Leif Kullman

Change and stability in the altitude of the birch tree-limit in the southern Swedish Scandes 1915–1975
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The birch tree-limit was determined altimetrically during 1970–75. In most of the 213 sites investigated, similar determinations had been made in 1915–16 mainly by Dr. Harry Smith. Annual ring counts were made on the seemingly oldest birches along vertical line transects, which gave data on the tree-limit advance, if any. Such a rise was indisputably recorded for 75% of the sites, with an unchanged altitude at the remaining ones.

The observed rises were correlated to a variety of habitat factors. The sites were classified into four groups, with 0 m, 5–20 m, 25–40 m, and over 40 m displacement. Each factor was graded, objectively or subjectively, and the percentage distribution of displacement classes upon grades of factor strength was calculated. This yielded an “ecological lowest common denominator” for the displacement groups with regard to each factor considered.

A clear relationship was found between changes in altitude of the birch tree-limit and changes in local snow conditions. Localities which, in 1915, had much snow and late thawing, showed a subsequent great rise, but little or no change in tree-limit was recorded for sites with a shallow snow cover. Intermediate cases showed moderate displacement. No relationship was found for degree of human impact.

According to age of stems, 2 m tall or more and growing above the 1915 limit, most of the colonization took place in the 1930’s, when a series of warm summers caused early thaw and rapid drying of the soil. Thus the rise was conditioned by seedling establishment mainly during the first half of the present century, coming to a halt about 1950, when the favourable climatic trend reversed. Birches already established, however, could grow on, up to the present day. The climatic amelioration in the earlier period is believed to have caused a decrease in meltwater, and in the soil, less moisture, earlier upwarming and higher temperatures.

In localities where the tree-limit remained unchanged, the scantiness of the snow cover, both before and during the period 1915–1975, may have prevented seedling establishment permanently through frequent droughts in the growth period.

Altitudinal birch limits in Scandinavia depend on a complex of habitat factors, of which the local climate and its effect on the edaphic conditions are important.

Key words: tree-limit, birch, succession, climatic change, snow cover, land usage, germination, establishment.

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The Swedish phytogeographer Göran Wahlenberg (1813, p. 35–38) was the first scientist to make a distinction between the tree-limit and the forest-limit. Ever since then research on both of these concepts has traditionally occupied a prominent place in Scandinavia and many informative monographs on these subjects have appeared, especially during the first few decades of the present century. Many of these papers contain a mass of detailed information on the altitudinal limits of different tree species (e.g. Smith 1920).

The idea of utilising these earlier data as the basis for a study of possible fluctuations in altitudinal limits during the present century therefore readily suggested itself. In view of the detailed and relatively well-substantiated information available in the phytogeographical literature suggesting that both the tree-limit and the forest-limit (for definitions see section, Explanatory remarks, terminology and abbreviations) were advancing, such an investigation seemed to offer both a worthwhile and an attractive field of research.

During recent years, furthermore, this problem has become increasingly relevant, since foresters have slowly but steadily become interested in timber production from and the forestry resources of such marginal, high-lying areas and also following the attempts of paleo-ecologists and quaternary geologists to interpret post-glacial climatic fluctuations in terms of more or less fictitious fluctuations of the tree-limit or forest-limit.

It appeared likely, therefore, that research directed towards a better understanding of the factors affecting and controlling the position of the tree-limit would be gained by studying such altitudinal shifts within a large and heterogeneous geographical region, with varied topography, climate, soil conditions, vegetation cover and land utilisation conditions.

Previous investigations

Previous investigations, both inspiring and pioneering, have been made in this field, particularly by Professor Ilmari Hustich (see e.g. 1958), who showed that a relationship existed between changes in the altitudinal limits of Scots pine (Pinus sylvestris L.) in N Finland during the 20th century and climatic changes.

The dynamics of the tree- and forest-limits of birch (Betula pubescens Ehrh. s. l.) and spruce (Picea abies (L.) Karst.) have not been systematically investigated to the same degree, particularly not in Sweden.

Prior to about 1930, the general opinion among phytogeographers and forestry research workers was that both the tree- and forest-limits in northern Europe were in a phase of retreat. About 1930, however, views changed and certain research workers began to maintain that tree distribution limits were extending both altitudinally and latitudinally at the same time as self-regeneration from seed was improving in both scale and frequency (see Hustich 1947, 1958 and the literature cited therein). At the same time, thanks to climatological research, a picture emerged from the observational data which more and more supported the view that since the close of the 19th century there had been a progressive climatic amelioration. Many biologists became aware of this postulate and they attempted to discover whether or not a relationship existed between this recent climatic change and certain biological fluctuations (cf. Erkamo 1956; Perring 1965).

In 1951 the Geographical Society of Finland arranged a symposium on various effects on plant and animal life of the climatic amelioration (The recent climatic fluctuation in Finland and its consequences, 1952). The same problems were discussed again by the Society during a meeting in
1976. Hustich (1978) gives a concentrated account of these discussions.

By sending a questionnaire to a large number of Norwegian farmers, foresters and similar people, Hesselberg & Birkeland (1940) tried to find out whether and how the birch had reacted in recent times. The replies they received were fairly unanimous; the birch forest-limit had risen in the past few decades and it had done so largely because of an improvement in the climate, although in many cases a decline in the degree of utilisation of this marginal region by man had also played a part. These results must be accepted with some reservations, due to the way the questionnaire was worded.

A considerably more reliable and more detailed picture was given by the results of Sandberg's (1940, 1958, 1960, 1963) investigations in Torne Lappmark in N Sweden. Although no concrete examples of increased altitudinal limits are cited, the reports of local birch expansion during the 1930's into formerly unforested areas appear to be convincing. Sandberg (op.cit.) noted that the birch had colonised depressions in which, previously, the accumulated depth of snow had been too great to permit tree growth. The birch expansion had been most obvious in the mountain heath and grassland communities of the more western and relatively locally maritime areas, in places formerly subject to prolonged snow-cover.

On the Norwegian side of the Sylene massif, which borders on my own investigation area, Nordhagen (1956, 1964), by taking repeated photographs of the same localities, over a period of years, discovered that certain hillslopes which did not bear a single birch shrub about 1920 had by the early 1950's become densely forested. He considered this to be due to a decrease in the duration of the snow-cover.

In an adjacent area on the Swedish side of the border, Smith (1957), from a comparison of belt transects made in 1919 and 1950, showed that the birch had increased its distributional area in this mountain region. He judged the cause to be the drying-out of the ground associated with an earlier disappearance of the snow from previously long-lying snowbeds.

From the Petsamo area, formerly in N Finland, Aario (1941) reported that the birch had expanded recently in areas where it had not grown for a long time.

Within a relatively limited area in the mountains of southern Norway, Ve (1930, 1940, 1951, 1968) has documented an upward expansion of birch, although he was unable to assess for certain the relative importance of the climatic improvement and the contemporary decline in the use of summer-farms (Sw, 'fäbdväslen'). At one locality (Ve 1940, p. 77) he showed that the forest-limit had remained constant since the beginning of the 19th century. At Vettismorki in S Norway Skar (1964) observed a marked advance of the birch up certain hillslopes and an obvious regeneration of the birch forest, with scattered old, and now dying, birches growing among a relatively young stand (cf. also Ve 1940). Skar (op.cit.) considers that anthropogenic factors were responsible for these changes only in exceptional cases. He found a lot of indications that at the end of the 19th century the mountain birch forest was becoming thinned-out and in a stage of decline. The naturally-occurring rejuvenation succession was thereafter accelerated by the change in climate.

By repeating the observations, made by an earlier research worker at the start of the present century, on the altitude of the forest-limit at several localities in southeastern Norway, Aas (1969) found that the forest-limit had advanced vertically by a mean value of 40 m. He believed the reason to be the occurrence of a series of favourable summers during the 1930's and 1940's. Faegri (1972), however, is not convinced that the upward expansion of the birch during this century has anything to do with the climatic amelioration.

Aims of the investigation

1. To determine in absolute terms any changes in the tree-limit of the birch (Betula pubescens Ehrh. s.l.) since the start of the present century, within a relatively large and geographically and ethnologically heterogeneous region.

2. To discover the general and ultimate cause of any observed changes in the tree-limit, i.e.
primarily changes in the climatic conditions and/or a decline in the utilisation of such areas by man.

3. Should the climatic factors turn out to be the most important, to investigate in detail how climatic changes have produced the observed changes in the position of the tree-limit and, if possible, from the conclusions drawn, to define the general factors which determine the height of the tree-limit of birch.

4. To indicate the most promising lines of approach for future research on both forest- and tree-limits.

5. To make certain comments applicable to paleo-ecological work on the basis of the results obtained from the present investigation.

6. To establish as accurately as possible, at all the localities investigated, the altitude of the present-day tree-limit so that future changes may be recorded in order to increase our knowledge and refine our understanding of the causes of such changes.

Realization

The work was carried out at the Department of Ecological Botany, Umeå University and started in 1970. Most of the fieldwork was done during the period 1972–1975.

The project has also included a study of the recent and post-glacial history of changes in the tree-limits of coniferous species. These results will be presented in subsequent papers.

Nomenclature

Nomenclature for vascular plants follows Lid (1974).

Acknowledgements

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I would like to thank most warmly Professor Bengt Pettersson and all my colleagues and the staff at the Department of Ecological Botany, Umeå University, for their help in both word and deed towards the successful completion of the work and its publication. I am also greatly indebted to Dr. Sven Kilander, who with his wide knowledge of both the subject and of the investigated area, has facilitated my work in many ways, as well as for placing his unpublished observations and maps at my disposal.

Finally I wish to thank most gratefully my friend Dr. Philip Tallantire, who has translated the manuscript into English and also made valuable and wise criticisms.
The investigated area

The 214 localities investigated are situated in the provinces of Sweden (Sw. 'landskap'), known as Jämtland, Härjedalen and Dalarna, distributed over an area of ca 40 × 200 km (Fig. 1) just east of the main watershed in the southern part of the Scandes mountain chain in Central Sweden (63° 23′–61° 53′N lat.; 13° 34′–12° 03′ E long.).

Topography, solid geology and drift deposits

This section has been compiled from information given in the following sources: Högbom (1920), G. Lundqvist (1951), Strömberg (1955, 1961), Hjelmqvist (1966), Jan Lundqvist (1969).

The solid rocks have usually been eroded to yield rounded and smoothed landforms. Only on the highest mountain massifs such as Helagsfjället, Sylarna, Snasahögarna and Härjångsfjällen (summits at ca 1500–1800 m a. s.l.), is the land relief more alpine in character.

Prominent features of many of the mountains, due to nappes and other tectonic thrust features, are relatively gently-sloping and level W- and NW-facing slopes and steep E- and SE-facing slopes. This topographic feature is very important because of its differential effect on the distribution of the snow cover.

Those forested or wooded valleys which are present within the investigated area are generally broad and more or less U-shaped. The valley bottoms seldom lie below an altitude of 600 m.

Within a wide central part of the investigated area, in Jämtland and the northern half of Härjedalen, the solid rocks are various kinds of calcareous tectonites. Both eastward and westward of this zone biotite-rich greywackes occur, with transitions to quartzites. A few of the highest mountain summits are built of Sylarna amphibolite. From the middle of Härjedalen down to the southernmost investigated localities in Dalarna the underlying rocks include light-coloured feldspathic quartzites, augengneiss and blastomylonite, light-coloured sparagmites and Vemdal quartzite.

The drift deposits above the birch forest-limit consist of moraine (including frost-shattered material), various types of glaciofluvial deposits and, to a minor extent, of lacustrine sediments.

The depth of all these superficial deposits decreases markedly with increasing altitude.

The deglaciation chronology of the investigated area is not yet known in any detail, although it seems probable that most of the area had become ice-free by about 7000 BC (Jan Lundqvist 1973).

Climate

Except where otherwise stated this section is based on data supplied by the Swedish Meteorological and Hydrological Institute (SMHI, Norrköping).
Change and stability of birch tree-limit in the Scandes

Fig. 2. The sites of the investigated localities in Jämtland and Härjedalen. ●: localities at which an upward displacement of the tree-limit occurred. ×: localities at which the tree-limit remained unchanged.

Fig. 3. The sites of the investigated localities in Dalarna. ●: localities at which an upward displacement of the tree-limit occurred. ×: localities at which the tree-limit remained unchanged.

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Continentiality—maritimity

The relative proximity of the investigated area to the Norwegian Sea and the Gulf Stream conditions a maritime-continental climatic gradient in a west—east direction across the area. Because of the hindrance to advection produced by the topography to the west of the southern part of the investigated area, a similar gradient, but in a north—south direction, exists hereabouts (Wällén 1968; Ångström 1974). Local divergences from the broad pattern described above are, however, very probable because of the broken nature of the topography over the area as a whole (Ångström op. cit.).

The thermic continentality—maritimity of the regional climate mentioned above is quite well correlated in Scandinavia with humidity (Hintikka 1963), in such a manner that areas with a local-maritime climate are characterised by generally humid weather and receive a relatively large part of their precipitation in the form of snow. Those areas with a local-continenta climate, on the other hand, are subject to relatively dry conditions and only a single seasonal maximum of precipitation, namely during the summer.

The annual temperature amplitude, i.e. the difference in mean temperatures for the warmest and coldest months in the year, forms a good indication of the character of the local climate and is considered to have a clear phytogeographical relevance (Hintikka op. cit.; Jim Lundqvist 1968).

The annual amplitude values for the normal period 1931–60 for all the meteorological stations situated within the investigated area (Figs. 2–3) are shown in Table 1.

Temperature

For only a few of the above-mentioned stations do continuous temperature records over long periods exist. The majority are typical valley-floor stations and therefore it is uncertain to what degree the data can be regarded as representative for the bioclimate prevailing at the tree-limit, although they probably indicate the regional trends in the thermoclimate within the investigated area. Generally speaking, the valley stations probably have a more continental climate than that which prevails at the tree-limit (cf. Jim Lundqvist 1968).

The annual mean temperatures and mean tri-term values for the period June-August are shown in Table 1. The station positions are shown in Figs. 2–3.

Precipitation

The very broken nature of the topography leads to very great differences in the precipitation falling at quite closely-situated localities.

Table 1. Climatic data for the meteorological stations within the investigated area. All are mean values for the normal period 1931–60, excepting the length of the vegetation period (mean for 1961–74). A: annual temperature (°C); B: temperature for the tri-term June-August (°C); C: annual temperature amplitude (°C); D: annual precipitation (mm); E: duration of snow cover (days); F: depth of snow remaining on May 15 (cm); G: date by which all snow had melted; H: length of vegetation period (i.e. mean daily temperature ≥ +6°C).

<table>
<thead>
<tr>
<th>Station</th>
<th>m a.s.l.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<td></td>
<td>+1.1</td>
<td>+10.00</td>
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<td>1012</td>
<td>218</td>
<td>27</td>
<td>30/5</td>
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<tr>
<td>Duved</td>
<td>385</td>
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<td>+12.07</td>
<td>23.4</td>
<td>656</td>
<td>188</td>
<td>2</td>
<td>11/5</td>
<td>132</td>
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<td>427</td>
<td>179</td>
<td>5</td>
<td>10/5</td>
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<td>+11.10</td>
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<td>566</td>
<td>187</td>
<td>5</td>
<td>14/5</td>
<td>122</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>608</td>
<td>195</td>
<td>8</td>
<td>14/5</td>
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<td>Bruksvällarna</td>
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<td></td>
<td></td>
<td></td>
<td>570</td>
<td>216</td>
<td>12</td>
<td>22/5</td>
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<tr>
<td>Ljusnedal</td>
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<td>2</td>
<td>9/5</td>
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<td>573</td>
<td>208</td>
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<td>702</td>
<td>197</td>
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<td>+13.07</td>
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<td>574</td>
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<td>Särna</td>
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<td>+12.5</td>
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<td>678</td>
<td>186</td>
<td>0</td>
<td>7/5</td>
<td>139</td>
</tr>
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</table>

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The annual mean values for all the relevant meteorological stations are shown in Table 1. The station positions are shown in Figs. 2–3.

**Snow cover**

None of the data for snow cover given for the various meteorological stations have any great relevance for the conditions which prevail at the tree-limit, where the snow cover varies widely from place to place. The official figures do, however, provide some idea of the broad regional trends within the area as a whole.

The annual mean values for the duration of the snow cover, the depth of snow present on May 15 each year, and the date for the disappearance of the snow cover, are shown in Table 1. All the values are taken from Pershagen (1969). The station positions are shown in Figs. 2–3.

Investigations by Melin (1943) and Ager (1964) showed that in general the depth of snow increases very greatly with increasing altitude. From the meteorological data it is clear that snow cover persists longer in the northern and western parts of the investigated area than in the southern and eastern parts.

**Wind direction**

Ager (1964) has summarised the mean annual frequencies for the various wind directions over the year for Storlien and Särna (Table 2). Storlien has a locally maritime climate, as shown by the higher frequency of westerly winds, as compared to Särna, which with its more continental type of climate, has more equal values for the winds from all directions, although with a slight excess of north-westerlies.

**Length of the vegetation period**

It is questionable whether the traditional practice of expressing the length of the vegetation period for a particular locality in terms of a predetermined air temperature threshold value has any real meaning. The most adequate measure would naturally be a vegetation period based on physiological estimates of plant productivity parameters. On practical grounds, however, the values for the length of the vegetation period at certain of the meteorological stations within the investigated area (shown in Table 1) are based on the number of 24 hr-periods during which the mean air temperature equalled or exceeded + 6°C. The data are taken from Perttu & Huszár (1976) and are mean values for the period 1961–1974.

Birches growing at the tree-limit have usually become fully-leafed by the middle of June at latest. By the middle of September or somewhat earlier the leaves have usually turned colour.

The start of leafing, following the snowy winter of 1975–76 was delayed by ca 3 weeks at some localities, compared with the other years. However, observations of these trees made during the following summer gave no indications that the very delayed leafing had any deleterious effects of any kind.

The assimilation period for tree-limit birch normally lasts about 80–100 days.

To use the leafing data as an indication of the macroclimate has little meaning, since the start of birch leafing can be very much modified by other factors, e.g. the soil conditions. At sites where there is little depth of frozen subsoil (Sw. ‘tjäle’) leafing may occur at appreciably lower air temperatures than is the case at deep-frozen sites.

**Recent climatic fluctuation**

During the 1880’s the climate over the whole of the Northern Hemisphere started to become warmer, now a well-established fact (cf. e.g. Ångström 1939, 1974; Hesselberg-Birkeland 1940; Ahlmann 1943, 1948; Johnson 1965; Lamb

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Table 2. Mean annual frequencies (%) of the various wind directions at Storlien and Särna during the normal period 1931–60.

<table>
<thead>
<tr>
<th>Wind direction</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
<th>calm</th>
<th>total</th>
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<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storlien</td>
<td>0.1</td>
<td>0.2</td>
<td>11.7</td>
<td>17.2</td>
<td>2.0</td>
<td>1.1</td>
<td>30.6</td>
<td>1.8</td>
<td>35.3</td>
<td>100</td>
</tr>
<tr>
<td>Särna</td>
<td>6.2</td>
<td>4.2</td>
<td>4.0</td>
<td>10.8</td>
<td>7.4</td>
<td>9.2</td>
<td>5.9</td>
<td>18.8</td>
<td>33.5</td>
<td>100</td>
</tr>
</tbody>
</table>

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The climatic amelioration was caused by an increase in cyclonicity (Ahlmann 1948; Blüthgen 1966), possibly associated with an increase, since ca 1915, in the amount of extra-terrestrial solar radiation (Frydendahl 1978). Prior to about 1915 the amelioration was primarily restricted to the winter months, i.e. the climate became more maritime. After that time the summers also became warmer and the climate became more continental in character (Wallén 1968).

According to Johnson's (op. cit.) calculations the degree of continentality (Conrad's continentality index) was appreciably greater during the period 1928–58 compared with the 1901–30 period. This increase was particularly marked in those parts of the investigated area which have a locally maritime climate, e.g. Storlien, where the greatest increase in degree of continentality was recorded. In mountain areas further south with a climate of local continental character the change was a relatively minor one.

The greatest temperature increases were recorded in locally maritime areas relatively far to the north (Ångström 1953); e.g. Eriksson (1943) reported that the annual mean air temperature for January at Jacobshavn in Greenland rose by 10°C between 1905 and 1936. In northern and central Scandinavia, however, the temperature changes have been appreciably smaller. Generally speaking, the values quoted for the mean temperature increase during the winter period are of the order of 1–3°C (cf. e.g. Hesselberg-Birkeland op. cit.; Liljequist 1943, 1950; Strand 1962). At Storlien, in the northwestern part of the investigated area, the mean air temperature for the months June-August rose by 1.4°C as compared with the decadal means for 1901-1910 and 1931-1940. The trend towards increasing warmth in summer seems to have halted about 1950 (Liljequist 1970; Lamb 1974).

The use of periodic mean values of air temperature may nevertheless serve to obscure certain conditions which are of vital importance for biological phenomena. It is therefore desirable that climatic trends should be described in terms of frequencies of temperature extremes (cf. Ångström 1942; Bryson et al. 1970; Climate Monitor 1977).

### Climatic fluctuation within the investigated area

All the climatic data referred to below have been supplied by SMHI, Norrköping.

The yearly mean temperatures for the triterm June-August for two meteorological stations situated within the investigated area are given in Figs. 4 and 5, viz. Storlien and Ljusnedal (for position see Fig. 2). The position of the recording instruments at Storlien was changed to a minor degree in 1963. During that year, however, observations were made at both the old and the new locations and the meteorological data obtained showed virtually no difference at all. On this account I consider that the use of data from the old and new station localities in one and the same diagram (Fig. 4) is justified. Unfortunately no observations exist for Ljusnedal for the years 1956, 1958, 1959, nor prior to 1917.

Storlien, at 595 m a. s. l., represents the most locally maritime part of the investigated area, whilst Ljusnedal at 585 m, although situated in a more continental area, is not representative for the most continental part of the area. Both the Storlien and Ljusnedal meteorological stations lie in the coniferous forest belt, 220 and 460 m, respectively, below the local tree-limit for birch.

The mean summer air temperatures at Storlien show a clear upward trend up to 1914, followed by a distinct temporary minimum at the start of the 1920's. This same minimum is shown by the Ljusnedal data. This picture of the course of the summer mean temperature wholly agrees with that given by Liljequist (1950) for Central Sweden in general.

During the decade 1921–1930 the June-August temperatures fluctuated quite markedly at both stations (cf. Liljequist op. cit.). Three extremely warm summers in a row occurred in 1925, 1926 and 1927. A clear temperature maximum is shown for the decade 1931–1940, followed by a weak decline thereafter.

The mean decadal summer temperatures (triterm June-August) for Storlien and Ljusnedal have been set out in Tables 3–4, together with an indication of the number of times per decade the mean temperature equalled or exceeded certain extreme values. The data for the period 1963–
1972 are all derived from the re-located station at Storlien. Judging from the values obtained during the summer of 1963, in which both the old and new station were operated, it is possible that the mean summer temperature values for the new station are on average a few tenths of a degree centigrade lower than they would have been at the former station.

Tables 3–4 show that the trend of increasing temperature culminated during the decade 1931–40. The unique character of this decade stands out most clearly, however, when the frequency data for certain extreme temperature values are examined (11°C for Storlien, the 11° and 12°C values for Ljusnedal). Neither earlier nor later during the whole period 1901–1975 has such a consecutive sequence of extremely warm summers occurred as during the abovementioned de-
Table 3. The decadal mean temperatures (June-August) recorded at Storlien (595 m a. s.l.), showing the number of years within each decade when the triterm mean equalled or exceeded 10°C, 11°C and 12°C, respectively.

<table>
<thead>
<tr>
<th>Period</th>
<th>June-August mean (°C)</th>
<th>10°C</th>
<th>11°C</th>
<th>12°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901-1910</td>
<td>9.23</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1911-1920</td>
<td>10.14</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1921-1930</td>
<td>9.54</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1931-1940</td>
<td>10.65</td>
<td>7</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>1941-1950</td>
<td>10.41</td>
<td>7</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1951-1960</td>
<td>10.18</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1963-1972</td>
<td>10.24</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4. The decadal mean temperatures (June-August) recorded at Ljusnedal (585 m a. s.l.), showing the number of years within each decade when the triterm mean equalled or exceeded 11°C, 12°C and 13°C, respectively.

<table>
<thead>
<tr>
<th>Period</th>
<th>June-August mean (°C)</th>
<th>11°C</th>
<th>12°C</th>
<th>13°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1930</td>
<td>11.13</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>1931-1940</td>
<td>12.15</td>
<td>9</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>1941-1950</td>
<td>11.58</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1963-1972</td>
<td>10.63</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5. The decadal mean temperatures for May recorded at Storlien (595 m a. s.l.), showing the number of years within each decade when the May mean equalled or exceeded 5°C and 6°C, respectively.

<table>
<thead>
<tr>
<th>Period</th>
<th>May mean (°C)</th>
<th>5°C</th>
<th>6°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901-1910</td>
<td>2.90</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1911-1920</td>
<td>4.05</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>1921-1930</td>
<td>3.30</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1931-1940</td>
<td>4.15</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1941-1950</td>
<td>3.65</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1951-1960</td>
<td>3.85</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1963-1972</td>
<td>4.53</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6. The decadal mean temperatures for May recorded at Ljusnedal (585 m a. s.l.) showing the number of years within each decade when the May mean equalled or exceeded 6°C, 7°C and 8°C, respectively.

<table>
<thead>
<tr>
<th>Period</th>
<th>May mean (°C)</th>
<th>6°C</th>
<th>7°C</th>
<th>8°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1930</td>
<td>5.35</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1931-1940</td>
<td>6.25</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1941-1950</td>
<td>5.85</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1963-1972</td>
<td>5.82</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

cade (cf. Lysgaard 1963). If the temperature for the individual years of this decade are examined, it is clear that the period 1933–1939 marks the culmination of the climatic amelioration.

This unique sequence of meteorologically extremely warm summers most probably entirely altered the chances of colonisation in new marginal habitats of populations of such plants which show distributions conditioned by a factor complex of temperature—soil moisture.

After 1945 the mean temperature for the summer period, June-August, appears to have entered a declining phase. This is particularly marked as regards the frequency of extremely warm summers. Nevertheless, the temperature conditions prevailing at the turn of the 19th century have not yet been reached.

The mean June temperature for the period 1961–74 is higher than that for the period 1931–60 in the southern part of the Scandes (Perttu & Huszár 1976).

The decadal values of the mean temperature in May are shown in Tables 5–6, together with the number of times per decade the mean May temperature equalled or exceeded certain extremes.
The distance between this hillslope and the nearest summer-farm has at no time been less than 15 km. Former livestock grazing here can therefore be ruled out. Nor are there any signs of former Lapp occupation of the area, reindeer fences etc. The hillslope receives a heavy snow cover (see Fig. 28) and becomes snow-free relatively late on in spring. The explanation for the observed rise in the tree-limit, therefore, is to be found in the general change in snow conditions known to have occurred in the investigated area during the present century. Both the birch forest-limit and the tree-limit run evenly across the entire hill slope and coincide pretty well with the upper limit of the avalanche cones. Higher up there is an obvious lack of fine-grade mineral matter in the soils, which has probably prevented the birch from ever attaining a higher altitude. Photo: August 5, 1977.

The tabulated values show that both the mean temperature value for May and the frequency of warm Mays rose after the turn of the present century. The maximum was attained somewhat later than the corresponding maximum for the summer (June-August) mean temperature. It is clear that the greatest positive deviations from the overall mean are shown by the temperature values for the locally maritime Storlien area during the most recent decades.

The decadal means of September temperature are shown in Tables 7-8, together with the number of times per decade that the September mean temperature equalled or exceeded certain extremes. It is clear from these figures that the climatic amelioration, with regard to September mean temperature, culminated before or about 1950.

So far as the existence of any similar differences in precipitation during the 1900's is concerned, the picture is still rather confused. According to Schytt (1973) there are no definite indications at all that a reduction in winter precipitation has taken place. Ångström (1942) considers that it is impossible to adduce any statistically significant change for the mean annual precipitation for northern Sweden during the periods 1861–1900 and 1901–1930. He nevertheless considers it probable that the increase in strength of the atmospheric circulation during the 20th century did result in increased precipitation in mountainous regions. At the majority of the meteorological stations in northern Sweden the mean annual precipitation increased during the period 1931/32—1958/59 according to Ager (1964).

Indications that climatic fluctuation of the present century also involved an increase in precipitation in the north of Scandinavia have been presented by, e.g. Östman & Henriksson (1942), Johannessen (1942), Wallén (1968), Rudloff (1967), Lamb (1974) and Heino (1978).

At the meteorological stations Storlien, Sveg and Särna within the investigated area (for positions see Figs. 2–3), mean annual precipitation in the decades after 1920 was higher than during the preceding 2–4 decades (Andersson 1970). Nevertheless, because of the methodological difficulties attending the recording of representative precipi-
tation values (Ångström 1941b, Hare 1971), all conclusions drawn about trends in precipitation are uncertain.

Because the present climatic fluctuation was initiated by a change in the pattern of the atmospheric circulation one might reasonably expect to find this reflected in changes in the frequencies of the various wind directions over the years. At Røros in Norway, ca 60 km to the west of the investigated area, Johannessen (1942), in a comparison of the wind data for the periods 1886–1895 and 1926–1935, found that there had been a marked decline in the frequency of northerly winds and a considerable increase in the frequency of westerly winds. For the other wind directions, as for calm air conditions, there had been small increases overall (cf. Johannessen 1970).

Main features of the vegetation

The investigated area lies wholly within the 'Northern Boreal Zone' (Ahti et al. 1968).

At virtually all the localities the birch is the tree species which forms the uppermost forest-limit and the tree-limit below the open vegetation cover of the mountain slopes (Sw. 'kalfjäll'), except in a very few places (see Kullman 1976b).

The tree-limit declines gradually from a maximum altitude of ca 1100 m in the southern part of the investigated area, to ca 800 m in the predominantly maritime parts lying further to the NW.

The subalpine birch belt, which lies between the tree-limit and the closed coniferous forests lower down, varies widely in vertical extent. In the southernmost parts of the area, with those localities which receive the smallest amounts of snowfall, it may be virtually absent, whereas in certain valleys further north, with an abundant snowfall, the altitudinal range of the birch belt may be 200–250 m.

The boundary between birch forest and coniferous forest has in many places been artificially depressed by human interference and by forest fires (see Fig. 7), both natural and deliberate (see Kullman 1976a).

It has been postulated that the continuous existence of certain types of mountain birch forest depends on the occurrence of periodic disasters, such as insect plagues, or human destruction etc. (see Kullman 1976a and b).

The mountain birch forests of the investigated region correspond quite well with those of Hämét-Ahti’s (1963) ‘continental subalpine’ and ‘oceanic subalpine’ subzones. The birch forests of the former subzone type are best developed in the southernmost part of the area where, as mentioned above, the climate is drier and the soil-conditions poorer. The detailed differences between the different types of mountain birch forest in the area are summarised in the accounts by Smith (1920) and Samuelsson (1917).

The coniferous forest-limit is almost everywhere formed by the spruce (Picea abies (L.) Karst.), although at a few localities in Dalarna the Scots pine (Pinus sylvestris L.) forms the coniferous forest-limit. In places near this limit the Scots pine sometimes increases in importance on the otherwise spruce-dominated forested slopes. On certain N-facing slopes spruce may form pure stands.

The vertical zonation of the vegetation over a large part of the investigated area has been studied by Kilander (1950, 1955, 1965). He deter-
mined the upper altitudinal limits for the alpine vegetation belts (see e.g. Sjörs 1963) to be as follows: low alpine belt 1300–1400 m; middle alpine belt 1600 m; high alpine belt >1600 m a.s.l. Only a few of the higher mountain summits in the area include the high alpine belt.

The vegetation within the tree-limit ecotone, i.e. the tract between the forest limit and the tree-limit of birch, is very varied in character. Dwarf-shrub heaths, in which Vaccinium myrtillus, Empetrum hermaphroditum and Betula nana alternate as dominants, cover wide areas. Where the snow-cover is longer-lasting and the supply of seepage from the snow-melt is more permanent and of longer duration grass heath and snow-patch communities, of mountain meadow or heath character, occupy relatively large areas instead.

In the southernmost part of the investigated area there are large tracts of lichen heaths (Cladonia spp.). On well-drained slopes which receive a deep, but not too long-lasting, snow-cover the landscape is dominated by metre-high willow thickets (Salix lapponum, S. glauca and S. lanata), with scattered junipers (Juniperus communis). Only in the northwestern part of the investigated area, where the maritime influence is relatively strong, do mire communities play any particular role within the vegetation of the tree-limit ecotone.

More detailed accounts of the vegetation of the area can be found in several of the works already mentioned (Smith op.cit.; Samuelsson op.cit; Kilander op.cit.). A recent and detailed vegetation map, with accompanying text, exists for one, relatively limited, part of the area, the Ot tfjäll mountain massif (Warenberg 1977).
Human impact around the tree-limit

In certain cases below, descriptions and maps from former land surveys such as the delineation of crown and private land (Sw. 'avvitrings') and enclosure awards (Sw. 'laga skifte'), made during the 19th century are referred to. These documents are kept at the County Archives, at the Land Survey Office of Jämtland province at Östersund. A list of all my informants about former land usage within the investigated area is given in Appendix I.

Prehistoric time

Far too little archaeological research has yet been carried out in the southern part of the Swedish Scandes. However, archaeological remains from hunting, fishing cultures with a neolithic mode of life have been known for a long time in many places within the investigated area. These finds were formerly considered to belong chronologically to the Younger Stone Age, i.e. post 3000 BC. Nowadays it is thought to be fairly certain that human activity occurred in the area as far back as the Older Stone Age, 4-5000 BC (Christiansson 1969; Selinge 1976). The majority of the occupation sites have been found along the shores of lakes and rivers, though sites at the tree-limit are by no means unknown.

The commonest archaeological remains within the area are pit traps for animals (Sw. ‘fangstgrop’). That certain of these date from the Stone Ages cannot be ruled out, but the majority are probably more recent. These pits were intended to trap elk and reindeer. In many places there are intricate systems of pits which extend from the tree-limit on one side of a valley to that on the other (Manker 1960; Selinge 1974; Jenssen 1977). To judge from the results of radiocarbon datings of these pits (Selinge op.cit) there are grounds for thinking that the investigation area was visited by hunters as long ago as the Bronze Age.

During the later part of the Iron Age, 700—ca 1000 AD, there was marked expansion of settlement within the area. The remains of small-scale dwelling-sites probably only seasonally occupied, have been found at many places at the present-day altitude of the birch forest belt (Hallström 1931, 1944; Janson et al. 1962). It is therefore not entirely inconceivable that the practice of shieling (summer-farming, Sw. ‘fäbdäväsén’) originated from the activities of Iron Age farmers at these altitudes (Janson et al., op.cit.; Selinge 1976). Skjølsvold (1969), however, is critical of this early dating of shieling and considers that hunting and fishing were still the most important economic activities during the Iron Age.

It is admittedly impossible, today, to decide to what extent the vegetation in general and the tree-limit in particular were affected to any permanent degree by the prehistoric cultures mentioned above (see Kullman 1976a). One phenomenon which is well worth noting in this connection, and one which often occurs when such areas become settled, is a drastic increase in the frequency of forest fires (cf. e.g. Lutz 1959; Zackrisson 1977)

Historic time

Permanent settlement

Permanent settlement within the investigated area, in most cases 3-400 m below the present tree-limit, dates from the early part of the Middle Ages (Selinge op.cit.).

During the 17th and above all, the 18th century, another quite widespread settlement phase set in, partly as a consequence of the discovery of workable copper and iron ore deposits here and there in the investigated area. Both the mining of the ore and its processing necessitated the local felling of large quantities of timber for fuel and
charcoal. This may have led to changes in the relative proportions of tree species in the forest, especially perhaps in the region between the coniferous forest and the mountain birch forest belts (Hülfers 1777; Hvarfner 1961; Kullman 1976a). There are indications from this period of a high frequency of forest fires (Kullman op.cit.), although the prevailing climatic conditions at this time were probably a contributory factor (cf. Zackrisson op.cit.)

**Shieling practice**

In about the 17th and 18th century an extensive development of shieling commenced in the mountains beyond the farming settlements (cf. e.g. Hülfers 1762, 1777; Lindén 1974; Hallinder 1977).

Every family in a farming hamlet (cluster of farmhouses, Sw. ‘by’) in the valley bottom had at least one summer farm (Sw. ‘fäbod’), although as a general rule they had 2–3 shielings, situated at different distances away from the home farm and grazed successively throughout the summer and early autumn. Some of these multiple shielings were only used in alternate years. The summer farms were usually occupied from the middle of June until the time of the first snowfalls in the autumn, usually in October. Although each family had its own shieling the farmers from each valley hamlet usually built their huts in the same place, such that similar clusters of dwellings arose on the mountain pastures as down in the valleys (Sw. ‘fäbodbyar’).

Within the investigated area the shielings were always situated in the mountain forest belt, never at the tree-limit itself or on the bare uplands above (see Fig. 8) as was frequently the case on the Norwegian side of the border mountains (Frödin 1919, 1929, 1952; Kiland 1942; Rudberg 1957). Scarcely any of the shielings lay higher than 100 m below the local tree-limit.

**Upland grazing**

The livestock, i.e. cows, sheep and goats, grazed on the generally unfenced (Bryng 1968) common grazings, within a radius of 2–3 km from the alm-huts (local informants). In those parts where forb-rich willow thickets were present, the grazing area might be extended, on certain days, beyond the forest-limit up on to the open uplands. Livestock grazing, in other words, has regularly occurred at and above the tree-limit at certain of the localities within the investigated area (Kellgren 1892; Lampa 1910; Boethius 1931; Frödin 1952).

Maps and descriptions made in connection with the middle and late 19th century land surveys (inter alia the Sw. ‘laga skifte’ and ‘avvittring’) indicate that the land situated above the forest-limit was generally classified as ‘wilderness’, from the grazing point of view. The main grazing area was undoubtedly the mountain birch forest belt (local informants; cf. also Frödin op.cit.).

The majority of the local informants considered that the livestock had not had any particular influence on the woody vegetation. Damage, due mainly to grazing by goats and sheep, had only been observed locally in the immediate vicinity of the huts.

Compared with cows and horses, goats and sheep graze closer to the ground and are more selective in their choice of trees and bushes (Steen 1958; Baadshaug 1974; Wielgolaski 1975).

Certain of the older informants seemed to re-
member that grazing goats and sheep held back the development of young birches growing in vicinity of the almhuts.

Kellgren (1892), an agricultural botanist who studied the conditions in the area, noted that the young foliage of birch was very attractive to livestock. The same author (1893) also stated that the birch’s worst enemy was domestic livestock. Anonymous (1906) relating his or her experiences within a small area in western Härjedalen, interpreted the localisation to dense juniper and willow thickets of birches growing at the tree-limit as being an expression of the high intensity of grazing.

It is well known from other regions that grazing by livestock can more or less entirely prevent effective regeneration of birch from seed (Chard 1953; Björn & Graffer 1963; Kinnaird 1968, 1974). Against these negative effects of grazing should be set for example, the positive effects of trampling, which certainly improves the chances for seed germination and establishment (Björn & Graffer op. cit.; Kinnaird 1968; Dunwiddie 1977). This is an important factor in any area close to the distributional limit for a species, where a closed vegetation cover may greatly inhibit regeneration from seed (cf. Hintikka 1963).

Within the investigated area, the fact that the field-layer vegetation of the tree-limit ecotone and below in the shieling areas was generally lush in character, renders it less likely that livestock would selectively graze on the young stages of birch (cf. Selsjord 1966). Henning (1895) noted the presence of birch seedlings just below the tree-limit at Storlien despite of quite a heavy grazing intensity (local informants; Hedberg 1939).

The general indications are that livestock did not deliberately graze birch seedlings and saplings (cf. Rolsted 1931).

According to Barth (1886) birch seedlings possess some kind of chemical defence mechanisms against being grazed. This does not seem an unreasonable suggestion, considering the analogous feature following birch defoliation by larvae of the geometrid (Peperid) moth (Oporinia autumnata) (see Haukioja 1976, 1977). According to Wielgolaski (1975) the increase in lignin content of the leaves and shoots of certain woody plants during the vegetation period explains their unpalatability (cf. also Arnold 1964).

When considering the quantitative aspects of livestock grazing, the very wide extent of the grazing areas must always be borne in mind. With the aid of information from the local population, about the number of animals of different kinds which were grazed on the shielings and the approximate area of the grazings, I have calculated that within some of the most intensively grazed parts of the investigation area (in western Härjedalen) at the height of the shieling phase (ca 1895), there was a grazing density of about 5 cows and 5 goats, and perhaps a few more sheep, per km². Liibek (1920) considered that a density of 50 livestock per km², in the upper part of the coniferous belt, is sufficient to make the establishment of seedlings impossible.

No deliberate attempts were made to improve the grazing areas. Hellbom (1884), namely, points out that in the pretty heavily grazed hill area of Svansjöfjället (Rutfjället) in western Härjedalen “fallen trees and shrubs are left to mould away” (transl. from Swedish), in contrast to the state of affairs in those parts of the mountain birch forest from which hay crops were obtained.

**Burning for grazing improvement**

Burning for grazing improvement (Sw. ‘betesbranning’) proved to be virtually unknown, except in a few cases, to local people in the area whom I interviewed (cf. Kullman 1976a).

**Hay-making**

A very important intent with the practice of shieling transhumance was the harvesting of winterfodder for the livestock.

In most places the hay made from sloping fens accounted for the major part of this winter fodder. A study of the descriptions and maps from the older land surveys (‘avvittring’, ‘laga skifte’) reveals that practically every mire in the investigated area was cut for hay. Even quite small mires, which lay well above the tree-limit and tens of kilometres away from the almhuts were visited and utilised for winterfodder production. As a general rule the mires were only cut for hay every other year (e.g. Öster 1936).
The woody vegetation growing on the upland mires which were cut for hay was to a certain extent regularly cleared (Frödin 1927, 1952; Kvarning 1961). As hay-making has now virtually ceased on these subalpine fens, the drier parts of many are nowadays rapidly becoming overgrown by shrubs and trees (cf. Moen 1976). Nevertheless it is difficult to imagine that such hay-cropping can have led to any widespread depression of the birch tree-limit, since the extent of such mires at this level is in general quite insignificant in most parts of the investigated area.

Certain types of highly-productive mountain birch forest, with a field-layer dominated by grasses and forbs, were also regularly cut for hay (local informants; Öster 1936; Jansson 1951). In these areas the vegetation structure and production potential was maintained by the systematic removal of older, more or less dying, tree trunks (see Hellbom 1884). However, as a general rule hay-making of this type has quite certainly not been carried out near to and above the forest-limit (local informants).

Lichen-harvesting

A large part of the winter fodder for the livestock consisted of lichens (Cladonia and Cetraria spp.). Where such lichen-rich areas existed, large quantities were raked off in the autumn. Wherever practicable such lichen-harvesting was also carried out at the tree-limit or above (local informants; Hülphers 1777; Kellgren 1892; Kellgren & Nilsson 1893; Öster 1936). Since both the settled farming population and the nomadic Lapps competed for these upland lichen stocks, the likely result was a total devastation of this natural resource over certain areas (cf. Kullman 1975). Geijerstam (1891), for instance, stated that “for tens of kilometres at a stretch the uplands have turned dark” (transl. from Swedish) due to over-harvesting of the available lichen stocks. Similar opinions were put forward by Kellgren (1893), Bergman (1948) and Berg (1952).

At most of the investigated localities, however, lichen-dominated communities can by no means have existed at the tree-limit at the turn of the century. Thus, the practice of lichen-harvesting is definitely a negligible factor for the present investigation.

Tree foliage harvesting

One form of fodder harvesting which is even older than hay-making is the cutting and drying of tree foliage (Sw. ‘lövtäkt’; see Malmström 1951). The majority of my local informants within the investigated area were well-acquainted with this activity, which is also well-documented from this same area (e.g. Kellgren 1892; Forsslund 1919; Jirlow 1945; Öster 1936; Rudberg 1957; Kvarning 1961). The dried birch foliage was primarily intended as fodder for the sheep and goats. Usually branches were cut, but sometimes whole young trees, 2–3 m tall.

Verbal information suggests that such foliage harvesting was even carried out at the forest-limit and at the tree-limit, although the main harvest was taken from the lower-lying forest areas, nearer to the permanent farmsteads.

Cheese-making

Cheese-making at the summer-farms demanded large supplies of firewood, which led to a certain thinning-out of the birch forest in the immediate vicinity of the huts (Järnefors 1932). There are no indications, however, that any shortage of these firewood supplies arose which might have led to tree-felling at either the forest-limit or the tree-limit.

Kellgren (1893), quite definitely maintained that such direct anthropogenic activities in the investigated area had had no effect on the natural altitudinal limit for birch.

Decline of shieling practice

Prior to the Land Enclosure Acts (Sw. ‘laga skif-te’) of the close of the 19th century, the grazing areas attached to the shielings were used jointly by the individual farming hamlets. The effects of the enclosure awards made such continued joint utilisation of the grazings and of the shieling hay-meadows and huts impossible, and led to the abandonment of many shielings. This meant a reduction in both the extent and intensity of all the various activities which have been described above. To see livestock grazing in the mountain birch forests nowadays is quite an occasion (Fig. 9).
Leif Kullman

Fig. 9. Nowadays livestock grazing near the tree-limit is a relatively rare phenomenon within the whole of the investigated area. The cattle visible in the photograph are grazing in a ravine just above a summer-farm (Nyvallen) on the slopes of Mt. Sonfjället. There is quite a growth of birch saplings in the ravine and it cannot be entirely ruled out that they are held back by being browsed on, in which case grazing may perhaps have prevented the birch colonisation here which would have been expected to have resulted from the earlier disappearance of the snow-cover during the present century. Photo: August 15, 1974.

Hay-making on the upland sedge-mires and forest in glades has gradually ceased from the turn of the present century onwards (local informants; Kilander 1940, 1942; Kvarning 1961). The furthest distant and least productive areas were first to be abandoned. From the late 1940's or early 1950's, hay-making has virtually stopped in the upland areas (local informants). Harvesting of lichen fodder seems already to have ceased in Jämtland during the 19th century, although in parts of Härjedalen and Dalarna it was still practised during the early decades of the present century. This decrease in the harvesting of lichens, like that of birch foliage, seems generally to have taken place earlier than the decline in hay-making in the uplands (Öster 1936; Frödin 1952; Kvarning op.cit.).

Although certain shielings were in existence for several centuries, the great majority were in fact only established towards the end of the 18th and during the 19th century, in connection with the spread of settlement up into many upland valleys (Kilander op.cit.; Rudberg 1957). It is important to emphasize that a large number of the investigated localities are situated so far from any known shielings that any effects due to the grazing of their livestock can be ruled out entirely (see Fig. 6).

As indicated above, shieling activity was always concentrated within the birch forest belt. Although the vegetation at the tree-limit may have been affected locally, this can scarcely have led to any general depression of the forest- or tree-limits for birch within the investigated area as a whole (cf. Rudberg op.cit.). This conclusion is supported by the fact that neither Smith (1920) nor Kilander (1955, 1965), both of whom studied the altitudinal limits for birch within areas in which shielings were still in existence, mention either grazing or hay-making as important factors affecting these altitudinal limits.

Lapps and reindeer grazing

A potential factor which may have lead to an artificial depression of the tree-limit at certain localities is the nomadic culture of the reindeer Lapps (see e.g. Ruden 1911; Barth 1915). Holmgren (1912), however, dismisses this contention as largely groundless and instead places the blame on damage caused by mass-outbreaks of insect larvae, snow avalanches etc.

More recent investigations have nevertheless more or less convincingly shown that in former times the Lapps had an unfavourable influence on the forested areas in the vicinity of their camp sites (e.g. Selander 1950; Hultblad 1968).

Written sources exist which indicate that Lapps practising a domestic reindeer economy were present in the investigated area in the mid-17th century (e.g. Wiklund 1928). There is a possibility that the Lapps did not come into the upland parts of Dalarna before the 18th century (Huss 1959). From a study of place-name traditions, Bergsland (1970) has found cause to suspect that there may have been Lapps present in the investigated area as early as the 14th century.

Prior to the revised Reindeer Grazing Act of 1928, the Lapps could in principle utilise the forested land within their own areas in any ways they wished, i.e. for firewood, for fencing posts, for building timber etc. Under the terms of the revised Act such utilisation could only be made with the permission of the State foresters and only made where there were no grounds for fear-
Visible signs of the former activities of Lapps in the investigated area are to be found in general on fairly flat terrain quite some way below the 1915/16 tree-limit (PTL). The oval patch of treeless ground visible on the left-hand side of the hillslope (arrow) in the photograph (850 m a.s.l.) has resulted from tree-felling by Lapps for their habitations and reindeer fences. There is hardly any reason to believe that in this well-forested and steep environment the Lapps ever specifically sought out the tree-limit as their source of timber supplies, or carried out any systematic felling of large areas of forest here. The W-facing slope of Lill-Stensdalsfjallet (locality 78). Photo: June 30, 1974.

ing that a lowering of the forest-limit would result (Cramér & Prawitz 1970).

The reindeer economy practiced prior to about 1925 was more intensive in character, i.e. the individual reindeer herds were smaller than those of today, but the degree of domestication was appreciably higher. The herd was kept much more together and when being moved from one grazing area to another the whole Lapp family followed along. The reindeer were strictly and permanently herded on the grazings and were driven home to the camp site every night for milking inside fenced paddocks, which were often built of close-set vertical birch stems. Such fences necessitated cutting of large quantities of birch from the forest (Ruong 1937; Manker 1947). Each family (or a few families together) often possessed several such paddocks, which were used in rotation (Ruong 1954). Hørbye (1861) considered that the cutting of birch by the Lapps in the mountain areas had a deleterious effect, leading to patches of open forest here and there on the birch-covered hillslopes.

During the 1920's the reindeer economy changed its nature and became much more extensive in character. The reindeer were no longer milked and were not so carefully herded. The oldfashioned nomadism, with regularly shifting camp sites, became replaced by a more permanently-settled form, with fixed dwellings situated at a considerable distance below the tree-limit. This new type of reindeer economy was considered to obviate the risk of over-grazing, previously a permanently present hazard (Manker 1945, 1947). Selander (1950), however, states that, at least in southwestern Lule Lapppmark in N Sweden, the effect was the exact opposite. Under the extensive type of economy the reindeer herds became larger and during the height of the summer grazing conditions sometimes led them to concentrate on particular areas (cf. also Hultblad 1968).

Despite all the information reported above, my opinion remains that felling and cutting of birches by the Lapps have only very locally within the investigated area led to any reduction in the altitude of the tree-limit. The older remains and signs of Lappish culture which I myself found, or which have been shown to me by local Lapps, in the great majority of cases lay a good way below the present-day tree-limit (cf. Kullman 1975 and Fig. 10). At several of the investigated localities it is clear that the terrain in the vicinity of the tree-limit is far too steep to have been suitable for camp sites, milking paddocks etc. Instead, the
traces of Lapp culture visible in nature are on flat areas, e.g. fluvioglacial outwash plains, quite obviously at a lower altitude than that of the tree-limit as it was at the turn of the present century.

The greatest potential danger to the tree-limit most probably was grazing by the reindeer. Modern food-habit investigations have confirmed that birch leaves and buds form an important part of the food of reindeer during the snow-free season of the year (e.g. Skuncke 1963; Kallio & Lehtonen 1973; Haukioja & Heino 1974; Warenberg 1977). Markgren (1961) considers that in Swedish Lappland the vertical spread of the birch is quite obviously hindered by reindeer grazing. A large part of the seedling crop derived from seed germination above the tree-limit is thought to be browsed off by the reindeer (cf. Blüthgen 1960).

In the subarctic birch forests of northern Finland, Kallio & Lehtonen (op.cit.) have shown that reindeer grazing may effectively prevent regeneration by seed of areas of birch forest killed off by the attacks of the larvae of the geometrid moth (Oporinia autumnata).

Höglund & Eriksson (1973), from their investigations in the upland parts of southern Härjedalen found that local, extremely intensive, reindeer grazing was capable of reducing the area covered by birch forest by about two-thirds. Helle (1966), working in Finland, found that dense herds of reindeer cause damage to birch seedlings (cf. also Kallio & Mäkinen 1978), but that this damage was restricted to extremely limited areas and had no effect on the situation in general.

Interviews made with the local population of the investigated area indicated quite clearly that reindeer regularly browse on the foliage of trees and shrubs, although grazing of saplings had only been observed by a few people. I have myself found birch saplings, 10–20 cm in height, at several localities within the investigated area, which were thickened basally in a manner which according to Kallio & Lehtonen (1973) is an indication of repeated grazing damage by reindeer.

A certain degree of caution is called for when assessing the effects of reindeer on the vegetation cover, since they are much more extensive grazers than are domesticated livestock. The reindeer selects only the uppermost and youngest shoots. Furthermore, food preference changes frequently during the snow-free season of the year (Skuncke 1963; Steen 1966; Gaare & Skogland 1975).

Reindeer grazing at the tree-limit is, and was in the past of fairly short duration and is mainly concentrated to the spring and autumn seasons. The majority of the summer grazing grounds were up in the mountains well above the tree-limit (Högström 1741; Ruong 1969).

There is also a possible positive effect connected with reindeer grazing which should not be neglected, viz. the trampling. This serves to disrupt any continuous surface layer of raw humus and exposing and breaking up the mineral soil over a multitude of small patches. This should aid in the regeneration of birch from seed (Helle 1966; Kallio & Mäkinen 1978).

When assessing the evidence presented in respect of the present investigation one should bear in mind that, although reindeer grazing is extensive during the snow-free season, this does not apply to the very earliest and very latest snow-free vegetational types, which are both subject to highly intensive grazing (Steen 1966; Warenberg 1977).

Quantitative data on the importance of reindeer grazing for the population dynamics of birch growing at its altitudinal limit are virtually nonexistent. Haukioja & Heino’s (1974) study of the subarctic birch forests of northern Finland nevertheless suggests that the greatest effect of reindeer grazing on the birch stands occurs a short distance below the tree-limit.

Even an approximate estimate of the possible fluctuations with time in the intensity of the grazing pressure at every single one of the investigated localities is quite impossible. A general impression can nevertheless be gained by considering the known variation in the total reindeer stock within the investigated area at different times.

The only change in reindeer numbers which has been drastic enough to possibly have had an effect on birch regeneration considered from the regional point of view, not just locally, is the very heavy decimation of the reindeer stock which was deliberately carried out during the period 1912–1916. So many of the reindeer in the area had reverted to the wild state at that time that
large scale slaughter was the only remedy, some 12 000 animals or more were then shot. The reindeer stock only recovered to its former strength at the end of the 1920’s (Lappfogdens i Jämtlands län, årsberättelse 1916; Burman 1970). By all accounts, the number of reindeer in the area just prior to the enforced slaughter, as well as just prior to the turn of the present century, was greater than at any other time during the rest of the present century (SOU 1966). The grazing pressure was then (i.e. 1900–1912) quite certainly heavier in certain parts of the area than the bearing capacity of the grazings, and this therefore resulted in a marked reduction in the area of lichen-dominated (Cetraria spp., Cladonia spp.) vegetational types (Lappfogdens i Jämtlands län, årsberättelse 1899, 1900).

Thus, everything points to the fact that the appreciable reduction in grazing intensity which took place during the period 1915–1925, had a potentially positive effect on the regeneration of birch from seed within the tree-limit ecotone.
Insect attack

An important factor in the population dynamics of the mountain birch forest is attack by a variety of leaf-eating insect larvae, in particular the caterpillars of the geometrid moths (*Oporinia autumnata* and *Operophthera* spp.). High densities can have such a devastating effect on the birch foliage that no recovery is possible within the short vegetation period and can lead to widespread destruction of the subalpine and subarctic birch forest, even to the extent of causing a local lowering of the altitudinal forest- and tree-limits (e.g. Holmgren 1912; Nuorteva 1963, Tenow 1972; Kallio & Lehtonen 1973, 1975).

According to Tenow (op.cit) serious caterpillar attacks took place in the southern part of the investigated area in the summers of 1882–84, 1888–92 and 1915–1922 (cf. also Kullman 1976a). Smith (1920), who carried out fieldwork in that same area during the period 1908–1919, did not mention such insect attacks. There are therefore good grounds for assuming that such devastating attacks were relatively localised and probably merely resulted in a temporary defoliation of the birches. The attacks can scarcely have been on such a scale that they led to a more or less general lowering of the tree-limit over the whole of the investigated area.
Investigation methods

Determination of altitude

The altitude of the tree-limit above sea level has been measured at each locality with a Paulin aneroid altimeter, which could be read with an accuracy of ± 1 m. The cited values have been rounded off to the nearest 5 m interval. The aneroid barometer was checked and overhauled annually by the makers.

The instrument was adjusted on the following standard basis:
1. for a latitude of 45°N
2. for the density of air at a temperature of +10°C
3. for a water vapour pressure equivalent to 1% of the barometer reading
4. the zero point on the scale was set to correspond to an air pressure of 762 mm of mercury.

 Corrections for changes in air temperature and pressure during the course of the day, using a barograph and whirling-thermometer, were not carried out (cf. Kilander 1955). Instead, subsequent corrections were made possible by carrying out frequently-repeated re-calibrations of the altimeter in relation to the close network of levelled heights shown on the official topographical maps (scale 1:50 000). Such checks were made at intervals which seldom exceeded one hour in length. Minor discrepancies which may occasionally have occurred, of the order of 20-30 m, were corrected by interpolation, on the assumption that any change in barometric pressure which was noted to have occurred during the interval between two consecutive checks, had taken place gradually. To aid such a procedure the time of day was always noted when observations were made. Whenever consecutive readings lay an appreciable distance apart vertically, the altimeter was always allowed to stabilise for 10-15 min. before the second reading was made (cf. Rindert 1975).

When making readings the altimeter was held by the observer at breast-height, taking care that the observer always stood at the same level as the base of the actual tree for which the altitude was being estimated. The values obtained in this way are considered to be accurate to the nearest 10 m (cf. Jim Lundqvist 1968; Rindert op. cit.). Most of the localities were visited on more than one occasion and differences in the altitudes obtained hardly ever exceeded 10 m. On the rare occasions when such was the case the final cited value is the arithmetic mean of all the readings made at that locality.

In certain cases determinations of altitude have been taken from the figures shown on the relevant ordnance maps. These values were always revised whenever the respective sheets of the modern Topographic map for Sweden were published in the meantime. For those parts of the investigated area for which no topographic map was yet available in print, copies of the provisional base-maps for the forthcoming topographic map sheets were obtained from the Swedish Ordnance Survey (Statens Lantmäteriverk).

Age-determination of trees

The absolute age of individual birch trees growing in the upland regions is sometimes difficult to determine, because of the customary multi-stemmed form of the birch and a great ability to reproduce vegetatively.

The age-determination results referred to in the present work have all been made at a fixed distance along each stem, measured from the stem base where it joins the rootstock, by taking core samples with an increment borer.

During the initial stages of the investigation, a number (22 in all) of sawn cross-sections (discs) of the stems of birches growing at the tree-limit in different parts of the investigated area were collected and examined. In just one case a few of the
annual rings were found to be discontinuous, i.e. had bore cores along different radii been taken from this stem for age determination the results would have also differed by a few years. The partial disappearance of certain rings all proved to be on the side of the stem facing the downhill slope and at the crooked base of the stem, which was asymmetric in cross-section due to recovery from prostration when young. To eliminate this source of error as far as possible the bore cores were always taken parallel to the hillside. Obviously, a core bored at a fixed point along a stem only yields a minimum estimate of the length of that stem at the particular point in time given by the age determination.

So far as is known, there are no reports for birch of more than one annual ring being formed per year (cf. Sterner 1911). Hustich (1949) found that double rings presented no problem in his dendrochronological work on Scots pine growing at the arctic tree-limit in N Finland. Elkington & Jones (1974) do not exclude the possibility of ‘frost-rings’ and ‘disappearing rings’ being formed in birches growing in Greenland. Beschel & Webb (1963) reported that in unfavourable summers no annual rings were formed in the wood of Salix spp. growing in the Arctic. However, so far as birch growing at the tree-limit is concerned, by taking repeated bore cores from five particular stems during the period from winter 1976/77 to winter 1977/78, I found that even during the exceptionally cold summer of 1977 a normal and perfectly distinct annual ring was laid down. According to Schøve (1954), missing rings are mainly a problem when dating very old stems, which is not the case in this investigation.

Each bore core was secured by binding it with refrigerator-tape. It was brought back to the laboratory, where I personally did the annual-ring counts from a week to at most a month later. Attempts were made, using various stains, to achieve a greater degree of contrast between summer-wood and autumn-wood, but none gave any better result than the use of water alone (cf. Eidem 1954). Before counting the bore cores were soaked in water for 5–10 min, after which the surface along which the annual rings were most clearly visible was finely pared with a scalpel. When viewed under a stereomicroscope, at a magnification of 15–25 x, and kept permanently moistened, the boundaries between the individual rings were very distinct on the flat surface so produced.

The results of the age determinations of the birch stems investigated have all been expressed in relation to 1975 as the starting point (also in the legends to the figures).

Use of previous data for the altitude of the tree-limit

Any conclusions about change or stability of the tree-limit are necessarily based to a large extent on comparisons of the present-day altitudes and those which are reported in literature, as far back in time as possible, for the particular localities concerned. An assessment of the reliability of such accounts is therefore of the greatest importance, as well as of their terminology.

The majority of the older data on tree-limit altitude are taken from Harry Smith’s monograph (1920, p. 102 ff), in which he mainly reports observations made in 1915 and 1916. Unfortunately, nowhere in the text does Smith make quite clear just what he meant by the term ‘tree-limit’ (Sw. ‘trädgrans’). The only unequivocal statement made is that the altitudes given refer to the altitudes above sea level at which the uppermost tree-sized birches were found growing along a 2–5 km stretch of hillslope (op. cit., p. 97). Just what he meant by ‘tree’ is not described in absolute terms either. From an examination of his photographs, however, it would seem that at times multi-stemmed birches, 2–2.5 m in height, were regarded as being trees (cf. op. cit., pp. 94, 116, 118). As a confirmation of this point of view is the mention (op. cit., p. 93) that the multi-stemmed birches, at most of man’s height, shown on the photographs published by Frödin (1916, Fig. 7 and Plate III), and classified by him as ‘bushes’, according to Smith belonged within the ‘birch region’, i.e. were regarded by him as ‘trees’. All the indications, therefore, are that Smith placed his ‘tree-limit’ at the level of the uppermost birches with stems at least 2 m in height. In all probability even individual multi-stemmed birches, which on morphological
grounds ought to be considered as 'bushes' (sensu Lindman 1914), were reckoned as 'trees' by Smith.

In actual fact the exact minimum height used by Smith in his 'tree' concept is not so very important, since at ca 70% of the localities described in the present investigation the uppermost birches with a minimum height of 2 m had stems of 2-2.5 m in height or more. At only ca 20% of the localities these birches were exactly 2 m in height and the vertical distances between such birches and those of a minimum height of 2.5 m growing on the same slopes were on average only ca 15 m (cf. Kilander 1955, p. 53). At some of the dry, nutrient-poor, localities in Härjedalen and Dalarna, the distances apart of these height categories were greater. Under similar conditions in N Finland, Armio (1963), for an altitudinal difference of 100 m, found a 37 cm decrease in mean stem height.

Smith's altitudinal determinations were made with two aneroid barometers (mean value used) and a whirling thermometer (op. cit., p. 91). A barograph was obviously not used for making corrections to the barometers for any changes in atmospheric pressure during the field-work.

When making his observations Smith obtained a value for the difference in air pressure (in mm of mercury) and temperature between a known starting-point and the particular locality, whereafter these values were converted to m a. s. l. using Professor P. G. Rosen's conversion table (Svenska Turistföreningens Årsskrift 1893, pp. 184-185), which is based on an equation worked out by W. Jordan and E. Hammer (see Jordan 1917). In principle this is the same formula as that on which the modern Paulin aneroid-barometer scale is based (information supplied by Micromatic International Co Ltd.). Jordan (op. cit.) states that the equation holds for altitudes up to 1000 m a. s. l. Smith's highest altitudinal determination was 1007 m. No grounds therefore exist for thinking that there is any systematic difference between my values and Smith's in this respect.

The mathematical calculations which were bound up with Smith's final values do allow a certain possibility for the occurrence of minor mistakes. Major miscalculations, however, are unlikely, since any such gross deviations would have been noted when comparisons with the values obtained at neighbouring localities were made. Despite a considerable amount of effort I have unfortunately been unable to locate Smith's original field notebooks containing the original basic data for his height determinations.

Accurate determination of altitude by Smith's method presupposes the existence of a large number of accurate spot heights in the vicinity of the tree-limit localities visited, i.e. reliable and detailed maps are essential. Smith (op. cit.) does not make clear just which maps he used, merely mentioning the existence of the then newly-published, ordnance maps (Sw. 'Generalstabsblad') at scales of 1:200 000 to 1:50 000. Almost certainly he used sheets 65 Duved and 71 Ljusnedal, on the first-mentioned scale, which were issued in 1904 and 1909 respectively. He was also probably able to avail himself of the provisional prints for the larger-scale versions of these maps, issued for the 1:50 000 and 1:100 000 scale sheets respectively (Dr. Sven Kilander, pers. comm.).

The map situation for the southernmost part of the area investigated by Smith was much less satisfactory at that time. Only a tourist map existed, with a few almost certainly inaccurate spot heights on it (Smith, op. cit., p. 90). The overlapping part of a Norwegian map of the adjacent region provided a few fixed points to work from. In 1919, however, the Swedish ordnance map sheet 76 Tännäs (probably a provisional edition) was issued and Smith was able to check the reliability of his altitudinal estimates. He states (op. cit. pp. 90-91) that there was complete agreement between his barometric heights for various topographic features and the corresponding values shown on the map.

Since Harry Smith followed the forest-limit during his wanderings (op. cit., pp. 1 and 91), he would probably have used the topographic features in its vicinity, for which spot-heights were available, when making his calibrations. A comparison of the altitudes given for Smith's probable calibration points on the old ordnance maps and the modern topographic maps shows very little difference in most cases. Only exceptionally is there more than 10 m difference in height and in these few cases, where it is obvious that Smith's values have been derived from the use of inaccurate spot heights, the altitudes have been corrected before being cited in the present investigation.
In certain cases, great difficulty arose in identifying Smith's localities by name. Because of these difficulties, quite a large proportion of Smith's 391 localities for which tree-limit altitudes are given have had to be rejected. Nevertheless, because Smith lists his localities in a more or less chronological order, and the fact that at least a proportion of them were recognisable, has meant that the sites of others could be re-identified with a great degree of certainty and used for comparison in the present investigation. Site identification was further facilitated by Smith's statement (op. cit., p. 97) that each height determination referred to the uppermost tree-sized birches present along that particular 2–5 km stretch of terrain.

Identification difficulties due to Smith's use sometimes of older local names for certain localities have been obviated thanks to the welcome help of Dr. Sven Kilander, who has both worked in that area himself and knew Harry Smith personally.

In principle all the identifiable localities from Smith's investigation were re-visited. These are representative for most of the habitat types present in the tree-limit ecotone within the studied region.

In a few cases it is obvious that Smith somehow or other did not discover the highest-growing birch-trees at a particular locality. The probable explanation is that he kept along the forest-limit, more or less parallel with the general contours, the whole time (cf. above). In such broken and rather undulating terrain, where the vertical distance apart of the forest-limit and the tree-limit is often quite appreciable, it is highly probable that the highest-growing trees have escaped his notice (e.g. localities 52 and 56).

Harry Smith was renowned as being a very careful 'fieldworker' (Dr. Sven Kilander, pers. comm.). It is therefore highly improbable that he ever knowingly tried to spare any effort in his attempts to find the highest-growing birches.

The main element of uncertainty attached to Smith's tree-limit altitude determinations is probably the difficulty of eliminating the effect of sudden changes in atmospheric pressure on the readings he made, because of the great scarcity, on the maps available at that time, of spot heights for cross-checking. The good results obtained by Smith in the southern part of his investigated area, mentioned above, nevertheless indicate that the margin of error as a whole is amazingly low; a value of ± 10 m seems a reasonable estimate.

In certain cases observations made prior to those of Smith have been used (Hisinger 1819, 1820; Hørbye 1861; Henning 1887; Sernander 1898; Birger 1908; Samuelsson 1917). All these investigators determined altitude with a barometer. Even fewer maps were available to them, however, than were available to Smith. Furthermore the exact nature of what they measured the altitude of is hardly made clear. In most cases the values probably refer to the limit of some kind of birch stand, i.e. they thus provide no more than a minimum altitude for the birch tree-limit at that particular time.

At certain localities the altitudinal limits for birch about 1950 were determined by Dr. Sven Kilander (1955). At these localities therefore, it is possible to elucidate the exact degree of tree-limit change after 1950. The uncertainties in Kilander's values are almost certainly less than those attached to Smith's calculations, because of the greatly improved maps issued in the meantime and the refined instruments.

**Age-determination transects**

As a complement to the data on the former extent of the tree-limit derived from a study of the literature, age-determination transects were investigated at ca 75% of the 213 localities studied. For 17% of the studied localities such age-determination transects provide the only evidence on which to draw conclusions about altitudinal shifts of the tree-limit.

The aim of the age-determination transects has been to assess the 'probability' that at any particular locality at least one birch of tree-height was growing at that particular altitude in 1915/16.

In principle the method adopted was that the ages of small numbers (seldom more than 5) of subjectively selected birch stems were determined at different altitudes along a vertical transect, from the present-day tree-limit down to the level at which birches of tree-height were known for certain to have been growing at the investigated locality about 1915. This latter level was arrived
at from data in literature and/or from visual assessment of the ages of the present-day trees, based on stem diameter, height, appearance of the bark and the degree of coverage by epiphytic lichens. Age determinations of the selected stems were then made from wood cores obtained with an increment borer. As the number of such age determinations increased, there was a corresponding improvement in the author’s capability of making a visual assessment of the age of particular stems, based on the criteria mentioned above, whereby the oldest stems in a particular birch stand at any particular altitude could in all probability be localised and their actual ages could then be exactly determined from bore cores.

Since most localities were visited more than once, supplementary age determinations could be made in those cases in which the data obtained from the literature about the altitude of the tree-limit in 1915/16 conflicted with the initial results given by the age-determination transect made at the same locality.

At certain of the investigated localities no age determinations could be made, or were impossible at certain altitudes along the transects, due to a variety of reasons such as breakage of the increment borer or loss of cores, nature conservation considerations, or because precise annual-ring counts were impossible on some cores due to aberrant wood anatomy etc. In a few cases no confirmatory age determinations were considered necessary, because the good agreement found between the visual assessment and the literature data was considered to yield a true picture of events.

The lateral extents of the age-determination transects were not predetermined. In dense forest stands widths were generally less than 50 m, whereas above the forest-limit, where the trees grow fairly far apart, a transect width of more than 50 m was necessary.

At particular altitudes along a transect where the ages of several stems were determined, the altitude value cited in the text really represents an approximation of ± 5 m, due to the slope of the ground at that point.

The practice adopted in the field was to start at the present-day tree-limit and work downwards, altering direction so as to include the oldest-looking stems at any particular altitude. Because of the irregular distribution of the available trees, particularly in the upper parts of the transects, the resulting transects have been more a zig-zag than a straight line, i.e. it proved impossible to maintain a fixed vertical interval for the age determinations made within any particular transect.

In general the cores for age determination were taken at a height of 10–20 cm above ground-level. For practical reasons bore cores could not be taken at ground-level, although ideally this would naturally have been desirable. Where obviously old stems (> 60 years) were encountered, the bore cores were taken at a height of 2 m above the base of the trunk. The age of only one stem per individual rootstock was determined. Old tree stumps and fallen trunks of former, well-grown, tree birches, which were obviously more than 2 m in height when alive, were always carefully searched for in the transects.

The approximate height of all the living stems investigated was estimated visually. The degree of uncertainty attached to such height determinations is likely to amount to only 10–20 cm for stems 2 to 4 m in height, and to a maximum of 0.5 to 1 m for longer stems.

Immediately after the investigation of the lower limit of any particular transect and the determination of its altitude with the altimeter, I returned uphill to the starting point of that transect and checked the initial altitude determination. If there was any difference between the two values, due to changes in the barometric air pressure in the meantime the altitudinal values determined at all the intervening points in the transect were corrected accordingly. The vertical distances apart of the different levels within each transect ought therefore to be pretty reliable.

### Photographic record

All the photographs were taken by the author, using a twin-lens reflex camera, a Yashica Mat-125 G (negative size 6×6 cm) with a 80 mm objective, 1:2.8.
Basic data from the investigated localities

Explanatory remarks, terminology and abbreviations

The basic data yielded by the field investigations are set out separately for each locality in turn, under five headings.

The localities have been consecutively numbered from N to S within the investigated area. Each has been named in accordance with the usage given on the topographical map sheets (see Maps). Site aspect is shown by capital letters immediately after the site name. The position of the present-day tree-limit (TL) is indicated for each locality by citing the respective coordinates from the Swedish National Grid, with an accuracy of ± 100 m.

Each of the named localities represents a vertical transect, running at right-angles to the local slope contours and with a breath of ca 50 m.

Abbreviations adopted are also used in the rest of all subsequent sections of the present paper.

The five main data headings and the respective abbreviations used are dealt with below, in the order in which they occur in the descriptions.

Present-day altitudinal limits

The present-day altitudes for four differently-defined birch limits are given for each locality. The heading is followed by the date (year) for which the data are valid.

Where no indication is given for any one of the four limits this implies that that particular limit was not recognisable at that particular locality.

Each of the four limits is referred to by its capital letter abbreviation given below, and each is followed by the altitude, in metres above sea-level, determined in the field. FL—forest limit: represents the highest point at a locality at which birches of tree-height (see below) form a more or less closed stand. The limit may be sharp and distinct, running as a line across the landscape, or disjunct, formed of scattered, but dense, clumps of birch trees. In the latter case a minimum of three such clumps, each covering an area of at least 5×5 m and comprising a minimum of 10 tree-sized stems, has been required before that particular altitudinal niveau was considered to lie below the forest-limit. Where the forest-limit was irregular, with wedge-shaped lobes or tongues thrusting out upslope, the forest-limit has been taken as being the highest-lying tips of such features.

The character of the forest-limit is in each case indicated after the respective altitudinal value.

The forest-limit data are cited for future comparative purposes only. MSL—mature stem limit: represents the altitudinal limit for still-living, or now dead, erect or fallen birch stems which were at least 2 m in height and alive in 1915/16. This limit provides the minimum altitude for the position of the tree-limit at that time and forms an important complement to the tree-limit data obtained in literature.

The position of the MSL has in the majority of cases been determined from the results of the age-determinations, generally from the annual-ring counts made on the bore cores, though in certain cases based solely on visual estimates.

Where the remains of fallen trunks or stumps of former well-grown trees, which seemed to have been at least 2 m in height in 1915/16, were encountered, these have also been taken into account in determining the altitude of the MSL.

TL—present-day tree-limit: represents the altitude, at any particular locality, at which the uppermost birch, with stem(s) at least 2 m in length, grows at the present-day; i.e. each value refers to a particular point in the terrain and has no generalised horizontal implication (cf. Kullman 1976a). The sole criterion for calling such a birch stem a ‘tree’ has been that good grounds existed (e.g. the snow-depth indicating lichen-limit (Sw. ‘olivacea-gräns’) or direct observations during the win-
Change and stability of birch tree-limit in the Scandes

For thinking that this stem is not completely snow-covered at any time during the winter.

SL—specie's limit: represents the highest altitude at a particular locality at which birch, irrespective of stem diameter or height, was found growing at the present-day.

Age-determination transect

For most localities the data given under this heading are the results obtained from the age determinations made at different levels within the transect made at that locality (for details see Investigation methods).

The data obtained at each investigated level are set out in the form of an alpha-numerical code, as follows: a = the altitude of the investigated transect level, in m a. s. l.; b = the age(s) of the stem(s) investigated; c = the mean length(s), in metres of the stem(s) investigated; d = the height above groundlevel, in decimetres, at which the bore core(s) for the age determination(s) was taken.

E.g. a b c d
915—39, 37, 31—3.0—2

Documentation

This section contains a summary, for that particular locality, of the data available in literature for the altitudinal limits for birch, primarily for the tree-limit, at earlier periods. This summary forms the basis for a comparison with the present-day limit.

The majority of the comparisons are with the data given by Smith (1920, pp. 102–107) from his field surveys made in 1915/16. These data are cited in an abbreviated form as follows: TL-Smith (a):b, where 'a' is the number given by Smith to that particular locality, and 'b' is the altitude in m a. s. l.

Past tree-limit (PTL)

This is the tree-limit altitude for the respective locality, derived either from literature or from the age-determination transect results, for the point in time (1915/16) chosen for comparison with the present-day (TL) value found there; i.e. the PTL values form the basis for the calculation of the degree of tree-limit displacement at each locality.

In certain cases the MSL results from the age-determination transect and the data obtained from the literature survey yielded different values for the tree-limit in 1915/16. To minimise any bias in the resulting calculations of the tree-limit displacement at such localities the higher of the two values obtained has been chosen for comparison with the present-day tree-limit value (TL).

All values cited for former positions of the tree-limit, however, have been rounded off to the nearest 5 m.

In all subsequent parts of the present paper the past tree-limit is simply referred to as the PTL.

Degree of change

The altitudinal extent of any displacements in the tree-limit between 1915/16 and the present-day are described below, as follows.

Apparent displacement, viz. the difference between the values of the TL and the PTL is given with values in m.

As already pointed out (see pp. 24 ff) some degree of uncertainty is especially attached to the older determinations of the altitudinal position of the tree-limit. In adverse cases, for example, one may imagine that one of Smith’s determinations was 10 m too low and that my own determination was 5 m too high, i.e. the calculated tree-limit displacement would be exaggerated by 15 m. So as to obviate, as far as possible, any such spurious augmentation, all the values for ‘Apparent displacement’ have been deliberately reduced if derived from comparison of the present-day altitude of the tree-limit (TL) with its former position as adduced from literary evidence alone (literary values higher than the MSL values), or in cases in which the latter values are the same as the MSL values. If, on the other hand, the PTL is based solely upon the MSL data (MSL values higher than literary values), then no correction has been made to the ‘Apparent displacement’ values, because of the fact that the vertical distances apart of the different levels in each age-determination transect are reliable (see pp. 26 f).

In general, the greatest magnitude of the correction factor used has been −15 m. For all localities which are situated in the vicinity (<1 km...
away from) of topographical features for which reliable spot heights were available in 1915/16 and which lay at about the same altitude as the MSL estimation points, the use of a smaller correction factor has been considered justified (either 10 or 5 m was subtracted).

The corrected value for the ‘Apparent displacement’ so obtained has been termed the ‘Significant displacement’. The use of this value, rather than the uncorrected ones, in the mathematical treatment of the data, ensures that any treeline changes discussed in the subsequent sections of this paper are the minimum values found and that the actual changes may well in certain cases have been greater.

The use of the term ‘significant’ should nevertheless not be taken too literally, since at best it only represents a probability that a change has occurred, i.e. that probability is directly proportional to the calculated value of the displacement.

The terms ‘displacement, shift, change etc.’ used later on in this paper, all refer to values of ‘Significant displacement’.
Investigated localities

1  Tjuvbodklumpen S (70 364  13 178)

Present-day altitudinal limits (1976)
FL:    810, lobes
MSL:  780, a fairly high number of stems
TL:    820, a 2.2 m high stem
SL:  825, a creeping, ca 1 m high stem

Age-determination transect
820 – 31 – 2.2 – 1
810 – 52, 44, 42, 35, 27 – 3.5 – 2
800 – 29 – 7.0 – 20
790 – 57, 47, 35, 34, 29 – 5.0 – 2
780 – 70 – 4.0 – 20
775 – 71 – 8.0 – 20

Documentation
That Smith observed this hill slope at a distance, e.g. from his locality 4, is an unavoidable conclusion. The presence of the lake Skurdalssjon at the foot of this hillslope enabled the approximate altitude of the forest-limit to be established with a fair degree of certainty. Probably the figure so obtained did not deviate appreciably from that of the vicinity in which he was (ca 750 m), so that he considered it was hardly worth the effort involved to make a separate determination of the tree-limit. The latter may reasonably well have lain higher than the forest-limit, although scarcely at the same altitude as it does today, since from Smith’s locality 4 the uppermost trees can clearly be seen silhouetted against the skyline, a point which is scarcely likely to have escaped his notice.

Past tree-limit
780
Apparent displacement: +40
Significant displacement: +40

2  Hästryggarna S (70 339  13 174)

Present-day altitudinal limits (1976)
MSL:  740, one stem
TL:  785, a ca 2 m high stem

Age-determination transect
No investigation made

Documentation
TL-Smith (5): 746. The summit of this hill is shown as 14 m lower in altitude on Smith’s map than on the modern topographical map. Smith’s tree-limit has therefore been corrected by +14 m.

Past tree-limit
745
Apparent displacement: +40
Significant displacement: +35

3  Larsvalen NV (70 323  13 159)

Present-day altitudinal limits (1976)
FL:    730, diffuse boundary
MSL:  705, one stem
TL:  740, a ca 2 m high stem

Age-determination transect
705 – 78 – 4.0 – 20

Documentation
TL-Smith (3): 723. The altitude of the nearby lake Skurdalssjon is shown as 13 m lower on Smith’s map than on the modern topographical map, Smith’s tree-limit has therefore been corrected by +13 m.

Bosseus (1929) published a photo of the so-called Printzskold Monument (Fig. 12) which stands on this hillslope at an altitude of 710 m a. s. l. It is quite clear from the photo that the immediate vicinity of the memorial stone, just prior to 1929, was treeless. Today it is surrounded by a dense stand of 2-3 m high young birches (Fig. 13).

Past tree-limit
725
Apparent displacement: +15
Significant displacement: +10

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Fig. 12. The Printzsköld Monument at locality 3, as seen on a photograph published by Bosaeus (1929). Low birch shrubs exist in the vicinity, but definitely no tree-sized birches.

Fig. 13. The same view as in Fig. 12. The monument is today surrounded by dense clumps of trees, vigorously-growing and 2 to 3 m high. The establishment of tree-stands has obviously increased local snow retention. Photo: March 1, 1977.

4 Skurdalsbergen N (70 323 13 141)

Present-day altitudinal limits

FL: 720, clumps of trees
MSL: 705, one stem
TL: 775, a ca 2.5 m high stem

Age-determination transect

705 – 62 – 4.5 – 20

Documentation

TL-Smith (12):682. For a similar reason as above, Smith’s value has been corrected by +13 m. According to the estimates of altitude made by Hisinger (1819) in this area, using an aneroid barometer, Skurdalssjön lay at 1916 Parisian feet, i.e. ca 622 m a.s.l., which is 73 m lower than the correct value. All his altitude estimations were made in the course of one single day, within a few hours of time; consequently, the above-mentioned error is assumed to be applicable to all. When Hisinger’s other results are converted to metres and corrected by adding 73 m, the following values are obtained: “limit of birch bushes”—ca 785 m, “limit of tree growth”—lower than 720 m, although no indication is given of the meanings of the terms “bush” and “tree”.

At an altitude of 715 m on the hillslope under discussion, there is the old standing-stone “Stenen i grönan dal”, which is thought to have marked the old route between Sweden and Norway (Festin 1934). In 1934 the stone was moved slightly, during its restoration, and thereafter photographed together with its environs. At that time there was a birch thicket (maximum height 1 m) behind the stone. Today the same spot is occupied by a dense stand of 2 – 3.5 m high birches.

Past tree-limit Degree of change
705 Apparent displacement: +70
Significant displacement: +65

5 Skurdalshöjden N (70 308 13 143)

Present-day altitudinal limits (1974)

MSL: 740, one stem
TL: 795, several individual trees bearing 2–2.5 m high stems
SL: 835–805, a few 1.5–1.8 m high shrubs; some were at least 2 m high at the beginning of the 1970’s

Age-determination transect

740 – 71 – 3.0 – 20

Documentation

Smith estimated the tree-limit on all sides of the Skurdalshöjden, except on the N-facing slope. The lack of any value for this point of the compass is probably best interpreted as indicating the absence of trees, above the valley floor, at 730–740 m of this side on the hill.

Past tree-limit Degree of change
740 Apparent displacement: +55
Significant displacement: +55

6 Skurdalshöjden E (70 306 13 153)

Present-day altitudinal limits (1972)

FL: 725, clumps of trees
MSL: 725, one stem
TL: 765, a 2.1 m high stem; only 5 m below there are some 3.5 m high stems

Age-determination transect

725 – 62 – 3.0 – 20

Documentation

TL-Smith (6):724. Smith calls this locality “Storlien”. The hill now called Skurdalshöjden, was in the past known as Storlifjället or Storlien (Flemström 1972).

Past tree-limit Degree of change
725 Apparent displacement: +40
Significant displacement: +35
7 Skurdalshöjden S (70 304 13 143)

Present-day altitudinal limits (1975)

FL: 770, tongues and clumps of trees, with a marked admixture of the hybrid Betula nana × pubescens.

MSL: 738, a small number of stems

TL: 815, several 2 m high stems which project above a dense and extensive metre high thicket of bushy birch

SL: 840, a few 0.4 m high shrubs

Age-determination transect

825 - 13 - 1.3 - 1

815 - 45, 43, 33, 32 - 2.0 - 2

800 - 30 - 2.5 - 2

785 - 39 - 3.2 - 2

785 - 22 - 3.2 - 20

730 - 60 - 5.5 - 20

720 - 77 - 5.5 - 20

Documentation

TL-Smith (7):730

Past tree-limit  Degree of change

730  Apparent displacement: +85

Significant displacement: +80

8 Skurdalshöjden SW (72 304 13 137)

Present-day altitudinal limits (1972)

FL: 780, tongues and lobes

MSL: 740, one stem

TL: 795, a ca 3 m high stem

SL: 820, a few metre high shrubs

Age-determination transect

740 - 71 - 3.5 - 20

Documentation

TL-Smith (9):739

Past tree-limit  Degree of change

740  Apparent displacement: +55

Significant displacement: +50

9 Skurdalshöjden W (72 307 13 136)

Present-day altitudinal limits (1972)

FL: 765, even limit

MSL: 740, one stem

TL: 785, a 2 m high stem

SL: 790, a few 10–20 cm high shrubs

Age-determination transect

740 - 74 - 4.0 - 20

Documentation

TL-Smith (10):745

Past tree-limit  Degree of change

745  Apparent displacement: +40

Significant displacement: +35

10 Rekdalshöjden N (70 262 13 115)

Present-day altitudinal limits (1974)

FL: 700, even limit

MSL: 755, a small number of stems

TL: 820, a few clumps of 2.5–3 m high stems, some of which had died quite recently

SL: 840, a 1.8 m high stem

Age-determination transect

820 – 46, 37, 35, 30, 28 – 2.7 – 2

775 – 54, 52, 49, 42, 41 – 3.0 – 2

755 – 64 – 4.0 – 20

755 – 93, 57, 37, 35, 31 – 3.5 – 2

720 – 71, 63 – 4.0 – 20

Documentation

TL-Smith (56):820. Although this mountain was unnamed on Smith’s map it was quite natural that he should refer to it in the text as “Rundvalen”, since it represents a spur from this mountain towards the NW. The summit altitude shown on Smith’s map is 6 m higher than that given on the modern topographical map. In consequence Smith’s value has been reduced accordingly.

Past tree-limit  Degree of change

820  Apparent displacement: 0

Significant displacement: 0

11 Rekdalshöjden W (70 253 13 112)

Present-day altitudinal limits (1974)

FL: 830, wedge

MSL: 815, a small number of stems

TL: 835, a small number of 2.5 m high stems of low vitality

Fig. 14. The tree-limit (835 m a.s.l.) at locality 11. All the birch stems are obviously quite young and have been severely deformed by the weight of the snow cover. Vaccinium myrtillus and Nardus stricta are the field layer dominants. Photo: June 12, 1974.
Age-determination transect
835 - 56, 47, 47, 44, 31 - 2.0 - 2
820 - 80, 74, 65, 54, 39 - 3.0 - 2
815 - 63 - 3.5 - 20

Documentation
TL-Smith (55):810. See locality 10. Mrs Gunborg Antholm and Mr Sten Olofsson, both of Storvallen, state that the birch limit is higher today than when they were young (about 50 years ago).

Past tree-limit | Degree of change
---|---
815 | Apparent displacement: +20
     | Significant displacement: +20

12 Rundvalen N (70 208 13 151)

Present-day altitudinal limits (1973)
FL: 755, tongues and clumps of trees
MSL: 785, one stem, very old, but impossible to date more accurately because of fungal attack
TL: 795, a single tree bearing five 3 m high stems

Age-determination transect
No investigation made

Documentation
TL-Smith (25):786

Past tree-limit | Degree of change
---|---
785 | Apparent displacement: +10
     | Significant displacement: +5

13 Rundvalen E (70 203 13 154)

Present-day altitudinal limits
FL: 755, diffuse limit
MSL: 785, a few stems
TL: 795, a small number of ca 2 m high stems

Age-determination transect
785 - 91 - 4.5 - 20

Documentation
TL-Smith (26):784. Mrs Gunborg Antholm, Storvallen, states that the birch limit is higher today than when she was young.

Past tree-limit | Degree of change
---|---
785 | Apparent displacement: +10
     | Significant displacement: +5

14 Rundvalen S (70 205 13 151)

Present-day altitudinal limits
FL: 790, even limit
MSL: 800, one stem
TL: 800, a 2.5 high stem, which pokes out of a 1-1.5 m high scrubby growth
SL: 805, a few metre high shrubs

Age-determination transect
800 - 88 - 3.0 - 20

Documentation
TL-Smith (29):803. Mrs Gunborg Antholm, Storvallen, states that the birch limit is higher today than when she was young.

Past tree-limit | Degree of change
---|---
803 | Apparent displacement: 0
     | Significant displacement: 0

15 Rundvalen W (70 207 13 147)

Present-day altitudinal limits
FL: 770, even limit
MSL: 785, a small number of stems
TL: 785, several 3-4 m high clumps of trees

Age-determination transect
785 - 71, 62 - 4.5 - 20
785 - 88 - 4.5 - 2

Documentation
TL-Smith (27):792

Past tree-limit | Degree of change
---|---
792 | Apparent displacement: −5
     | Significant displacement: 0

16 Blåhammarkläppen WNW (70 139 13 161)

Present-day altitudinal limits
FL: 870, clumps of trees
MSL: 855, one stem
TL: 915, a sparse clump of 2.5-3 m high stems

Age-determination transect
915 - 37, 36, 26 - 2.7 - 2
855 - 64 - 3.0 - 20
835 - 87 - 4.0 - 20

Documentation
TL-Smith (36):890. Mrs Gunborg Antholm, Storvallen, states that the birch limit is higher today than when she was young.

Past tree-limit | Degree of change
---|---
890 | Apparent displacement: +25
     | Significant displacement: +10

17 Blåhammarkläppen W (70 123 13 122)

Present-day altitudinal limits (1976)
FL: 875, lobes and small clumps of trees
MSL: 850, one stem
TL: 940, two 2.3 m high stems, much deformed by the weight of snow

Age-determination transect
940 - 26 - 2.3 - 2
935 - 32 - 3.5 - 2
930 - 39 - 3.5 - 2
920 - 37 - 2.5 - 2
875 - 55, 45, 34, 34, 30 - 3.3 - 2
850 - 85 - 5.0 - 20

Documentation
TL-Smith (35):896. Mrs Gunborg Antholm, Storvallen, states that the birch limit is higher today than when she was young.

Past tree-limit | Degree of change
---|---
895 | Apparent displacement: +45
     | Significant displacement: +30

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<table>
<thead>
<tr>
<th>Location</th>
<th>Altitudinal Limits</th>
<th>Degree of Change</th>
<th>Notes</th>
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<tbody>
<tr>
<td><strong>Graslidfjall N</strong> (70 162 13 172)</td>
<td><strong>Present-day altitudinal limits (1975)</strong>&lt;br&gt;FL: 830, even limit&lt;br&gt;MSL: 825, one stem&lt;br&gt;TL: 900, a 2.5 m high stem</td>
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<tr>
<td><strong>Age-determination transect</strong>&lt;br&gt;900 - 26 - 2.5 - 2&lt;br&gt;895 - 35, 35 - 3.5 - 2&lt;br&gt;880 - 46 - 3.5 - 1&lt;br&gt;870 - 81, 68, 61, 42, 39 - 5.0 - 2&lt;br&gt;825 - 61 - 5.0 - 20&lt;br&gt;810 - 78 - 6.0 - 20</td>
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<td><strong>Documentation</strong>&lt;br&gt;TL-Smith (37):862. Mrs Gunborg Antholm, Storvallen, states that the birch limit is higher today than when she was young.</td>
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<tr>
<td><strong>Past tree-limit</strong>&lt;br&gt;860</td>
<td>Apparent displacement: +45&lt;br&gt;Significant displacement: +30</td>
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<tr>
<td><strong>Lilhammaren N</strong> (70 179 13 203)</td>
<td><strong>Present-day altitudinal limits (1977)</strong>&lt;br&gt;FL: 800, lobes and small clumps of trees&lt;br&gt;MSL: 790, a small number of stems&lt;br&gt;TL: 830, five 2.5 m high stems borne by two individual trees&lt;br&gt;SL: 835, a few 1 - 1.5 m high shrubs</td>
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<td><strong>Age-determination transect</strong>&lt;br&gt;830 - 57, 51, 47, 38 - 2.5 - 2&lt;br&gt;810 - 42 - 2.5 - 2&lt;br&gt;805 - 61, 41, 38 - 4.0 - 2&lt;br&gt;795 - 73, 56, 42 - 4.5 - 2&lt;br&gt;795 - 39 - 5.0 - 20&lt;br&gt;790 - 73, 64, 51, 31 - 3.5 - 20</td>
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<tr>
<td><strong>Documentation</strong>&lt;br&gt;TL-Smith (38):838. Smith probably calibrated his altimeter at pt. 898 or pt. 892 shown on his map. The latter spot height is also shown on the modern topographical map. Kilander (1955) gives values for the altitudinal limits for birch on this hillslope, made in 1951. The results were as follows:&lt;br&gt;880, a nearly-prostrate shrubby birch&lt;br&gt;870, a shrubby birch&lt;br&gt;867, a 1.5 m high birch thicket&lt;br&gt;860-855, a 2 m high birch thicket&lt;br&gt;840, a thicket, together with a few 3 m high trees&lt;br&gt;835, forest</td>
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<tr>
<td><strong>Past tree-limit</strong>&lt;br&gt;860</td>
<td>Apparent displacement: +70&lt;br&gt;Significant displacement: +70</td>
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<td><strong>Getvalen NW</strong> (70 195 13 228)</td>
<td><strong>Present-day altitudinal limits (1977)</strong>&lt;br&gt;FL: 860, clumps of trees with ca 3 m high stems&lt;br&gt;MSL: 805, a small number of stems&lt;br&gt;TL: 875, several individual trees with 2-3 m high stems</td>
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<td><strong>Age-determination transect</strong>&lt;br&gt;875 - 31, 30 - 2.8 - 2&lt;br&gt;870 - 39, 32 - 3.0 - 2&lt;br&gt;855 - 52, 42, 38, 35 - 3.0 - 2&lt;br&gt;835 - 35 - 4.5 - 20&lt;br&gt;805 - 71 - 6.0 - 20</td>
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<td><strong>Documentation</strong>&lt;br&gt;TL-Smith (40):820. See locality 19.</td>
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<tr>
<td><strong>Past tree-limit</strong>&lt;br&gt;815</td>
<td>Apparent displacement: 0&lt;br&gt;Significant displacement: 0</td>
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<td><strong>Getvalen NW</strong> (70 204 13 236)</td>
<td><strong>Present-day altitudinal limits (1977)</strong>&lt;br&gt;FL: 840, clumps of trees, 3 m high&lt;br&gt;MSL: 810, one stem&lt;br&gt;TL: 850, several 2-3.5 m high stems</td>
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<td><strong>Age-determination transect</strong>&lt;br&gt;850 - 52 - 3.5 - 2&lt;br&gt;840 - 91, 45, 38, 25 - 3.0 - 1&lt;br&gt;810 - 61 - 7.0 - 20</td>
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<tr>
<td><strong>Documentation</strong>&lt;br&gt;TL-Smith (42):736. Mrs Gunborg Antholm, Storvallen, states that the birch limit is higher today than when she was young. Dr Sven Kilander has placed his unpublished results for the altitudinal limits of birch, made in 1951, at my disposal, viz:&lt;br&gt;880, prostrate stems (Kilander 1955)&lt;br&gt;855, an almost 3 m high tree</td>
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855, the more or less distinct limit for small clumps of birch

<table>
<thead>
<tr>
<th>Past tree-limit</th>
<th>Degree of change</th>
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<tbody>
<tr>
<td>810</td>
<td>Apparent displacement: +40</td>
</tr>
<tr>
<td></td>
<td>Significant displacement: +40</td>
</tr>
</tbody>
</table>

23 Ingolvskalet N (70 203 I3 249)

**Present-day altitudinal limits (1975)**
- FL: 800, even limit
- MSL: 815, one stem
- TL: 845, a 3 m high stem

**Age-determination transect**
- 845 – 32 – 3.0 – 2
- 830 – 24 – 2.5 – 2
- 815 – 51, 44, 43, 38 – 4.0 – 2
- 815 – 76 – 5.0 – 20
- 800 – 69 – 6.5 – 10
- 800 – 88 – 5.5 – 20

**Documentation**
TL-Smith (43):773. Mrs. Gunborg Antholm and Mr Sten Olofsson, both of Storvallen, state that the birch limit is higher today than when they were young.

Kiland er (1955) estimated the upper limit for ‘low-grown forest’ to lie at 790 m in 1951, and on the same occasion found several ca 2 m high birch thickets growing at 845–840 m.

<table>
<thead>
<tr>
<th>Past tree-limit</th>
<th>Degree of change</th>
</tr>
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<tbody>
<tr>
<td>815</td>
<td>Apparent displacement: +30</td>
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<tr>
<td></td>
<td>Significant displacement: +30</td>
</tr>
</tbody>
</table>

24 Storsnasen N (70 203 I3 259)

**Present-day altitudinal limits (1976)**
- FL: 760, wedge
- MSL: 760, a small number of stems
- TL: 795, a 2.3 m high stem

**Age-determination transect**
- 790 – 47, 42, 30 – 2.5 – 2
- 760 – 69 – 4.0 – 20

**Documentation**
TL-Smith (44-46): max 779. Mr Sten Olofsson, Storvallen, states that the birch limit is higher today than when he was young.

<table>
<thead>
<tr>
<th>Past tree-limit</th>
<th>Degree of change</th>
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<tbody>
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<td>780</td>
<td>Apparent displacement: +15</td>
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<td></td>
<td>Significant displacement: 0</td>
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</table>

25 Storsnasen NE (70 197 I3 264)

**Present-day altitudinal limits**
- FL: 805, even limit
- MSL: 760, one stem
- TL: 865, two 2.5 m high stems
- SL: 875, a 0.9 m high shrub

**Age-determination transect**
- 865 – 31 – 2.5 – 2
- 855 – 26 – 2.0 – 2
- 845 – 25 – 2.2 – 2
- 845 – 45, 37, 35, 34, 32 – 1.5 – 1
- 820 – 43, 38, 34, 33, 28 – 2.3 – 2
- 810 – 42, 40, 39, 37, 37 – 2.5 – 2
- 760 – 71 – 5.5 – 20

**Fig. 15.** Birches growing 10 m below the tree-limit (880 m a.s.l.) at locality 26. Around 1940 there were, at most, only birch shrubs less than 1 m high growing here. The photo was taken just before the trees burst into leaf and it is obvious that only a slight increase in the duration of the snow-period would make their continued existence at this locality impossible. Photo: June 6, 1974.

**Fig. 16.** Birches growing 30 m below the tree-limit (880 m a.s.l.) at locality 26. Stem base age of the oldest one was 39 years. These stems are growing very close to the local snowline at leafing time and have now attained a length at which they are very liable to be broken by the weight of snow. Photo: June 6, 1974.
Storvallen, states that the birch limit is higher today than when he was young. Kilander’s (1955) determinations on this hillslope in 1951 gave the following results:

- 855–850, several birch thickets, ca 1 m high.
- 810, scattered arborescent birches
- 785, small, low-growing, clumps of trees

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +70</td>
</tr>
<tr>
<td>Significant displacement: +55</td>
</tr>
</tbody>
</table>

27 Storsnasen SE (70 165 13 277)

**Present-day altitudinal limits (1974)**

- FL: 800, clumps of trees
- MSL: 810, a small number of stems
- TL: 875, a small group of birches, with ca 2.5 m high stems

**Age-determination transect**

| Degree of change | Apparent displacement: +75 |
|------------------|
| Significant displacement: +60 |

Fig. 17. On both sides of this ridge at locality 28 (805 m a.s.l.) birch has colonised wide areas of ground which receive a relatively long-lasting snow cover. On the other hand, on the crest of the ridge, which is dry in summer and retains only a thin snow cover in winter, there has been no birch colonisation since 1915/16. Photo: June 5, 1974.
Fig. 18. The largest birch tree indicates the position of the tree-limit in 1915/16 (PTL at locality 28; 825 m a.s.l.). A stem core taken ca 1 m above the snow surface gave an age of 71 years. Despite the depth of snow still lying here (ca 1 m) birch leafing is quite well advanced. Photo: June 5, 1974.

28 Norder-Tväralumpen E (70 149 13 269)

Present-day altitudinal limits (1974)

MSL: 825, a small number of stems
TL: 915, four ca 2.5 m high stems

Age-determination transect
915 – 33 – 2.5 – 2
890 – 37, 28 – 3.5 – 2
850 – 44, 42, 40, 36, 34, 34 – 2.7 – 2
825 – 51 – 5.0 – 1.3
825 – 55, 50, 27 – 3.3 – 2
825 – 71 – 6.0 – 20
805 – 99, 94, 35 – 4.0 – 2
805 – 1 14 – 4.0 – 20

Documentation
TL-Smith (51):803. Mrs Gunborg Antholm and Mr Sten Olofsson, both of Storvallen, state that the birch limit is higher today than when they were young.

Kilander (1955) recorded the following birch limits in 1951:
855, a 1 m high thicket
875, five big bushes
865, a 2 m high thicket
830, a fringe of shrubs and low trees

Past tree-limit Degree of change
825 Apparent displacement: +90
Significant displacement: +90

29 Norder-Tväralumpen SE (70 142 13 268)

Present-day altitudinal limits (1977)

MSL: 790, a small number of stems
TL: 905, a small clump of 2.5 m high stems

Age-determination transect
905 – 45, 38 – 2.5 – 2
850 – 40 – 5.0 – 20
790 – 85, 75 – 4.0 – 20

Documentation
TL-Smith (52):804. Mrs Gunborg Antholm and Mr Sten Olofsson, both of Storvallen, state that the birch limit is higher today than when they were young.

Past tree-limit Degree of change
805 Apparent displacement: +100
Significant displacement: +85

30 Getryggen E (70 132 13 268)

Present-day altitudinal limits (1973)

MSL: 810, a small number of stems
TL: 920, a 2 m high stem

Age-determination transect
920 – 32 – 2.0 – 2
880 – 58, 51, 50, 44, 34 – 4.0 – 2
853 – 55, 50, 40, 38, 36 – 4.5 – 2
840 – 34 – 4.5 – 20
815 – 48 – 5.5 – 20
810 – 64 – 6.0 – 20
795 – 7 – 6.0 – 20

Documentation
TL-Smith (53):812. Mrs Gunborg Antholm and Mr Sten Olofsson, both of Storvallen, state that the birch limit is higher today than when they were young.

Past tree-limit Degree of change
810 Apparent displacement: +110
Significant displacement: +95

31 Getryggen SE (70 119 13 259)

Present-day altitudinal limits (1973)

MSL: 845, even limit
TL: 890, a small number of individual trees with 2-3 m high stems

Age-determination transect
890 – 54 – 3.0 – 10
890 – 60 – 2.0 – 2

Documentation
TL-Smith (54):808.

Dr. Sven Kilander has placed the following unpublished results of his own observations in 1948, at my disposal:
880, shrubs
845, a solitary tree
845, an isolated birch thicket

Past tree-limit Degree of change
810 Apparent displacement: +80
Significant displacement: +65

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Fig. 19. The tree-limit at locality 32 (935 m a.s.l.). Photo: August 6, 1972.

Fig. 20. The same as shown in Fig. 19. This birch has become established long after 1915/16, obviously as a result of the more rapid disappearance of the snow-patch after that time. Photo: June 7, 1974.

Fig. 21. The same tree as shown in Figs. 19-20. A comparison of the photographs indicates that no change in the vitality of this birch has occurred in 1972-1977. Maximum snow depth here does not exceed 30 cm, i.e. the photo provides no support for the view that, as a tree, the closer to the tree-limit birch grows the greater need it has for a deeper snow cover as a protection against the increasing severity of the local climate with increasing altitude. Photo: March 2, 1977.

32 Getryggen S (70 115 13 244)

Present-day altitudinal limits (1978)

| FL: 840, wedges and small clumps of trees | MSL: 835, a small number of stems |
| TL: 930, a 2.5 m high stem |
| SL: 945, a 1.8 m high stem |

Age-determination transect

930 - 26 - 2.5 - 2
925 - 52 - 2.7 - 2
920 - 56 - 4.5 - 2
905 - 53 - 2.3 - 2
835 - 69 - 5.0 - 20

Documentation

TL-Smith (58):830.

Kilander (1955) recorded the following values in 1948-51:

920, a 1.5 m high thicket
916-985, a good number of fairly tall and slender shrubs and birch thickets, of which the highest measured 2.5 m, at 916 m altitude
895, several trees, forming a thicket of 25 m² in extent; he draws attention to the fact that these trees had obviously increased in height only a short time previously.

852, scattered trees
830-825, spearpoints of forest

Past tree-limit Degree of change
835 Apparent displacement: +95
   Significant displacement: +85

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Fig. 22. A birch tree growing 25 m below the tree-limit (930 m a.s.l.) at locality 32, where the tree-limit has risen by 85 m since 1915/16. The stoutest stem had a stem base age of 53 years. Photo: March 2, 1977.

Fig. 23. The same tree as in Fig. 22. A comparison of these two photos shows the same depth and distribution of the snow cover here in 1977 and 1978. Photo: March 24, 1978.

33 Blåhammarfjället SSW (70 114 13 221)
Present-day altitudinal limits (1972)
FL: 880, clumps of trees
MSL: 845, one stem
TL: 895, a small number of 2–2.5 m high stems

Age-determination transect
895 – 41, 30 – 2.5 – 2
845 – 76 – 3.5 – 20

Documentation
TL-Smith (31): 854

Past tree-limit Degree of change
855 Apparent displacement: +40
Significant displacement: +25

34 Stor-Ulvafjället N (70 099 13 239)
Present-day altitudinal limits (1975)
FL: 865, clumps of trees
MSL: 865, a small number of stems
TL: 915, a 3.2 m high stem

Age-determination transect
915 – 31 – 3.2 – 2
890 – 43, 40, 40, 37, 31 – 4.3 – 2
865 – 79 – 4.0 – 20

Documentation
TL-Smith (59): 884

Past tree-limit Degree of change
885 Apparent displacement: +30
Significant displacement: +15

35 Stor-Ulvafjället SE (70 088 13 246)
Present-day altitudinal limits (1975)
FL: 855, clumps of trees

36 Lill-Ulvafjället N (70 076 13 272)
Present-day altitudinal limits (1975)
MSL: 870, a small number of stems
TL: 875, two individual trees, each bearing several ca 3 m high stems

Age-determination transect
875 – 63, 47 – 3.0 – 2
870 – 35, 28, 28 – 3.5 – 2
870 – 77 – 5.0 – 20
840 – 91 – 5.0 – 2

Documentation
TL-Smith (62): 851

Past tree-limit Degree of change
870 Apparent displacement: +5
Significant displacement: +5

37 Lill-Ulvafjället E (70 069 13 279)
Present-day altitudinal limits (1975)
FL: 815, wedge
MSL: 850, several stems
TL: 895, a 2.5 m high stem

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Age determination transect
895 - 32 - 2.5 - 2
890 - 31 - 2.0 - 2
885 - 33 - 3.5 - 2
870 - 31, 30 - 2.5 - 2
865 - 33 - 2.5 - 2
850 - 74 - 4.5 - 20
835 - 77 - 4.5 - 2.0

Documentation
Smith unquestionably visited this locality (cf. Smith 1920, p. 122). The absence of any cited altitude is almost certainly because the tree-limit lay between 829 and 851 m, the values determined at the nearest localities on either side of the locality now under discussion.

Past tree-limit
850

Apparent displacement: +45
Significant displacement: +45

38 Lill-Ulvåfjället SW (70 063 13 249)

Present-day altitudinal limits (1975)
TL: 900, a 3.1 m high stem

Age-determination transect
900 - 47 - 3.1 - 2
890 - 33, 25 - 1.0 - 2

Documentation
Smith probably visited this locality. The absence of any altitudinal record may therefore be taken as an indication that no trees were growing above the valley bottom, at ca 870 m.

Dr Sven Kilander’s unpublished results from 1951 are as follows:
900, ca 0.5 m high shrubs
890, two shrubs with coarse-grown stems, 0.5 m and 0.75 m high, respectively.

Thanks to the detailed description given for this locality, there is no doubt whatsoever that the birches described by Dr. Kilander in 1951 are identical to those which were included in my age-determination transect made in 1975, i.e. the mean increase in stem length during the period 1951–1975, 10 cm/year, is therefore a very precise value.

Past tree-limit
<870

Apparent displacement: +30
Significant displacement: +30

39 Ö Endalshöjden E (70 008 13 285)

Present-day altitudinal limits (1975)
FL: 820, even limit
MSL: 840, a small number of stems
TL: 860, two 3.5 m high stems
SL: 870, several 1.5 m high shrubs, some of which were dead

Age-determination transect
870 - 40 - 1.5 - 2
860 - 30, 29 - 3.5 - 2
845 - 54, 38 - 3.3 - 2

Fig. 24. The tree-limit (900 m a.s.l.) at locality 38. The birch had a stem base age of 47 years. It is growing in a dwarf-shrub heath with Vaccinium myrtillus and Betula nana as field-layer dominants. Dr. Sven Kilander noted the presence of this birch in 1951, at which time it was 0.5 m high. Despite the relatively unfavourable development of the climate since 1950, this stem has managed to continue growing very well, a fact which indicates that the position of the tree-limit is not immediately controlled by the ambient air temperature and its fluctuations during the vegetative period. Photo: August 19, 1975.

840 – 80, 74 – 5.0 – 20
835 – 95, 93, 86, 83, 58 – 3.0 – 2

Documentation
TL-Smith (65):829

Past tree-limit
840

Apparent displacement: +20
Significant displacement: +20

40 Gåsen W (69 998 13 318)

Present-day altitudinal limits (1972)
FL: 905, clumps of trees
MSL: 900, a small number of stems
TL: 935, a 3 m high stem

Age-determination transect
900 – 84 – 3.5 – 20

Documentation
TL-Smith (68):909. Smith calls this locality “Gåsån”, which is very probably identical with the actual locality mentioned above (cf. Kilander 1955, p. 52).

Kilander (op. cit.) quotes the following altitudinal limits, based on observations made 1950-51:
960, a prostrate bush
952, a 1.5 m high thicket
945–25, several low shrubs
935, a 1.75 m high shrub
923, several bushes, maximum height 2.5 m
924, a ca 3 m high thicket

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42, Leif Kullman

920, a group of trees, forming a lobe of forest

<table>
<thead>
<tr>
<th>Past tree-limit</th>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>910</td>
<td>Apparent displacement: +25</td>
</tr>
<tr>
<td></td>
<td>Significant displacement: +15</td>
</tr>
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</table>

41, Laptentjakke W (70 075 13 297)

Present-day altitudinal limits (1976)
FL: 925, a group of trees
MSL: 920, a small number of stems
TL: 1005, a 5 m high stem

Age-determination transect
1005 – 43 – 5.0 – 2
1005 – 33 – 5.0 – 20
985 – 46, 41 – 4.5 – 2
985 – 35 – 4.5 – 2
955 – 45, 44, 44, 34 – 4.3 – 2
920 – 85 – 4.0 – 20

Documentation
TL-Smith (73): 964.

Dr. Sven Kilander has placed his unpublished results for altitudinal limits, made in 1943, at my disposal. These are cited below, together with his published results (Kilander 1955):
1013, a shrub
975, a 3 m high tree
940, a few 4–5 m high trees
940, a forest fragment

Past tree-limit | Degree of change
965 | Apparent displacement: +40
| Significant displacement: +25

42, Laptentjakke NW (70 087 13 291)

Present-day altitudinal limits (1972)
FL: 925, even limit
MSL: 875, a small number of stems
TL: 950, several individual trees, bearing 2 – 2.5 m high stems

Age-determination transect
No investigation made

Documentation
TL-Smith (77): 883

Past tree-limit | Degree of change
885 | Apparent displacement: +65
| Significant displacement: +50

43, Mettjebrettjakke W (70 109 13 288)

Present-day altitudinal limits (1974)
FL: 885, even limit
MSL: 885, one stem
TL: 935, a 2.5 m high stem

Age-determination transect
925 – 53, 44, 41 – 3.3 – 2
910 – 46 – 3.0 – 2
885 – 80, 62, 37 – 4.0 – 2
885 – 63 – 4.0 – 20

Fig. 25. A group of birches growing 10 m below the present-day tree-limit (935 m a.s.l., locality 43) and which became established after 1920. Across this shallow depression, at right angles to the slope, there is a pronounced ecological gradient with regard to the time of the snow-melt in spring, which is reflected in the composition of the vegetation. All the birches have become established in the same part of this gradient. In other words, birch colonisation and the upward displacement of the tree-limit appear to have been directly related to the more rapid disappearance of the snow cover, during the first half of the present century. Nardus stricta dominates the vegetation of the lowest part of the ground depression, with dwarf-shrub heaths, dominated by Vaccinium myrtillus and Betula nana, respectively, at successively higher levels. Photo: June 10, 1974.
Change and stability of birch tree-limit in the Scandes

TL-Smith (79): 884. This locality is named “Stråten” on Smith’s map.

**Past tree-limit**  
885  
Degree of change  
Apparent displacement: +50  
Significant displacement: +35

44 Stråten WNW (70 131 13 295)  
**Present-day altitudinal limits (1974)**  
FL: 875, even limit  
MSL: 865, one stem  
TL: 945, a 2 m high stem  
SL: 950, a 2.5 m high, dead stem, with basal live shoots several decimeters in length.

**Age-determination transect**  
930 – 58, 45, 45 – 3.0 – 2  
905 – 48, 44, 38 – 3.0 – 2  
880 – 53, 49, 46, 37 – 4.5 – 2  
865 – 76 – 4.5 – 20  
855 – 68 – 5.0 – 20

**Documentation**  
TL-Smith (87 or 88): 863 or 871

45 Hårdeggen NW (70 149 13 315)  
**Present-day altitudinal limits (1974)**  
FL: 865, even limit  
MSL: 840, several stems

870  
Degree of change  
Apparent displacement: +75  
Significant displacement: +65

46 Hårdeggen N (70 150 13 321)  
**Present-day altitudinal limits (1974)**  
FL: 855, even limit  
MSL: 855, one stem  
TL: 935, two, single-stemmed, ca 2.5 m high individual trees

**Age-determination transect**  
935 – 32,25 – 2.5 – 2  
925 – 30 – 3.0 – 2  
855 – 150, 106, 98, 58 – 3.5 – 2  
855 – 78 – 3.5 – 20  
840 – 71 – 4.0 – 20

**Documentation**  
TL-Smith (90): 836

47 Västerån N (70 133 13 342)  
**Present-day altitudinal limits (1977)**  
FL: 875, a small, dense clump of trees  
MSL: 855, a small number of stems  
TL: 890, a small number of 3.5 – 4 m high individual birches

**Age-determination transect**  
890 – 53 – 3.5 – 2  
875 – 36, 33, 32 – 2.5 – 2  
855 – 93 – 4.5 – 20

**Documentation**  
TL-Smith (92): 850. Smith almost certainly calibrated his altimeter at pt. 926 shown on his map. This spot-height lies at ca 940 m according to the modern topographical map. Smith’s values have therefore been corrected by +14 m.

**Past tree-limit**  
855  
Degree of change  
Apparent displacement: +80  
Significant displacement: +80

48 W of Bunnran NNE (70 122 13 363)  
**Present-day altitudinal limits (1974)**  
FL: 800, lobe  
MSL: 850, one stem  
TL: 855, a 2.5 m high stem

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Fig. 26. The tree-limit (935 m a.s.l.) at locality 46, a locality characterised by the large quantities of snow present in the extensive snow-field nearby at the time of birch leafing. In all probability these snow-fields covered an appreciably larger area at the same time of the year in 1915/16, thereby making tree colonisation at that time impossible. Photo: June 8, 1974.
Age-determination transect
No investigation made

Documentation
TL-Smith (93):850. Smith’s value has been corrected by +14 m for similar reasons as for locality 47.

Past tree-limit  Degree of change
850  Apparent displacement: +35
       Significant displacement: +20

49  NW of pt 1242 N (70 144 13 381)

Present-day altitudinal limits (1974)
FL:  785, clumps of trees
MSL: 875, two stems
TL:  880, a small number of 2 m high stems

Age-determination transect
875 – 51, 39 – 3.5 – 2
875 – 64, 64 – 3.5 – 20
860 – 71 – 4.0 – 20
830 – 73, 69 – 4.0 – 20
815 – 117, 98, 70, 57 – 2.5 – 2
800 – 103, 97, 28 – 4.0 – 2

Documentation
TL-Smith (95):800. Smith’s value is probably too low, because he was unaware of the existence of the highest-lying trees, which grow on sites hidden by rises in the ground of this otherwise fairly flat terrain.

Past tree-limit  Degree of change
875  Apparent displacement: +5
       Significant displacement: +5

50  N of pt 1242 N (70 146 13 393)

Present-day altitudinal limits (1974)
FL:  835, lobes
MSL: 835, a small number of stems
TL:  860, a small dense clump of trees, bearing 2.5–3 m high stems

Age-determination transect
860 – 93, 63, 51, 42 – 2.7 – 2
835 – 66 – 3.2 – 20
835 – 95, 81, 65 – 3.6 – 2
815 – 117, 98, 70, 57 – 3.5 – 2
815 – 73 – 6.5 – 20

Documentation
TL-Smith (96):835

Past tree-limit  Degree of change
835  Apparent displacement: +25
       Significant displacement: +15

51  Grötjmjölhögen S (70 155 13 416)

Present-day altitudinal limits (1972)
FL:  800, lobe
MSL: 805, one stem
TL:  805, a small number of 2–2.5 m high stems

Age-determination transect
No investigation made

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### Change and stability of birch tree-limit in the Scandes

#### 55 N Kyrkstensskäftet N (70 166 13 469)

**Past tree-limit** 830

**Degree of change**
- Apparent displacement: 0
- Significant displacement: 0

**Present-day altitudinal limits (1972)**
- **FL**: 795, lobes
- **MSL**: 790, a small numbers of trees
- **TL**: 820, several 2.3 m high stems

**Age-determination transect**
- No investigation made

**Documentation**
- TL-Smith (103):785. Smith, in conformity with general usage on the maps of his time, calls this and the following three localities “Rekdalshöjden.”

#### 56 N Kyrkstensskäftet NE (70 163 13 474)

**Past tree-limit** 790

**Degree of change**
- Apparent displacement: +30
- Significant displacement: +30

**Present-day altitudinal limits (1972)**
- **FL**: 800, lobes
- **MSL**: 790, one stem
- **TL**: 830, a small number of 2.5—3 m high stems

**Age-determination transect**
- No investigation made

**Documentation**
- TL-Smith (104):786. Smith’s account of the position of the two, relatively close-together, spot-height, localities 104 and 105 is somewhat obscure. This is of minor importance, however, since it is clear from Smith’s data that the tree limit was relatively uniform in altitude all over the actual hillslope under discussion.

#### 57 N Kyrkstensskäftet E (70 153 13 483)

**Past tree-limit** 790

**Degree of change**
- Apparent displacement: +40
- Significant displacement: +40

**Present-day altitudinal limits (1972)**
- **FL**: 800, even limit
- **MSL**: 780, a small number of stems
- **TL**: 850, several 2–2.5 m high stems

**Age-determination transect**
- No investigation made

**Documentation**
- TL-Smith (105):785. See the remarks under locality 56.

#### 58 N Kyrkstensskäftet SSE (70 124 13 487)

**Past tree-limit** 750

**Degree of change**
- Apparent displacement: +65
- Significant displacement: +55

**Present-day altitudinal limits (1972)**
- **FL**: 750, clumps of trees
- **MSL**: 750, one stem
- **TL**: 830, several 2–2.5 high stems

**Age-determination transect**
- No investigation made

**Documentation**
- TL-Smith (107):727. The nature of the terrain is such that it cannot be ruled out that Smith overlooked the highest-lying trees here.

#### 59 Kyrkstensfjället (Kyrkstenen) E (70 107 13 491)

**Past tree-limit** 750

**Degree of change**
- Apparent displacement: +20
- Significant displacement: +10

**Present-day altitudinal limits (1976)**
- **FL**: 790, even limit
- **MSL**: 790, one stem
- **TL**: 835, a group of 3–4 m high stems
- **SL**: 855, a small number of 1–1.5 m high stems growing on a rockface ledge

**Age-determination transect**
- 835 – 38, 37, 32 – 3.5 – 2
- 830 – 48, 48, 30 – 2.3 – 2
- 790 – 72 – 4.0 – 20

**Documentation**
- TL-Smith (121):814

#### 60 Rekhuvudet SW (70 163 13 505)

**Past tree-limit** 845

**Degree of change**
- Apparent displacement: +20
- Significant displacement: +10

**Present-day altitudinal limits (1971)**
- **FL**: 850, even limit
- **MSL**: 835, one stem
- **TL**: 870, a small number of 2–2.5 m high stems

**Age-determination transect**
- No investigation made

**Documentation**
- TL-Smith (110):845

#### 61 Ottfjallet NE (70 133 13 777)

**Past tree-limit** 845

**Degree of change**
- Apparent displacement: +25
- Significant displacement: +10

**Present-day altitudinal limits (1976)**
- **FL**: 775, even limit
- **MSL**: 775, several stems
- **TL**: 855, a 2 m high stem
- **SL**: 890, a 1.5 m high stem

**Age-determination transect**
- 855 – 28 – 2.0 – 2
- 835 – 30 – 2.0 – 2
- 830 – 37 – 3.0 – 2
- 815 – 45, 35, 28, 22 – 3.0 – 2
- 775 – 78 – 4.5 – 20

---

*Acta phytogeogr. suec. 65*
62 Ottfjället NE (70 115 13 593)

**Past tree-limit**

850

*Degree of change*

Apparent displacement: +15

Significant displacement: 0

**Present-day altitudinal limits (1971)**

**FL:** 870, clumps of trees

**MSL:** 865, one stem

**TL:** 930, a dense clump of trees, with 2.5 – 3 m high stems

**Age-determination transect**

865 – 74 – 5.5 – 20

**Documentation**

In 1950 Kilander (1955) noted the presence of several 1.5 m high shrubs at 900-903 m altitude.

**Past tree-limit**

865

*Degree of change*

Apparent displacement: +65

Significant displacement: +50

**63 Ottfjället SE (70 111 13 591)**

**Present-day altitudinal limits (1971)**

**FL:** 845, wedge

**MSL:** 805, a small number of stems

**TL:** 935, a small number of 2 – 2.5 m high stems

**SL:** 960, a small number of 1.5 – 1.8 m high shrubs, the top parts of which were deadwood

**Age-determination transect**

805 – 81 – 5.0 – 20

**Documentation**

In 1950 Kilander (1955) noted the presence of several 1.5 m high shrubs at 900-903 m altitude.

**Past tree-limit**

865

*Degree of change*

Apparent displacement: +65

Significant displacement: +50

**64 Ottfjället (Pucklarna) SSW (70 099 13 577)**

**Present-day altitudinal limits**

**FL:** 865, clumps of trees

**MSL:** 885, a small number of stems

**TL:** 935, a 2 m high stem

**Age-determination transect**

920 – 35 – 2.5 – 2

915 – 22 – 2.5 – 20

915 – 42,32 – 2.5 – 2

910 – 27 – 2.1 – 2

905 – 32 – 2.3 – 2

900 – 33 – 2.7 – 2

895 – 32 – 3.0 – 2

895 – 28 – 2.8 – 10

895 – 63,20 – 3.0 – 20

890 – 53 – 3.0 – 10

885 – 33 – 2.5 – 2

880 – 58 – 3.0 – 2

880 – 22 – 3.0 – 20

870 – 66 – 3.5 – 20

865 – 46, 42, 33 – 5.0 – 2

**Documentation**

TL-Smith (118):842.

In 1950, Kilander (1955) noted the following altitudinal limits:

858, 845, 840, spearpoints of more or less continuous thickets; 848 a large tree

**Past tree-limit**

855

*Degree of change*

Apparent displacement: +25

Significant displacement: +25
TL: 825, a multi-stemmed birch, the longest stem 4 m high.

**Age-determination transect**

825 – 55, 37 – 3.0 – 2
815 – 112 – 6.5 – 20

**Documentation**

TL-Smith (120):826

**Past tree-limit**

825

**Degree of change**

Apparent displacement: 0
Significant displacement: 0

68 Middagsvalen NE (70 069 13 609)

**Present-day altitudinal limits (1974)**

FL: 810, even limit
MSL: 800, one stem
TL: 825, a few 2 m high stems

**Age-determination transect**

825 – 37, 32 – 2.0 – 2
800 – 62 – 4.0 – 20

**Documentation**

Smith’s maximum tree-limit for this small hill was 826 m (= preceding locality)

**Past tree-limit**

800

**Degree of change**

Apparent displacement: +25
Significant displacement: +25

69 Middagsvalen W (70 067 13 605)

**Present-day altitudinal limits (1974)**

FL: 810, even limit
MSL: 800, several stems
TL: 820, a few 2 – 3 m high stems
SL: 825, a small number of 0.5 – 1 m high stems

**Age-determination transect**

820 – 34, 27 – 3.0 – 2
805 – 62 – 3.0 – 2
800 – 84, 69 – 5.5 – 20

**Documentation**

See locality 68

**Past tree-limit**

800

**Degree of change**

Apparent displacement: +20
Significant displacement: +20

70 S Kyrkstenskaftet SE (70 074 13 488)

**Present-day altitudinal limits (1974)**

FL: 805, lobes
MSL: 830, a small number of stems
TL: 870, a small number of 2 – 3 m high stems

**Age-determination transect**

870 – 47, 43 – 2.5 – 2
850 – 84, 81, 56 – 3.0 – 2
830 – 78 – 3.5 – 20

**Documentation**

TL-Smith (122):838

**Past tree-limit**

840

**Degree of change**

Apparent displacement: +30
Significant displacement: +15

71 Pt. 1011 S (70 066 13 459)

**Present-day altitudinal limits (1974)**

FL: 920, lobe
MSL: 920, one stem
TL: 945, a 2.5 m high stem

**Age-determination transect**

940 – 48, 30, 28 – 3.0 – 2
920 – 74, 64 – 4.0 – 2
920 – 65 – 4.5 – 13
895 – 35 – 5.0 – 20
890 – 72 – 5.0 – 20

**Documentation**

TL-Smith (123):845

**Past tree-limit**

890

**Degree of change**

Apparent displacement: +55
Significant displacement: +55

72 Stor-Stensdalsfjället S (70 068 13 456)

**Present-day altitudinal limits (1972)**

FL: 890, clumps of trees
MSL: 865, one stem
TL: 945, a few 2 – 2.5 m high stems

**Age-determination transect**

865 – 74 – 3.5 – 20

**Documentation**

TL-Smith (124):851. Smith gives values for four, imperfectly localised, points from E to W along this hill-slope. The positions of the furthest-east and furthest-west of these localities (pts. 124 and 127) can be determined with a fair degree of certainty (my localities 72 and 73, respectively), thanks to other, easily identified, localities in their immediate vicinities.

**Past tree-limit**

865

**Degree of change**

Apparent displacement: +80
Significant displacement: +80

73 Stor-Stensdalsfjället S (70 074 13 438)

**Present-day altitudinal limits (1972)**

FL: 860, clumps of trees
MSL: 900, several stems
TL: 965, a 2 m high stem

**Age-determination transect**

900 – 82 – 3.5 – 20

**Documentation**

TL-Smith (127):915. See locality 72.

**Past tree-limit**

915

**Degree of change**

Apparent displacement: +50
Significant displacement: +35

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Fig. 27. The uppermost tree-sized birch at locality 75 (990 m a.s.l.). At leafing time the nearest snow-patch is ca 5 m away from this birch tree. Judging from the dimensions of the stem, the stem base age would not exceed 25 years. Photo: June 29, 1976.

Fig. 28. The arrow marks the position of the tree shown in Fig. 27. The establishment of this birch, and thus the rise in the tree-limit as well, is obviously related to the local snow accumulations seen on the photo, which by all accounts were even more widespread at the same season of the year in 1915/16. Photo: June 29, 1976.
76  Sjäntja N (70 068 13 396)

Present-day altitudinal limits (1977)
FL: 895, clumps of trees
MSL: 895, one stem
TL: 905, a small number of 2 – 2.5 m high stems

Age-determination transect
905 – 35 – 2.5 – 2
895 – 89 – 5.0 – 20
880 – 79 – 6.5 – 20

Documentation
TL-Smith (131):900

Past tree-limit  Degree of change
900  Apparent displacement: +5
Significant displacement: 0

77  Tubbeke SE (70 049 13 428)

Present-day altitudinal limits (1974)
FL: 915, even limit
MSL: 910, one stem
TL: 940, a 2.5 m high stem
SL: 970, several 0.5 – 1.5 m high shrubs

Age-determination transect
940 – 33 – 2.5 – 2
920 – 44, 43, 41, 40, 39 – 2.8 – 2
910 – 65 – 4.5 – 20
900 – 80 – 5.0 – 20

Documentation
TL-Smith (134):910. From Smith’s isohypsic map (Karta I) it is clear that he calibrated his altimeter on the summit of this small hill, at 1032 m, a value which coincides exactly with that given on the modern topographical map.

Past tree-limit  Degree of change
910  Apparent displacement: +30
Significant displacement: +25

78  Lill-Stensdalsfjället W (70 046 13 441)

Present-day altitudinal limits (1974)
FL: 920, diffuse limit
MSL: 930, several stems
TL: 955, scattered trees and small clumps of trees, maximum height 2.5 m

Age-determination transect
955 – 45, 38, 33, 31, 24 – 2.3 – 2
930 – 68, 45, 41, 39, 37 – 5.0 – 2
930 – 71 – 5.0 – 20

Documentation
TL-Smith (137):905

Past tree-limit  Degree of change
930  Apparent displacement: +25
Significant displacement: +25

Fig. 29. A ring count of a stem core taken 2 m above the ground gave an age of 71 years for this well-grown birch, which thereby indicates the position of the tree-limit in 1915/16 (PTL). The birches growing higher up the hillslope have all attained tree height considerably later than that date. Locality 78, 930 m a.s.l. Photo: June 30, 1974.

79  Lill-Stensdalsfjället N (70 039 13 455)

Present-day altitudinal limits (1974)
FL: 885, tongues and lobes
MSL: 870, a small number of stems
TL: 970, several 2.5 m high stems

Age-determination transect
970 – 55, 42 – 2.5 – 2
960 – 36 – 3.5 – 2
910 – 38 – 2.2 – 2
880 – 73, 53 – 5.5 – 20

Documentation
TL-Smith (140):878. Smith mentions values for three, rather imprecisely located, places on this hillslope. The easternmost of these has been selected for comparison, with the TL value for the eastern part of the N-facing hillslope.

Past tree-limit  Degree of change
880  Apparent displacement: +90
Significant displacement: +80

80  Lill-Stensdalsfjället ENE (70 022 13 469)

Present-day altitudinal limits (1974)
FL: 850, clumps of trees
MSL: 865, a small number of stems
TL: 920, an isolated clump of trees, ca 3 m high

Age-determination transect
865 – 69 – 3.5 – 20

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Past tree limit | Degree of change
--- | ---
875 | Apparent displacement: +45
 | Significant displacement: +35

81 Smällhögarna NW (70 018 13 478)

Present-day altitudinal limits (1974)
FL: 875, clumps of trees
MSL: 880, one stem
TL: 920, two 3.5 m high stems

Age-determination transect
920 – 42 – 3.5 – 2
905 – 51 – 3.0 – 2
880 – 65 – 5.5 – 20

Documentation
TL-Smith (143):870

Past tree limit | Degree of change
--- | ---
880 | Apparent displacement: +40
 | Significant displacement: +40

82 Smällhögarna NNE (70 018 13 487)

Present-day altitudinal limits (1976)
FL: 890, clumps of trees
MSL: 890, a small number of stems
TL: 935, a 2.3 m high stem
SL: 940, a 1.9 m high stem

Age-determination transect
935 – 42 – 2.3 – 2
925 – 38, 36, 35, 33 – 2.8 – 2
890 – 79 – 4.5 – 20

Documentation
TL-Smith (144):905

Past tree limit | Degree of change
--- | ---
905 | Apparent displacement: +30
 | Significant displacement: +25

83 Smällhögarna E (69 993 13 475)

Present-day altitudinal limits (1974)
FL: 875, clumps of trees
MSL: 885, several stems
TL: 925, a 3 m high stem

Age-determination transect
925 – 22 – 3.0 – 20
915 – 60, 55 – 3.0 – 2
915 – 31 – 3.0 – 20
885 – 79 – 6.0 – 20

Documentation
TL-Smith (145):903

Past tree limit | Degree of change
--- | ---
905 | Apparent displacement: +20
 | Significant displacement: +10

84 Gruvsmällen SSE (69 954 13 459)

Present-day altitudinal limits (1974)
FL: 945, small clumps of trees
MSL: 955, mouldering remains of quite coarsely-dimensioned, old stems
TL: 955, a 3.2 m high stem

Age-determination transect
955 – 42 – 3.2 – 2
945 – 61, 57, 53, 48 – 4.0 – 2

Documentation
Since this locality was almost certainly visited by Smith, the absence of any value for the tree-limit here can probably be assumed to indicate that trees were either absent, or present in only very small numbers (i.e. overlooked).

Past tree limit | Degree of change
--- | ---
955 | Apparent displacement: 0
 | Significant displacement: 0

85 Vållåvalen N (69 970 13 490)

Present-day altitudinal limits (1972)
FL: 920, clumps of trees
MSL: 920, one stem
TL: 960, small clumps of trees, bearing 2 m high stems

Age-determination transect
900 – 67 – 3.0 – 20

Documentation
TL-Smith (147):910

Past tree limit | Degree of change
--- | ---
910 | Apparent displacement: +30
 | Significant displacement: +20

86 Vållåvalen S (69 965 13 513)

Present-day altitudinal limits (1972)
FL: 975, wedge
MSL: 915, one stem
TL: 980, a small number of 2 m high stems

Age-determination transect
915 – 74 – 3.5 – 20

Documentation
TL-Smith (149):920

Past tree limit | Degree of change
--- | ---
920 | Apparent displacement: +55
 | Significant displacement: +50

87 Vållåvalen ESE (69 965 13 515)

Present-day altitudinal limits (1972)
FL: 950, clumps of trees
MSL: 940, a small number of stems
TL: 985, a multi-stemmed individual tree, ca 2 m high

Age-determination transect
No investigation made
Change and stability of birch tree-limit in the Scandes

88 Luspentjarve N (69 930 13 481)

Present-day altitudinal limits (1972)
FL: 915, clumps of trees
MSL: 940, three stems
TL: 940, three 3.5 m high stems

Age-determination transect
940 – 78 – 3.5 – 20

Documentation
TL-Smith (152):937
Past tree-limit Degree of change
940 Apparent displacement: 0
Significant displacement: 0

89 Luspentjarve E (69 935 13 492)

Present-day altitudinal limits (1974)
FL: 900, clumps of trees
MSL: 920, one stem
TL: 960, a small number of 2 – 2.5 m high stems

Age-determination transect
960 – 31 – 2.3 – 2
930 – 102 – 3.5 – 2
920 – 58 – 4.0 – 20
910 – 72 – 4.0 – 20
900 – 80 – 4.5 – 20

Documentation
TL-Smith (153):940. Smith’s observations can scarcely have been made on the actual S-facing slope of the mountain, since at no point does this slope extend as low down as 940 m a. s. l. and today it is completely destitute of any vestiges of birch growth. With the greatest probability his value instead refers to the S-facing flank of one of the morainic ridges which are present on the E-facing slope of the mountain.

Past tree-limit Degree of change
940 Apparent displacement: +20
Significant displacement: +10

90 Gråsjöfälttlet W (69 939 13 506)

Present-day altitudinal limits (1974)
FL: 945, tongues and lobes
MSL: 950, one stem
TL: 990, a 2 m high stem
SL: 1000, a small number of 0.5 m high shrubs

Age-determination transect
990 – 32 – 2.0 – 2
980 – 34 – 2.5 – 2
975 – 51, 37, 35, 32 – 3.0 – 2
965 – 31 – 4.5 – 20
960 – 27 – 4.0 – 20
950 – 81 – 4.5 – 20

Fig. 30. The tree-limit at locality 89 (960 m a.s.l.). The longest stem had a stem base age of 31 years. The displacement of the tree-limit at this locality, characterised by marked snow accumulation, has nevertheless remained relatively slight, because of the absence of suitable edaphic conditions above the altitude of the 1915/16 tree-limit. Photo: July 2, 1974.

91 Gråsjöfälttlet ENE (69 943 13 514)

Present-day altitudinal limits (1974)
FL: 910, even limit
MSL: 925, a small number of stems
TL: 990, a 2 m high stem

Age-determination transect
990 – 31 – 2.0 – 2
975 – 42 – 3.5 – 2
965 – 38, 34 – 3.0 – 2
955 – 33 – 3.5 – 2
940 – 32, 30 – 2.7 – 2
925 – 74 – 5.0 – 20

Documentation
TL-Smith (157):936
Past tree-limit Degree of change
965 Apparent displacement: +25
Significant displacement: +15

92 Trondfjäll S (69 934 13 539)

Present-day altitudinal limits (1976)
FL: 950, clumps of trees
MSL: 975, one stem

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Fig. 31. At locality 92 the 1915/16 tree-limit (PTL) is indicated by the birch tree shown, 975 m a.s.l. A core from this particular tree, taken 2 m above the ground, gave an age of 78 years. The vegetation in the immediate vicinity is dominated by Vaccinium myrtillus. Photo: July 5, 1976.

TL: 1010, a multi-stemmed birch, maximum height 2 m
SL: 1025, a small number of 0.5 – 1.5 m high shrubs

Age-determination transect
1010 - 22 - 2.0 - 2
985 - 56 - 3.0 - 2
985 - 28 - 1.8 - 2
980 - 30 - 2.0 - 2
975 - 78 - 4.0 - 20

Documentation
TL-Smith (161):975

Past tree-limit Degree of change
975
Apparent displacement: +35
Significant displacement: +25

94 Trondfjäll NW (69 951  13 539)

Present-day altitudinal limits (1971)
FL: 940, tongue
MSL: 940, one stem
TL: 950, a 2.3 m high stem

Age-determination transect
940 – 89 – 4.0 – 20

Documentation
For localities situated on either side of the one under discussion, Smith cites values of 950 and 910 m, respectively. The actual tree-limit probably lay somewhere in between these two values.

Past tree-limit Degree of change
940
Apparent displacement: +10
Significant displacement: 0

95 Trondfjäll N (69 962  13 559)

Present-day altitudinal limits (1971)
FL: 875, tongue
MSL: 905, one stem
TL: 905, a few 3 m high stems

Age-determination transect
905 – 77 – 3.0 – 2
905 – 68 – 3.0 – 20

Documentation
TL-Smith (163):910

Past tree-limit Degree of change
910
Apparent displacement: -5
Significant displacement: 0

96 V Endalshöjden SW (70 028  13 197)

Present-day altitudinal limits (1976)
FL: 870, clumps of trees
MSL: 870, a small number of stems
TL: 905, a clump of stems, maximum height 3 m

Age-determination transect
905 – 76, 58, 49, 40, 39 – 2.7 – 2
900 – 57 – 3.0 – 20
870 – 85 – 4.5 – 20

Documentation
TL-Smith (29):830.
In 1949 Kilander (1955) found an extensive stand of arborescent, bushy birches at ca 900 m, as well as a 3 m and a 4 m high tree growing at 872 m.

Past tree-limit Degree of change
900
Apparent displacement: +5
Significant displacement: +5

97 Fruntimmersklumpen E (69 970  13 253)

Present-day altitudinal limits (1977)
FL: 870, a few small clumps of 2 – 2.5 m high stems
MSL: 865, a multi-stemmed birch, including the mouldering remains of former stems which exceeded 2 m in length

Acta phytogeogr. suec. 65
Change and stability of birch tree-limit in the Scandes

TL: 905, an individual tree with five 2–2.5 m high stems

**Age-determination transect**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>905</td>
<td>39–2</td>
<td>2.3–1</td>
<td></td>
</tr>
<tr>
<td>875</td>
<td>58–3</td>
<td>3.0–2</td>
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<tr>
<td>875</td>
<td>34–2</td>
<td>3.0–13</td>
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<tr>
<td>870</td>
<td>37,35</td>
<td>2.5–2</td>
<td></td>
</tr>
<tr>
<td>865</td>
<td>63–3</td>
<td>3.0–2</td>
<td></td>
</tr>
</tbody>
</table>

**Documentation**

Smith (1920, p. 122) visited this area, but makes no mention of any arborescent birches, which suggests that no such specimens grew above the floor of the valley (ca 850 m a.s.l.). Sporadic trees may, however, have gone unnoticed in this very broken terrain, with its multitude of low ridges and hillocks rising above the relatively gently-sloping hillside.

**Past tree-limit**

905

**Degree of change**

Apparent displacement: +40

Significant displacement: +40

98 Hammaren E (69 909 13 246)

**Present-day altitudinal limits (1977)**

**FL:** 900, small clumps of trees

**TL:** 920, four 2–2.5 m high stems

**SL:** 945, a 1.3 m high shrub;

975, several ca 30 cm high shoots

**Age-determination transect**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
</tr>
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<td>920</td>
<td>39–2</td>
<td>2.5–2</td>
<td></td>
</tr>
<tr>
<td>890</td>
<td>45,43,33,39–2.5–2</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>890</td>
<td>35–3</td>
<td>3.5–20</td>
<td></td>
</tr>
<tr>
<td>885</td>
<td>27–2</td>
<td>2.2–2</td>
<td></td>
</tr>
<tr>
<td>885</td>
<td>84,76</td>
<td>2.5–2</td>
<td></td>
</tr>
</tbody>
</table>

**Documentation**

Smith (1911, p. 506) reproduces a photograph showing bushy birches, 0.5 m high, growing at 920 m altitude. The tree-limit, therefore, at the beginning of the present century, lay below 920 m. Smith’s isohypsomeric map (Karta 1), however, indicates that isolated clumps of trees, or solitary trees, were growing hereabouts at ca 900 m.

In 1951 Kilander (1955) found a 3 m high tree growing at 918 m, as well as a 1 m high shrub at 995 m and a low-growing clump of trees at 900 m altitude.

**Past tree-limit**

900

**Degree of change**

Apparent displacement: +20

Significant displacement: +10

99 Helagsfjället S (69 780 13 320)

**Present-day altitudinal limits (1975)**

**TL:** 955, a 2 m high, multi-stemmed birch

**Age-determination transect**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
</tr>
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<tbody>
<tr>
<td>955</td>
<td>40–2</td>
<td>2.0–2</td>
<td></td>
</tr>
</tbody>
</table>

**Documentation**

Kilander (1955) gives the following observations made in 1950:

985, a 1.75 m high tree

981, a shrub

980, a thicket, maximum height 1.5 m

957, a thicket, 2 m high

100 Njåmeletjarve SSW (69 823 13 204)

**Present-day altitudinal limits (1975)**

**FL:** 885, clumps of trees

**MSL:** 885, a small number of stems

**TL:** 885, a few 3 m high stems

**SL:** 900, a dead, 1.5 m high stem, surrounded by basal shoots a few dm in length

**Age-determination transect**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
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<td>885</td>
<td>55,42,38–3.0–2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>885</td>
<td>64,31–3.0–20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>865</td>
<td>82,75,74,53,43–3.0–20</td>
<td>20</td>
<td></td>
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</tbody>
</table>

**Documentation**

TL-Smith (391):875. Smith (1951, p. 374) states that the forest-limit in 1915 lay at 870 m and had advanced to 925 m by 1950. The latter value is probably too high, since no birch forest grows above 905 m anywhere between Njåmeletjarve and Predikstolen (cf. Faxén 1951, p. 454).

**Past tree-limit**

885

**Degree of change**

Apparent displacement: 0

Significant displacement: 0

101 Njåmeletjarve SW (69 815 13 216)

**Present-day altitudinal limits (1975)**

**FL:** 905, scattered clumps of trees

**TL:** 930, a 2.5 m high stem

**Age-determination transect**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>930</td>
<td>38–2</td>
<td>2.5–2</td>
<td></td>
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<tr>
<td>920</td>
<td>58–2</td>
<td>2.7–2</td>
<td></td>
</tr>
<tr>
<td>910</td>
<td>56,43,35–2.5–2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>905</td>
<td>63–2</td>
<td>2.5–13</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>62–2</td>
<td>3.5–20</td>
<td></td>
</tr>
</tbody>
</table>

**Documentation**

TL-Smith (390):880

**Past tree-limit**

900

**Degree of change**

Apparent displacement: +30

Significant displacement: +30

102 Predikstolen SSW (69 788 13 269)

**Present-day altitudinal limits (1975)**

**FL:** 900, clumps of trees

**TL:** 1035, a 2.1 m high stem

**Age-determination transect**

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>62,33–2.3–2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>990</td>
<td>60,28–3.0–2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>960</td>
<td>62,51,38,38–3.0–2</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Documentation**

TL-Smith (388):885. Smith (1920, p. 102) noted creeping shrubs growing at 1000 m. When he revisited this

Acta phytogeogr. suec. 65
Fig. 32. The tree-limit (1015 m a.s.l.) at locality 103. One of the stems has quite recently been broken by the weight of the snow cover. Photo: August 2, 1973.

Fig. 33. The same tree as in Fig. 32. The longest stem has become considerably more bent down than it was in 1973. Photo: August 1, 1976.

Fig. 34. The same tree as in Figs. 32–33. Some of the basal shoots are in process of growing to tree-size. A comparison with the earlier figures shows that there has been a continuous regression of the low-growing willow shrub (Salix sp.) in front of this birch. Photo: July 12, 1977.

Fig. 35. The birch shown in the three fore-going views (Figs. 32–34) is growing more or less at the spot indicated by the arrow. The hillslope here receives an extremely deep snow cover, which is liable to avalanche. Photo: April 4, 1975.
locality in 1950, he found that the tree-limit had risen to 990 m, at which altitude the highest-lying stems were ca 3 m high (Smith 1951).

**Past tree-limit**  
**Degree of change**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Husvålen SSE (75 765 13 506)</td>
<td>950, clumps of trees</td>
<td>855, a small number of stems</td>
<td>1015, a few 2.1 m high individual birches with a large number of metre-high basal shoots</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 1015 - 21 - 2.1 - 2
- 995 - 43, 32, 31, 28 - 4.0 - 2
- 955 - 38, 38, 29, 26 - 3.5 - 2
- 855 - 81 - 4.0 - 20

**Documentation**

TL-Smith (191): 925

**Past tree-limit**  
**Degree of change**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Husvålen SSW (75 769 13 492)</td>
<td>900, clumps of trees</td>
<td>880, one stem</td>
<td>930, a 2.5 m high stem</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 930 - 34 - 2.5 - 5
- 880 - 74 - 3.0 - 20

**Documentation**

TL-Smith (193): 934

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nedre Lillvålen WSW (69 768 13 485)</td>
<td>900, diffuse limit</td>
<td>900, a small number of stems</td>
<td>925, a 2.5 m high stem</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 890 - 88 - 3.0 - 20

**Documentation**

TL-Smith (194): 920

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herrjängsåsen S (69 901 13 329)</td>
<td>980, a 2.3 m high stem, which looked quite young; in addition to this tree there were only young</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Present-day altitudinal limits (1977)**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunsjöfjälet W (69 806 13 451)</td>
<td>890, even limit</td>
<td>890, a few stems</td>
<td>930, a clump of trees, maximum height 3 m</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 930 - 39, 33, 32 - 3.0 - 15
- 890 - 79 - 3.5 - 20

**Documentation**

TL-Smith (197): 920

**Past tree-limit**  
**Degree of change**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunsjöfjäll W (69 828 13 447)</td>
<td>975, clumps of trees</td>
<td>975, a small number of stems</td>
<td>1025, a few 2.5 - 3 m high stems</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 1025 - 27 - 3.0 - 2
- 1010 - 40, 31, 27 - 2.5 - 2
- 1010 - 30 - 1.5 - 1
- 990 - 45, 41, 36, 34, 28 - 3.0 - 2
- 875 - 67 - 4.5 - 20
- 965 - 69 - 5.0 - 20

**Documentation**

TL-Smith (199): 974

**Past tree-limit**  
**Degree of change**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunsjöfjall W (69 852 13 441)</td>
<td>925, even limit</td>
<td>925, one stem</td>
<td>960, a few 2-3 m high stems</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 960 - 31 - 3.0 - 2
- 950 - 29, 25 - 2.0 - 2
- 940 - 29 - 3.0 - 20
- 930 - 44, 41 - 4.0 - 20
- 925 - 72 - 4.0 - 20

**Documentation**

TL-Smith (202): 945

**Past tree-limit**  
**Degree of change**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herrjängsåsen W (69 901 13 329)</td>
<td>980, a 2.3 m high stem, which looked quite young; in addition to this tree there were only young</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Present-day altitudinal limits (1977)**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL-Smith (203): 945</td>
<td>945</td>
<td>945</td>
<td>945</td>
</tr>
</tbody>
</table>

**Age-determination transect**

- 945 - 31 - 3.0 - 2
- 935 - 29, 25 - 2.0 - 2
- 925 - 29 - 3.0 - 20
- 925 - 44, 41 - 4.0 - 20
- 925 - 72 - 4.0 - 20

**Documentation**

TL-Smith (203): 945

**Past tree-limit**  
**Degree of change**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herrjängsåsen W (69 901 13 329)</td>
<td>980, a 2.3 m high stem, which looked quite young; in addition to this tree there were only young</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Present-day altitudinal limits (1977)**

<table>
<thead>
<tr>
<th>Location</th>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>920, a 2.3 m high stem, which looked quite young; in addition to this tree there were only young</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Acta phytogeogr. suec. 65**
The tree-limit (1025 m a.s.l.) at locality 107 is formed by a birch tree growing in a thicket of willow (Salix spp.) and juniper (Juniperus communis) shrubs about 1 m high. The birch is unlikely to be more than 25–30 years old. Photo: July 31, 1973.

two single birches present on this hillslope, above the level of the valley floor (ca 920 m a.s.l.): at 960 m a 2 m high stem and at 950 m a single specimen with two 1.2 m high stems

Documentation
Smith (1920, p. 119) states, with regard to the mountain plateau S of the Herrjång massif (at ca 920 m altitude)—“.... despite favourable soil conditions here, there is no trace .... of tree-growth at 920 m above s.l.”.
Boberg (1920, p. 92) states that no trees were to be seen on the S-facing slope of Herrjångsåsen, or on the level slope below.

Past tree-limit  Degree of change
<920  Apparent displacement: +60
       Significant displacement: +60

110  Vargtjärnstöten E (69 821 13 432)

Present-day altitudinal limits (1973)
FL:  900, even limit
MSL: 890, a few number of stems
TL:  950, a 2.5 m high stem

Age-determination transect
890 – 82 – 3.5 – 20

Documentation
TL-Smith (208):900

Past tree-limit  Degree of change
900  Apparent displacement: +50
       Significant displacement: +40

111  Vargtjärnstöten SSW (69 819 13 429)

Present-day altitudinal limits (1973)
FL:  950, lobes and clumps of trees
MSL: 930, a few stems
TL:  990, a small number of stems, maximum height 2 m
SL:  1010, a few bushes, 0.5 m high

Age-determination transect
990 – 37, 33, 28, 27, 24 – 2.0 – 1
980 – 34 – 3.5 – 2
965 – 39, 33, 28, 23 – 3.0 – 2
930 – 62 – 4.0 – 20

Documentation
TL-Smith (210):949
Kilander (1955) determined the altitudinal limits for birch, in 1950 and 1952, as follows:
1000, bushes, a good metre in height
975, bushes, about one metre in height
968, a bush almost 2 m in height
956, a 3.5 m high tree
930, strips of forest

Past tree-limit  Degree of change
950  Apparent displacement: +40
       Significant displacement: +30

112  Stortuvan SSW (69 814 13 404)

Present-day altitudinal limits (1973)
FL:  935, wedge
MSL: 900, a few stems
TL:  935, a small number of 2 – 2.5 m high stems

Acta phytogeogr. suec. 65
Fig. 38. Several of these birch stems were at least 2 m long in 1915/16, i.e. the tree-limit at this locality (no. 113) has remained unchanged. The terrain is fairly flat and receives an inconsiderable snow cover. Nowadays, as in 1915/16, large parts of this area become snow-free long before the time at which the birches break into leaf. Photo: April 7, 1975.

Age-determination transect
900 - 69 - 4.5 - 20

Documentation
TL-Smith (213):904
Kilander’s (1955) observations, made in 1950, are as follows:
929, a thicket
920, a 3 m high shrub
917, sparse forest

Past tree-limit
905

Degree of change
Apparent displacement: +30
Significant displacement: +25

113 Kesudalen SSE (69 832 13 377)

Present-day altitudinal limits (1975)
FL: 895, tongues and lobes
MSL: 925, two stems
TL: 925, a sparse clump of trees, with stems 3 – 3.5 m high

Age-determination transect
925 – 69, 64 – 3.5 – 20
915 – 36 – 2.5 – 2
895 – 51 – 6.0 – 20
895 – 64 – 4.0 – 20

Documentation
TL-Smith (215):880. Smith probably overlooked the highest-lying birches here, which grow in a broken terrain, often hidden from view.

Kilander (1955) determined the following altitudinal limits for birch in 1950.
935-925, multitude of thickets, maximum height 2.5 m
905, a clump of four trees
895, a forest lobe

Past tree-limit
925

Degree of change
Apparent displacement: 0
Significant displacement: 0

114 Kesudalen S (69 839 13 403)

Present-day altitudinal limits (1973)
FL: even limit
MSL: 875, one stem
TL: 930, a small number of 2 – 2.5 m high stems

Age-determination transect
875 – 91 – 4.5 – 20

Documentation
TL-Smith (214):904. This value is mentioned in Smith’s text (1920, p. 105) in such a relationship to other nearby localities, which can be identified with fair certainty, that it is highly probable that he is referring to precisely the place on the S-facing slope of the valley which is locality 114.

Dr. Sven Kilander (pers. comm.) states that continuous forest extended up to an altitude of 875 m in 1950.

Past tree-limit
905

Degree of change
Apparent displacement: +25
Significant displacement: +20

115 Torkilstötén NE (69 791 13 420)

Present-day altitudinal limits (1975)
FL: 895, even limit
MSL: 870, one stem
TL: 950, a small number of 2 – 2.5 m high stems

Age-determination transect
950 – 26 – 2.5 – 2
870 – 88 – 4.5 – 20

Documentation
TL-Smith (217):860. Mr Johan Jonsson, Ljungdalen, states that the birch limit lies higher today than when he was young.

Past tree-limit
870

Degree of change
Apparent displacement: +80
Significant displacement: +80

116 Torkilstötén SE (69 781 13 422)

Present-day altitudinal limits (1975)
FL: 945, even limit
MSL: 910, one stem
TL: 960, several 2.5 – 3 m high stems
SL: 995, a 0.5 m high shrub

Age-determination transect
960 – 34, 23 – 3.0 – 2
945 – 46, 38, 35, 32 – 5.0 – 2
930 – 53, 40, 35, 32 – 6.5 – 2
910 – 62 – 6.0 – 20

Documentation
TL-Smith (219-221):max. 921

Past tree-limit
920

Degree of change
Apparent displacement: +40
Significant displacement: +35

Acta phytogeogr. suec. 65
117 Stötldiden SE (69 765 13 406)

Present-day altitudinal limits (1975)
FL: 920, clumps of trees
MSL: 905, a small number of stems
TL: 965, a few 2 m high stems

Age-determination transect
960 – 50 – 2.5 – 13
905 – 84 – 3.0 – 20

Documentation
TL-Smith (222):909

Past tree-limit Degree of change
910 Apparent displacement: +55
Significant displacement: +45

118 Viksjovalen E (69 735 13 434)

Present-day altitudinal limits (1975)
FL: 880, clumps of trees
MSL: 875, a few stems
TL: 895, a few 2-3 m high stems

Age-determination transect
895 – 44, 39, 37 – 2.7 – 2
875 – 78 – 3.5 – 20

Documentation
TL-Smith (223):890

Past tree-limit Degree of change
890 Apparent displacement: +5
Significant displacement: 0

119 Viksjovalen W (69 734 13 417)

Present-day altitudinal limits (1975)
FL: 920, clumps of trees
MSL: 905, one stem
TL: 925, a few 2 – 2.5 m high stems

Age-determination transect
905 – 68 – 2.8 – 20

Documentation
TL-Smith (224):888

Past tree-limit Degree of change
905 Apparent displacement: +20
Significant displacement: +20

120 N Gröndörrstoten S (69 769 13 391)

Present-day altitudinal limits (1975)
FL: 985, even limit
MSL: 935, a few stems
TL: 1005, a 2 m high stem

Age-determination transect
1005 – 26 – 2.0 – 2
1000 – 17 – 2.5 – 2
990 – 46 – 3.0 – 13
980 – 47, 47, 39, 37, 34 – 3.5 – 13
965 – 53, 46, 43, 40, 37 – 4.0 – 13
935 – 66, 60 – 4.5 – 20

Doc. phytogeogr. Suec. 65

121 S Gröndörrstoten S (69 756 13 388)

Present-day altitudinal limits (1976)
FL: 940, even limit
MSL: 900, one stem
TL: 965, a 2.5 m high stem

Age-determination transect
965 – 26 – 2.5 – 2
945 – 48, 44, 38, 36, 34 – 3.0 – 2
925 – 52, 44, 41, 40 – 4.5 – 13
900 – 91 – 5.0 – 20

Documentation
TL-Smith (227):910. Mr Johan Jonsson, Ljungdalen, states that the birch limit lies higher today than when he was young.

Past tree-limit Degree of change
910 Apparent displacement: +55
Significant displacement: +45

Fig. 39. The tree-limit (965 m a.s.l.) at locality 121. The birch had a stem base age of 26 years. It is growing in a vegetation characteristic of habitats with a fairly long-lasting snow cover combined with nutrient-rich soil conditions. Characteristic species include: Anthoxanthum odoratum, Deschampsia caespitosa, Galium boreale, Geranium sylvaticum, Polygonum viviparum, Ranunculus acris, Solidago virgaurea and Viola biflora. Photo: August 1, 1973.
Fig. 40. The tree-limit (965 m a.s.l.) at locality 124. These birches were only seedlings at the close of the 1940's. They now suffer greatly from the effects of snow pressure. The vegetation is a dwarf-shrub heath dominated by Vaccinium myrtillus, interspersed with patches of pure Nardus stricta, i.e. the area does not become snow-free until quite late on in spring. Photo: July 9, 1975.

122 Pt. 977 (Gruvfjallet) E (69 745  13 394)

Present-day altitudinal limits (1973)

FL:    860, clumps of trees
MSL:   885, one stem
TL:    920, a 2 m high stem
SL:    935, a 1.8 m high stem

Age-determination transect

885 – 62 – 3.5 – 20

Documentation

TL-Smith (228):891

Past tree-limit Degree of change
890     Apparent displacement: +30
Significant displacement: +25

123 Grönfjälet E (69 728  13 396)

Present-day altitudinal limits (1973)

FL:    860, small clumps of trees
MSL:   910, one stem
TL:    925, a small number of 2.5 – 3 m high stems

Age-determination transect

910 – 67 – 3.5 – 20

Documentation

TL-Smith (231):921

Past tree-limit Degree of change
920     Apparent displacement: +5
Significant displacement: 0

124 Grönfjälet S (69 724  13 392)

Present-day altitudinal limits (1975)

FL:    865, clumps of trees
MSL:   930, one stem
TL:    965, a 2 m high stem

Age-determination transect

965 – 26 – 2.0 – 2
955 – 26, 26 – 2.3 – 2
950 – 57, 33, 32, 31, 30 – 2.5 – 2
930 – 60 – 4.0 – 20
915 – 52 – 3.2 – 20

Documentation

TL-Smith (233):909

Past tree-limit Degree of change
930     Apparent displacement: +35
Significant displacement: +35

125 Flatruet (Falkvälen) NNE (69 653  13 447)

Present-day altitudinal limits (1977)

FL:    880, clumps of trees
MSL:   885, one stem
TL:    925, a multi-stemmed birch, maximum height 2.2 m
SL:    945, a 1.8 m high stem

Age-determination transect

945 – 15 – 1.8 – 1
925 – 29, 22 – 2.2 – 1
895 – 31, 25 – 2.3 – 2
885 – 63, 35, 34, 30, 27, 25 – 4.5 – 2
885 – 104 – 5.0 – 20

Documentation

TL-Smith (240):890. Mr Albert Långström, of Skärkadal, states that the birch limit lies higher today than when he was young (about 50 years ago).

Past tree-limit Degree of change
890     Apparent displacement: +35
Significant displacement: +25

126 Flatrueet (Hårändesbäcken) NNE (69 641  13 468)

Present-day altitudinal limits (1975)

FL:    890, clumps of trees
MSL:   915, one stem
TL:    915, a few 3 – 4.5 m high stems

Age-determination transect

915 – 36, 34, 30, 28 – 4.0 – 2
915 – 82 – 3.5 – 20

Documentation

TL-Smith (241):903

Past tree-limit Degree of change
915     Apparent displacement: 0
Significant displacement: 0
Fig. 41. Young, multi-stemmed, birches growing 20 m below the tree-limit (925 m a.s.l.) at locality 125. In front of them is a narrow belt of *Salix lapponum*, together with patches of *Betula nana*. Photo: July 27, 1973.

Fig. 42. The same birch clump as shown in Fig. 41. During the intervening period (1973–1977) some of the central group of tree-sized stems have died off, while other stems have thinned-out somewhat. In the dense thicket of birch, visible on the right-hand side of the central group mentioned above, some of the stems seem to be in process of becoming tree-sized, while the others have suffered a decline, like some of the stems to the left of the central group. The fringing willow thicket has remained more or less unchanged in extent. Photo: July 11, 1977.

Fig. 43. The same view as in Figs. 41–42. The maximum depth of the snow cover in this birch stand is a little over 1 m. Photo: February 26, 1978.

Fig. 44. The tree-limit (915 m a.s.l.) at locality 126 has remained unchanged throughout the present century. The large birch tree was already at least 2 m high at the end of the 19th century. The terrain is relatively flat and the snow cover is shallow, usually melting-away long before the birches have burst into leaf. Photo: April 6, 1975.

127 Särvvålen NW (69 647 13 497)

*Present-day altitudinal limits (1975)*

- **FL:** 920, clumps of trees
- **MSL:** 920, a few stems
- **TL:** 920, a large number of 3–4 m high stems

*Age-determination transect*

- 920 – 59, 49 – 3.5 – 20
- 920 – 42 – 4.0 – 2
- 910 – 30 – 4.0 – 20
- 900 – 64 – 4.0 – 20

*Documentation*

TL-Smith (243):927. Smith does not state just which part of Särvvålen his observation refers to. Almost certainly, however, he would have selected the locality where the tree-limit lay highest, which, to judge from the altitude of the MSL here, was probably on the NW-facing hillslope.

*Acta phytogeogr. suec. 65*
Change and stability of birch tree-limit in the Scandes

Past tree-limit
925

Degree of change
Apparent displacement: –5
Significant displacement: 0

128 V Stoljan NNE (69 618 13 511)

Present-day altitudinal limits (1975)
FL: 880, even limit
MSL: 890, one stem
TL: 920, a few 2 – 2.5 m high stems

Age-determination transect
890 – 67 – 4.5 – 20

Documentation
TL-Smith (245):890. Smith is here probably referring to the NE-facing hillslope, since at no point does the N-facing slope descend as low as 890 m.

Past tree-limit
980

Degree of change
Apparent displacement: +30
Significant displacement: +20

129 Ö Stoljan NE (69 602 13 517)

Present-day altitudinal limits (1975)
FL: 890, wedge
MSL: 905, mouldering remains of quite coarsely-dimensioned, old arborescent stems
TL: 905, a multi-stemmed birch, maximum height 2.2 m

Age-determination transect
905 – 50 – 2.2 – 2
895 – 76 – 4.0 – 20
880 – 69 – 5.0 – 20

Documentation
TL-Smith (246):884. Smith is here probably referring to some place on the NE-facing hillslope, somewhat further E than the foregoing locality. This interpretation is based on the fact that at no point does the N-facing slope proper descend as low as 884 m.

Past tree-limit
905

Degree of change
Apparent displacement: 0
Significant displacement: 0

130 Ö Stoljan NE (69 595 13 527)

Present-day altitudinal limits (1975)
FL: 870, wedge
MSL: 885, a large tree-stump, formerly bearing an arborescent and very old stem
TL: 885, a few 2.5 – 3 m high stems

Age-determination transect
870 – 68 – 5.0 – 20

Documentation
TL-Smith (247):887

Past tree-limit
885

Degree of change
Apparent displacement: 0
Significant displacement: 0

131 Ö Stoljan S (69 576 13 515)

Present-day altitudinal limits (1975)
FL: 880, wedge
MSL: 900, one live stem, together with a large tree-stump, one metre in height
TL: 910, dense 2 m high clump of trees

Age-determination transect
910 – 40, 38, 27, 26 – 2.0 – 3
900 – 69 – 3.0 – 20
880 – 61 – 4.0 – 20

Documentation
TL-Smith (252):904

Past tree-limit
905

Degree of change
Apparent displacement: +5
Significant displacement: 0

132 Ruändan SSE (69 565 13 542)

Present-day altitudinal limits (1975)
FL: 935, clumps of trees
MSL: 935, a few stems
TL: 950, a multi-stemmed 2 m high birch

Age-determination transect
950 – 42 – 2.2 – 1
945 – 27 – 1.8 – 1
935 – 28, 27, 25 – 2.0 – 1
935 – 52, 45, 33 – 3.0 – 20
930 – 75, 50 – 3.5 – 20

Documentation
TL-Smith (251):927

Past tree-limit
930

Degree of change
Apparent displacement: +20
Significant displacement: +20

133 Svartmorhöjden S (69 585 13 476)

Present-day altitudinal limits (1974)
FL: 920, even limit
MSL: 940, a few stems
SL: 955, a few multi-stemmed 1.5 m high shrubs

Age-determination transect
955 – 51 – 1.5 – 1
945 – 48, 48 – 3.0 – 2
940 – 52, 49, 40, 33, 27 – 2.8 – 2
940 – 76 – 4.0 – 20
925 – 70, 44, 43, 37, 35, 35 – 3.0 – 2
910 – 69 – 4.5 – 20

Documentation
TL-Smith (253):900

Past tree-limit
940

Degree of change
Apparent displacement: +5
Significant displacement: +5

Acta phytogeogr. suec. 65
134 Falkvälen SSW (69 608 13 421)

Present-day altitudinal limits (1975)
FL: 890, clumps of trees
MSL: 900, one stem
TL: 930, a small number of 3 – 3.5 m high stems

Age-determination transect
930 – 41, 40 – 3.3 – 2
915 – 42, 28 – 3.0 – 2
910 – 60 – 4.0 – 3
905 – 60, 47, 46, 40 – 2.8 – 2
900 – 75 – 5.0 – 20

Documentation
TL-Smith (255):902

Past tree-limit Degree of change
900 Apparent displacement: +30
Significant displacement: +20

135 Korpåsen S (69 612 13 407)

Present-day altitudinal limits (1975)
FL: 910, even limit
MSL: 920, a small number of stems
TL: 955, several 2.5 – 3 m high stems

Age-determination transect
955 – 87, 82, 63 – 2.8 – 2
940 – 61, 59, 56, 50, 37 – 3.0 – 2
920 – 107 – 4.5 – 20

Documentation
TL-Smith (256):930

Past tree-limit Degree of change
930 Apparent displacement: +25
Significant displacement: +15

136 Stor-Axhögen S (69 644 13 329)

Present-day altitudinal limits (1976)
FL: 950, clumps of trees
MSL: 965, a large tree-stump, formerly bearing an arborescent and very old stem.
TL: 1005, two individual birches with 3 m high stems
SL: 1010, an individual tree, with three dead stems, not long ago ca 2 m high, with live basal shoots several dm long

Age-determination transect
1005 – 32 – 3.0 – 2
985 – 60, 59, 54, 45 – 3.0 – 2
955 – 51, 45, 38, 25 – 3.3 – 2
955 – 55 – 4.5 – 20
945 – 40 – 5.0 – 20
925 – 69 – 5.0 – 20

Documentation
TL-Smith (263):940

137 Lill-Axhögen S (69 659 13 306)

Present-day altitudinal limits (1976)
FL: 950, clumps of trees
MSL: 960, one stem
TL: 990, a small number of 2.5 m high stems

Age-determination transect
990 – 50, 46 – 2.5 – 2
975 – 48, 41, 30 – 3.5 – 2
965 – 49, 42, 41, 37 – 2.5 – 2
960 – 65 – 3.0 – 20

Documentation
TL-Smith (265):925

Past tree-limit Degree of change
960 Apparent displacement: +30
Significant displacement: +20

138 Mittåhammarens S (69 671 13 281)

Present-day altitudinal limits (1972)
FL: 935, even limit
MSL: 925, a few stems
TL: 945, several 2.5 – 3 m high stems

Age-determination transect
925 – 86 – 4.5 – 20

Documentation
TL-Smith (267):932

Past tree-limit Degree of change
930 Apparent displacement: +15
Significant displacement: +10

139 Lill-Mittåklappen NW (69 659 13 281)

Present-day altitudinal limits (1972)
MSL: 900, a few stems
TL: 900, a small number of 2 – 3.5 m high stems

Age-determination transect
900 – 64 – 3.5 – 20

Documentation
TL-Smith (270):890

Past tree-limit Degree of change
900 Apparent displacement: 0
Significant displacement: 0

140 Lill-Mittåklappen NE (69 659 13 281)

Present-day altitudinal limits (1972)
FL: 900, clumps of trees
MSL: 915, a dead, very coarsely-dimensioned stem
TL: 920, a few 2 m high stems

Age-determination transect
895 – 79 – 3.5 – 20

Acta phytogeogr. suec. 65
**Past tree-limit**

915

Degree of change

Apparent displacement: +5

Significant displacement: 0

---

141 Lill-Mittåklappen E (69 650 13 291)

**Present-day altitudinal limits (1972)**

- **FL:** 900, even limit
- **MSL:** 890, a few stems
- **TL:** 930, a small number of 2.5 – 3 m high stems

**Age-determination transect**

890 – 91 – 4.0 – 20

**Documentation**

TL-Smith (271):915

**Past tree-limit**

915

Degree of change

Apparent displacement: +5

Significant displacement: 0

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142 Lill-Mittåklappen S (69 642 13 289)

**Present-day altitudinal limits (1975)**

- **FL:** 910, clumps of trees, which form strips running parallel to the contours
- **MSL:** 910, one stem
- **TL:** 960, a small clump of trees, with stems 2.5 – 3 m in height

**Age-determination transect**

960 – 50, 47, 39 – 2.8 – 2
935 – 47, 45, 29 – 3.0 – 2
910 – 80 – 6.0 – 20
860 – 72 – 5.0 – 20

**Documentation**

TL-Smith (273):880. Henning (1887, p. 10) describes the vegetation cover of this hillslope without making the slightest mention of the occurrence of even scattered trees on the S-facing slope itself, above the level of

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**Fig. 45.** The present-day tree-limit (TL) at locality 142 is formed by a dense stand of birch stems bowed down by the weight of the snow cover and which were at most a few decimetres in length in the mid-1920’s. They had probably only colonised this spot at about that same time. The birches are growing in a dwarf-shrub heath dominated by Vaccinium myrtillus and Betula nana, also with species such as Anthoxanthum odoratum, Deschampsia flexuosa, Nardus stricta, Rumex acetosa ssp. lapponicus and Solidago virgaurea. The species composition of the vegetation strongly suggest that the site is subject to a long-lasting snow cover. Photo: July 23, 1975.

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**Fig. 46.** The arrow marks the position of the birch stand in Fig. 45. Birch growth here in 1915/16 was probably impossible because of the slower disappearance of the large snowfield here at that time. Photo: July 13, 1972.
the valley floor. The kind of vegetation cover he describes suggests an appreciable accumulation of snow here in winter.

<table>
<thead>
<tr>
<th>Past tree-limit</th>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>910</td>
<td>Apparent displacement: +50</td>
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<tr>
<td></td>
<td>Significant displacement: +50</td>
</tr>
</tbody>
</table>

143 Stor-Mittåkläppen NE (69 638 13 287)

Present-day altitudinal limits (1975)
FL: 885, a few number of stems
MSL: 895, a small number of 2–3 m high stems
Age-determination transect
885 – 67 – 3.5 – 20

Documentation
TL-Smith (274):895. Smith gives three values (pts. 274–276), from “NW to S”, for Stor-Mittåkläppen. It is obvious that they refer to the NE-, E-, and SSE-facing hillslopes, respectively.

<table>
<thead>
<tr>
<th>Past tree-limit</th>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>895</td>
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<td>Significant displacement: 0</td>
</tr>
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</table>

144 Stor-Mittåkläppen E (69 623 13 288)

Present-day altitudinal limits (1975)
FL: 850, clumps of trees
MSL: 925, one stem
TL: 1005, a small number of 2 m high stems
Age-determination transect
1005 – 31 – 2.0 – 2
985 – 34 – 2.0 – 2
980 – 34 – 2.5 – 2
960 – 46, 29, 25 – 3.5 – 2
925 – 67 – 3.5 – 20
905 – 88, 61 – 6.0 – 20

Documentation
TL-Smith (272):900. See locality 143.

<table>
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<td>Significant displacement: +80</td>
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</tbody>
</table>

145 Stor-Mittåkläppen SSE (69 617 13 288)

Present-day altitudinal limits (1975)
FL: 910, clumps of trees
MSL: 960, one stem
TL: 960, a small number of 2–3.5 m high stems
SL: 980, a 1.5 m high stem
Age-determination transect
960 – 91 – 3.5 – 20
960 – 58, 38, 32 – 2.5 – 2
935 – 74 – 4.0 – 20
935 – 63, 51 – 4.0 – 2

Documentation
TL-Smith (276):926. See locality 143.

<table>
<thead>
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<th>Degree of change</th>
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<tbody>
<tr>
<td>890</td>
<td>Apparent displacement: +50</td>
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<td>Significant displacement: +40</td>
</tr>
</tbody>
</table>

146 Gruvvalen SSW (69 611 13 261)

Present-day altitudinal limits (1975)
FL: 925, clumps of trees
MSL: 920, a few stems
TL: 935, a small number of 2.5 m high stems
Age-determination transect
935 – 42, 31 – 2.5 – 2
930 – 41, 38, 30 – 3.0 – 2
920 – 101, 89, 66 – 4.5 – 2
920 – 70 – 4.5 – 20
915 – 76 – 5.0 – 20

Documentation
TL-Smith (277):925

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<td>Apparent displacement: +10</td>
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<tr>
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<td>Significant displacement: +5</td>
</tr>
</tbody>
</table>

147 Vallarfjället SW (69 536 13 311)

Present-day altitudinal limits (1974)
FL: 880, clumps of trees
MSL: 895, one stem
TL: 950, a 2 m high stem
Age-determination transect
895 – 68 – 4.0 – 20

Documentation
TL-Smith (284):910

<table>
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<td>Apparent displacement: +40</td>
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<td>Significant displacement: +30</td>
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</tbody>
</table>

148 Vallarfjället SE (69 536 13 314)

Present-day altitudinal limits (1974)
FL: 880, clumps of trees
MSL: 885, a few stems
TL: 940, a 2 m high stem
Age-determination transect
885 – 78 – 5.0 – 20

Documentation
TL-Smith (283):890

<table>
<thead>
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<th>Degree of change</th>
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<td>Apparent displacement: +50</td>
</tr>
<tr>
<td></td>
<td>Significant displacement: +40</td>
</tr>
</tbody>
</table>

149 Kappruet WNW (69 534 13 430)

Present-day altitudinal limits (1975)
FL: 925, wedge
MSL: 930, a few mouldering remains of old arborescent stems
TL: 930, a small number of 2–2.5 m high stems
Age-determination transect
925 – 82 – 4.5 – 20

Documentation
TL-Smith (286):920

Past tree-limit
Degree of change
930
Apparent displacement: 0
Significant displacement: 0

150 Kappruet S (69 525 13 450)

Present-day altitudinal limits (1974)
FL: 975, even limit
MSL: 985, one stem
TL: 985, several 2.5 – 4.5 m high stems

Age-determination transect
985 – 38 – 4.5 – 2
985 – 65, 40 – 4.0 – 20
975 – 68, 50 – 3.5 – 2

Documentation
TL-Smith (288):979

Past tree-limit
Degree of change
985
Apparent displacement: 0
Significant displacement: 0

151 Am1kroken S (69 500 13 415)

Present-day altitudinal limits (1976)
FL: 1005, clumps of trees
MSL: 1015, mouldering remains of a quite coarsely-dimensioned, old stem
TL: 1030, a small number of 2 – 2.5 m high stems
SL: 1050, a few 0.5 – 1.5 m high shrubs

Age-determination transect
1005 – 60 – 4.0 – 20
995 – 92 – 5.0 – 20

Documentation
A few kilometres E of this locality Smith recorded the highest tree-limit for the whole country, at 1007 m. It would therefore seem highly probable that the tree-limit at this precise locality in fact lay very near 1007 m altitude, otherwise Smith would almost certainly have noted the fact, since he determined the tree-limit on several other slopes of this particular mountain.

Past tree-limit
Degree of change
1015
Apparent displacement: +10
Significant displacement: +10

152 Am1kroken W (69 505 13 410)

Present-day altitudinal limits (1973)
FL: 950, lobes and clumps of trees
MSL: 970, several stems, together with the mouldering remains of a very coarsely-dimensioned tree
TL: 970, a large number of 2.5 – 4 m high stems

Age-determination transect
970 – 95, 68 – 4.0 – 20

Documentation
TL-Smith (289):960. Smith gives no definite indication of the aspect of this site. That it can scarcely be the S-facing hillslope is clear from the argument advanced under locality 151, and Smith gives other values which definitely refer to the N- to NE-facing slope. The E-facing slope nowhere descends so low as 960 m, i.e. only the W-facing slope is left.

Past tree-limit
Degree of change
970
Apparent displacement: 0
Significant displacement: 0

153 Between Am1kroken and Roaldsstoten SSW (69 485 13 426)

Present-day altitudinal limits (1973)
MSL: 1005, one stem
TL: 1015, a small number of clumps of trees, with 2 – 3 m high stems

Age-determination transect
1005 – 73 – 4.0 – 20

Documentation
TL-Smith (297):1007. In 1915 the highest altitudinal tree-limit in the country was recorded at this locality.

Past tree-limit
Degree of change
1005
Apparent displacement: +10
Significant displacement: 0

Acta phytogeogr. suec. 65
154 Ännfjäll NNE (69 487  13 398)

Present-day altitudinal limits (1976)
FL:  910, clumps of trees
MSL:  945, several stems
TL:  960, small clumps of 3 – 4 m high stems

Age-determination transect
945 – 80 – 4.0 – 20

Documentation
TL-Smith (307):954

Past tree-limit  Degree of change
955  Apparent displacement: +5
Significant displacement: 0

155 Fjälländan S (69 460  13 474)

Present-day altitudinal limits (1975)
FL:  955, clumps of stems
MSL:  985, one stem
TL:  1020, a 2.0 m high stem
SL:  1040, a 0.6 m high shrub

Age-determination transect
1020 – 32 – 2.0 – 1
1015 – 33 – 2.0 – 2
1005 – 40, 36, 28, 25 – 2.5 – 2
985 – 69 – 3.5 – 20
960 – 71, 62 – 4.0 – 20
945 – 68 – 4.0 – 20

Documentation
TL-Smith (298):1002

Past tree-limit  Degree of change
1000  Apparent displacement: +20
Significant displacement: +10

156 Fjälländan SSE (69 460  13 487)

Present-day altitudinal limits (1973)
FL:  925, clumps of trees
MSL:  945, one stem
TL:  975, a small number of 2 – 2.5 m high stems

Age-determination transect
945 – 67 – 4.5 – 2.0

Documentation
TL-Smith (295):940

Past tree-limit  Degree of change
945  Apparent displacement: +30
Significant displacement: +30

157 Between Uggarna and Fjälländan S
(69 455  13 466)

Present-day altitudinal limits (1975)
FL:  960, clumps of trees
MSL:  930, a few stems
TL:  960, a small number of 2.5 – 3 m high stems

Age-determination transect
960 – 60, 37, 35 – 2.7 – 2
930 – 94 – 5.0 – 20

Documentation
TL-Smith (299):956

Past tree-limit  Degree of change
955  Apparent displacement: +5
Significant displacement: 0

158 Uggarna SE (69 452  13 460)

Present-day altitudinal limits (1975)
FL:  975, lobe
MSL:  955, one live stem, together with the mouldering remains of several coarsely-dimensioned, very old, stems
TL:  995, a small number of 2 – 2.5 m high stems

Age-determination transect
995 – 43 – 2.5 – 1
975 – 83, 54, 49, 43, 40 – 3.0 – 2
975 – 57, 51, 50 – 4.0 – 20
955 – 70, 70, 62 – 4.0 – 20

Documentation
TL-Smith (300):954

Past tree-limit  Degree of change
955  Apparent displacement: +40
Significant displacement: +30

159 Gråstöten S (69 445  13 404)

Present-day altitudinal limits (1974)
FL:  955, even limit
MSL:  1040, one stem
TL:  1040, a multi-stemmed, 2.5 m high birch

Age-determination transect
1040 – 65 – 2.5 – 17
1040 – 19 – 2.5 – 2
995 – 40, 39, 32, 30, 30 – 2.5 – 2
995 – 69 – 3.0 – 13
970 – 55, 51, 49, 46, 42 – 2.5 – 2
960 – 63 – 3.5 – 20

Documentation
Hisinger (1820), using a mercury barometer, determined the “birch limit” on this hillslope to be 3261.88 Sw feet (i.e. 968 m) in 1819. Two hours previously he had determined the altitude of the highest point to be 3762.00 Sw feet (i.e. 1117 m), which is 6 m lower than the modern value. Hisinger’s “birch limit” ought therefore to be corrected to 974 m a.s.l. The term “birch limit” should refer to some kind of closed stand of birch, since at certain other localities he also determined what he called “the limit of the highest-growing bushy birches”, which ought probably to agree more or less with the definition of the “tree-limit” used in the present investigation.

Immediately to the E and W of this locality Smith records values of 942 and 948 m, respectively. Since he certainly must have passed by the S-facing slope of Gråstöten, it would therefore seem probable that he would have made particular mention of the fact if the tree-limit value there had deviated appreciably from...
Fig. 48. The tree-limit at locality 159 has remained stable during the present century. The terrain above the tree-limit is characterised by pronounced snow deflation. This locality is generally free of snow long before the birches burst into leaf and the vegetation is scarcely influenced by snow meltwater at all during the vegetation period. Photo: April 27, 1976.

those cited above. Nevertheless, the highest-growing birches on that slope are scattered very far apart and do not stand out well against the boulder strewn and quite steep, hillslope. There is therefore a strong probability that Smith overlooked the highest-lying birches here.

Past tree-limit
1040

Apparent displacement: 0
Significant displacement: 0

160 Grästöten SW (69 452 13 395)

Present-day altitudinal limits (1974)
FL: 960, wedge
MSL: 950, a few stems
TL: 965, a small number of 2 – 2.5 m high stems

Age-determination transect
950 – 70 – 4.0 – 20

Documentation
TL-Smith (304):948

Past tree-limit
950

Apparent displacement: +15
Significant displacement: 0

162 Ännfjället W (69 472 13 379)

Present-day altitudinal limits (1975)
FL: 980, lobe
MSL: 995, one stem
TL: 1035, a 2.2 m high stem

Age-determination transect
1035 – 17 – 2.2 – 1
1030 – 30 – 2.5 – 2
980 – 65 – 5.5 – 20
965 – 61 – 5.0 – 20

Documentation
TL-Smith (305):960

Past tree-limit
995

Apparent displacement: +40
Significant displacement: +40

163 Ormruet N (69 466 13 355)

Present-day altitudinal limits (1975)
FL: 925, lobe

Acta phytogeogr. suec. 65
MSL: 930, one moulder ing, very coarse stem, which at one time was appreciably more than 2 m in height
TL: 955, a small number of 2-2.5 m high stems
SL: 960, a few 0.5 m high shrubs

Age-determination transect
955 - 31, 26 - 2.5 - 1
940 - 38 - 3.0 - 2
920 - 103 - 5.0 - 20

Documentation
TL-Smith (331): 942

<table>
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<tbody>
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<td></td>
<td>Apparent displacement: +15</td>
</tr>
<tr>
<td></td>
<td>Significant displacement: +10</td>
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</tbody>
</table>

164 Rösvålen S (69 622 13 236)

Present-day altitudinal limits (1975)
FL: 920, clumps of trees
MSL: 910, one stem
TL: 945, a 2.3 m high stem

Age-determination transect
945 - 31 - 2.3 - 2
930 - 31, 30 - 3.0 - 2
920 - 44, 43, 36, 35 - 4.5 - 2
920 - 40 - 4.5 - 20
910 - 104 - 6.0 - 20

Documentation
TL-Smith (334): 920

<table>
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<th>Degree of change</th>
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<tr>
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<td>Apparent displacement: +50</td>
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<tr>
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<td>Significant displacement: +40</td>
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</table>

165 Gierterbaune S (69 634 13 198)

Present-day altitudinal limits (1975)
FL: 910, clumps of trees
MSL: 885, a few stems
TL: 920, a clump of stems, maximum height 2 m

Age-determination transect
885 - 79 - 4.0 - 20

Documentation
TL-Smith (335): 920

Past tree-limit | Degree of change |
<table>
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<tbody>
<tr>
<td>920</td>
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<tr>
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<tr>
<td></td>
<td>Significant displacement: 0</td>
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166 Kejsarn SW (69 653 13 146)

Present-day altitudinal limits (1975)
FL: 960, clumps of trees
MSL: 925, a few stems
TL: 975, clumps of 2 - 3 m high stems

Age-determination transect
925 - 82 - 4.5 - 20

Documentation
TL-Smith (336): 926

<table>
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<th>Degree of change</th>
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<td>925</td>
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<tr>
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<td>Apparent displacement: +50</td>
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<tr>
<td></td>
<td>Significant displacement: +40</td>
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</table>

167 Haftorsstöten ESE (69 647 13 135)

Present-day altitudinal limits (1975)
FL: 880, clumps of trees
MSL: 905, one stem
TL: 945, a small number of 2.5 m high stems

Acta phytogeogr. suec. 65

Fig. 49. In response to a more rapid snow-melt on the leeward side of the ridge visible in the background the birch tree-limit at locality 161 has risen 50 m in altitude since 1915/16. The approximate position of the present-day tree-limit is shown by the arrow. Photo: April 27, 1976.
### Change and stability of birch tree-limit in the Scandes

#### Age-determination transect

<table>
<thead>
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<th>Year</th>
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<th>Apparent displacement</th>
<th>Significant displacement</th>
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<td>930</td>
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</table>

#### Documentation

TL-Smith (339):890.

In 1819 Hisinger (1820), using a mercury barometer, found that the "birch limit" at Ljusnetjärn, i.e. on the SE-facing slope of Haftorsstoten, lay at 3095.14 Sw feet (equivalent to 919 m). The height determined for Ljusnetjärn is 4 m higher than the modern value, i.e. the corrected value for Hisinger's "birch limit" is thus 915 m a. s. l. As mentioned above (locality 159), the "birch limit" is assumed to refer to some kind of closed stand of birch.

Hörbye (1861, p. 133) determined "the birch limit" to lie at a maximum height of 2890 Norw. feet on the E-facing slope of Haftorsstoten. At the same time he determined the altitude of certain nearby points in the terrain, the modern heights of which above sea-level are precisely known. This enables a correction of the above-mentioned "birch limit" value to be made, to ca 900 m a. s. l. The latter value is therefore a minimum value for the tree-limit (cf. Nordhagen 1928).

#### Past tree-limit

<table>
<thead>
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<tbody>
<tr>
<td>905</td>
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</tbody>
</table>

#### Present-day altitudinal limits (1975)

**FL:** 925, clumps of trees (distinct FL on the Norwegian side of the border)

**MSL:** 930, a few stems

**TL:** 1030, a clump of 2.5 m high stems

#### Age-determination transect

<table>
<thead>
<tr>
<th>Year</th>
<th>Degree of change</th>
<th>Apparent displacement</th>
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#### Documentation

TL-Smith (340):955

### Gronvålen S (69 625 13 141)

#### Present-day altitudinal limits (1975)

**FL:** 900, wedges and clumps of trees

**MSL:** 915, a few stems

**TL:** 955, a 2.5 m high stem

#### Age-determination transect

<table>
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#### Documentation

TL-Smith (342):923

### Present tree-limit

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### Gruvsjöhöjden SSW (69 563 13 098)

#### Present-day altitudinal limits (1973)

**FL:** 920, clumps of trees

**MSL:** 905, one stem

**TL:** 945, a 3 m high stem

#### Age-determination transect

<table>
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<tr>
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<th>Degree of change</th>
<th>Apparent displacement</th>
<th>Significant displacement</th>
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#### Documentation

TL-Smith (343):906

### Present tree-limit

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### Gronfjallet W (69 579 13 148)

#### Present-day altitudinal limits (1972)

**FL:** 950, clumps of trees

**MSL:** 900, a few stems

**TL:** 975, a small number of 2.5 – 3 m high stems

**SL:** 990, a 1.8 m high stem; 1000, a 0.75 m high shrub

#### Age-determination transect

<table>
<thead>
<tr>
<th>Year</th>
<th>Degree of change</th>
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<th>Significant displacement</th>
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<tr>
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#### Documentation

TL-Smith (344):909

### Present tree-limit

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<th>Apparent displacement</th>
<th>Significant displacement</th>
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</thead>
<tbody>
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<td></td>
</tr>
</tbody>
</table>

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*Acta phytogeogr. suec. 65*
Present-day altitudinal limits (1972)
FL: 925, wedge
MSL: 935, one stem
TL: 960, a small number of 2.5 – 3 m high stems

Age-determination transect
935 – 64 – 4.0 – 20

Document  
TL-Smith (345):945. Mr Paulus Middagsfjäll, Gronda-  
len, states that the birches now grow higher-up than  
they did when he was young (about 60 years ago).
Past tree-limit: 945
Degree of change  
Apparent displacement: +15
Significant displacement: +5

Present-day altitudinal limits (1975)
FL: 920, small clumps of trees
MSL: 930, a few stems
TL: 960, a small number of 2.5 m high stems

Age-determination transect
960 – 39 – 2.5 – 2  
940 – 39, 32, 32 – 3.5 – 2  
930 – 105, 85, 51 – 4.0 – 20  
920 – 103 – 4.0 – 20

Document  
TL-Smith (346):932
Past tree-limit: 940
Degree of change  
Apparent displacement: +30
Significant displacement: +20

Present-day altitudinal limits (1975)
FL: 955, lobes and clumps of trees

MSL: 925, a small number of stems
TL: 975, a 3.2 m high stem

Age-determination transect
975 – 44 – 3.3 – 2  
960 – 33 – 2.3 – 2  
955 – 34, 34 – 2.8 – 2  
945 – 52, 51, 48 – 3.5 – 2  
925 – 76 – 4.0 – 20

Document  
TL-Smith (347):923
Past tree-limit: 925
Degree of change  
Apparent displacement: +50
Significant displacement: +40

Past tree-limit: 930
Degree of change  
Apparent displacement: +35
Significant displacement: +25

Fig. 50. All the birch trees visible as darker spots in the extensive willow thickets (Salix spp.), became established after 1915/ 16 and represent an upward displacement of the tree-limit by 25 m. The birches are watered for a large part of the summer by meltwater from the snow-field above. In all probability this meltwater supply was appreciably greater in 1915/16 and at that time prevented any effective birch colonisation within the tract of ground lying between the past and the present-day tree-limits here at locality 176. Photo: July 12, 1972.
Fig. 51. A regular front of birches forming the forest-limit (990 m a.s.l.) at locality 177. The birches became established here at the end of the 1920's. The lighter-coloured vegetation, immediately in front of the birches, is a dwarf-shrub heath dominated by Vaccinium myrtillus, Betula nana, together with herbaceous species, while Nardus stricta grass heath is dominant still higher up. The vegetation thus shows a clear zonation, which depends on differences in the time of the snow-melt. It is therefore a reasonable surmise that birch establishment here (i.e. the rise in the tree-limit) is related to an upward shift of all these zones, due to an earlier disappearance of the snow cover. Photo: June 16, 1973.

Fig. 52. The arrow marks the position of the birch front at locality 177 (see Fig. 51). This locality is situated within a pronounced snow accumulation area. The climatic amelioration during the present century has almost certainly led to a more rapid disappearance of the snow-fields, a circumstance which completely altered the ecological conditions and thereby the local vegetational zonation. Photo: June 16, 1973.

955 - 56, 39, 37, 36, 27 - 5.0 - 2
950 - 68 - 5.0 - 20
920 - 91 - 6.0 - 20

**Documentation**
Smith must almost certainly have viewed this particular hill-slope from quite close quarters in 1915/16. Had the tree-limit thereabouts exceeded ca 950 m a. s.l. he would undoubtedly have made an aneroid reading here. As it stands the value cited is highly probable, judging from the tree-limit altitudes for all the nearby, comparable, localities.

<table>
<thead>
<tr>
<th>Past tree-limit</th>
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</thead>
<tbody>
<tr>
<td>950</td>
<td></td>
</tr>
<tr>
<td>Apparent displacement: +50</td>
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</tr>
<tr>
<td>Significant displacement: +40</td>
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</table>

178 Ösjökäppen SSW (69 555 13 214)

*Present-day altitudinal limits (1974)*

**FL:** 1010, clumps of trees
**MSL:** lacking on and above the valley floor, ca 965 m a. s.l.
**TL:** 1025, two 2.2 m high stems

*Age-determination transect*

| 1025 - 31 - 2.2 - 1 |
| 1015 - 36, 32, 28, 27 - 3.0 - 2 |
| 1000 - 41, 37, 33 - 3.5 - 2 |

**Documentation**

The fact that at the nearby locality 177, the tree-limit obviously lay at 950 m in about 1915, increases the probability that the tree-limit at the actual locality con-
Concerned was not much higher at the same time. Furthermore, Smith’s isohypsic map (Karta 1) shows that there was no birch forest growing on this hillslope, i.e. that the present-day tree-limit is probably considerably higher than it was in 1915.

**Past tree-limit**

*Degree of change*

<965  
Apparent displacement: +60  
Significant displacement: +60

179 Ramundberget N (69 574 13 237)

**Present-day altitudinal limits (1977)**

**FL:** 920, clumps of trees  
**TL:** 975, a small number of 3 – 3.5 m high stems

**Age-determination transect**

975 – 45, 44, 30 – 3.2 – 2  
960 – 30, 26 – 3.0 – 2  
955 – 41 – 5.0 – 20  
950 – 41 – 4.0 – 20

**Documentation**

TL-Smith (349):933

**Past tree-limit**

935  
Apparent displacement: +40  
Significant displacement: +35

180 Ramundberget S (69 544 13 244)

**Present-day altitudinal limits (1975)**

**FL:** 980, even limit  
**MSL:** 980, one stem  
**TL:** 1000, a 2.3 m high stem

**Age-determination transect**

1000 – 31 – 2.3 – 2  
990 – 45, 37 – 2.5 – 2  
980 – 49, 48, 42, 33, 24 – 4.5 – 2  
980 – 66 – 5.0 – 20  
960 – 24 – 5.0 – 20  
945 – 57 – 6.0 – 20  
930 – 102 – 7.0 – 20  
920 – 54 – 4.5 – 20

**Documentation**

TL-Smith (350):912

**Past tree-limit**

980  
Apparent displacement: +20  
Significant displacement: +20

181 Kariknallarna E (69 512 13 235)

**Present-day altitudinal limits (1975)**

**FL:** 950, even limit  
**MSL:** 950, a few stems  
**TL:** 960, a small number of 2.5 – 3 m high stems  
**SL:** 1005, a 1.5 m high stem

**Age-determination transect**

905 – 87 – 5.0 – 20

**Documentation**

TL-Smith (351):900

---

**Fig. 53.** A clump of birches, which became established long after 1915/16, is visible just on the edge of the large and deep snow-field, at the time of birch leafing. Nowadays birch would be virtually unable to colonise this particular site by seed, because of the effects of the increased supply of snow meltwater after ca 1950. Well-established birches, however, are still quite capable of holding out fairly well, despite the changed environment, because of their stem pliability, although with increasing age they become broken down one-by-one by the weight of the snow cover. The vegetation growing in front of the snow-field is a willow thicket (*Salix* spp.) almost 1 m high. Locality 181, 950 m a.s.l. Photo: June 16, 1973.

**Past tree-limit**

905  
Apparent displacement: +55  
Significant displacement: +55

182 Skenörsfjallet S (69 505 13 199)

**Present-day altitudinal limits (1975)**

**FL:** 975, small clumps of trees  
**MSL:** 975, one stem  
**TL:** 1075, a 2 m high stem

**Age-determination transect**

1075 – 32 – 2.0 – 1  
1050 – 35 – 2.3 – 1  
1015 – 45, 35, 33, 33, 23 – 2.5 – 1  
975 – 64 – 4.0 – 20

**Documentation**

Sernander (1905) mentions that a tree-limit exists on this hillslope, and in a later paper (1910) maintains that the plateau lying at the foot of the mountain is situated in the uppermost birch forest region. This is probably to be interpreted as meaning that small, discrete, stands of birch, as well as occasional solitary trees, were growing here up to an altitude of 970–980 m at the beginning of the present century.

**Past tree-limit**

975  
Apparent displacement: +100  
Significant displacement: +100

---

*Acta phytogeogr. suec. 65*
Change and stability of birch tree-limit in the Scandes

183 Stor-Skarven ESE (69 479 13 238)

Present-day altitudinal limits (1973)
FL: 965, clumps of trees
MSL: 900, one stem
TL: 970, several 3 m high stems

Age-determination transect
970 - 45 - 3.0 - 2
900 - 68 - 5.5 - 20

Documentation
TL-Smith (352): 896

Past tree-limit Degree of change
900 Apparent displacement: +70
Significant displacement: +70

184 Lill-Skarven SE (69 448 13 234)

Present-day altitudinal limits (1974)
FL: 1040, clumps of trees
MSL: 950, very old, but age-determination impossible because of damage from fungal attack
TL: 1065, a 2.5 m high stem
SL: 1075, 0.3 - 0.7 m high shrubs

Age-determination transect
1065 - 32 - 2.5 - 2
1060 - 32 - 2.5 - 2
1040 - 60, 50, 49, 37, 31 - 4.0 - 2
1030 - 35 - 4.0 - 2
1030 - 19 - 4.0 - 20
1025 - 68, 56, 34, 31, 30 - 4.0 - 2
1015 - 39, 33 - 4.0 - 3

1015 - 22, 16 - 4.0 - 20
1010 - 88, 84, 80, 58, 29 - 5.0 - 2
1000 - 27 - 5.0 - 20
990 - 104, 75, 70, 64, 53 - 5.0 - 2

Documentation
TL-Smith (353): 949. That the tree-limit lay higher-up than the altitude given by Smith, can not be entirely ruled out, although at most it can have been at 1010 m (cf. Kullman 1976a, p. 122).

Henning (1887) has given a fairly detailed account of both the flora and the vegetation cover of this particular hillslope. Nowhere does he give so much as a hint that birch was growing anywhere hereabouts at that time (cf. Kullman op. cit.).

Past tree-limit Degree of change
950 Apparent displacement: +115
Significant displacement: +110

185 Lill-Skarven SW (69 443 13 223)

Present-day altitudinal limits (1972)
FL: 960, clumps of trees
MSL: 930, one stem
TL: 1010, a small number of 2.5 – 3 m high stems

Age-determination transect
1010 - 39, 37 - 2.7 - 2
985 - 40, 38, 37 - 3.0 - 2
955 - 50, 36, 34, 31 - 5.0 - 2
930 - 74 - 5.0 - 20

Documentation
TL-Smith (358): 945

Fig. 54. The photograph (locality 186) was taken during a storm with accompanying driving snow (no snow fall), on the westward side of a ridge (915 m a.s.l.). The local birch tree-limit coincides with the point of change-over from snow accumulation to snow deflation. More or less similar snow deflation areas as the one shown in the photograph, immediately above the tree-limit, are characteristic of most of the localities in the investigated area at which the tree-limit was found to have remained unchanged since 1915/16. Photo: April 20, 1974.

Acta phytogeogr. suec. 65
Fig. 55. Tree-limit (1010 m a.s.l.) at locality 189. The birch probably has a stem base age which scarcely exceeds 30 years. Photo: June 26, 1970.

Fig. 56. The same tree as shown in Fig. 55. The shoot system has obviously increased somewhat during the period 1970–1977. Photo: July 14, 1977.

<table>
<thead>
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<tbody>
<tr>
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<td>Significant displacement: +55</td>
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</table>

186 Storvallsruet W (69 414 13 253)

Present-day altitudinal limits (1972)
FL: 895, clumps of trees
MSL: 915, one stem
TL: 915, a few 2–4.5 m high stems

Age-determination transect
915 – 68 – 4.5 – 20

Documentation
TL-Smith (355):914

<table>
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<td>Significant displacement: 0</td>
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</table>

187 Lillvålen S (69 429 13 227)

Present-day altitudinal limits (1972)
FL: 930, clumps of trees
MSL: 935, one stem
TL: 935, a few 2 m high stems

Age-determination transect
935 – 61 – 4.0 – 20

Documentation
TL-Smith (357):927

Acta phytogeogr. suec. 65

<table>
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<td>Significant displacement: 0</td>
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</table>

188 Hamrafjället E (69 449 13 209)

Present-day altitudinal limits (1977)
FL: 935, sparse clumps of trees
MSL: absent, both on and above the valley floor (altitude ca 920 m)
TL: 975, a small number of 2–2.5 m high birches

Age-determination transect
975 – 36, 30 – 2.5 – 2
960 – 41 – 3.0 – 2

Documentation
Birger (1908, p. 112) gives the “birch limit” as 931 m. Smith’s statement “Hamrafjäll Ö ... 900”, probably applies to the SE-facing hillslope, since on the E-facing proper a value of 900 m is impossible.

<table>
<thead>
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</table>

189 Hamrafjäll SE (69 446 13 207)

Present-day altitudinal limits (1977)
FL: 990, dense clumps of trees
Fig. 57. The tree-limit (1010 m a.s.l.) at locality 189. The stems are somewhat older than those shown in Fig. 55. The surrounding vegetation is bilberry heath (Vaccinium myrtillus) with scattered shrubs of willow (Salix spp.) and juniper (Juniperus communis). Photo: June 26, 1970.

Fig. 58. The same tree as in Fig. 57. The left-hand stem has become very much more bent over since 1970, but is not yet completely dead. The right-hand stem has produced a much greater mass of foliage during the same period. Photo: July 14, 1977.

MSL: 950, a few stems
TL: 1010, a few 2.5 m high birches

Age-determination transect
955 - 59 - 6.0 - 20
950 - 62 - 6.0 - 20

Documentation
TL-Smith (359): 900. See locality 188.
Birger (1908: p. 112) states that the lowest value for the “birch limit” on Hamrafjället is found on the E-facing slope, viz. at 931 m. This value thus represents the minimum altitude for the tree-limit on the slope in question.

Past tree-limit
955
Apparent displacement: +55
Significant displacement: +55

190 Hamrafjället S (69 446 13 203)

Present-day altitudinal limits (1977)
FL: 990, clumps of trees
MSL: 940, one stem
TL: 1010, a few 2 – 2.5 m high birches
SL: 1015, a 1.5 m high shrub

Age-determination transect
990 – 56, 54, 53, 51, 38 – 3.5 – 2
965 – 58, 46, 43, 42, 32 – 4.0 – 2
950 – 55, 53, 50, 49, 36 – 7.0 – 2
940 – 77 – 6.0 – 20
930 – 55, 48, 40 – 7.0 – 2
930 – 81 – 5.0 – 20

Documentation
For reasons mentioned under locality 189, the tree-limit lay above 931 m at the beginning of the present century.
Birger (1908: Tafl. 8, Fig. 20) reproduces a photograph in which this hillslope, although not appearing absolutely distinct, is clear enough to make it obvious that the belt of birch forest present between ca 920 and 990 m today, was entirely absent at the beginning of the present century.

Past tree-limit
940
Apparent displacement: +70
Significant displacement: +70

191 Hamrafjället SSE (69 445 13 195)

Present-day altitudinal limits (1977)
FL: 960, small clumps of trees
MSL: not above 925 m
TL: 1060, a small number of 2 – 2.5 m high stems

Age-determination transect
1060 – 28 – 2.0 – 2
1055 – 29, 23, 21 – 2.5 – 1
1010 – 42, 40, 39, 35, 32 – 2.7 – 1
965 – 30 – 4.5 – 20
960 – 43, 37, 35, 29, 29 – 3.5 – 2
960 – 33 – 5.5 – 20
935 – 34 – 9.0 – 20
930 – 48 – 6.0 – 13
925 – 48 – 7.0 – 20

Acta phytogeogr. suec. 65
Fig. 59. In the upper part of the birch forest belt the most important mortality factor for stems which have attained a certain thickness and length is simply mechanical injury from the weight of accumulated snow. Younger, more slender, stems are better able to withstand snow pressure, since they are still pliable enough to bend under its weight without breaking. Locality 191, 960 m a.s.l. Photo: August 2, 1976.

Fig. 60. These birches grow 20 m below the tree-limit at locality 192. Their development has been carefully followed by taking photographs at yearly intervals, always from the same viewpoint. The long-lasting snow cover and fertile soil conditions here give rise to a vegetation dominated by a mixture of grasses and herbs, together with willow thickets (Salix spp.). The arrow indicates a birch stem permanently damaged by the weight of the snow cover. Photo: July 6, 1972.

**Documentations**

TL-Smith (361):968 (cf. Kullman 1976 a, p. 120).

Sernander (1905) estimated the "rational tree-limit" to lie at 890 m, at the same time as the height of the summit plateau was determined as being 1030 m. The latter value is appreciably too low. It is impossible, however, to decide from his account to just what particular point on the plateau that value refers. Sernander's report is thus of little use in the present connection.

Past tree-limit

<table>
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<tr>
<th>Degree of change</th>
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<td>+80</td>
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<td>Significant displacement:</td>
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</table>

192 Hamrafjället SSW (69 442 13 185)

Present-day altitudinal limits (1977)

| FL: 1050, clumps of trees | MSL: 975, several stems | TL: 1085, a multi-stemmed individual tree, of maximum height 2.2 m |

Age-determination transect

| 1085 - 35, 25 - 2.2 - 2 |
| 1080 - 38 - 1.9 - 2 |
| 1070 - 39 - 2.2 - 2 |
| 1065 - 35, 32, 30, 30 - 2.7 - 2 |
| 1050 - 41, 41, 34, 30 - 3.0 - 2 |
| 1020 - 26 - 4.0 - 20 |
| 1005 - 52 - 5.0 - 20 |
| 995 - 48 - 5.0 - 20 |
| 975 - 86, 78 - 5.5 - 20 |

Documentation

Henning (1887) determined the "birch's upper limit" to be at 1024 m (corrected value).

Birger (1908) found the "highest-lying outposts of birch" at 1030 m. For further discussion concerning
Fig. 61. The same view as in Fig. 60. Apart from the fact that the birch stem marked by the arrow in Fig. 60 has died off completely and is hidden by the surrounding vegetation, no obvious changes have occurred here in 1972–1977. Photo: July 10, 1977.

Fig. 62. The same view as in Figs. 60 and 61. These birches which all have stem base ages not exceeding 55 years, grow in an environment characterised by a deep snow cover and a late snow-melt. Their establishment here has obviously been dependent upon an amelioration of these particular habitat factors since 1915/16. Photo: May 22, 1977.
these two particular values see my earlier paper (Kullman 1976a, p. 119)

**Past tree-limit**

**Degree of change**

<table>
<thead>
<tr>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1030</td>
<td>197</td>
<td>955</td>
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</table>

**Apparent displacement:** +55  
**Significant displacement:** +55

193 Hamrafjället N (69 455 13 190)

**Present-day altitudinal limits (1977)**

<table>
<thead>
<tr>
<th>FL</th>
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<th>TL</th>
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</thead>
<tbody>
<tr>
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<td>955</td>
<td>970</td>
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</table>

**Age-determination transect**

| 970 | 69 | 5.0-2 |
| 965 | 64 | 5.5-20 |

**Documentation**

TL-Smith (362):940

**Past tree-limit**

<table>
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<tbody>
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</table>

194 Malmagsvålen SW (69 507 13 144)

**Present-day altitudinal limits (1974)**

<table>
<thead>
<tr>
<th>FL</th>
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</tr>
</thead>
<tbody>
<tr>
<td>980</td>
<td>975</td>
<td>985</td>
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</table>

**Age-determination transect**

| 985 | 69, 63, 60, 48, 38-2.5-2 |
| 975 | 85-5.0-20 |

**Documentation**

TL-Smith (364):960

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +10</td>
</tr>
<tr>
<td>Significant displacement: +10</td>
</tr>
</tbody>
</table>

195 Rutfjallet (Lillruten) NNE (69 498 13 099)

**Present-day altitudinal limits (1972)**

<table>
<thead>
<tr>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>905</td>
<td>930</td>
<td>965</td>
</tr>
</tbody>
</table>

**Age-determination transect**

| 930 | 75-4.5-2 |

**Documentation**

TL-Smith (366):944

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +20</td>
</tr>
<tr>
<td>Significant displacement: +20</td>
</tr>
</tbody>
</table>

196 Gråstöten NE (69 465 13 129)

**Present-day altitudinal limits (1974)**

<table>
<thead>
<tr>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>935</td>
<td>925</td>
<td>980</td>
</tr>
</tbody>
</table>

**Age-determination transect**

| 980 | 64, 38, 34-2.7-2 |
| 975 | 26-2.0-2 |
| 945 | 64, 49, 41, 40, 39-4.0-2 |
| 925 | 65-4.5-20 |

**Documentation**

TL-Smith (367):938.

Sernander (1898, p. 329), in 1895 or 1896, determined the altitude of the “tree-limit” to be 870 m, while at the same time determining the altitude of the nearby lake Malmagen as 755 m, a value which is 26.5 m too low. The altitude of Sernander’s, otherwise undefined, tree-limit thus needs correcting to 900 m.

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +40</td>
</tr>
<tr>
<td>Significant displacement: +35</td>
</tr>
</tbody>
</table>

197 Storkläppen NE (69 429 13 167)

**Present-day altitudinal limits (1974)**

<table>
<thead>
<tr>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>900</td>
<td>965</td>
</tr>
</tbody>
</table>

**Age-determination transect**

| 965 | 38-2.5-2 |
| 950 | 53, 39, 27-3.5-2 |
| 925 | 41, 39, 38, 33, 29-4.0-2 |
| 900 | 73, 64-5.0-20 |

**Documentation**

TL-Smith (368):947

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +20</td>
</tr>
<tr>
<td>Significant displacement: +20</td>
</tr>
</tbody>
</table>

198 Svanåkläppen SSW (69 398 13 180)

**Present-day altitudinal limits (1974)**

<table>
<thead>
<tr>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>975</td>
<td>940</td>
<td>945</td>
</tr>
</tbody>
</table>

**Age-determination transect**

| 975 | 62, 53, 47, 29-4.5-2 |
| 970 | 28-4.0-2 |
| 940 | 79, 62-5.0-20 |

**Documentation**

TL-Smith (370):942

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +35</td>
</tr>
<tr>
<td>Significant displacement: +30</td>
</tr>
</tbody>
</table>

199 Svanåkläppen E (69 398 13 185)

**Present-day altitudinal limits (1974)**

<table>
<thead>
<tr>
<th>FL</th>
<th>MSL</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>915</td>
<td>945</td>
</tr>
</tbody>
</table>

**Age-determination transect**

| 945 | 45-2.5-3m high birches |
| SL | 950, a 1.7 m high stem |

Acta phytogeogr. suec. 65
Change and stability of birch tree-limit in the Scandes

Age-determination transect
915 - 70 - 5.0 - 20

Documentation
TL-Smith (371):900

Past tree-limit
915
Apparent displacement: +30
Significant displacement: +30

200 Svanåkläppen N (69 402 13 184)

Present-day altitudinal limits (1972)
FL: 900, clumps of trees
MSL: 900, a few stems
TL: 960, a small number of 2 - 2.5 m high stems

Age-determination transect
900 - 89, 62 - 5.5 - 20

Documentation
TL-Smith (369):915

Past tree-limit
915
Apparent displacement: +45
Significant displacement: +40

203 Rödfjället S (69 336 13 213)

Present-day altitudinal limits (1972)
FL: 875, clumps of trees
MSL: 950, a few stems
TL: 950, a small clump of 4 - 5 m high stems

Age-determination transect
950 - 93 - 5.0 - 20

Documentation
Lacking

Past tree-limit
950
Apparent displacement: 0
Significant displacement: 0

204 Rödfjället E (69 340 13 247)

Present-day altitudinal limits (1972)
FL: 845, small clumps of trees
MSL: 925, two stems
TL: 925, a small number of 3 - 4 m high stems

Age-determination transect
925 - 62 - 4.0 - 20
870 - 69 - 4.5 - 20

Documentation
Lacking

Past tree-limit
925
Apparent displacement: 0
Significant displacement: 0

205 Brattriet S (69 280 13 234)

Present-day altitudinal limits (1975)
FL: 1015, clumps of trees
MSL: 975, one stem
TL: 1115, two 2.1 m high stems

Age-determination transect
1115 - 26 - 2.1 - 1
1075 - 28, 25 - 2.5 - 1
1035 - 41 - 3.0 - 2
1015 - 73, 62, 41, 32, 32 - 4.0 - 2
975 - 98 - 4.0 - 20

Documentation
TL-Smith (378):972

Past tree-limit
975
Apparent displacement: +140
Significant displacement: +140

206 Sånsjället S (69 081 13 821)

Present-day altitudinal limits (1973)
MSL: 1025, a single live stem, together with remains of former stems which were at least

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Fig. 63. The birch stems seen in the photo (locality 205) represent the highest-known present-day tree-limit (TL) in the whole of Sweden (1115 m a.s.l.). The stem base age of the left-hand one is 26 years. The vegetation is dominated by Vaccinium myrtillus and Betula nana. Photo: July 21, 1975.

2 m in height and were fairly old when they died
TL: 1025, multi-stemmed 3.5 m high birch

Age-determination transect
1025 - 61 - 3.5 - 20

Documentation
Lacking

Past tree-limit Degree of change
1025 Apparent displacement: 0
Significant displacement: 0

207 Korpflyet SSE (69 062 13 720)

Present-day altitudinal limits (1974)
FL: 1050, small clumps of trees
MSL: 960, a few stems
TL: 1110, a multi-stemmed 2 m high birch

Age-determination transect
1100 - 34 - 2.0 - 2
1110 - 34 - 1.5 - 2
1100 - 46 - 2.2 - 2
1090 - 23 - 2.0 - 2
1035 - 68, 41, 36, 32 - 3.0 - 2
1015 - 59 - 2.7 - 10
985 - 57, 49, 48, 41 - 3.0 - 2
960 - 73 - 3.5 - 20
950 - 65 - 3.5 - 20

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Fig. 64. This birch forms the tree-limit (1025 m a.s.l.) at locality 206. The age of the thickest stem, estimated 2 m above the ground, is 61 years. In other words, the tree-limit here has remained unchanged since 1915/16. In the immediate vicinity of the birch the vegetation is bilberry heath (Vaccinium myrtillus), while Cladonia alpestris is dominant further away from the tree. Photo: August 15, 1973.

Documentation
The tree-limit would be expected to have lain at approximately the same altitude (1025 m) as that of the previous locality, because the two localities lie quite close together and the topography and edaphic conditions at both sites are similar.

Past tree-limit Degree of change
1025 Apparent displacement: +95
Significant displacement: +95

208 Gråsidan SSE (69 086 13 788)

Present-day altitudinal limits (1974)
FL: 940, clumps of trees
MSL: 970, a mouldering stump of a very old arborescent birch
TL: 970, a small number of multi-stemmed birches, maximum height 4 m
SL: 985, a few 1 - 1.5 m high shrubs;
1010, a 0.5 m high shrub

Age-determination transect
970 - 66, 64 - 4.0 - 2
970 - 58 - 4.0 - 13
965 - 36 - 2.3 - 2
960 - 99 - 3.0 - 2
960 - 82 - 3.5 - 20
955 - 11 - 2.8 - 2
In this type of environment, with virtually no supply of snow meltwater during the entire vegetative season, neither at present nor at all likely in the past as well, the tree-limit has remained stable. The birch in the foreground has grown in height from 0.2 to 2.8 m since the mid 1960’s, an amazingly rapid growth rate for a birch growing very close to the tree-limit. This indicates that the tree-limit here is not directly climatically conditioned. Locality 208, 995 m a.s.l. Photo: August 16, 1974.

At locality 210, which has a rather shallow snow cover and becomes snow-free early on in the spring, the open ground above the tree-limit (930 m a.s.l.) has never offered the pre-conditions for any upward displacement of the tree-limit. The stem age of the tree, cored 2 m above ground-level, was 70 years. The dominant vegetation here is bilberry heath (Vaccinium myrtillus). Photo: July 19, 1974.

### Documentation

**Lacking**

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: 0</td>
</tr>
<tr>
<td>Significant displacement: 0</td>
</tr>
</tbody>
</table>

**209 Jakobshöjden SW (68 94 1 13 178)**

**Present-day altitudinal limits (1975)**

- **FL:** 955, lobes and clumps of trees
- **MSL:** 955, a few stems
- **TL:** 980, a small number of 3 m high stems

**Age-determination transect**

- 980 – 61 – 3.0 – 2
- 975 – 40 – 3.0 – 2
- 965 – 33 – 3.0 – 2
- 960 – 49 – 3.0 – 2
- 955 – 64 – 3.5 – 2
- 945 – 76 – 3.5 – 2

**Documentation**

TL-Smith (458):957. This value is a personal communication to Smith from Gunnar Samuelsson. It is quite clear that Samuelsson did not consider multi-stemmed birches 2 m in height as being trees (cf. Samuelsson 1917, p. 96). It is therefore highly probable that birches of the former type were present at an altitude somewhat above 957 m (e.g. 965 m).

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: +15</td>
</tr>
<tr>
<td>Significant displacement: +15</td>
</tr>
</tbody>
</table>

**210 Östra Barfredhågna SSW (69 876 13 219)**

**Present-day altitudinal limits (1975)**

- **FL:** 870, stands of very sparse forest
- **MSL:** 930, one stem
- **TL:** 930, a small number of 2.5 – 3 m high stems

**Age-determination transect**

- 930 – 70 – 2.8 – 20
- 925 – 72 – 4.0 – 20
- 920 – 54 – 3.0 – 13
- 920 – 50, 47 – 2.5 – 2
- 910 – 71 – 3.5 – 20
- 910 – 83 – 2.5 – 2
- 890 – 141 – 4.0 – 13

**Documentation**

Samuelsson (1917, p. 120) has given a summarised description of the tree-growth on the S-facing slope of this mountain, from which it is clear that the conditions at that time very much resembled the situation at the present-day.

**Past tree-limit**

<table>
<thead>
<tr>
<th>Degree of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent displacement: 0</td>
</tr>
<tr>
<td>Significant displacement: 0</td>
</tr>
</tbody>
</table>

*Acta phytogeogr. suec. 65*
82 Leif Kullman

211 Molnet SSE (68 771 13 460)

*Present-day altitudinal limits (1975)*

**FL:** 1050, clumps of trees  
**MSL:** 975, a few stems  
**TL:** 1070, a multi-stemmed, 2.4 m high birch

*Age-determination transect*

<table>
<thead>
<tr>
<th>Year</th>
<th>Age</th>
<th>Height</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1070</td>
<td>19</td>
<td>2.1</td>
<td>+25</td>
</tr>
<tr>
<td>1060</td>
<td>49</td>
<td>2.0</td>
<td>+25</td>
</tr>
<tr>
<td>1025</td>
<td>64</td>
<td>2.0</td>
<td>+25</td>
</tr>
<tr>
<td>1005</td>
<td>65</td>
<td>2.5</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>64</td>
<td>3.0</td>
<td>+25</td>
</tr>
<tr>
<td>980</td>
<td>60</td>
<td>4.0</td>
<td>+25</td>
</tr>
<tr>
<td>975</td>
<td>72</td>
<td>4.0</td>
<td>+25</td>
</tr>
</tbody>
</table>

*Documentation*

Samuelsson (1917, p. 95) states that the forest-limit on this hillslope was as high as that for locality 212, i.e. 995 m, and that above this altitude there was a belt of birch shrub. A comparison of Samuelsson’s Fig. 4 (op. cit.) and present-day conditions (see Kullman 1976b, Fig. 3) reveals that the local boundaries between clumps of trees and boulderfield have remained relatively constant since 1912. It is highly probable that stunted birch-forest, which Samuelsson would almost certainly have classified as birch shrub (cf. locality 209), in 1912 grew as high up as the level of the present-day forest-limit, i.e. 1050 m a.s.l. In addition, Samuelsson maintains that scattered solitary birches, which from all accounts could have measured 2 m in height, grew well above the altitude of the uppermost birch stands on the E- and S-facing slopes of Molnet.

**Past tree-limit**  
**1075**

*Degree of change*

<table>
<thead>
<tr>
<th>Year</th>
<th>Apparent displacement</th>
<th>Significant displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1075</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 67. The relatively flat terrain at and above the tree-limit (900 m a.s.l.) at locality 213 has almost certainly 'at all times' retained a relatively shallow snow cover and has become snow-free again early on in the spring. A surplus of snow was quite certainly not a limiting factor which prevented higher colonisation by the birch at the beginning of the present century. Thus, the climatic amelioration, here and at similar localities was unable to affect the actual position of the birch tree-limit, since the only environmental change induced was even less favourable to birch colonisation, viz. a decreased supply of meltwater, leading to increased dryness of the soil in summer, especially during the unique succession of abnormally warm summers during the 1930’s. Photo: July 21, 1974.

212 Nipfjället S (68 741 13 429)

*Present-day altitudinal limits (1975)*

**FL:** 1025, clumps of trees  
**MSL:** 1000, mouldering remains of an arborescent, very old birch  
**TL:** 1025, a small number of 2 – 2.5 m high stems

*Age-determination transect*

<table>
<thead>
<tr>
<th>Year</th>
<th>Age</th>
<th>Height</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1025</td>
<td>48</td>
<td>4.5</td>
<td>+25</td>
</tr>
<tr>
<td>1025</td>
<td>40</td>
<td>4.5</td>
<td>+25</td>
</tr>
<tr>
<td>1024</td>
<td>28</td>
<td>4.5</td>
<td>+25</td>
</tr>
<tr>
<td>1020</td>
<td>24</td>
<td>2.4</td>
<td>+25</td>
</tr>
<tr>
<td>1010</td>
<td>28</td>
<td>2.5</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>61</td>
<td>3.0</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>44</td>
<td>3.0</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>34</td>
<td>3.0</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>28</td>
<td>2.4</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>24</td>
<td>2.4</td>
<td>+25</td>
</tr>
<tr>
<td>990</td>
<td>20</td>
<td>2.5</td>
<td>+25</td>
</tr>
<tr>
<td>985</td>
<td>59</td>
<td>4.5</td>
<td>+25</td>
</tr>
<tr>
<td>985</td>
<td>43</td>
<td>3.2</td>
<td>+25</td>
</tr>
</tbody>
</table>

*Documentation*

Lacking

213 Städjan WSW (68 717 13 455)

*Present-day altitudinal limits (1974)*

**FL:** 860, even limit  
**MSL:** 900, mouldering remains of a fairly coarsely-dimensioned stem, over 2 m in length  
**TL:** 900, a 3 m high stem

*Age-determination transect*

<table>
<thead>
<tr>
<th>Year</th>
<th>Age</th>
<th>Height</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>65</td>
<td>3.0</td>
<td>+25</td>
</tr>
<tr>
<td>895</td>
<td>64</td>
<td>3.8</td>
<td>+25</td>
</tr>
</tbody>
</table>

*Documentation*

Lacking

**Past tree-limit**  
**900**

*Degree of change*

<table>
<thead>
<tr>
<th>Year</th>
<th>Apparent displacement</th>
<th>Significant displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Present-day altitudinal limits (1974)</th>
<th>FL: 895, wedge</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSL: 890, a few number of stems</td>
<td></td>
</tr>
<tr>
<td>TL: 905, a small number of 2.5 m high stems</td>
<td></td>
</tr>
<tr>
<td>SL: 920, mouldering remains of two recently dead stems, which were at least 2 m in height and 25–30 years old</td>
<td></td>
</tr>
<tr>
<td>A few still living, 2 dm high basal shoots</td>
<td></td>
</tr>
</tbody>
</table>

### Age-determination transect

<table>
<thead>
<tr>
<th>900 – 44, 29, 18 – 3.0 – 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>890 – 79 – 5.0 – 20</td>
</tr>
</tbody>
</table>

### Documentation

Samuelsson (1917) gives the altitude of the forest-limit as 900 m.

### Past tree-limit

<table>
<thead>
<tr>
<th>900</th>
</tr>
</thead>
</table>

### Degree of change

- **Apparent displacement:** +5
- **Significant displacement:** 0
Analysis of primary data

The relationship between the degree of displacement of the tree-limit and the effect of various environmental factors, which may be relevant in explaining such changes, has been investigated in an attempt to find the cause or causes. The results are presented below.

The basic philosophy motivating such a treatment of the data has been: The greater the degree of displacement of the tree-limit found to have taken place, the greater the probability that the prime operative factor causing the observed shift can be ascertained from its close relationship over the widest area to interlinked environmental factors. In other words, those investigated localities at which the greatest and least degrees of displacement are recorded ought to exhibit most clearly the ecological characteristics which determine, or control, the presence or absence of a change in the tree-limit.

The analyses are intended to elucidate any quantitative differences in the operative factors in relation to different degrees of Significant displacement.

The statistical relationships have been mainly investigated by calculating for each environmental factor, the percentual distribution of a small number of quantitative classes, within each of four different intervals with respect to the magnitude of the Significant displacement.

The results are presented in the form of histograms, in which each horizontal column (displacement interval) representing 100 %, is subdivided into the proportions represented by each of the quantitative classes of a certain environmental factor. This provides a graphic representation of the degree of the displacement of the tree-limit in relation to the quantitative expression of the respective environmental factor.

The (present-day) estimated quantitative values for the environmental factors considered are set out in Appendix I.

**Significant displacement and its relation to geographical position**

Out of the total of 213 localities at which the dynamics of the tree-limit was investigated, a positive Significant displacement was found to have occurred at 160 (ca 75 %). At the remaining 53 localities (ca 25 %) the position of the tree-limit remained unchanged. In no case was an undisputable lowering of the tree-limit found to have taken place. The greatest upward shift of the tree-limit was 140 m (localities 102 and 205).

The number of localities for each of the eight displacement intervals is shown in Table 9. The mean values (with standard deviation) for the altitude of the tree-limit within the investigated area as a whole in 1915/16 (PTL) and in 1975 (TL) are shown in Table 10.

The geographical distribution of the localities with or without a positive value of Significant displacement is clear from Figs. 2 and 3.

---

**Table 9. The numbers of localities for which the recorded values for the altitudinal displacement of the tree-limit (1915/16–1975) fell within each of 8 classes of magnitude.**

<table>
<thead>
<tr>
<th>Tree-limit displacement (m)</th>
<th>No. of localities</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>53</td>
</tr>
<tr>
<td>5–10</td>
<td>23</td>
</tr>
<tr>
<td>15–20</td>
<td>26</td>
</tr>
<tr>
<td>25–30</td>
<td>31</td>
</tr>
<tr>
<td>35–40</td>
<td>28</td>
</tr>
<tr>
<td>45–60</td>
<td>24</td>
</tr>
<tr>
<td>&gt;60</td>
<td>28</td>
</tr>
</tbody>
</table>

**Table 10. Mean (x) and standard deviation (s.d.) for the altitude of the tree-limit (m a. s. l.) in 1915/16 and 1975, respectively, at all the 213 investigated localities taken together.**

<table>
<thead>
<tr>
<th>Year</th>
<th>x</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1915/1916</td>
<td>896.92</td>
<td>±67.23</td>
</tr>
<tr>
<td>1975</td>
<td>930.92</td>
<td>±69.14</td>
</tr>
</tbody>
</table>

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There are virtually no clearly marked regional differences distinguishable in the degree of displacement of the tree-limit over most of the investigated area. The proportion of localities at which no change was recorded is, however, definitely greater in Dalarna and the southernmost part of Härjedalen, compared to the remainder of the investigated localities. It is also clear from the locality descriptions and Figs. 2 and 3, that the degree of displacement of the tree-limit can differ very markedly even between two neighbouring localities (e.g. the following pairs of localities: 20, 21; 45, 46; 61, 62; 103, 104; 144, 145).

**Continentality/maritimity**

The relative degree of local thermic continentality or maritimity has for a long time been considered to play a determining role in the absolute altitude of the tree-limit, when seen in a broader, regional, perspective (e.g. Brockmann-Jerosch 1919; Kilander 1965; Mork 1968, 1970). Furthermore, it was shown earlier that the degree of recent climatic change differed between areas with a continental resp. maritime character of the regional climate.

There are therefore good grounds for considering whether or not the changes in the tree-limit, in the different parts of the investigated area with a similar local climate, have also been similar within the period studied.

Unfortunately there are only a few meteorological stations within the area which provide the data necessary for forming a proper picture of the differing climatic regimes present.

Each locality has been classified with regard to climatic type, on a basis of available meteorological data (Table 1), Ångström’s (1974, Fig. 23) map of the extent of areas of local continentality or local maritimity in Sweden, and certain opinions about climatic differences between different parts of the investigated area expressed in literature (Jalas 1950; Hintikka 1963; Kravtsova 1972).

When classifying the climate of each locality attention has also been paid to the large-scale topography of the surrounding area, which might be expected to deflect certain airmasses, or to cast an orographic rainshadow. In a few cases personal knowledge of local weather conditions, especially snow accumulation and rate of melting, has also been considered. Nevertheless, it must be pointed out that the classification is approximate, although by and large giving some indication of the regional distribution of local climates.

The percentual distributions, within each of the four displacement intervals and within the material as a whole, for the total numbers of localities belonging to each of the four local climate categories, are shown in Fig. 68.

The result shows incontrovertibly that the highest frequency of category 4 (local continental climate) is found within the 0-interval, i.e. that representing a non-displaced tree-limit during the 1915/16—1975 period. This frequency value decreases steadily for each higher interval. The frequencies of the local climate types 2 and 3 are
greater for the three highest displacement intervals, compared with the lowest. In other words, areas characterized by local continentality of the climate have only to a relatively small degree been characterized by an upward shift of the tree-limit.

Aspect

The aspect of a locality, i.e. the compass point towards which the ground surface faces, is particularly important regarding the altitude of the tree-limit thereabouts. Generally speaking, the highest tree-limits are recorded from S- to SW-facing slopes, while N- to NE-facing slopes yield the lowest values (cf. Smith 1920; Kilander 1965). The underlying reason is the relationship between the amount of incident solar radiation and local snow-accumulation (e.g. Lundqvist 1968; Perttu 1972).

Quite obviously this factor called for investigation in relation to the extent of tree-limit displacement at each locality. To this end the aspect of each site investigated in the field was determined with a hand compass, and assigned to the nearest of eight main compass points.

The results of the statistical treatment of the data, in histograms for the four displacement intervals and the 8 compass points, compared to that for the material as a whole, are shown in Fig. 69.

Only for ESE- to SE-facing sites was a consistent and unequivocal relationship to tree-limit displacement found. The percentage of sites facing ESE and SE increases with increasing upward displacement of the tree-limit.

Apparently, the ecological conditions were such that they favoured an upward shift of the tree-limit at ESE- to SE-facing localities.

Depth and duration of snow cover

As mentioned already, both Sandberg (1940, 1958, 1960, 1963) and Nordhagen (1956, 1964), as well as Smith (1957), considered that a direct relationship existed between the expansion of the birch in recent decades and changes in the duration of the local snow cover. There was therefore a strong motive to check this relationship using the data obtained in the present investigation.

![Histogram](image)

The snow conditions pertaining to each locality were summarised and values assigned, on a four-degree scale. The assessments were made on a basis of field observations from the time just prior to, and during, birch-leafing at each locality, i.e. the time of year at which the local differences in the snow cover and their relation to the microtopography of the area are revealed most clearly. Many of the localities were also either visited, or examined through binoculars at a distance, during the depths of winter. The field observations have been complemented with data obtained from the local population and the local police about the situation and extent of hillslopes subject to accumulation of great depths of snow and considered dangerous from avalanches.

The classification, at each locality, is valid for the area between the PTL and the TL. At localities where no tree-limit change occurred the classification was made for the stretch of ground extending 100 m above the TL. Four grades of snow cover were used.

The results of the standard treatment of the data, in relation to the displacement- intervals, are shown in histogram form in Fig. 70, which reveals quite clearly a good positive correlation between
The slope angle may exert such an effect through its relationship to such other factors as local depth and duration of snow cover, groundwater drainage, mechanical effects of snow accumulation, frequency of avalanches, solar energy budget, depth of soil and soil composition etc.

Although very much a non-active factor in itself, the angle of slope requires investigation in relation to the locally documented displacements of the tree-limit, since it might provide an indication of the potential action of other environmental factors.

At each locality the mean angle of slope of the ground between the PTL and the TL, has been estimated from a study of the contours shown on the respective sheets of the topographical maps, scale 1:50,000, or larger if available. At localities for which a static tree-limit was recorded for the 1915/16-1975 period, the angle of slope over the stretch of ground 100 m above the present-day tree-limit was estimated. The angle of inclination data have been subdivided into five categories. The results of the standard treatment of the data are shown in Fig. 71.

The only relatively clear trend found is that localities with slopes of $<5^\circ$ inclination were less frequently represented in the two highest dis-

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**Fig. 70.** Percentual distributions of each of the 4 grades of depth and duration of local snow cover within each of the 4 tree-limit displacement intervals and within the material as a whole (Total). The classification is as follows: 1. Extreme deflation area, mean maximum depth of snow cover 0–20 cm, ground surface becoming snow-free long before birch-leafing occurs; 2. Areas intermediate in character between grades 1 and 3, mean maximum snow depth, over a relatively wide area, ca 1 m, ground snow-free just prior to birch-leafing; 3. Extreme accumulation area, extensive and deep snowbeds still present at and after the time of birch-leafing, although between such snowbeds there may be local patches of bare ground; 4. Conditions as for grade 3, but in addition known to be subject to avalanches. (n = number of localities)

**Fig. 71.** Percentual distributions of each of the 5 categories of angle of slope within each of the 4 tree-limit displacement intervals and within the material as a whole (Total). The classification is as follows: 1. $<5^\circ$; 2. $5^\circ-10^\circ$; 3. $11^\circ-20^\circ$; 4. $21^\circ-30^\circ$; 5. $>30^\circ$. (n = number of localities)
placement intervals than they were in the two lowest classes, i.e. on gentle slopes there was less tendency for any upward shift of the tree-limit to have occurred and it is obvious that no further correlation exists between angle of slope and tree-limit displacement.

**Slope morphology**

This concept embraces the ecological presupposition that the possibilities for tree growth vary with the geomorphology, slopes of different topographic nature bearing different degrees of tree cover.

As with angle of slope, geomorphological differences are coupled with the effects of such factors as the depth and duration of the snow cover, groundwater drainage, soil depth and composition, insolation etc.

Six different categories of slope morphology were used to classify the conditions pertaining at each locality between the PTL and a point ca 100 m above the TL, or to 100 m above the TL in cases where the tree-limit had remained static 1915/16–1975. The localities were classified on a basis of field notes and a large number of photographs.

The results of the standard comparisons of the percentual distributions of the six categories of slope morphology, within the four displacement intervals and the material as a whole, are shown in Fig. 72.

It is obvious that categories 1 and 3 are predominant among the localities belonging to the displacement interval 0 (i.e. static tree-limit) and category 1 is unrepresented in higher classes. Category 2 localities are unrepresented in displacement interval 0 simply because of the way in which this category has been defined, but are predominant in the higher intervals. Categories 4 and 5, concave slopes, are predominantly represented by localities belonging to the highest interval (tree-limit displacement >60 m).

There is thus in geomorphological terms a clear distinction between localities at which the tree-limit has remained static and those at which it has advanced. The terrain in which the latter are situated is more or less broken, whereas for the former the terrain is much smoother, or only gently undulating.

**Local land usage**

The various types of land usage at the tree-limit have already been described in general terms in the chapter on Human impact around the tree-limit.

To categorise the kind and degree of human influence for each locality in detail, however, is a much more difficult matter. The classification presented below, used for the localities in the investigated area, is therefore based on the carefully-considered probability that the usage(s) documented for a wider region is/are applicable for the respective locality in question. The chosen sub-divisions comprise forms of land usage which have either ceased entirely, or markedly declined.
in both extent and intensity during the present century.

The localities have been assigned to five different land-usage categories on a basis of archival evidence, e.g. the maps and reports of former land surveys such as the delineation of Crown and private land (Sw. ‘avvitttring’) and enclosure awards (Sw. ‘laga skifte’), which provide relatively objective descriptions of the land usage in the respective areas at different times in the middle and late 19th century. These data have been supplemented by information derived from interviews with the older members of the local popula-

tion (see Appendix II) and by direct observations in the field of the remains of hay-drying poles, fences, evidence of Lappish encampments etc.

A detailed study of the available topographic and ethnological descriptions and natural history accounts from the investigated area has yielded a rich harvest of local data. A full bibliography of all my sources would unfortunately take up too much space. The most important works consulted are cited in the chapter on ‘Human impact around the tree-limit’ and themselves contain further information on earlier sources. A general selection of the more important works consulted is provided in Appendix III. The results of the standard treatment of the data, for each displacement interval and for the material as a whole, are shown in Fig. 73.

The only correlations found were that a higher proportion of the localities of land-usage category 5 (i.e. no documented form of human impact) and a lower proportion of category 3 (i.e. Lappish activities) were represented in the higher displacement intervals, i.e. with gradually increasing values for the upward shift of the tree-limit.

There are thus no indications that cessation of human influence led to a subsequent rise in the altitude of the tree-limit. The present upward extension of birch is definitely not a re-colonisation of lost territory.

**Chronology of birch expansion in the belt between PTL and TL**

The ages obtained for all the stems investigated in the age-determination profiles and which were growing above the tree-limit of 1915/16 (PTL) have been summarised in Fig. 74 (107 localities altogether).

The ages have been converted into the absolute years concerned and the data so obtained have been grouped into quinquennia. The numbers of dated stems represented by each quinquennium are indicated along the vertical axis of the graph, with the time interval shown along the horizontal axis.

These quinquennial intervals have been termed ‘colonisation periods’, irrespective of whether the stems concerned were produced from seed during that particular period, or whether they were already present but under-developed, i.e. as
Fig. 74. Absolute distributions for successive quinquennia of the numbers of pioneer birch stems (for all the localities taken together), shown by annual ring counts of stem basal cores to belong to trees which colonised above the PTL during the respective quinquennium.

Fig. 75. Absolute distributions for successive quinquennia of the numbers of localities at which the present tree-limit altitude (TL) was first colonised during the respective quinquennium. The approximate date of tree-size attainment for the stems representing each quinquennium, according to growth rate estimates, is indicated at the top of certain bars.

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prostrate shrubs. A wholly satisfactory answer to that problem was impossible, since the cores for dating had to be taken, for practical reasons, some way (10–20 cm) above the stem base at ground-level.

At all events, however, the data provide an indication of the earliest period during which the stems started to grow in length faster than previously (i.e. entered a growth-acceleration period). In most cases, however, it is most likely that the colonisation-period or perhaps more correctly a few years beforehand, is a good approximation of the establishment time of individual birches (cf. Fries 1964).

Besides, Smith (1920) states that at the time of his surveys there was no belt of low-growing birch bushes above the tree-limit itself. With very few exceptions the bushes that were present grew at most 20–50 m above the tree-limit. Were a majority of the dated stems not derived from seedling birches established after that time (1915/16), then Smith would necessarily have given a vastly different picture of the tree-limit vegetation in his account, i.e. a belt of birch bushes would have been generally present.

Furthermore, in several cases I was able to count the rings in cores taken at ground-level and 20 cm higher up the same stems, and the age difference never proved to be greater than six years.

Fig. 74 gives an overall picture of the chronology of the phases during which colonisation of successively higher altitudes was most intense in the particular altitudinal belt considered, i.e. between the PTL and the TL.

In summary, Fig. 74 shows that after 1910–1914 birch colonised the region above the tree-limit, at that time, at an ever-increasing rate which culminated during the period 1940–44, or perhaps a little earlier if allowance is made for the time taken to grow from seedling to a 10 to 20 cm-long stem (see p. 92). After the 1940–44 quinquennium the birch colonisation at successively higher altitudes was abruptly reduced.

**The colonisation of the present-day tree-limit level**

For 95 of the localities at which a rise in the altitude of the tree-limit was recorded, data also exist for the ages of the oldest stems of tree birches growing at the TL. These stems can right-

![Fig. 76. Percentual distributions of each of the 11 quinquennial colonisation periods within each of 3 tree-limit displacement intervals and within the material as a whole (Total). The periods have been coded as follows: – 1. 1960–64; – 2. 1955–59 etc. backwards in time.](image)

ly be regarded as being those of the pioneer colonists of their particular locality. In Fig. 75 these data have been set out in such a way that the number of localities with the same quinquennial colonisation of the present-day tree-limit level forms the vertical axis and the quinquennial periods of years, i.e. the periods of actual seedling colonisation at the particular altitude, forms the horizontal axis.

It is obvious from Fig. 75 that prior to 1915–19 birch colonisation at the altitude of the TL had occurred at only a small number of localities (ca 11 %). In general this process occurred appreciably later on, and in fact it is indicated that the maximum was first attained in 1940–44. Because of the slight inexactitude in the dating method the time of this intense colonisation falls, however, within the preceding quinquennial period (1935–39). Individual birches (trees or shrubs) were present at the TL-level in 1950 at ca 95 % of the localities at which age-determinations of tree-limit stems were made and at which the tree-limit had risen.

Fig. 75, however, gives no indication of any possible differences between localities which might exist if account were taken of the degree of the shift in the tree-limit throughout the investigated area. To investigate this problem Fig. 76 was constructed, in which the same data as above were used, for each quinquennial period, but now subdivided as histograms showing the percen-
tual representation of each of 11 quinquennial periods within each of three tree-limit displacement intervals compared with the distribution for the whole body of data.

Fig. 76 shows quite clearly that with increasing degree of displacement of the tree-limit (1915/16–1975) the attainment of the present-day tree-limit (TL) was, on average, progressively delayed. This suggests that throughout most of the period up to about 1950 the conditions for birch colonisation became more favourable at a continually increasing altitude, i.e. favourable conditions for birch expansion did not set in simultaneously over the whole of the available area between the PTL and the TL.

**Establishment of the TL**

In the previous two sections the timing of the birch expansion within the investigated area as a whole has been established for the belt between the PTL and the TL, as well as at the TL.

The question arises, at what period(s) of time did the birch stems growing at the TL attain a minimum height of 2 m, i.e. when did these birches become trees? A complete answer demands a knowledge of the mean annual growth in length of birch stems, involving a tree-ring analysis of the stems of the pioneer individual birches. This would have taken an excessively long time to accomplish and was impracticable. Instead, a rough answer has been attempted by making an analysis of the mean annual growth in length of 16 representative stems from trees growing at the TL. The basis for this work has been counts of annual-rings from cross-sections sawn at 10 cm-intervals up the stem, from the base to the top.

Stems adjudged to be 30–50 years old from the Ottfjäll massif in Jämtland and from Skarvarna and Klasberget in Härjedalen were investigated. All the 16 stems were growing on fairly gentle hillslopes covered with a Vaccinium myrtillus-dominated dwarf-shrub heath. The maximum mean depth of the snow cover was about 1 m.

The annual mean increase in stem length (with s.d.) for the period 1940–1965 was found to be 8.6±0.31 cm. In comparison, Kjelvik (1973) and Wielgolaski (1975) recorded mean annual increases for the past few decades of 6–11 cm for birch growing in the upper part of the subalpine belt in Norway. Haglund (1905) cites a value of 4–7 cm for birches growing in the subalpine belt in northernmost Sweden.

On a basis of the present value (8.6 cm/year) a certain opinion can be formed about the times at which the respective pioneer stems at 95 localities, attained tree size (i.e. a minimum stem length of 2 m). On average it took 21 years for a stem to grow from a length of 20 cm to 2 m. By adding this figure to the respective colonisation-periods (quinquennia) in Fig. 75 the resulting (see Fig. 75) conclusion is, that, at ca 62 % of the localities in question, the TL was established at that particular altitude at some time after 1955. Allowing for the unavoidable inaccuracy in dating, due to coring some decimetres above ground-level, this date is more probably ca 1950.

A more direct measure of eventual changes in the altitude of the tree-limit after 1950 can be obtained by comparing the data for the TL found in the present investigation with the data available for the same localities given by Kilander (1955 and pers. comm.) and Smith (1951) for the local tree-limit at about 1950 (for details see the locality descriptions). In this way data for 21 of the total 214 localities in the investigated area were available.

At 12 of the 21 localities (i.e. ca 57 %) the altitude of the tree-limit at about 1950 lay >5 m lower than at the present-day (TL). At the remaining 9 localities the tree-limit was either the same as at present, or was insignificantly lower. The localities available for comparison are not entirely representative of the localities investigated over the area as a whole, but they do provide some idea of the tree-limit changes since 1950.

**Minimum age of stems of trees growing at the TL**

As mentioned above, the age determinations of stems of birches growing at the TL were primarily those of the obviously oldest stems of birches of tree-height. In certain cases, however, stems appreciably younger than those of the pioneer birches were dated. The ages and growth rates of such stems provide useful information about the growth conditions for birches at the tree-limit during about the last 25 years (1950–1975).
Table 11. Attainment of tree-height (≥2 m) of birches which colonised the present tree-limit (TL) at different times within the period 1950–1965.

<table>
<thead>
<tr>
<th>Colonisation period</th>
<th>No. of stems dated</th>
<th>Date at which they attained tree-height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951–55</td>
<td>11</td>
<td>1972–76</td>
</tr>
<tr>
<td>1956–60</td>
<td>4</td>
<td>before 1976</td>
</tr>
<tr>
<td>1961–65</td>
<td>1</td>
<td>before 1976</td>
</tr>
</tbody>
</table>

The data set out in Table 11 show the numbers of such stems, ordered according to the quinquennia in which colonisation occurred, which grew in length by a minimum value of 1.8 m after about 1950. The probable dates at which these stems attained tree-height (≥ 2 m) are also indicated, based on the mean annual growth rate of 8.6 cm/year, established previously.

The results clearly show that an increase in stem length, from 10–20 cm to ≥ 2 m, was possible, even into the 1970’s, for birches growing at the TL at localities for which a rise in the birch tree-limit was evidenced.

Relationship between the degree of tree-limit displacement and the altitude of the PTL

The mean values and standard deviations have been calculated for the PTL and the TL for all the localities within each of the four displacement intervals (Table 12).

As a generalisation, the table shows that the greater the increase in the altitude of the tree-limit, the lower the absolute altitude of the tree-limit was in 1915/16 at the respective locality. At localities at which the tree-limit has remained more or less unchanged during the present century, the tree-limit altitude in 1915/16 was relatively higher than elsewhere, whereas at the present-day it is relatively lowest. This radical reversal of the relative altitude of the tree-limit in the two contrasted groups of localities indicates that in most cases the birch tree-limit is not conditioned by the action of thermoclimatic factors on the physiological processes which control plant productivity. Had such been the case, then the degree of displacement of the tree-limit should have been directly proportional to the absolute altitude of the local tree-limit in 1915/16. Instead, one must suppose that the local thermoclimate controls the position of the birch tree-limit in some indirect manner, i.e. by affecting a habitat factor, or factors, which is/are operative over a wide area (i.e. altitudinal interval). The greater the action-radius of the said factor or factors, the greater the degree of displacement of the local tree-limit.

Changes in the growth rate and vitality of individual birch stems during the present decade

The growth in length of the stems of 47 birches of, or just under, the minimum for tree-height was studied on 8 representative sample plots (10x10 m). The plots were laid out in 1972–73 and checked in 1975 or 1977, although a few plots were visited annually. Photographs, taken in different years, provide confirmatory evidence in some cases for the degree of growth in length which took place (see Figs. 19, 20, 21; 32, 33, 36, 37; 41, 42, 43; 55, 56; 57, 58; 60, 61, 62).

All the stems were growing within the local limits for the altitudinal rise in the tree-limit 1915/16–1975 at each of the following four localities: Hamrafjället (S-SE aspect), Ännfjäll (W aspect), Flatruet (N aspect) and Ottfjället (S aspect). Stem lengths were measured each time with a rod marked off in decimetres.

The results are set out in Table 13, which shows that 69% of the stems increased in length during the present decade. The few cases in which stems decreased in length are explained by stem breakage at the base due to the weight of snow in winter, or to grazing of the tips by hares in winter.

Where the snow cover is deepest the stems are bent so low by the weight of snow that the hares can usually easily reach the tips of even

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Table 13. The means (x) and standard deviations (s.d.) for the annual increase in length (dm) of birch stems during the period 1972/73–1975/77. The stems from the eight plots are subdivided into three groups, according to whether stem length increased, remained unchanged, or decreased.

<table>
<thead>
<tr>
<th>Length change</th>
<th>No. of stems</th>
<th>x (dm)</th>
<th>s.d. (dm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase</td>
<td>32</td>
<td>0.81</td>
<td>0.39</td>
</tr>
<tr>
<td>Unchanged</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease</td>
<td>5</td>
<td>3.04</td>
<td>3.3</td>
</tr>
</tbody>
</table>

The means are seen to have suffered loss or disappeared entirely. This is perhaps explained by the fact that the stems photographed were growing closer to the present-day tree-limit than were the stems on the sample plots as a whole.

For individual birches with their main stem broken basally by the weight of snow accumulation in winter, a rapid and prolific regeneration from preexisting basal shoots was visible.

At 46 of the entire 214 investigated localities living or dead birches (0.3—2.5 m in height) were present above the TL. At 8 of these 46 localities these birches were either dead or in an extremely poor condition (just a few basal shoots still alive). In all cases they were, or had been, quite young birches, scarcely exceeding 25 years in age. The cause of death in certain cases was obviously from the mechanical effects of accumulated snow, although the presence of a few dead, yet still upright, stems indicates that other factors were also at work.

The conclusion from the data reported in this section must be that there has been no general reduction in the vitality of the birches which were responsible for colonising the belt between the PTL and the TL, i.e. which became established there during the course of the present century. The death, or reduced vitality, of a minor proportion of the birch stems kept under observation may be nothing exceptional, but simply represents a quite normal successional phenomenon in the population dynamics of birch growing near to its altitudinal tree-limit.

The greatest threat to the continued existence of the stems of well-established birch trees is without any doubt the straightforward mechanical effect of the pressure of wet snow during the period of the snow-melt in spring (see Fig. 59) and perhaps locally the effects of sporadic avalanches in winter.

Summary of results

The relationship between the degree of displacement of the birch tree-limit, or its virtual stability, during the present century (1915/16—1975) and the local magnitude of certain environmental factors has been investigated.

The results of these analyses indicate that cer-
taint abiotic factors, such as the nature of the local macroclimate, site aspect, depth and duration of the snow cover, angle of slope and slope morphology, have differed, at least qualitatively, when studied in relation to the local degree of displacement, or otherwise, of the tree-limit.

The intensity of some of these factors was found to be directly proportional to the extent of the altitudinal rise in the tree-limit. No such relationship was found to exist with a variety of human influences and their cessation or diminution.

When the data were examined with regard to the timing of the birch colonisation, which resulted in the increased altitude of the tree-limit in different parts of the investigated area, the following results were obtained:

1. Colonisation of the belt between the PTL and the TL started during the first few years of the 20th century. The process speeded-up after ca. 1910–1914 and had a maximum at the end of the 1930’s. A distinct reduction in the extent of birch colonisation in the above-mentioned belt is evident from the period 1940–1950 onwards.

2. At the start of, or mid-way during, the 1940’s, individual birches (trees or shrubs) were already present at the altitude of the TL at 80% of the investigated localities at which an undoubted altitudinal rise in the tree-limit has been evidenced and at which age-determination transects have been made. By about 1950 this figure had risen to 95% of the above-mentioned localities. The period 1940–44, or more correctly probably slightly earlier (1935–39), appears to have been one in which conditions were particularly favourable for birch colonisation above the PTL. This period in fact coincides with the culmination of the recent climatic amelioration, at least as far as the mean temperature for the triterm June-August is concerned (see the section on The recent climatic fluctuation).

3. At 57–62% of all the localities at which an undoubted altitudinal rise in the tree-limit was evidenced and where tree-limit birches were dated, the pioneer birches now growing at the TL first attained tree-height after about 1950.

4. The TL was established most recently at localities at which the scale of the altitudinal increase was greatest, i.e. the conditions determining birch colonisation at the tree-limit became favourable at successively higher altitudes over a period of time, not everywhere between the PTL and the TL at once.

5. The absolute rise in the altitude of the birch tree-limit has on average been inversely proportional to the local position of the tree-limit in 1915/16 (PTL). This suggests that air temperature only exerts an indirect control, most probably via some other local habitat factor(s).

6. The stems of a small number of subjectively chosen birches growing near the TL have on average increased in length by at least 1.8 m during the past 25 years, i.e. after the culmination of the recent climatic amelioration.

7. There are no indications of any general diminution in vitality during the present decade of those birches which have colonised the belt between the PTL and the TL since 1915/16.

8. An important cause of the death of well-established stems in the present-day birch populations at the tree-limit is simply mechanical damage from the pressure of the wet snow cover during the time of the spring snowmelt. Grazing of the apical shoots of side and main branches by hares in winter may also be important locally, especially in modifying the form of such birch trees.
Discussion and general conclusions

The nature of the factors causing change or stability of the tree-limit

An altitudinal rise of the tree-limit for birch during the past 60 years has been found to be a general phenomenon over the whole of the investigated region. The basic cause of this positive displacement of the tree-limit must therefore have been a factor operative over a wide area, although the obvious fact that the degree of displacement differed considerably even between adjacent localities, indicates that the resultant effect of this prime factor can be modified to greater or lesser degree by the local habitat factors, both past and present.

The statistical treatment of the data has enabled the identification of some of these habitat factors and their lowest common denominator. Thereby an attempt has been made to identify the basic cause(s) of the tree-limit displacement and to add to our knowledge about the tree-limit as a natural phenomenon.

As mentioned above, in certain cases quite large differences were found in the degree of displacement at neighbouring localities. This makes it highly probable that the factors concerned all show marked differences in intensity over quite short horizontal distances. Various abiotic factors fulfil this requirement and would therefore appear to be those most probably concerned. The relevant biotic factors, human impact on the landscape included, do not normally exhibit such sharp horizontal discontinuities in nature near the tree-limit as do certain abiotic ones (cf. Klikoff 1965; Barry & van Wie 1974).

The statistical treatment of the data has also revealed an indisputable relationship between a number of interdependent abiotic habitat factors, of varying degrees of intensity, and the degree of displacement of the tree-limit. On the other hand, no such relationship was found with the degree of human impact on the landscape or type of land usage. Nowhere within those parts of the investigated area in which a positive altitudinal displacement of the tree-limit was recorded were any remains of former trees found, which might have indicated that the tree-limit advance was simply due to a re-colonisation of areas formerly deforested by human interference with the landscape. According to Holmgren’s (1912) investigations in northern Scandinavia, dead birch stems lying on the ground surface can be preserved for 70–80 years and Barth (1915) states that birch bark can be preserved for ca 100 years. Summer-farm transhumance culminated at about the turn of the century. Had this farming activity been responsible for a widespread depression of the tree-limit then the remains of some of the trees formerly present ought to have still been visible, at least at a few of the localities within the investigated area at which a positive displacement of the tree-limit was recorded. Perhaps the frequent occurrence of dense thickets of Salix spp. and Juniperus communis enabled some regeneration of birch, to occur which may explain why there was no general lowering of the tree-limit in heavily grazed areas (cf. Anonymous 1906).

The proven fact that the conditions for birch colonisation improved at an ever-increasing altitude is a further indication that in general terms the upward altitudinal displacement of the tree-limit has formed part of a primary, not a secondary ecological succession. Had the upward birch expansion been merely a re-colonisation of lost territory, one would have expected to find that this had occurred contemporaneously over the whole area between the PTL and the TL, considering that there is seldom any shortage of viable birch seed in the lower part of the low-alpine belt (see below). On the whole, therefore, human utilisation of the tree-limit region, although formerly quite intensive at many of the investigated localities, did not lead to a depression of the birch tree-limit (cf. Kilander 1965). A more open question, however, is whether the tree-limit would
have risen during the past 60 years at certain of the investigated localities if the degree of grazing pressure had remained stable, instead of steadily decreasing or ceasing entirely. It is conceivable that grazing might have led to the failure of all the attempts of birch colonisation at higher altitudes following the improvement in the natural environmental conditions (climatic amelioration).

At lower and middle levels within the subalpine belt it is quite clear that the present-day increase in forest tree density is at least to some extent due to the cessation of grazing and hay-making (see Fig. 77).

Thus it is obvious that the upward shift of the tree-limit since 1915/16, generally speaking, has been caused by changes in some natural, non-human, environmental factors.

**Relationship between degree of displacement and type of habitat**

As mentioned previously, a positive relationship has been shown to exist between the degree of intensity of certain abiotic environmental factors and the degree of displacement of the local tree-limit. All these environmental parameters have an effect on the depth and duration of the snow cover at each of the investigated localities. However, a direct causality is not immediately obvious, since the snow conditions are intimately related to other ecological factors, as mentioned above (cf. Watt & Jones 1948; Poore & McVean 1957; McVean & Ratcliffe 1962).

Nevertheless, there is no doubt at all that the degree of recent upward displacement of the tree-limit at any particular locality is an expression of the degree of change of the snow conditions thereabouts.

On average, characteristic snow-accumulation areas have exhibited the greatest degrees of displacement of the tree-limit, whereas those localities for which no change in the tree-limit altitudes were found are situated in snow-deflation areas, and in between these two extremes the tree-limit displacement has also been intermediate in scale.
Extent and duration of the snow cover

Before a closer elucidation and explanation of the natural course of events involved in the tree-limit changes can be attempted, the general principles underlying the distribution of snow in mountainous areas must be discussed.

It has long been known that the uneven distribution of the snow cover in the alpine and upper part of the subalpine belt follows a definite pattern. The winds, which bring and deposite snow in the particular part of the mountain chain in which the investigated area lies, blow for the most part from the west or north-west. Most of the snow is deposited on the lee-side of terrain features, i.e. on east- and south-east facing slopes. On the windward side of the mountains the snow fills up all depressions in the terrain, whilst more even parts of the slopes receive a relatively minor snow cover and become snow-free early on in the spring. Any depth of snow deposited on such slopes during windless conditions is later removed by storms, being carried away and re-deposited on the leeward sides, where it builds up the typical wind-compacted snowdrifts.

The above information has mainly been drawn from the following sources: Högbohm 1897, Vester gren 1902, Hamberg 1907, Enquist 1916, Smith 1920, Lundqvist 1969.

The geological structure of the area produces a characteristic macro-relief, with more or less gentle W-facing hillslopes and short, steep, E- and SE-facing slopes. The long windward and steep leeward slopes, in turn, greatly facilitates snow accumulation on the E- and SE-facing sides of the mountains, where the insolation conditions further serve to prolong the retention of these, primarily orographically-conditioned, snow accumulations (cf. Lundqvist 1968; Perttu 1972). The insolation conditions nevertheless play a minor role in determining the site of localities with a predominantly long-lasting snow cover. It is by no means unusual to find even thermically-favourable S-facing slopes which receive and retain an extremely deep snow cover and which are extremely susceptible to avalanches (cf. Enquist op. cit.).

As a general rule the above-mentioned pattern of alternating localities receiving inconsiderable or massive snow covers is found to be pretty stable from year to year (cf. Sernander 1905; Enquist 1910; Kronfuss 1967). However, the boundaries between these two contrasting types of localities have obviously been displaced during the first half of the 20th century (evidence presented below). Several different explanations can be put forward to account for the displacement postulated above:

1. an absolute diminution in the annual snowfall.
2. an earlier and more complete melting-away of the snow cover, due to an increase in the supply of advective heat.
3. increased solar radiation in springtime.
4. a reduction in the frequency of winds from a westerly direction, i.e. diminished wind-drift of snow from windward to leeward localities.
5. various combinations of the above 4 factors.

Postulates 1, 3 and 4 are not supported by the meteorological observations made during the 60-year period under discussion (cf. Blühgen 1942, Pershagen 1969, Johanni sen 1970, Schytt 1973), whilst postulate 2 agrees entirely with the known climatic changes (as described in the section The recent climatic fluctuation).

Evidence for an earlier snow-melt

As stated above, the major cause of the diminution in the depth and duration of the snow cover has without any doubt been an increase in the amount of snow melting-away during spring and early summer, due to an increased supply of warmth. Schytt (1962, 1967) has shown that the decline in the extent of glaciers and permanent snowfields during the present century has been controlled by changes in the temperature conditions in summer, in the length of the ablation period, and in the insolation conditions. Ablation, in other words, is a function of altitude (m. a. s. l.) of a locality. In principle, therefore, a thermic amelioration will result in an upward displacement of the ablation gradient. Glacier retreat has been a well-known expression of the climatic amelioration during the present century (cf. Faegri 1934; Ahlmann 1943; Karlén 1973; Karlén & Denton 1975; and others).

Bergström (1955) and Lundqvist (1969) have studied the changes in the extents of those glaciers which are present within the investigated area. They found that after attaining a maximum extent about 1908 the glaciers thereafter continu-
ally retreated up to the 1960’s, with a particularly rapid retreat after ca 1930 and a marked slowing down in the rate of retreat again after ca 1950.

Also the permanent and semi-permanent snowfields within the investigated area have declined both in frequency and extent in parallel with the retreat of the glaciers. The result has been a general drying-out of the soils in the alpine and subalpine belts, by a reduction in the supply of meltwater from the snowbeds during the main summer period (Smith 1957).

Local informants within the present area of investigation have reported that former streams have dried-up and that certain high-lying fens have become much drier, although when assessing such reports one must bear in mind the fact that such mires and fens which are no longer mown for hay, may also have altered the hydrological conditions (cf. Kullman 1977a). A similar drying-out of the fens in other parts of northern Fennoscandia has also been reported (Hustich 1937, 1940; Huse 1965).

A particularly good example of the earlier onset of the snowmelt latterly is given by comparing Sernander’s (1905) description of the snow conditions in 1904 on the SE-facing hillslope of Hamrafjall (locality 191), with those at the present-day. Sernander (op. cit.) describes a snowfield of immense horizontal extent, just above the tree-limit, which remained so until the middle of July. From 1969-1975 I have myself observed this same snowfield, and each year, by the middle of June, or in the latter half of June at latest, it had already become split up into a small number of discrete snow patches, each a few hundred m² in extent. Even these snow patches had disappeared entirely by the end of July (even during the cold summers of 1977 and 1978), whereas in a photo taken by Sernander in August 1904 (Sernander op. cit.) the situation resembles that which at present exists during the first part of July.

A further piece of evidence for the earlier disappearance of the snow-beds at the present-day is furnished by a diary observation made by two visitors to part of the investigated area in 1796 (Robsahm & Schwab 1938). On August 18th they crossed the upland plateau at the foot of the ESE and SE slopes of Lill- and Stor-Skarven (localities 183 and 184 respectively) and noted that snowdrifts were present on these slopes. Nowadays (1969–78) all the snow has disappeared here by the end of July.

In the Scottish Highlands, too, former semi-permanent snowbeds have gradually disappeared during the course of the climatic amelioration of the present century (Watt & Jones 1948) and gradual changes in the vegetational composition of these areas have been recorded (McVean 1958). An increased permanency of the snowbeds in the same area has once more been noted since the mid-1960’s (Spink 1969).

For certain of the habitat types represented in the investigated area, therefore, the final disappearance of the snow is earlier than it was in 1915/16. Thereby, that part of the summer which is most favourable, from the temperature conditions point of view, to the vegetation for growth, maturation and reproductive processes, including seedling establishment, is thus prolonged.

Smith’s (1957) studies in part of the investigated area showed that the area covered by those plant communities which require a moderate to considerable degree of ‘protection’ by the snow cover decreased during the period 1919–1950, while those communities requiring a shorter snow cover increased their coverage correspondingly. This can scarcely have been due to anything other than an earlier disappearance of the snow cover and a consequent increase in soil aridity.

**Characteristic habitat features of localities with a recorded rise in tree-limit**

**Duration of snow cover**

The factor common to all the localities at which a rise in the birch tree-limit was recorded is the occurrence of orographically-determined snow accumulation, i.e. an ample snow cover. In other words, the depth of the snow cover is appreciably greater than that which would be expected from the local snowfall data alone, and in consequence the duration of snow cover is prolonged.

The greatest accumulations (vertical and horizontal extent) of snow here coincide with the sites at which the greatest displacements of the tree-limit were recorded. Localities at which more moderate displacements of the tree-limit were recorded are those at which the accumulation of snow in winter is, relatively speaking, slight but...
unbroken over fairly large vertical distances.

The nature of the local climate, the angle of slope and the aspect of a locality are factors which are indirectly correlated with the degree of displacement of tree-limit. As shown above, the way in which the climate has changed during the present century has led to an increased rate of melting of permanent or semi-permanent snow-beds. Such a development of the climate has been the pre-condition for the recorded rise in the birch tree-limit.

Smith (1920) found that at localities receiving an ample snow cover the tree-limit coincided with the position of the margin of the retreating snow at the time of birch leafing (cf. also Hustich 1937; Nordhagen 1943), a circumstance which can be similarly demonstrated at many localities at the present-day (see Figs. 15, 16, 53).

That the altitudinal tree-limit has risen in an inverse relationship to its absolute altitude in 1915/16, as shown above, indicates that the degree of displacement has been conditional on a corresponding decrease in the intensity of a factor which depresses the local tree-limit. The only probable factor is the depth and duration of the local snow cover, which has been proven to be very susceptible to variations of the thermoclimate. This conclusion is further supported by the results of the present investigation, which indicate that, in many cases, the birch tree-limit ceased to rise any further once a topographically and edaphically unfavourable niveau was reached (see section ‘Slope morphology’), i.e. plano-convex landscape forms with little snow accumulation and low soil moisture conditions.

That a clear relationship exists between the birch tree-limit displacement and ‘nival phenology’ is shown at many places within the birch expansion belt by the presence of a fringe of young birches surrounding depressions in the ground occupied by long-lasting snow-beds (see Fig. 25). A similar phenomenon has been shown in the case of spruce growing in the forest tundra ecotone in north-western Canada (Larsen 1965).

It is especially interesting, in this connection, to note that in the Cascade Range in the United States Franklin et al. (1971) found that a recent immigration of the tree *Abies lasiocarpa* into subalpine meadows has taken place, which they ascribe to the recent climatic change. In British Columbia, Brink (1959) and Fonda & Bliss (1969) have shown that certain coniferous tree species have colonised formerly treeless areas of heathland near the tree-limit, following alterations in the local snow conditions.

**Vegetation period**

It is naturally tempting to see a plausible explanation for the rise in the birch tree-limit as a direct consequence of a lengthening of the vegetation period, from the increased rate of melting of the snow cover and/or an improvement in the air temperature conditions during the vegetation period. In other words, in 1915/16 the potential net assimilation rate was insufficient to permit tree growth in the belt where the tree-limit has since risen (cf. Boysen-Jensen 1932; Sarvas 1970). However, this general tree-limit theory has not been accepted by e.g. Wardle (1974) and Holtmeier (1974).

A further argument against the above supposition is the fact that after 1950, when the climatic amelioration culminated and reversed, the upward displacement of the altitudinal birch limit came more or less to a complete halt, whereas the shoots of already-established birch individuals above the PTL continued to grow in length, and still do. Analogously, Zackrisson (1978) found that natural regeneration by seed of pine and deciduous trees, on a lake-shore in a river in N Sweden, was strictly concentrated to the period 1930–1955. This was thought to be related to the climatic amelioration and consequent annual water-level (i.e. meltwater) fluctuations.

**Germination—establishment**

The conclusion to be drawn is that it is the joint combination of edaphic conditions and seed germination/seedling establishment which reacts sensitively to the climatic fluctuations and which determines the ultimate altitudinal position of the tree-limit. According to Wardle (1974) the forest-limit for *Nothofagus solandri* in New Zealand is controlled in a similar manner, by a series of critical threshold values for the habitat factors which are operative during the first summer after germination.

The general conclusion is that the rise in the
tree-limit is brought about by the increased possibilities for seed germination and seedling establishment provided by an earlier and more complete disappearance of the snow cover and a subsequent decrease in meltwater influence. So far as seed germination is concerned, the decrease of soil moisture, by itself would be expected to be a less important factor. According to research results presented by e.g. Heikinheimo (1915), Linkola (1930), Sarvas (1937), Børsset (1962) and Kinnaird (1974), germination does not occur unless there is already a high degree of moisture present. In fact, an excess of water does not hamper germination provided it has fairly high oxygen content (Mork 1944). The latter condition ought always to be fulfilled for the localities dealt with, since the supply is non-stagnant snow meltwater of low temperature. In an experimental study from the Rocky Mountains, Holway & Ward (1963) found that the cold meltwater had a pronounced delaying effect on certain phenological phases of many species of vascular plants, although it is not quite easy to decide definitely whether it was the increase in soil temperature, or the decrease of soil moisture, which was the operative factor.

The main positive effect of a decrease of soil moisture is probably on seedling establishment. This is suggested by an investigation by Bannister (1964), who showed that root penetration and seedling establishment by *Erica cinerea* and *E. tetralix* were very poor in wet soils. The same can be expected to hold for birch, with its normally deep root penetration (cf. Laitakari 1934). McVean (1956) has experimentally demonstrated a high degree of mortality of birch seedlings in very wet and badly aerated environments. Furthermore, in snow-rich environments with a high proportion of finer soil fractions and water saturated soil, the seedlings are permanently stressed by frost-heave.

A drying out of the soil should in fact be favourable for both germination and seedling establishment primarily because of the consequent rise in soil temperature (Holway & Ward 1965). In the Himalayas, Mani’s (1962) work has namely shown that, during June, the temperature of the upper layers of soil gradually increased with increasing distance from the margins of the retreating snow patch. According to Mork (1944) birch seed germination at the forest-limit requires soil surface temperatures which are hardly ever attained in ‘normal’ summers. The reduced extent of the snowbeds ought therefore to have improved the chances of successful birch colonisation at certain places above the PTL.

Since the birch normally develops a vertical main-root very early on during its life-cycle (Laitakari op. cit.), it is obvious that seedling establishment is greatly hampered in front of long-lasting snow fields, where the vertical gradient of soil temperature is very steep (Mani op. cit.). Smith (1920) states that the majority of birch seedlings which he found were growing in the ‘warm Dryas-heaths’, a fact which further emphasises the importance of soil surface temperatures in this connection. Havranek (1972) has carried out experiments with seedlings of *Larix decidua* and *Picea abies* near the tree-limit in the Alps. He found that the soil surface temperature represented an important limiting which controlled the dry matter production of both tree species.

That an improvement in the soil surface temperatures, in particular, occurred during the first half of the present century is evidenced in several different ways, viz:

1. The ‘palsas’ (peat hummocks with a permanently frozen ice core) or ‘palsa-like’ features which Smith (1920) encountered in the investigated area do not appear to exist at the present day (Lundqvist 1969). A similar disappearance of such features has been reported from other places situated close to the southern boundary for ‘palsas’ in Sweden (Wramner 1967).

2. Henning (1895) states that the sloping fens on Snasahögarhisa, situated in the northwestern part of the investigated area, were still frozen 30 cm below the ground surface at the end of July, whereas nowadays there is no such frozen peat in these mires at all in July.

Earlier in the present paper it was pointed out that the birch colonisation above the PTL was most intensive during a period which coincided with the maximum intensity of the present climatic fluctuation, so far as the absolute frequency of exceptionally warm summers is concerned. In this context it is interesting to note Leach & Polunin’s (1936) observation, in Finnmark in northern Norway, during the very warm summer of 1930, that birch seedlings were found to be

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present in that part of a snowbed locality which melted away last of all. This suggests that a succession of only a few summers more favourable than average is sufficient to enable birch to colonise areas from which it was previously excluded because of the presence of too long-lasting snow patches. Holmgren (1912), likewise, found that in several places in the subalpine belt in northern Scandinavia birch seedlings colonised the peripheral parts of snow patches during summers in which the rate and extent of the snowmelt were above average, but were unable to survive through a subsequent unfavourable summer. Furthermore, in the eastern Pyrenees, Braun-Blanquet (1948) found that following a succession of only a few extremely snowy winters the Nardus-dominated grass-heaths became strewn with the seedlings of typical chionophiles, e.g. Sibbaldia procumbens and Salix herbacea.

All the indications are that, before any successful birch colonisation and establishment in new areas can occur, a succession of summers with above-normal air temperatures is necessary. This is precisely what occurred during the culmination of the recent climatic fluctuation.

Since it is primarily seed germination and the initial establishment of birch seedlings which seem to take place periodically in the peripheral parts of snowbeds and snow patches, one dares to draw the conclusion that the immediate causes of displacements of the tree-limit are the periodic fluctuations in the climatically-conditioned edaphic factors during the vegetation period. If e.g. winter survival was a decisive factor, then one would expect to find the habitats in question strewn every summer with birch seedlings. But this is definitely not the case.

Seed production

Besides the onset of more favourable edaphic conditions for germination and seedling establishment, which followed as a consequence of the earlier melting-away of the snow, the germination percentage, i.e. seed quality and quantity of Betula pubescens (coll.), is also influenced by the air temperatures prevailing during the summer (Sarvas 1937, 1948; Söyrinki 1938; Mork 1944; Kallio & Mäkinen 1978).

Blüthgen (1966) considered that the increased length of the vegetation period (as defined meteorologically) during the present century, had led to improved seed production and seed maturity by birches growing in the subalpine belt.

During certain years at least, the birches which form the tree-limit, and even birch shrubs above the tree-limit may produce viable seed (Henning 1889; Smith 1920; Söyrinki 1938; Sarvas 1952; Kullman 1976a; Kallio & Mäkinen op.cit.). It is nevertheless doubtful whether fluctuations in the quantity and quality of the seeds produced by birches growing in the upper part of the birch belt are a limiting factor for birch regeneration from seed within and above this vegetation belt (cf. Sarvas 1948), since because of the relatively great seed production by the birch, and its excellent distribution potential (Heikinheimo 1915; Resvoll-Holmsen 1928; Sarvas op.cit.; Kinnaird 1968) an additional supply of seed from birches growing at lower altitudes, whose seed quality probably varies less, can always be counted upon (cf. Aminoff 1907).

Smith (1920) reported finding birch seeds several hundred metres above the nearest tree-limit birches. Elven & Ryvarden (1975) recorded a dispersal distance of 4 km. Similar observations have also been reported from melting snowdrifts in Norwegian mountain areas (Lid 1937).

One may assume that on hillslopes which receive an ample snow cover, the potential seed supply is always high enough to render any possible fluctuations in seed viability virtually unimportant, since in such habitats the birch seed is distributed and accumulated according to the same principles as described for the snow (cf. Porsild 1951). During the period of the snow-melt it is by no means uncommon, in certain places, to find the snowdrifts covered with a quite thick layer of birch seeds (see Fig. 78).

Heavy snow cover

The purely mechanical effects of the weight of snow in winter may also conceivably play a certain role in the population dynamics of the mountain birch. Vestergren (1902) has suggested that these effects may act as a differentiating factor on the composition of the vegetation along the gradient from bare and wind-exposed to snowpatch
Fig. 78. At localities receiving a deep snow cover a shortage of birch seed is very seldom a factor limiting birch colonisation. Accumulations of birch seed and catkin scales arise in such areas according to the same physical principles which condition snow accumulation. During early summer the snow drifts are often found to be covered by quite a thick layer of wind-drifted birch seeds and catkin scales. The south-facing flank of Annfjället, Härjedalen, 975 m a.s.l. Photo: June 12, 1971.

localities. Ve (1940) has also maintained that the occurrence of even just a few extremely snowy winters is sufficient to more or less wipe out the birch cover over large areas, simply by the mechanical action of the weight of snow. The mechanical effects of the snow cover have been intensively studied in the Alps. For woody species the negative effects arise when the snow cover starts to settle during the snowmelt period. The combined action of this downward settling motion and the innate propensity of the mass of snow to slide downhill, leads to internal stresses and strains within the wet snow mass, both locally and along the whole hillslope. The movement of the body of snow, induced in this way, varies from several metres to just a few millimetres per day. Projecting shoots and branches are subject to mechanical forces which are proportional to the local degree of slope of the ground, to the depth of the snow cover and to the temperature of the snow (Ramsli 1951; Lenz 1967; In der Gand 1968a, b).

By building different kinds of mechanical hindrances along such snow accumulation slopes the scale of such snow movements can be reduced and the losses of coniferous transplants exposed to such danger can be significantly reduced (In der Gand op.cit.), a fact which would suggest that snow pressure may represent a negative factor for natural tree regeneration in such places as well.

As shown above, there is no doubt that mecha-
nical damage due to snow pressure represents a dominant mortality factor for birch stems which exceed a certain length (ca 1 m). When birch stems reach a certain size they lose their earlier elasticity and break in two. On hillslopes which receive a particularly heavy snow cover, therefore, the mean age of the birch stems is often quite low, despite the fact that the birch population as a whole maintains its continued presence on the site (cf. Kullman 1976b, 1977a).

The increase in the rate of melting of the snow, in consequence of the climatic amelioration, ought in principle to have reduced the degree of risk of damage from the mechanical effects of snow pressure for already established birches (see Figs. 15 and 16).

Solifluction

Another factor, which is also correlated with the depth of the snow cover and which needs to be considered in relation to the rise in the birch tree-limit during the first half of the present century, is solifluction, a phenomenon which occurs on hillslopes of which the upper soil layers become saturated with water during the greater part of the vegetation period because downward drainage is prevented by the frozen state of the underlying soil layers (Lundqvist 1969).

According to Sernander's (1905) investigation at Hamrafjallet (locality 191), the position of the local forest-limit was related to some degree to the lower-limit of active solifluction on the hillslope. A comparison of Sernander's (op. cit.) description with present-day conditions shows that the intensity of solifluction there has decreased strongly and that birch trees have become established on ground which was formerly subject to solifluction.

The surface and subsoil creep which constitutes the phenomenon termed solifluction must in principle constitute a great strain on the rooting system of the birch. Högbom (1914), for instance, reports having seen birches on Vargjärnstöten (locality 110 or 111) which had been killed off by solifluction. Solifluction ought nevertheless only to effect the earliest colonisation and establishment stages of birch to a minor degree, (cf. Kallio & Mäkinen 1978) whilst presenting a considerable danger to larger trees and shrubs with a well-developed root system. Seedlings with root systems restricted to the upper part of the moving layer of soil escape being damaged in this way (cf. Coker 1966).

Frost-drought

A reduced risk of damage from frost-drought can be ruled out as the factor responsible for an improvement in birch rejuvenation from seed, in the particular types of localities considered here, since the mean snow depth is ca. 1 m or more and thus the stems do not project above the snow surface until they are ca. 10 years old. If frost-drought had been a limiting factor prior to 1915/16 a broad belt of birch shrubs would have been present on all such slopes above the PTL (cf. Wardle 1974). There is no evidence that such was ever the case.

Ground vegetation

If we take a look at type of ground vegetation in which those birches which became established after 1915/16 are growing today, we find that the majority are situated in that part of the ecological gradient ‘windexposed-snowpatch’ which is dominated by Vaccinium myrtillus or Betula nana—Empetrum hermaphroditum. The field layer in question consists of a rather heterogeneous plant assemblage in which Solidago virgaurea, Tritellis europaea, Viola biflora, Deschampsia flexuosa, Lycopodium annotinum and the lichen Nephroma arcticum are fairly frequently present.

This vegetation type most closely corresponds to that of Smith's (1920) 'moss-rich bilberry heath'. Smith's (1957) studies, within part of the investigated area, on the vegetational changes between 1919 and 1950, as revealed by repeated line transects, indicate that it was precisely the 'moss-rich bilberry heath' and the 'moss-rich Betula nana—Empetrum heath' which increased their area at the expense of such communities as Nardus heath, Anthoxanthum grass-heath and Carex bigelowii heath. These grass-heath and sedge-heath communities all demand a snow cover of longer duration than that tolerated by the dwarf-shrub heaths which have replaced them. By means of comparative vegetational analyses, Nordhagen (1928) has shown that a similar development is
the most likely response to an amelioration of the climate.

In some localities a disharmonious element of more or less typical snowbed species occurs, e.g. *Alchemilla alpina*, *Gnaphalium supinum*, *Lycopodium alpinum*, *Rumex acetosa* ssp. *lapponicus*; *Sibbaldia procumbens*. In Torne Lappmark, in northern Sweden, Sonesson & Lundberg (1974) have found a similar vegetation in localities which have fairly recently been invaded by birch. The presence of such species indicates that the vegetation of these areas has only relatively recently changed from a type which was more adapted to a snow cover of longer duration than that experienced at the present-day. Watt & Jones (1948), from their studies of snowbed communities in the Scottish Highlands, thought that changes in the relative dominance of *Nardus stricta*, *Carex bigelowii* and *Deschampsia flexuosa* were detectable, as a response to the recent periodic fluctuations in the duration of the snow cover. McVean & Ratcliffe (1962), consider that the decline in *Nardus stricta* in Scotland is due rather to the decrease in soil moisture than to any of the other effects correlated with a shortening of the duration of the snow cover.

Regarding the conditions for germination and seedling establishment of birch in *Nardus* heath, Henning (1895), Söyrinki (1938) and Gjaerevoll (1956) all maintain that the roots of birch seedlings have great difficulty in penetrating the thick humus layer in closed swaths of *Nardus*, whereas Resvoll-Holmsen (1928) and Henning (op.cit.) have found that conditions are quite favourable wherever the *Nardus* sward is less dense.

The *Nardus* sward is regularly interrupted by small patches over which mosses form the dominant plant community (cf. Gjaerevoll op.cit.). These patches represent areas subject to regular local flooding during the snow-melt period and it is conceivable that these weak points in the otherwise closed sward may be colonised by birch during climatic periods in which meltwater supplies diminish. It is known that moss-carpetts may be favourable substrates for birch seed germination (e.g. Vaartaja 1954; Kinnaird 1974). In any case, during the driest summers the result would have been an opening-up of the vegetation cover, whereby tree seedlings, including those of birch, should have been able to colonise and become established in the interstices between the steadily shrinking *Nardus* tussocks.

Generally speaking, it is probable that seed germination and seedling establishment have been favoured in this way in habitats which are usually influenced by meltwater during the summer, and where drought never represents a limiting factor for the colonisation phase of birch.

At quite a number of localities, during the present century, newly-established birches could be found growing in metre-high and dense thickets of willows (*Salix* spp.) and/or Juniperus communis (see Fig. 36). According to Smith (op.cit.) the combined area of such thickets remained more or less stable during the period 1919–1950. That the *Salix* thickets, to a considerable extent, changed from a herb-rich to a grass-rich type during the same period, is considered to have been due to the gradual diminution in the supply of meltwater which took place. Areas of bare soil are always to be found in places within these thickets, so that the explanation for the birch colonisation is probably to be sought for in changed soil temperature and/or soil moisture conditions, rather than in a lessening of plant competition.

The reduced illumination conditions found within the *Salix* thickets are not considered to be a limiting factor for seed germination and seedling establishment in such places (cf. Resvoll-Holmsen 1928; Sarvas 1950; Black & Wareing 1955).

The juvenile birches which grow up in this type of vegetation are probably well-protected from the ill-effects of mechanical pressure from the overlying snow cover by the encircling shrubs of *Salix* spp. and/or *Juniperus communis* (cf. Holtmeier 1974).

**Characteristic habitat features of localities with no recorded rise in tree-limit**

**Duration of snow cover**

It has been demonstrated that a characteristic feature of those localities at which little or no altitudinal shift in the tree-limit was recorded, is a relatively sparse snow cover and a relatively early onset of the snow-free period.

At the present-day, any appreciable meltwater influence has already ceased long before the birch
comes into leaf. Thus the relatively late disappearing of the snow during the very first decades of this century was by no means so late that an excess of meltwater was then a factor controlling vegetational composition. In all probability, a pronounced aridity during summer prevailed here even before the start of the climatic amelioration, the effect of which should have been to further increase the aridity during summer. This could only have involved a deterioration in the habitat-conditions for birch.

The effect of insufficient water supply is probably most detrimental during the early stages of the life-cycle of birch (cf. Jenssen 1947; Tranquillini 1957). Admittedly, few studies have yet been made on seed germination and seedling establishment of birch in mountainous areas, but both these stages in all likelihood require an ample supply of soil moisture for their success (Heikinheimo 1915; Linkola 1930; Sarvas 1937; Børset 1962; Kinnaird 1974) and a not too-impoveryished substrate (Perttula 1941). Vaartaja (1954) emphasizes that *Betula pubescens* is extremely susceptible to soil drought just after germination. Very high values for seedling mortality have been recorded from wind-exposed localities subject to pronounced summer-drought (Söyrinki 1938; Perttula op. cit.).

**Depth of surface deposits**

The distribution of the unconsolidated surface deposits in the mountains to a certain degree exhibits the same pattern as the distribution of snow. The morainic and fluvio-glacial deposits, although carried by glacier, water, and wind movements respectively, are generally deeper in terrain depressions than on elevations, and to leeward of obstacles, i.e.: accumulations are deepest in basins and at the foot of E- and SE-facing slopes. As a general rule the depth of the surface deposits in mountain regions decreases from the valley bottom towards the mountain summits (Tanner 1914; Lundqvist 1969; Soyez 1971).

To a certain extent at least, in exposed localities with only a shallow snow cover and a more or less stable tree-limit, the finer fractions of the soil will have been removed by meltwater and wind erosion, and re-deposited in those localities which receive a deep snow cover, and at which in fact the tree-limit has risen (Faegri 1934; Söyrinki 1938; Mannerfelt 1945; Retzer 1974). Localities with a shallow snow cover, generally speaking, therefore experience difficulty in retaining their already inconsiderable supply of soil water, because of the relatively shallow depth of the soil there and its unfavourable (coarse-grade) texture (cf. Retzer op. cit.). In addition, as shown above, such localities are restricted to plano-convex landscape forms, which are subject to increased insolation and to wind exposure, both of which further increase the natural soil aridity (cf. Frödin 1916). Gaiser (1951) has shown that for *Quercus alba* in Ohio, the negative effect, on growth in tree height, of a shallow soil cover is reinforced on plano-convex landscape features, compared to elsewhere.

In his report on investigations into the chronology of the retreat of the inland ice sheet in the region presently under discussion, Eriksson (1914) drew attention to the fact that the birch seemed unable to establish itself on sites where the finer fractions of the morainic deposits were absent. He considered that the texture of the mineral soil was an important factor to bear in mind when considering the question of the altitudinal tree-limit for birch.

At certain localities in the investigated area, at which little or no rise of the tree-limit was recorded the importance of the ‘water-supply—morainic soil’ type factor complex was quite clearly visible, for example on the N-facing slope of Trondafjäll (locality 95) where a narrow natural ‘allée’ of sturdy birch trees runs up towards the tree-limit on both sides of a small stream. The streambed is only slightly incised into the hillside and does not itself give rise to any particularly increased depth of snow cover thereabouts. On either side of the birch allée the morainic soil cover is very thin and the ground very dry and there is virtually no tree growth at all. The birches in the allée are undoubtedly just as exposed to the weather as they would be at any other point in the surrounding terrain, which is gently-sloping, has only a shallow snow cover and coarse and shallow morainic deposits. The only habitat factor which is radically different in the allée compared to the surrounding areas is the water supply. In the immediate vicinity of the stream the stable
and ample water supply has enabled the birches to establish and to grow into 7–8 m high trees, whereas only a short distance away just a few low-growing birch shrubs are capable of growing.

The above-mentioned example supports Frödin’s (1916) conclusion, based on his experiences in Lule Lappmark in northern Sweden, that the local water supply is of vital importance in explaining the regional variations seen in the altitudinal birch tree-limit, although this hypothesis has been disputed by Tengvall (1920).

Leach & Polunin (1932) considered that the limiting factors for the distribution of birch in Finnmark in northern Norway were edaphic, rather than directly climatic. The importance of the water supply and its permanency in conditioning the ultimate altitudinal limits for vascular plants in general has been claimed by Webster (1961). Gorchakovski (1965) maintains that the forest-limit in the Urals is only primarily climatically conditioned in areas in which there is a sufficiency of fine-grade mineral matter in the soil (cf. Ellenberg 1966).

**Ground-level temperatures and frost-heave**

Near the tree-limit, the very high ground-level temperatures attained in summer (cf. Aulitzky 1961; Wardle 1974) and the occurrence of frost-heave (cf. Vaartaja 1954) in certain of the habitats with only a shallow snow cover are further factors which might selectively have hindered recent birch colonisation there.

Linteau (1948) has demonstrated that seedlings of yellow birch (*Betula lutea*), in Quebec, Canada, to a high degree were killed or damaged by heat during summer, especially on exposed sites (cf. also Haig 1936). The same risk should be considered to be relatively high in habitats with little snow-cover within the present investigation area. Localities with a late snow-melt are not exposed to this danger to the same degree, due to the cooling effect of the evaporation of the snow meltwater (cf. Holway & Ward 1963).

**Frost-drought**

It is rather unlikely that a relatively shallow snow cover could have been responsible for the failure of the tree-limit to rise at the present localities, due to a permanent or increased risk of frost-drought or mechanical erosion of shoots by ice and snow. These latter factors are often thought to be major obstacles to birch survival in habitats with a shallow snow cover (cf. e.g. Elkington & Jones 1974).

According to investigations made on coniferous tree species in Central Europe (Michaelis 1934; Baig et al. 1974) frost-drought damage, to those parts of the plant which project above the snow cover, occurs very frequently near the tree-limit and determines its ultimate position. Experimental investigations on Mt. Washington, New Hampshire, on *Picea mariana*, *Abies balsamea* and *Betula papyrifera*, however, indicate that winter desiccation caused by high wind velocities when the soil is frozen is by no means a universal lethal factor at the tree-limit (Marchand & Chabot 1978). It is suggested that the position of the tree-limit in that area is explained in terms of reproduction biology and demography.
My own field studies in the investigated area during the winter period have shown that it is by no means uncommon to find that birches of treesize or less, growing at the tree-limit, have the major part of their shoot systems and buds exposed to wind and weather above the snow cover throughout the winter. Often only the unbranched lower parts of the birch stems receive any protection from the snow (cf. Leach & Polunin 1932).

It frost-drought were to represent a primary reason for the absence of birch trees above a certain altitude, then there ought to be a belt of shrub birches, successively lower in height, above the tree-limit. Furthermore, these shrubs ought for the most part to be completely buried beneath the snow during the winter and to be shaped in conformity with the morphology of the snowdrifts (cf. Wardle 1974). Such a belt of birch shrubs is not present in either that part of the mountain chain covered by the investigated area, or e.g. in Lule Lappmark in northern Sweden (Frödin 1916). The present investigation has shown that in most cases (ca 80%) the present tree-limit (TL) and the species limit (SL) coincide. In any case, as a deciduous species, the birch should be little liable to damage from frost-drought, and as far as I am aware no such damage has been convincingly reported for birch growing in the mountainous regions of Scandinavia. On the other hand it has been reported for other deciduous tree species growing at the tree-limit in other parts of the world e.g. Nothofagus solandri (Wardle 1972) and Larix europaea (Nägeli 1969: Holtmeier 1974).

Investigations on Betula verrucosa in Central Europe made by Geurten (1950), showed that transpiration occurred through the periderm and lenticels, even in wintertime, and then especially on the S-facing and lower parts of the stems. Therefore, it cannot be entirely ruled out that a reduction of transpiration by the snow cover has a positive value, especially for the survival of the lower stems and of the initial seedling stages. Whether this is really a controlling factor for birch establishment in this type of habitat or not, can only be finally decided experimentally, although the facts presented in the present investigation argue against this possibility. Furthermore, birches growing in the tree-limit ecotone in Scandinavia only very exceptionally exhibit morphological abnormalities directly attributable to frost-drought damage, e.g. a ‘table-top’ shoot system (cf. Kihlman 1890; Fries 1913), or the presence of shoots which have died back to the level of the snow cover. The follow-up studies made on individual birches growing near the tree-limit within the investigated area did not yield indications, either, that frost-drought represented a serious mortality factor, for well-established stems at least.

Mechanical damages
Brich shoots which stick up 0–50 cm above the snow-cover in winter are sometimes subject to mechanical erosion by ice and snow crystals carried by the wind along and just above the snow surface (cf. Samuelsson 1917; Werenskiold 1925). Occasionally, nearly all the low-growing basal shoots are debarked in this way, although despite this a few scattered shoots often somehow manage to survive and grow to tree height. The phenomenon, in my experience, is rather uncommon, in both space and time, and can hardly have any direct influence on the local position of the tree-limit (cf. Turner 1968; Holtmeier 1974) and has nothing at all to do with the recent altitudinal changes in the tree-limit.

Influences of reindeer
The effects of reindeer (Rangifer tarandus) grazing and trampling represent a further factor which must be taken into account in localities which receive only a shallow snow cover in winter. During the spring calving season the reindeer herds are greatly attracted by bare patches of ground and may cause considerable erosion of soil and vegetation (e.g. Warenberg 1977). The statistical treatment of the tree-limit data from the investigation area as a whole yielded no support for the view that the localities at which little or no rise in the tree-limit was recorded were those which were previously more affected by Lappish activities, including reindeer grazing, than the other localities.

Since both localities with a very early snow-melt and localities with long lasting snow cover are attractive to reindeer, although at different times of the year, the difference in the tree-limit
reaction between these two contrasting types of habitats, has apparently no connection with eventual changes in the degree of reindeer activity.

To sum up, it has been established that the absence of any significant rise in the tree-limit at localities characterized by a shallow snow cover is correlated, according to the evidence presented above, with the pronounced aridity of the soil which characterizes these localities and which becomes more and more pronounced in the course of the summer. The general increase in mean summer temperature during the first half of the present century, mentioned above, will have exacerbated this propensity to summer drought at these localities. Thus the ecological requirements for successful germination and seedling establishment will have either deteriorated or remained stable during the same period of time.

The altitudinal position of the birch tree-limit seems to a high degree to be determined by those environmental factors which primarily affect the habitat conditions for seed germination and the seedling stages. The same conclusion has been drawn regarding the arctic tree-limit (Sochava 1940 [cited in Tikhomirov 1962]; Tikhomirov 1961, 1962, 1970).

Those factors which lead to mortality among well-established saplings and trees are not necessarily the same ones which condition the ultimate position of the tree-limit (cf. Sochava op.cit.; Wardle 1974). This is further emphasised in a fascinating study of the local migrations of spruce clones at the tree-limit in the Rocky Mountains, USA, by Marr (1977), who showed that seed germination and seedling establishment are dependent upon entirely different habitat factors than those which control the growth and subsequent vitality of the shoots of successfully established saplings and young trees, a point also made by Larsen (1965) and in regard to the palaeohistory of spruce in Fennoscandia by Tallantire (1972, 1977).

**Summarised conclusions**

1. At ca 75% of the investigated localities the altitude of the birch tree-limit increased. At the remaining localities the tree-limit remained unchanged between 1915/16 and 1975.

2. The basic cause for the rise in the tree-limit was the increase in the frequency of extremely warm summers, in which respect the decade 1930–39 was wholly unique.

3. There are no indications that the cessation of human impact was the primary cause of the altitudinal displacement.

4. The decisive ecological difference between those localities at which a rise in the tree-limit occurred, and the rest, lies in differences in the depth and duration of the snow cover. The former localities are situated in typical snow accumulation areas, the latter in deflation areas.

5. The degree of displacement recorded was proportional to the extent and duration of the snow cover.

6. Depth and distribution of snow cover and of surface deposits are interrelated, together forming a factor-complex which determined the degree of change of the birch tree-limit and its local differences. The tree-limit at all the investigated localities is basically controlled by the interaction of edaphic and climatic factors.

If the tree-limit was determined by the level at which the local climate no longer is favourable enough to support a sufficient net assimilation for tree-growth, then one would have expected to find that the tree-limit rise would have ceased about 1950, at the time of the culmination of the present climatic fluctuation. However, the seedlings established by that time have continued to grow into trees (stems ≥ 2 m high) and therefore, technically, the tree-limit has continued to rise at most places even after 1950 (1950–1975), although there has been practically no new birch colonisation (i.e. seed germination with seedling establishment) at higher altitudes since 1950 anywhere in the investigated area.

7. At those localities at which a rise in the birch tree-limit was recorded, the main effect of the more favourable summertime weather was a more rapid melting-away of the relatively-deep winter snow cover, which resulted in an earlier drying-out of the soil during the vegetation period. There are many indications which suggest that the birch expansion was conditional upon the increase in surface soil temperature and the decrease in soil moisture which occurred as a result of the diminished snow meltwater supply.

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Seed germination seems to have been favoured mainly by the increase in soil temperature, whilst seedling establishment has obviously been favoured by both the warming up and the drying-out of the surface soil.

The unique, long-term, series of extremely warm summers during the decade 1930–39 provided very good growth conditions for the newly-colonised birch seedlings and enabled them to mature sufficiently to survive the subsequent return of less favourable conditions.

8. The absence of any rise in the birch tree-limit at ca 25% of the investigated localities is related to the existence there of permanently unfavourable conditions for seed germination and seedling establishment. The most probable operative factors were damage by drought and/or high air temperatures during the vegetation period.

Nothing suggests that a shallow winter snow cover *per se* should present any hindrance for the growth of tree-birches.

9. No unequivocal evidence was found for the hypothesis that frost-drought or the mechanical effects of wind-driven snow and ice particles, represent factors limiting the altitudinal tree-limit for birch.

10. For birch stems growing in the tree-limit ecotone, and which have attained tree height, or almost so, the most important lethal factor is the mechanical effect of the weight of the snow cover during the period of the snow melt. The more rapid disappearance of the snow cover during the culmination phase of the climatic fluctuation resulted in a reduction of the above factor, without which a rise in the tree-limit, of the proportions recorded, would probably have been impossible.

11. In general terms the tree-limit, like the vegetation cover as a whole, may be considered as relatively unstable in snowy, locally maritime areas, because in such areas the spatial variation in the depth of the snow cover is a very important differentiating factor and one which reacts relatively soon to any change in the thermoclimate.

12. The problem of the birch tree-limit should be studied in the future by such methods as population-ecology studies of the earliest stages in the life-cycle, since it is obviously possible for birches, once established, to continue to grow and survive at a higher altitude than that at which colonisation is possible (i.e. the 'potential tree-limit' at any period). Productivity studies of trees growing in the tree-limit ecotone therefore, can never yield any definite answers about the true nature of the factors which determine the position of the birch tree-limit.

It is most important that future investigations should be so designed as to separate the differing ecological effects of the depth and the duration of the snow cover.

13. On a basis of the research results obtained so far it is interesting, from a palaeoecological viewpoint to try to form some opinion about the probable effects of different types of climatic change on the altitudinal position of the birch tree-limit.

It is now quite clear that even quite an appreciable rise in the mean temperature of the summer-months (June–August) only results in a rise in the tree-limit at typical snow-accumulation localities. Even here it may be restricted by the absence of a suitable depth or particle-size composition of the surface soil deposits. Furthermore, appreciable increases in mean summer temperatures will lead to a decrease in the supply of snow meltwater and in soil humidity, which can be expected to hamper any further rise in the tree-limit and ultimately even to lead to a fall, perhaps even to the replacement of the subalpine birch belt by other tree species e.g. pine.

The effects of a radical diminution in solid precipitation should be roughly the same as those already described above.

A long-term decline in mean summer temperatures would be expected, first and foremost, to lower the tree-limit in pronounced snow-accumulation localities, whilst at snow deflation localities the tree-limit would probably remain unchanged for a longer period of time.

Therefore, when considering the tree-limit in palaeoecological terms, one must expect to find that climatic fluctuations do not everywhere, or simultaneously, lead to the same pattern of vegetational change.

Attempts to reconstruct the course of the post-glacial climate by palaeoecological methods, i.e. from birch tree-limit change, can therefore be expected to be most successful in locally-maritime areas, characterised by a heavy accumulation of snow, for the reasons outlined under point 11 above.
### References

#### Abbreviations

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<tr>
<td>APhS</td>
<td>Acta Phytogeographica Suecica</td>
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<td>BN</td>
<td>Botaniska Notiser</td>
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<td>GFF</td>
<td>Geologiska Föreningens i Stockholm Förhandlingar</td>
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<tr>
<td>SBT</td>
<td>Svensk Botanisk Tidskrift</td>
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<td>SGU</td>
<td>Sveriges Geologiska Undersökning</td>
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<td>SMHA</td>
<td>Statens Meteorologisk-hydrografiska anstalt</td>
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<td>SMHI</td>
<td>Sveriges Meteorologiska och Hydrologiska Institut</td>
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<td>STF</td>
<td>Svenska Turistföreningen</td>
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Maps

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Nya Grövelsjökartan, 1: 25 000.
Topografisk karta över Sverige, 1: 50 000: 16 C Idre NW, SE (provisional editions); 17 C Funäsdalen NW, NE; 17 D Hede SE; 18 C Sylarna NW, NE, SW, SE; 18 D Storsjö NW, SW; 19 C Storlien NW, SW, SE; 19 D Åre SW.
Turistkarta över Ödøre fjäll med omgivningar, 1: 50 000.
Appendices

Appendix I. The estimated strengths of the different ecological factors at each of the localities at which these were assessed (for details of scale gradings see the respective figure legend). The factors are as follows: 1 Maritimity—continenity; 2 Aspect; 3 Depth and duration of snow cover; 4 Angle of slope; 5 Slope morphology; 6 Local land usage.

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Appendix II. Local informants

Halvar Andersson, Ljungdalen
Gunborg Antholm, Storvallen
Karl Backén, Funäsdalen
Olle Blint, Ljungdalen
Edor Burman, Funäsdalen
Bengt Ellis, Funäsdalen
Elias Fjällgren, Mittådalen
Per-Oskar Fjellner, Vendalen
Jonas Jonasson, Tännadal
Stina Jonasson, Tännadal
Johan Jonsson, Ljungdalen
Algot Lindqvist, Ottsjö
Per Lundberg, Ljungdalen
Albert Långström, Skärkdalen
Paulus Midtagsfjäll, Gröndalen
Martin Mårtensson, Ljusnedal
Sten Olofsson, Storvallen

Appendix III. Supplementary references concerning the former local land-usage within the different parts of the investigated area. Abbreviations are the same as in ‘References’

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