, can we draw a sharp line between the forest and the surrounding treeless heath or moraine. Almost everywhere else we have to operate with many illines inside a wide belt where the forest ebbs out to scattered, often small, deformed trees, bushes or low seedlings, cf. Kaylova (1964). Sometimes the forest-line or the tree-line is formed by two or three different species.

Fig. 1. Idealized forest-limits and tree-lines, see explanation in text.

Fig. 1 shows an idealized arrangement of the different tree and forest-lines. The local pattern of these lines is similar whether we approach the polar, the maritime or the altitudinal line of trees. The principal difference is that as we approach the maritime or the altitudinal line of trees, the distance between the outermost trees and the closed or continuous forest is short, whereas in the continental Sub-Arctic this belt is often very wide.

The expression economic forest-line (1) or the timber-line proper as marked on Fig. 1, is here understood to mean the limit beyond which commercial cutting of trees endangers natural regeneration; also the expression productive forest-line has been used. At least in part, the expression economic forest-lines coincides with the generative forest-line of Kihlman-Kairamo (1890) and the rational forest-line of Heikinheimo (1921).

On the forest-tundra and the northern tree-lines

The expression physiognomic forest-line (2) means the limit of the forest itself, regardless of its reproductive capacity. In the belt between the economic forest-line and the physiognomic forest-line the generative reproduction occurs only at intervals of many years (cf. Renval 1912, H 1948). Thus the forest is there, but it must be handled carefully. In subsequent discussion this line will be referred to simply as the forest-line because without careful investigations we simply do not know where the economic forest-line runs, whereas the physiognomic limit of forest is what we see in the landscape. In egod years mature seeds develop as far as the forest goes towards the north, to the shore of the ocean or towards the summit of a mountain. In such years the economic and the physiognomic forest-lines coincide. This definition of the physiognomic forest-line corresponds to the evaluation of the concepts vegetative and empirical forest-limits (Kihlman-Kairamo 1890).

The expression tree-line (3) is here understood to mean the absolute polar, maritime, or altitudinal limit of trees regardless of species; the polar tree-line is in fact formed by different species in different areas. The definition of the concept tree varies, however, see above. The marking of the tree-line on a map always assumes a certain degree of subjectivity.

The polar, maritime or altitudinal species-line or the northern limit of a certain tree species (4) is understood to mean the line of the most advanced outposts attained by a tree-species, irrespective of whether the outermost individual is a seedling, a bush or a tree, or whether the growth is prostrate or tree-like.

To these forest- and tree-lines we could in some areas — still very small — add a superstation-lines, which marks the efforts of man to expand the forest northwards or towards the summits of mountains.

If necessary — to describe the genesis of a forest-tundra area — the historical forest-lines or the line of former outposts (5) of the forest and tree-line species might be added. Such a historical tree-line is the tree-line during the postglacial thermal maximum (cf. Andreiev 1954 and Tikhomirov 1956). The remnants of these trees are now buried in the peat, sometimes hundreds of miles outside the forest-line of today.

The concept Arctic belongs to those often used but vague geographical concepts such as Tropics, Savanna, etc. Different opinions have been advanced regarding the delimitation of the southern limit of the Arctic, cf. the recent compilations by Polunin (1951), Britton (1957), H 1953, etc.

Two definitions have been more used than others, the 50°F (10°C) Isotherm of the warmest month and the Norden-viölt lines, see Hare (1952). I suggest (as earlier, in H 1952) that the polar tree-line should be regarded as the southern limit of the Arctic, mainly because such a line is more easily mapped. The tree-line is, of course, a concrete thing, whereas isotherms, etc., are interpolated
The forest-tundra zone, roughly approximated using various sources. South of the forest-tundra is marked, very tentatively only, a vast belt which some prefer to call the Sub-Arctic, some the Boreal zone. Regarding the subdivision of the Boreal, see Rouskau 1952, HaaK 1954, Sjörs 1961, H 1949 and others.

Abstractions, which widely fluctuate over hundreds of miles from year to year (see Thomas 1950). Locally, it might be difficult to map the tree-lines instead of the species-line, but for most purposes the short distance between these lines is of no importance.

Between the outermost limit of a tree-species (regardless of size) and the forest-line proper is a transitional belt of varying breadth in which isolated trees as well as small groves or large isles of forests occur, particularly along the rivers. This transitional belt is mostly called forest-tundra (Lyesotundra, Waldtundra). The forest-tundra may attain a breadth of hundreds of miles in Canada or Siberia, but in maritime regions such as the Labrador coast.

II. THE NORTHERN TREE-LINES

A. Conifer species

Maps 3—4, 6—14 below are mainly drawn according to information contained in a number of published paper or reports, of which the majority is listed in 'References'. My own experience is restricted to the Quebec-Labrador Peninsula, northern Ontario and Fennoscandia. Among the general papers consulted for
this purpose must be mentioned Derecaji kustavski, Flora Murm. Obl., Flora USSR, Hultén (1950), Munns (1938), Native Trees of Canada, Petrov (1930), Rowe (1959), Sárvás (1964), Schmucker (1942) and an earlier edition (H 1952) of the Conifer chapter in this paper. Compare also Krylov (1961), Köppen (1888–89), Samoiluk and Dedov (1934), Shiladynovkova (1938), Shimanjuk (1962) and Tolmachev (1954) regarding the Eurasian tree-lines. Unfortunately, the information in the literature regarding the ranges of the tree-species is often confused and confusing and it is difficult to combine the data available. Thus, the maps below represent to a marked degree a rather subjective interpretation only. The excellent geobotanic map of the Soviet Union (Lavrko and Sochava 1954, 1956) gives abundant information regarding the main forest types and their distribution, but this map is not easy to use for the mapping of the different tree species. Map 3 above gives an idea of the general forest-line in the Soviet Union based on the northernmost distribution of Lyesotundra.

In some parts the forest-line or the tree-lines are not well known. The polar species-lines shown here are, therefore, very tentative and to a high degree rough interpolations only. The Eurasian tree-line is roughly 20,000 km long. The observations are generalized and the scale of the map does not allow many details. To illustrate how the northern range of two wellmapped tree-species, Scotch pine and Norway spruce, look on a larger scale, two more detailed maps are included here.

Theoretically, the lines on the maps are species-lines (i.e. line 4 on Fig. 1), but due to the scale of the maps and the information available, the lines might just as well be called tree-lines; in some parts such a line in fact marks the forest-line.

1. Picea. The spruce is, beside Larix, the most important tree species in the boreal forest regions and in the forest-tundra. Map 4 shows the polar tree or species-line of the genus Picea, including Picea excelsa Link (= P. Abies (L.) Karst.), P. obovata Ledeb., P. ajanensis Fisch., P. glauca (Moench.) Voss., P. pitchenensis (Bong.) Carr. and P. mariana (Mill.) BSP.

The taxonomic status of the Siberian spruce, Picea obovata, has been questioned i.a. by Lindquist (1948), who thinks it should be called P. Abies var. obovata (Ledeb.) Fellen., whereas Russian taxonomists always consider it a distinct species. At any rate, the Norway spruce and the Siberian spruce undoubtedly intergrade between the Kola Peninsula and the Pechora, cf. map 4, Tolmachev (1954, p. 148), Regel (1940) and others. This question has been discussed very early; Schüeke (1875–75, p. 159) wrote that a Abies obovata Ledeb. nur als eine klimatische Form der gewöhnlichen Fichte (Picea vulgaris Lb.) zu betrachten ist.

Map 5 shows the distribution of Norway spruce in north-western Europe.
The Norway spruce forms the polar coniferous tree-line in the Kola Peninsula, cf. Tolmachev (1, c, p. 68) and reaches Mesen in the east in the forest-tundra. Its northernmost locality in Norway is near Nelden, at 69° 47' N. Lat. according to T. Ruden (in letter); some observers believe that the isolated localities of spruce in the Varanger have developed from seeds of cones which were brought by Lapps. According to Lundquist (1, c, p. 263) an isolated outpost occurs on the Rybachii Peninsula.

The ecology of the spruce at the tree-line in the Kola Peninsula is described in a classic work by Kihlman-Kairamo 1890, cf. also Kruglov 1962.

Why the spruce tree-line west of the Kola Peninsula runs south of the pine tree line has caused much speculation among the forest scientists (cf. Hagem 1917 and others). Some believe that the cause may be historical, due i.a. to forest fires, others believe that there is a climatic reason for this discrepancy. However, already Schröeder (1873-75, p. 57) notes that edile Ursache dass die Grenze (der Fichte) nicht höher gegen Norden (an der Nordküste Norwegens) geht, ist kaum in ungünstigen klimatischen Verhältnissen zu suchen. Die mehr oder weniger waldreicher Thäler sind aber durch hohe, weit gedehnte, nackte Felsen von einander getrennt, die im allgemeinen jede Verbreitung durch Selbstsaat geradezu unmöglich machen.

The Siberian spruce (P. abies) forms the Polar tree-line from about the Kanin Peninsula to Jamal, in an area where the influence of man on the northern forests was devastating in earlier times, see p. 32. According to some authors, the spruce particularly often forms large eisof forest islands outside the forest limit proper, see Anderssen (1956) and Larsen (1964). Spruce reaches the Barents Sea in the Bay of Haipodorsk (Tolmachev 1, c, p. 69) and Korotchatka, see map 4. It also grows scattered along the lower Petchora (e.g. near Naryn and near Mar where it is planted nowadays).

The probably most striking (and most uncertain) locality of isolated tree individuals outside their range of distribution is the spruce-locality reported 1842 by the wellknown Russian explorer Pachtuov on the coast of Novaya Zemlya, at about 71° n. Lat. This locality has not been confirmed since and there is no mention of it in Tolmachev 1960. Medvednyov (1864, p. 543) that erwäre der Gewähsmann nicht von so erprobter Zuverlässigkeit, so hätten wir das Recht an dieser kaum glaublichen Mitteilung zu zweifeln, weil Novaja-Semilja für baumlose gilt. However, as others of Pachtuov's observations have later been confirmed, this report of a prostrate spruce on Novaya-Zemlya should be believed according to Köppen (1889, p. 522): sofüllig dort ausgewöhnliche Fichtensamen konnten keinen und in günstigen Jahren zu kleinen Sträuchern erwachsen, deren Existenz desdassel aber nicht gesichert ist, da die Fichten in diesen hohen Breiten keine Zeit hätte Samen zu bilden.

In central Siberia spruce grows farther north, a result of the increased continentiality. Although spruce reaches 69°30' N. Lat. in the Yenisey region, larch is there northernmost coniferous tree-species; according to Sochava (1930) even in Jamal the larch reaches slightly north of spruce. Spruce reaches its northernmost locality (cf. Flora USSR, 1934) at Chantangi, 71°15' N. Lat. and also grows near the Lena River, scattered up to 70°20' N. Lat. In the big river valleys where the local climate is more suitable (the rivers bring warmer water from inland) and wind-shelter is provided, spruce grows farther north than in the open peatlands between the rivers; this is, of course, true also for other tree species and for other areas.
In North America, we have two clear-cut species, white spruce (Picea glauca) and black spruce (P. mariana). Although both have approximately the same northern limit, they are well separated taxonomically\(^1\) and partly also ecologically.

It has been customary to designate the black spruce as the 'hardier' of the two, but this is erroneous. In exposed situations, where black spruce occurs only as a prostrate shrub with abundant vegetative reproduction, white spruce can grow as a small tree with a straight stem. Farther south black spruce usually grows in bogs or muskegs, whereas white spruce grows in well-drained and generally richer soils. Both species may form extensive, uniform spruce lichen forests, as may also the Siberian spruce near Norils (Dobrov 1933, H 1951); lichen woodlands with Norway spruce as the dominant tree seem to be very rare. While black spruce reproduces abundantly by layering, this is seldom the case with white spruce (H 1950).

Towards the north, the ecological differences between the two species prevail. In areas with sedimentary bedrock or in big river valleys where the soil is less acid and the shores loamy, white spruce reaches farther north than black spruce. This is the case, for instance, in Alaska (see Study 1958 p. 172 and Spetzman 1959, p. 41), and in the area east of Mackenzie, where white spruce is the dominant conifer in the open woodland as well as in the forest tundra (MacKay 1958, p. 100—101). The same pattern, i.e. the selective effect of bedrock on the distribution of spruce, appears from Tverrell's (1895—96) and Hansen's (1903) descriptions of the area between Coppermine and Hudson Bay; compare also Larsen's recent papers of 1964 and 1965. In the Hudson Bay Lowland white spruce mostly occupies extreme maritime localities on small dry ridges near the sea (cf. Ritchie 1957, Moer 1954, Sjörs 1961 and H 1957). White spruce forms more commonly the maritime tree-line on the cold islands off Labrador (cf. H 1949). The dominance of white spruce at the polar maritime tree-line on the Hudson Bay east coast is due also to the sedimentary bedrock on the islands (H 1950). White spruce grows higher up on the Brooks Range in Alaska than Norway spruce on mountains in Scandinavia, Kola Peninsula or Ural at the same latitude. White spruce reaches, for instance, 2,700 feet in the Anaktunuk Pass (Britton 1957, p. 32); at this latitude the coniferous tree-line reaches about 1200—1500 feet only in Scandinavia; this is a case of the so-called 'Masseehebung'-effect, well-known from the Alps.

Two races of white spruce occur in western Canada, namely P. glauca var. albertiana (Brown) Sarg. and P. glauca var. Porsildii Raup. Their still unclear northern limits are not shown specifically in Fig. 4.

\(^1\) Note, however, Larsen's statement from Canada's Northwest Territories: «Apparently intermediate forms between Picea mariana and P. glauca occur in abundance» (1965, p. 53).
The Siberian fir (Abies sibirica Ledeb.) is widely distributed in the Siberian taiga and in the valley of the Yenisey, where it extends well beyond the Arctic Circle (Flora U.R.S.S. 1934). Regarding the remarkable Abies-locality at Yenisey at 71°53', n. Lat. (cf. KJELLMAN's notes and TOLMANOV, 1960, p. 67). The locality is situated 100—150 miles from the present range of the fir. It must, however, be kept in mind that isolated conifer trees or bushes are favoured by man as firewood in bad weather and also often destroyed by reindeer.

The Siberian fir is a continental species with a range similar to that of Siberian pine. Ecologically, as well as in its ability to reproduce by layering, the Siberian fir is similar to other fir species.

The Canadian balsam fir, Abies balsamea (L.) Miller, ranges from the eastern slope of the Rocky Mountains to the Atlantic coast, but is not as continental as A. sibirica. Balsam fir is found, among other places, on the islands along the Atlantic coast of Labrador (H 1949). The Cordilleran alpine fir, A. lasiocarpa (Hook.) Nutt. (A. balsamea sp. lasiocarpa (Hook.) Boivin), ascends in the Yukon to 2,000 m. above sea level (PORFIELD 1951) but does not extend into the forest-tundra proper.


Scotch pine is the dominant conifer at the tree-line in northern Scandinavia. The isolated populations of Scotch pine in the northernmost valleys of Norway are of great interest from a genetic point of view, and should deserve close study (cf. H 1958 and map B). They are the Scandinavian counterparts of the isolated forest 'islands' which occur in the forest-tundra in the north of the Soviet Union or Canada. The northernmost pine forest in the world is situated in Stabursdalen at 70°18' N. Lat. (the northernmost pine tree at 70°29' N. Lat., cf. RUDEN 1935, p. 313) and MIKOLA 1952; the reproduction seems usually to be satisfactory also at this northern latitude. Pine had earlier a wider distribution as JOS. (1925) has shown, cf. H 1938. Re. the relation between the pine forest-line and the general flora in such areas, cf. LAINE 1964.

Scotch pine occupies a large area, reaching from the Atlantic to the Sea of Okhotsk, although the pine which occurs in the eastern part of this area is distinguished by Russian authors as P. silvestris var. jahutensis Suk, from the 'western' pine called P. silvestris sp. lapponica Fries; several other varieties (forms or ecotypes?) have been distinguished.

Scotch pine is not the dominant tree in the forest-tundra east of Petchenga, but it reaches the Arctic circle at Yenisey. Except in the northernmost Urals and on the lower Ob, Scotch pine goes farther north than the Siberian cembra-pine, cf. SOCHAIA (1930).

The Siberian pine has, see map 7, a typical continental range, compare Abies sibirica. It has been found on the Kola Peninsula near Murmansk and near Zemsoi on the south coast (Fl. Murm. Obl.) far from its ordinary range. Pinus sibirica is the only conifer species in the north which was once primarily used for other purpose than wood and fuel; the whole tree was cut to get the seeds ('cedar-nuts'). PARKELA (1930, p. 230—31) describes attempts to plant cembra pine in northern Finland during the last century; several crop failures in the last century were partly a reason for this interest. Because the cembra seeds were an important trade article in the north, it is not certain that the cembra pine localities in Kola are spontaneous.
The Siberian dwarf pine (P. pumila or P. cembra var. pumila) is a «Krumholz»-species. Thus, it differs ecologically and morphologically considerably from the other conifers in the northern part of the boreal region. In eastern Siberia the dwarf pine grows in a higher latitude and altitude than that reached by pine elsewhere; it often forms a clear belt above the larch forests on the mountains. Ecologically it is similar to P. mugo (P. montana) of the European Alps, although P. pumila belongs in the section Pinaster, whereas P. mugo belongs to the section Strobus. The Siberian dwarf pine forms the polar limit of conifers in the Kolyma and Anadyr regions, but never reaches tree-size. Its distribution is very similar to the area of Chosenia macrolepis, see below. According to TIKHOMIROV (1949) the dwarf pine is physiognomically very strong. The dwarf pine does not occur east of the Bering Strait (TOLMACHEV 1960, p. 74), although that has been suggested.

Pinus Banksiana or jack pine is the commonest pine species in the boreal Canada. It is a continental species and reaches the coast only along the north shore of the Gulf of St. Lawrence and in Nova Scotia (the pine in Newfoundland is the eastern white pine, P. Strobus L.). It seems that FERNALD's view (1919) that jack pine is restricted to Pre-Cambrian bedrock, sandy plains, eskers or moraines is more or less correct, on H 1950. The peculiar range of the jack pine in north-eastern Canada is difficult to explain. One theory is that the species has not reached its climatic limit in the north-east; there are wide areas of suitable localities east and north-east of its present range. It should be noted that the cones of the jack pine usually open after forest fires or during periods of exceptionally hot weather. An interesting feature is that the jack pine near its northern limit in Ontario seems to grow taller than it does near its eastern limit. In western Canada, jack pine reaches the Mackenzie Basin, where it meets the lodgepole pine (P. contorta var. latifolia). The range of neither species extends into the forest-tundra proper.

4. Larix. Regarding the distribution of the Eurasian species of the genus Larix, I have here not followed DYLIS (1948), who divides the Siberian larch into two species, Larix sibirica Ledeb. s. str. and L. Sukaczewii Dylis. TOLMACHEV (1960, p. 69) keeps the two species larch species together as L. sibirica, which, however, is divided into two races: L. sibirica ssp. ruxica (Rgl.) Suk. and L. sibirica var. polaris Dyl. Regarding L. sibirica s. str.; compare, except DYLIS (1.6.), also ARMBOURG and ESLUND 1962.

The Siberian larch appears to be a non-aggressive species, restricted to shores of rivers and lakes, mountain slopes, bogs and similar places (cf. SAMBUK 1930) and the same applies to its western species or sub-species. It is interesting to note how closely SAMBUK's description of the behaviour of the larch in the Pechora region parallels that of the tamarack (L. laricina) in eastern Canada.
The Dahurian larch is the most prominent conifer of the Eurasian polar treeline, it reaches farther north than any other coniferous species, see map 11. According to TOLMACHEV (1960, p. 72) it grows at Pjasiva at 70°30' N. Lat. and in the valley of Novoy River, north of Chattanga, at 72°37' N. Lat. The larch grove on Tit-Ari-island at 72° N. Lat. in the Lena River (TkHOMIBOV 1957, p. 36) is often described.

In Siberia, larch often forms the polar tree-line, and towards the east also the forest-limit. But the North American larch or tamarack (L. laricina (Duroi) Koch), although widespread in the forest-tundra, rarely forms forests; in Labrador larch may occasionally form lichen woodlands (H 1954).

The large peatlands of the Sub-Arctic Hudson Bay Lowland (H 1957) are covered for miles with low, sparse and pure larch forest; the even age is partly
a result of the attacks by larch-sawfly some decades ago. But towards the cold bay white spruce forms the maritime tree-line proper (cf. Mohn 1954), mainly on the sandy ridges, i.e. the only localities with good drainage in the surrounding peatlands.

Across north-western Canada larch, together with white and black spruce, forms the polar tree-line, generally a little behind the spruce.

The Alaskan larch has been distinguished as L. alaskensis Wight, a name which has not been accepted generally; Rare (1947) considers it a geographic race (L. laricina var. alaskensis (Wight) Raup), which extends into north-western Canada.

5. Juniperus, Tsuga and Thuja. The juniper (Juniperus communis L.) is never tree-like in the far north. However, it reaches farther north than other conifers, and for this reason its range (including J. communis var. montana Altt., var. nana Loud. and J. sibirica Burgd.) is shown on map 10. The juniper (s. l.) is also the only almost completely circumpolar conifer, cf. H 1952 and Hultén 1962; it is the only conifer native to Greenland, Iceland, and perhaps Novaya Zemlya (see H 1952, p. 151).

Neither hemlock species (Tsuga), nor cedar or arbor-vitae (Thuja) species reach the forest-tundra, even though the eastern white cedar (Thuja occidentalis L.) does reach southern James Bay, and Tsuga heterophylla (Raf.) Sarg. and T. Mertensiana (Bong.) Carr. grow in southern Alaska.

Map 11 combines the maps above of Picea, Abies, Pinus and Larix. Only the northernmost species of the different conifer genera have been taken into account in this connection. Note the great difference between the four corners of the Arctic and Sub-Arctic, i.e. Alaska, Labrador, Fennoscandia and Anadyr.

B. Deciduous species

Tree-sized birch, poplar, and aspen reach the polar tree-line in many places. In a few localities some deciduous species reach higher latitudes than the conifers. Species of alder and willows also grow as small trees near or at the polar tree-line and in some cases far beyond it. Particularly from the point of reforestation these small bushes, trees and groves are of importance, because in their shelter conifer seedlings can develop into trees more easily than on the barren tundra. However, the distribution of many of these species is not sufficiently known, and the maps are therefore very tentative. Maps 12—14 include only Alnus, Betula, Populus, Salix and Chouenia (closely related to Salix and of great importance in eastern Siberia). Many birch and particularly willow species never reach tree-size; these species thus form a transition between the arborescent species and the prostrate woody perennials of the Arctic.

1. White birch (Betula papyr.). Map 12 shows the polar tree-line (incl. as usual the species-line) of the so-called white birches, which in reality includes a number of species (or varieties?). Ecologically and taxonomically these species are so near each other that it is difficult to distinguish the species in areas where the ranges overlap.

In northern Europe the commonest birch at the polar tree-line is usually called Betula pubescens Ehrh. However, there are at least two common, though hardly distinguishable, birch types in the subalpine stande (EHMET-ARTI 1963, p. 7). Kihlman-Kashkino (1899, p. 163) wrote that "die systematische Trennung der subalpinen Birke von der thalawärtš und weiter gegen Süden waldbildenden Form einer natürlichen Gruppierung nicht entspricht." Mindendorf (1864, p.
It must be strongly pointed out that the line on map 12 is very tentative only, pending increased knowledge about the taxonomy of Betula.

In North America there seems to be a greater difference between the small-sized birch species (B. borealis, B. minor, etc., see below) and tree-sized white birches, at least according to my impressions from north-eastern Canada. B. papyrifera Marsh. s. l. is the northern white birch species nearly all over northern Canada. In eastern Canada B. papyrifera var. cordifolia (Reg.) Fern. goes farthest north. In western Canada and Alaska the main birch in the inland is B. papyrifera var. humilis Fern. and Raup. (= B. resinifera Britton), compare Dough (1966).

The white birch is, however, not as common in the northern forests of Canada as in Europe; one reason is the great influence of man in northern Europe; white birch is to a high degree favourably affected by the activities of man, it easily grows after fires. Its prolific vegetative reproduction allows the birch to fast expand its area. Re. the distribution pattern of white birch in Labrador and the Hudson Bay region, see H 1949 and H 1957, and in Keewatin and Mackenzie, for instance, Mackay 1958. In Alaska white birch seems to be a little more common than in Canada and together with white spruce it extends more northwards than any other tree species, except balsam poplar (Sooopoulos 1958).

2. Mountain birch species. It is impossible to map the northern range of the so-called mountain birch species, i.e. Betula tortuosa Ledeb. and related species. The mountain birches usually grow as low trees; such forests are often compared to eucalyptus gardenes. The low, twisted, often many-branched mountain birch has no forestry value, except as fuel for the local population. The open mountain birch forests, the 'northern savannas' are, nevertheless, useful in reforestation because pine seedlings grow well in such woods. Particularly in northernmost Europe the area of mountain birch has increased, due to forest fires and lumbering.

The main mountain birch species in Europe is mostly called B. tortuosa Ledeb. According to Hylander (1965, p. 299–300) this name should be avoided, the mountain birches in Fennoscandia belong to B. pubescens s.l., compare Hämijärvi (1963). Hultén wrote recently in desperation that the taxonomy within the genus Betula is today more confused than ever (1958, p. 66). There are some related species 'to' B. tortuosa which ecologically seem to be almost similar, e.g. B. subarctica Orl. (Fl. Murm. Obl. III, p. 126) in the Kola Peninsula (probably in northern Scandinavia as well), and B. callida Notó, which occurs in Iceland, in Scandinavia and as far as the Yenisey (Lindquist 1945, p. 181).

According to Hämijärvi (l.c.) B. tortuosa is distributed as far as N. W. Siberia, perhaps even to the Lena River --- but no continuous, pure subarctic birch forest zone can be distinguished. --- However, this birch seems to be common in the forest-tundra and may occasionally form pure stands,
which east of the Pechora River ••• are probably only present near villages and burnt-over areas. Leskov regarded the southern limit of the mass occurrence of mountain birch as a good indicator of the boundary between the forest-tundra and the taiga (quoted acc. to HÄämet-Ahti l.c.).

In Siberia, B. Kusmischeffii (Reg.) Suk., B. Cajanderi Suk. and B. Ermanii Cham. seem to be the vicariant or substitution taxon of B. tortuosa, at least ecologically. Dealing with the circumpolar mountain birch forests, HÄämet-Ahti writes (l.c., p. 3) that it is obviously fully correct to interpret all the B. Ermanii forests as Pacific counterparts to the Atlantic B. tortuosa forests. According to Vassiljev (1956, p. 128 etc.) B. Cajanderi might be the equivalent of B. Ermanii in the Anadyr area.

In North America mountain birch is of no importance near or at the conifer tree-line. The effect of man has been smaller in the North American taiga than in similar parts in Eurasia. Re. Betula minor (Tuck.) Fern., Fernald wrote that it closely simulates the Arctic Eurasian and Greenland bush, there passing as B. alba var. tortuosa (Ledeb.) Schneider ••• e (1945, p. 307). But B. minor never forms similar large Sub-Alpine or Sub-Arctic forests as B. tortuosa. Another Canadian species is B. borealis Spach (= B. microphylla Bunge?). In western North America the water birch, B. fontinalis Sargent, grows scattered up to the polar tree-line, see map in Douc (1966).

3. Populus. Popolars of the Section Tacamahaca reach commonly the conifer tree-line in eastern Siberia, in Alaska and Canada and in a few cases go beyond it.

The balsam poplars have a strong capacity to form vegetative shoots and easily invade recently deposited river shores (cf. H 1957, p. 18—20). Poplars and aspen have male and female inflorescences on different trees, which, of course, considerably restricts their generative reproduction capacity in the margins of their areas. Balsam poplar and aspen often form large clones by vegetative reproduction; they also rot easily.

The Eurasian balsam poplar (P. suaveolens Fisch.) has a northern range which is very similar to Pinus pumila and Chosenia macrolepis, see map 13. It grows scattered and also as a rather high tree on rich alluvial habitats in the far north.

In North America P. balsamifera L. (= P. tacamahaca Michx.) reaches the forest-tundra (cf. i. a. Duttley and Leske 1951) along river banks and southern slopes with good soil and less permafrost than the surroundings, and it goes beyond the coniferous tree-line in westernmost Canada and Alaska.

Map 18 shows the northern limits of the aspen species of interest in this connection, i. e. P. tremuloides L. in Eurasia and Iceland, see below, and P. tremuloides in Canada and Alaska. Aspen roots can lie for tens of years in the ground and suddenly grow up, after a fire, for instance. Aspen sometimes forms large prostrate shrubs on exposed mountain plateaus, but on some suitable southern slopes in the forest-tundra in Utajoki and Finnmark elegant stands of high aspen grows where pine and birch are more or less twisted and deformed.

The northern aspen and poplar species need more study from several points of view, not least in regard to their importance in reforestation.

Other Populus-species, such as P. trichocarpa Torr. & Gray, grow in Alaska, but do not reach in the forest-tundra proper.

4. Alnus, Salix, Chosenia and Sorbus are represented at or very near the conifer tree-line; in many cases, mainly as bushes, they reach beyond it.

Map 14 roughly illustrates the northern range of alder and willow 'trees'; their distribution is not as well known as the ranges of spruces, larch, etc.
The alders are important as ecol makers and as shelter for conifers near the tree-line. From the reforestation point of view, the distribution of alder is of great importance and should be much more studied, particularly its ecology in the north.

Willows grow as small trees in the forest-tundra; in very few cases tree-sized Salicaceae reach beyond the conifer tree-line. However, the taxonomy of the circum-polar willows is not clear. On map 14 I have tried to outline the distribution of such Salix-species which are known to reach tree-size even in the far north. Willows can often play the same pioneer role as mountain birch and alder in the forest-tundra. At the tree-line on the west coast of Hudson Bay, for instance, the best developed young white spruce trees grow in high willow thickets (H 1957).

In northern Scandinavia tree-like Salix caprea L. goes up to Varanger. In parts of Siberia at the polar tree-line the tree-sized S. viminalis L. and S. speciosa Hook. are of some importance. S. speciosa also grows in Alaska, here called S. alaxensis (Anders.) Cow. (Raup 1945, p. 115). S. alaxensis grows 25 feet high on the Arctic slope (Spetzen 1959, p. 45) and is there the main source of firewood, cf. Johansen 1924. S. jenisseiensis, a similar species, grows as a 5—6 metres high tree at Lena up to 70°45' N. Lat. (Nordin 1958, p. 849). In Canada S. Bebbiana Sarg. (which also grows in Arctic, see Vassiliev 1956) reaches tree-size but does not extend near the tree-line.

Chosenia macrolepis (Turcz.) Kom. is an anemochore 'willow'-species, which usually grows as a high tree in north-eastern Siberia, see map 14, where in places, together with Populus suaveolens, it is the only tree species, cf. also the map of Pinus pumila. Nordin, see above, mentions the species from Lena River at about 70°45' N. Lat., where it grows as a 8—10 m high tree.

Sorbus aucuparia L. occurs scattered as a small tree in the forest-tundra. In northern Scandinavia the mountain ash (usually its var. glabrata (W. & G.) Hedl.) grows as far north as the white birch (Rüden 1936, p. 312); it also is sometimes seen high up in the Sub-Alpine region on the northern mountains in Scandinavia as in the Kola Peninsula (Khimen-Kaimo 1890, p. 75) and in Iceland (Greinivdi 1942, p. 217). Greenland's mountain ash is another species, S. decora (Sarg.) Schneid. v. groenlandica (Schneid.) Jones, which also grows in Labrador, but rarely in the forest-tundra. Because of the scarce information available the distribution of the Sorbus-species is not mapped here.

The deciduous species are not easy to map; some genera are still taxonomically unclear. But all over the circum-polar forest-tundra there are at least some deciduous species which reach tree-size and, thus, are of importance for the understanding of the effect of the climate on tree growth.

(1945) the vicarious species of the European A. incana in Canada is A. rugosa (DuRoi) Spreng. v. americana (Reg.) Fern., which however does not reach into the forest-tundra.

In Fennoscandia Alnus incana Moench. v. borealis Norrl. goes far to the north as a small tree up to 70°30' N. Lat. and in the Kola Peninsula to 69°30', here a variety of Alnus incana is called A. kolaëniis Orl. (Fl. Murm. Obl. III, p. 200). In northern Eurasia and Siberia A. fruticosæ Rupr. reaches in Chatanga 71°45' N. Lat. and in Taimyr 70°45' N. Lat., often as a small tree.

In northwestern Canada A. tenella Nutt. commonly reaches tree-size. In Eastern Canada A. crispa (Ait.) Pursh. grows in the far north, but does not attain tree-size. A. crispa is an important species on lake shores and near the summits of the coastal mountains of Labrador, for instance. According to Fernald

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III. COMPARISON OF THE TREE-LINES OF CONIFEROUS AND DECIDUOUS SPECIES

The similarity of the ecology of tree-line trees has often been stressed. The description above and the maps show how different the species composition is in different parts of the circumpolar tree-line.

I have below (see map 15) tried to illustrate the possible difference in distribution of different tree species and 'tree-types' by dividing the species concerned into three categories: evergreen conifers, larch and broad-leaved species. The main difference between these tree-types is their different response to winter climate. The following collective tree-lines (incl. the relevant species-lines) are compared:

1. a combination of the tree-lines of all evergreen conifers mapped above, except *Pinus pumila* and *Juniperus* spp.
2. the tree-line of larch.
3. a combination of the tree-lines of deciduous species which reach tree-size.

Owing to our unsatisfactory knowledge of the willow, mountain birch and alder species, the line 1 on map 15 is, however, in fact a combination of the ranges of white birch (coll.), poplar, aspen and Chosenia, which can all attain tree-size even at their northernmost localities.

If we compare these different tree-lines on map 15, we note that there is not a particularly great degree of difference, except in eastern Siberia.

The pattern of these three physiologically and ecologically different tree-lines should be analyzed according to their response to the climate. It might also be of interest from the point of view of the possibility of reforestation in the future. However, this problem will be dealt with in another connection.

The occurrence of tree-sized broad-leaved species but no spontaneous conifer species in Iceland and Greenland must be noted. Which is the real reason for this great anomaly from the usual pattern of the tree line? Another anomaly on the map 15 is the absence of larch in northern Scandinavia, for which it is hard to assume a climatic factor; perhaps the Fennoscandian Pre-Cambrian shield forms a barrier, compare Kashin and Kozobrodov (1966) and Zimskulling (1935).

One point in this connection is stressed by Kavukhov (1961, p. 4): 'If spruce in winter loose more moisture than birches, this is due to the fact that the transpiration surface of spruce in winter is hundreds of times larger than that of birch trees. In spruce the water balance is disturbed more violently and more frequently in winter and spring than in birch trees and this often leads to their ruin. For this reason the forest tundra of the Kola peninsula is composed primarily of birch trees, which, in turn, occur in low-lying and sheltered places. Spruce begins to appear somewhat farther south, in the shelter of the birch belt.' Although this statement is only partly correct (note man's influence in creating

The birch forests in European Russia, for instance) there is certainly some truth in it. Is the absence of suitable hardy mountain birch species one reason why the distribution of conifers is so restricted west of Hudson Bay?
IV. GENERAL REMARKS ON THE FOREST-TUNDRA

The circumpolar forest-tundra, or the Sub-Arctic s. str., is different from place to place in its topography, in bedrock and quaternary history.

Sedimentary and Archæan bedrock alternate over the forest-tundra zone as limited on map 2 above. The influence of the bedrock on the floristic composition of the vegetation is wellknown (compare the serpentine-discussion) as also the fact that a certain content of lime is often found in the habitats of the northernmost outposts of certain species. A welldrained southern exposition is in itself a positive factor in this connection, particularly if associated with positive soil factors, compare the extensive literature concerning the 'sårbergs' in northern Sweden (Sjöns 1956, etc.).

Norway spruce seems to grow well i.a. on Cambro-Silurian sedimentary bedrock or on till of such material. Scotch pine, as jack pine a.o., is on the other hand more prominent in areas dominated by more acid bedrock. Siberian larch on its western border 'prefers' sedimentary bedrock or limestone and dolomite outcrops, but avoids the Pre-Cambrian bedrock. The important components of the Canadian taiga and forest-tundra, white and black spruce, differ in this respect, as the wellknown explorer Low (1895) pointed out long ago. Black spruce occurs generally on more acid bedrock and on soil with low pH-values, whereas white spruce grows on rich clayey and alluvial soils in river valleys; large areas in Labrador lack white spruce because of this edaphic difference between the two species. The mosaic of white spruce and black spruce grows at the tree-line in northwestern Canada can partly be explained by the bedrock pattern.

White spruce, Siberian larch, cedar and balsam poplar seem to prefer or at least not to avoid basic sedimentary bedrock. Treeline species which seem to prefer acid bedrock are jack pine, black spruce and aspen.

In many parts of the forest-tundra zone there are large peatland areas, where tree growth is restricted. However in some areas trees grow well on peat. The accumulation of peat slowly changes the influence of the underlying bedrock. In the Hudson Bay Lowlands (cf. H 1957, Ktøeræn 1938, Sjöns 1961, etc.) black spruce grows on old peat soils, probably at earlier times covered with larch or white spruce. The conditions are probably in many ways similar in northern Russia and western Siberia. Generally, however, peatlands restrict tree growth and the polar tree-line reaches northwards not on peatlands but in river valleys and on south-exposed low mountain slopes.

A problem which has often been discussed is the relation between permafrost and tree growth. If we try to compare only large scale maps of the southern limit of permafrost and the northern limit of trees it is difficult to find a correlation. This is because permafrost in fact does not restrict the growth of all tree species to the same degree.

Recently Hopkins and others (1955) have made a study of the relation between permafrost and tree growth in Alaska. They point out (p. 157) that 'small willow shrubs and isolated pure stands of balsam poplar on river flood plains generally indicate the presence of unfrozen ground; the minimum depths of permafrost beneath tall willows on flood plains is about 8 feet, under pure stands of mature aspen or white birch 4 feet and under mixed white spruce and balsam poplar 3 feet, whereas black spruce can grow in wet tundra or muskeg with permafrost only 1 foot under the ground. On the lower reaches of the river Kolyma larch grows almost in moss alone, for under the mosses in the forest there is pure ice (Sirvinskas 1963, p. 774). The wellknown black spruce islands in the north (cf. Andrew 1956, H 1957, Sjöns 1961), which are a common feature of large peatlands near the tree-line, are favorable sites for the preservation of permafrost. The occurrence of palsa bogs at the southern line of permafrost correlates well with the northern tree-line (Auren 1927, H 1939 and others).

The only conifers which seem to avoid permafrost and even 'semipermafrost' are Scotch and jack pine. Their root systems generally go deep, whereas black spruce (cf., for instance, Horton and Leks 1961) and larch have a rather shallow root system.

The destructive effect of a fire is very strong in the forest-tundra (H 1954), because of the insufficient supply of seeds for regeneration. Usually conifers in such localities are followed by birch; the effective sprouting of the birch stumps left over by the fire is an important factor. This succession accounts to a high degree for the character of the Utsjoki pseudo-tundras in northwestern Finland and is, of course, seen all over the circumpolar forest-tundra. The effect of fires on the species composition of the forest-tundra cannot be underestimated. Lutz writes re conditions in Alaska that as a result of repeated fires, areas formerly in white spruce may become essentially treeless, supporting herbaceous or shrub communities. Fireweed-grass and dwarf birch-willow may become so firmly established that it is difficult for forest-tree seedlings to become established. Natural reconversion of such lands to forest may require 100 to 200 years. Fires are most likely to result in replacement of white spruce forest by relatively permanent treeless communities at the upper altitudinal and latitudinal limit of forest growth (1955, p. 92). The areas of lichen woodlands which occur scattered in the forest-tundra zone are plainly the most susceptible. The fires also account for a certain paludification of the forests, etc. (cf. H 1957, p. 36-37). Sjöns (1961) describes the effects of forest fires in the forest-tundra zone in northern Finland and mentions cases of char coal, stumps, etc. of pine far away from the present trees and stands in the forest-tundra. The farther north we go, the more destructive is the effect of forest fires, particularly on spruce. In Labrador the effect of forest fires is wellknown and causes the emergence of tundras on formerly wooded slopes.
Thus, the succession of tree species in the forest-tundra and the predominance or scarcity of deciduous tree species in places can be attributed not only to the effects of the climate or of bedrock, permafrost and other edaphic factors, but also to the effect of fires in earlier times. It is probable that fires that in the forest-tundra have been largely caused by man. There is already an extensive literature on this subject.

In some parts of the forest-tundra land rises continuously because of the isostatic movement as a result of the glaciation. At least along the west coast of Hudson Bay it seems as if the species have advanced in accordance with the speed of the rising of the land. In areas with low shores and peatlands, there are restrictive edaphic conditions for some tree species, such as pine, balsam fir, aspen and white birch (see H 1957), but for some other tree species we don’t know if the reasons for their absence along the shores of Hudson Bay and James Bay is due to edaphic conditions or to a slow expansion in postglacial time; in this area the macroclimate itself is no restrictive factor. Bell (1897) points out that balsam poplar generally avoids the sea. Ritchie has illustrated how the white spruce forest invades the younger shrub-dominated plains near Hudson Bay and is ultimately replaced by a black spruce community on large peat mounds (1957, p. 432), compare also Mor 1954 and H 1957.

The supposed vegetation during the last glaciation is of interest. The forest tree-line existed at that time near the Charpaitans and in the Ukraine, but in eastern Siberia forest occurred north of the Arctic Circle at Lena and Chatsby. In the area of the Lena mountains the composition of the forest was about the same during the whole Quaternary period as today (Frenzel 1960). This certainly had a great effect on the tree species composition in that area today, cf. Bjarfskaia 1965.

In North America only Alaska was free of ice during the last glaciation as well as earlier. According to Benningsoff (1954) the fossil flora in the unglaciated Fairbanks district from about 22,000 years ago revealed no contrast to the present vegetation. During the last 13,000 years glacial advances and retreats in the Cook Inlet region have been accompanied by shifts in the distribution of the coastal Sitka-spruce forest, the spruce-birch interior forest, and tundra bog vegetation, but apparently without changes in the distribution of the species in the region. Benningsoff concludes that some facts suggest partition of floras by the Bering Strait in late-Pleistocene time, with no subsequent exchange of forest species (1954, p. 216), cf. Codinaux 1963. This is an important fact when dealing with the historical distribution of tree-line forming species.

Only one conifer species is in present time circumpolar in the forest-tundra, Juniperus communis s.l. Not even among deciduous trees, there seems to be any species (except Salix alaxensis (S. species) which sometimes reaches tree-size) which occurs on both sides of the Bering Strait. Whether this is a result of differ-
There is also in this respect a marked difference between the different tree species. Some tree species have a rapid vegetative reproduction through layering or other means, some are easily eliminated after cutting or fire, etc. The spruces and larches as also the deciduous tree species have generally a good vegetative reproduction. The pines, on the other hand, hardly ever (except the Siberian dwarf pine) have any layering or similar means of vegetative reproduction.

The influence of man has, thus, also been selective in regard to the species structure of the forest-tundra and the tree-lines.

Earlier Russian authors describe vividly the effect of man’s activity along the important trade route from Mesen to Obdorsk. The forest-tundra in European Russia was more densely populated in the 16. and 17. century than in the beginning of this century (MINSKOROZ 1864, SMIRKOV 1911 and POHLE 1917). On the other hand, the Polyarnij Ural, for instance, was until fairly recently affected by man (GOLODROV 1926). Omitting a large number of references to man’s activity at the forest-line, I, however, here only quote NAUMENKO (1966, p. 49) on Larix dahurica in the Kolyma basin (see map 9): “The natural and anthropogenous factors, among which the fires are of major importance, contribute to the decrease of the forest protective potential of the area in question. It is an urgent necessity to establish a forest shelter-belt about 150—200 km wide and to accomplish in it a special complex of measures of forest-protection and reforestation.” Exactly the same was said about the northernmost forests in Finnish Lapland in the 1910’s and 1920’s. How many decades will it take before the same urgent need suddenly is felt in Alaska and Canada?

The Lapps in Scandinavia and Finland have changed large parts of the northernmost forests and created a forest tundra or spesudo-tundrae (SIRÁN 1961). According to HIKKINEN (1921) one Finnish settler-family in the forest tundra used annually 120—130 m³ wood for fuel only, i.e. roughly the annual growth of about 600 hectares, if we assume that the annual increment in the northernmost pine forest is about 0.2 m³ per hectare (Lars 1924).

The fire-wood problem in the North American Arctic was in many places on the coast easily solved by driftwood from the great rivers. The Eskimos moving in the barren grounds in northwestern Canada had, however, difficulties, cf. TVERELL 1896—7. It is difficult to know how much man has been responsible for the present irregularity of the tree-line in the Northwest Territories, but seemingly, however, less than in Eurasia.

The role of reindeer in the forest-tundra has been much discussed. Reindeer and caribou destroy young seedlings and also older trees during the hornfelling time in the autumn. RENVALL (1919) extensively studied the subject in Finnish Lapland. He recommended several measures against the damage done by the reindeer in the northern Scotch pine forests where the reproduction from seed is uncertain. ANDREEV (1954) observed that at least 75% of all dead trees at or near the tree-line were destroyed by reindeer; he advocated strong control measures against reindeer grazing in the forest-tundra.

The effect of the reindeer is not always negative. Reindeers move around with tree seeds in their cloves and skin, a ‘soil-borne’ dispersal of seeds which should be more thoroughly investigated. With the ‘parcels of Cladina lichens used for reindeer travelling in winter, pine and spruce seeds have occasionally been brought long distances (cf. H 1958).

In North America the destructive effect of the large caribou herds on tree growth have not been studied as extensively as the damage done by reindeers in northern Europe; the caribou do not to any high degree move in commercially exploited forests. RITCHIE (1959) describes the effect caused by caribou in grazing areas in northern Manitoba which has changed the structure of the lichen vegetation, compare also CLARKE (1940), HARPPE (1955) and H 1951.

In recent years the way of life has changed strongly also in the Sub-Arctic. The nomads are not moving any more. Lapps, Samojedls, Jakutes and Chukchis a.o. Arctic and Sub-Arctic peoples live normally in huts. Thus, the direct destructive effect of man in vast areas of the forest tundra has considerably decreased during the recent decades. Isolated farms have been left in the far north in Finland and Scandinavia when people move southwards or into the nearest villages and towns. The urbanisation has increased all over. The Kola Peninsula was formerly inhabited mainly by Reindeer Lapps or by Lapps living in fishing in coastal waters. This area has now one of the highest urbanisation percentages (85%) anywhere. In Canada and Alaska, Indians and Eskimos in the forest-tundra have moved into large government-planned or -sponsored settlements and only partly make their living out of game and fish.

The forest-tundra itself is, therefore, less densely populated nowadays than in the last centuries. On the other hand, the need of raw materials for an increased forest industry brings also the hitherto inaccessible resources into consideration. This means increased movement of the forest industry into the forest-tundra. It also means an increased understanding of the need for reforestation wherever possible. These problems of the foresters in Scandinavia and Finland will soon be the problems of USSR, Canada and Alaska.

Many and various opinions have been expressed in recent decades regarding the possibility of reforestation of the forest-tundra. There is a clear correlation between the views of the forest scientists in this respect and the quality of climate at the time when they expressed their views. See H 1948. Scientists working at the beginning of the century in northern Europe were rather pessimistic about the possibilities of moving the economic forest-limit to the north. The forest-limit concept was also earlier considered a rather static one, but now we know that this phytogeographical border certainly is a very dynamic one. The tree-line moves north when the climate improves and stagnates again
when the summer climate gets colder for longer periods. The pessimistic view still prevailing in the twenties regarding tree planting in the north has however gradually changed into a more optimistic view, particularly often expressed during and immediately after the well verified climatic improvement in the thirties, cf. H 1948, MIKOLA 1950, 1959, ERKKO 1956 and SIRKIN 1961.

We can move towards active reforestation by preserving the outposts of the forest and by increasing the possibilities of natural regeneration at the present polar tree-line. Man can also create completely new forests using the same species as those which make up the nearest natural forests or by introducing entirely new species which, in other places with similar conditions have done well. Nowadays, tree planting has been done successfully in Iceland and northernmost Norway and it has been tried in Greenland of all places, thus, preventing further political disturbances by eliminating the need to look for timber in <Vinlandes>.

Finally a short survey re. the correlation between climatic factors and tree-growth at the tree-line. Such a correlation can be established by using two different approaches:

a) we can compare the present tree-line with isotherms of the warmest months, a much used method, and, thus, visually get an idea of the correlation between climate and tree-line. We can also use in this context temperature sums of the summer or of the growth season or more elaborate indices composed of temperature, precipitation, radiation, etc.

b) we can correlate the annual tree growth (easiest to use and measure is growth in thickness) of trees in the north with temperature series and with combined climatic indicators using, for instance, multiple regression analysis.

In many connections I have pointed out that climate in the north changes from year to year and that this climactic hazard coefficients as I have called it (H 1948, etc.), is particularly great in the north. Thus, when using isotherms and other climatic devices it must be clearly understood which period they represent.

Isotherms are only crude measurements for illustrating the climate — still more crude than the tree-line approximations on the maps above. But to the north the July isotherm, however, gives a still rough but yet an increasingly accurate correlation with the tree growth. The duration of different growth processes of the forest-tundra pine are concentrated to July. The July Isotherm at the tree-line itself must, therefore, be a better indicator of tree growth than in more southern parts of the boreal forest region, where precipitation comes in as an added influence.

A new approach was introduced by THORNTWATTS in the thirties and used for instance by HARE (1950) to delineate the boreal forest formation in eastern Canada. THORNTWATTS's annual evapotranspiration function is an accumulating logarithmic function of monthly mean temperatures and the tree-line in eastern Canada seems rather nicely to follow HARE's advice.

Enqvist's climactic constants (1933) for the tree-lines in Sweden is methodologically of a certain interest. Meteorological stations at, outside and inside the tree-line in question were placed in a coordinate system based on number of days and the maximum temperature during these days. According to Enqvist spruce at its tree-line needed at least 65 days with a maximum temperature of at least 12.5°C to survive. The result is, of course, too exact to be true. The idea was later adopted in a modified way, for instance, by HOPKINS (1959), who tried to evaluate some characteristics of the forest and tundra regions in Alaska.

Of interest in this connection is also an important paper by JEFFREY (1960) on the climatic pattern between 40° and 70°N. lat. and its influence on the distribution of species. JEFFREY operated with the January and July mean temperatures and the logarithm of winter precipitation. HINTIKKA (1963) has used an approach similar to JEFFREY's.

An older method to illustrate the correlation of climate/tree-line is to apply mathematical analysis to define the correlation between the growth of the trees in the north and the climate at the nearest meteorological station. ERLANDSON (1936), pioneer in this field, showed adequately that the mean temperature in July is a good indicator, a fact previously, of course, recognized but not so well illustrated as in his classic paper. Later HUSTIC and ELVING (1944) tried a multiple regression analysis using radial growth series of pine from northernmost Finland compared with a differentiated series of climatic indicators. Here, too, the simple July-temperature emerged as the best single indicator. Our paper also demonstrated the important stage effect, i.e. the related effect of a very favourable or a very bad summer on the growth of the tree-line pine in the following years. A similar approach with a greater material and with much longer series was worked out by SIRKIN in 1961.

The annual variations in the growth processes at the tree-line are very prominent and are, of course, not restricted only to growth in thickness. All the vegetative and generative processes of the northernmost trees are interlocked with each other and concentrated to an extremely short growth season at the tree-line. Years with good cone production affect other growth processes of the trees, an interesting subject, which is not yet sufficiently studied. The maximum of female flowering coincides, for instance, with maximum growth of length of the shoots, and this maximum again occurs one year after a good summer in which radial growth reaches its maximum.

We have to understand the physiology of the forest-tundra tree-species to understand in a deeper sense the ecology of the tree-line.
ACKNOWLEDGEMENTS

This paper was originally prepared as an aid to the participants in the UNESCO-sponsored Symposium on Sub-Arctic Ecology in Helsinki 1966. I thank Professor P. Kallio for much encouragement and inclusion of the paper in the Third Report of the Kevo Sub-Arctic Station.

Grateful thanks are tendered to I.A. following participants in the Sub-Arctic Symposium: Dr. T. Arnt, Mr. E. Einarsson, Professor E. Huttunen, Professor P. Molin, and particularly Dr. Iain Simmons for addenda and corrections to both facts and language. Unfortunately, because of the fact that the printing was already in a very advanced stage during the Symposium, only a part of the corrections etc. suggested could be taken into account in this connection.

REFERENCES

The literature mentioned below covers only partly the vast field of research which has gone into the forest-tundra and tree-line question, cf. the comprehensive Arctic Bibliography.


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