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Cold Damage and Plant Mortality in Experimental Provenance Plantations with Scots Pine in Northern Sweden

Köldskador och plantdöd i proveniensförsök med tall i Norrland

by

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Introduction

This paper deals with the problem of severe cold damage to Scots pine, which causes heavy mortality among plants. It is not only the extent and the intensity of the damage, but also its somewhat unusual type and origin that will be discussed here.

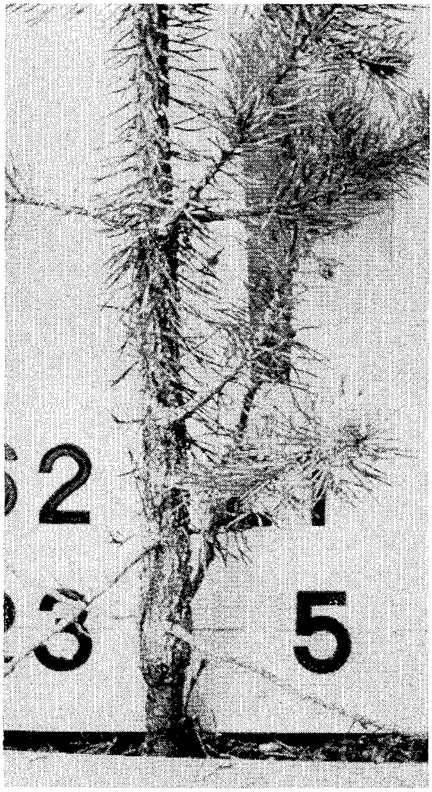
Of all the different and intricate manifestations of cold damage, the emphasis is laid here upon the dieback of the cambium or of the phloem and cortex around the stem, resulting both in basal stem girdle (Figs. 1 and 2) and in the development of frost canker (Fig. 3). It is true that several other kinds of damage occur simultaneously (Fig. 4), and that not seldom, but it is the basal stem girdle that decides the fate of the damaged plants and young trees, and this more than often results in heavy mortality among plants.

The manifestation of the singular cold damage should to a great extent be connected with the extreme climate in some years. On the other hand, in years with normal weather conditions no damage to Scots pine has been observed, and one is almost inclined to say that it does not occur at all. It is most interesting to note some peculiar features in the weather conditions in the years when severe cold damage occurs. Rainy and also comparatively frequent cool summers and autumns, followed by sudden drops of temperature and fluctuations in the weather conditions during the winters, with periods of extreme low temperatures, should be mentioned in the first place. Conspicuous fluctuations of the diurnal air temperature in late winter and early spring complete the picture. The compact snow cover in winter, alternate freezing and thawing of the snow in spring, make up the second characteristic feature of the extreme climatic conditions.

It is not easy to estimate the effect of a single weather factor and also the interaction of several meteorological factors upon the origin of cold damage. Cold damage as a phenomenon associated with the hardening processes in plants thus becomes an intricate problem.

The manifestation of basal stem girdle is functionally associated with years of extreme weather conditions and takes place after indefinite intervals over a period of some years. Although cold damage of this kind does not often occur, it exercises a grave negative influence upon the development of individual plants and plantations, and results in devastating consequences to practical silviculture.

During the last decade widespread cold damage was particularly conspi-



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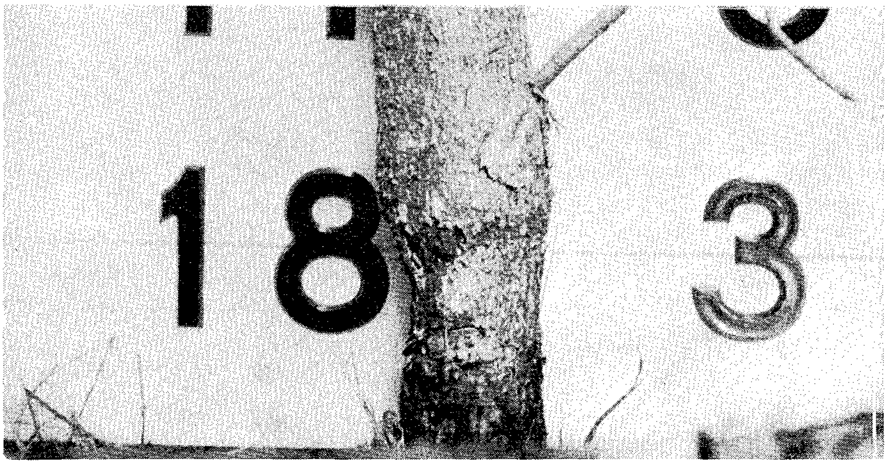

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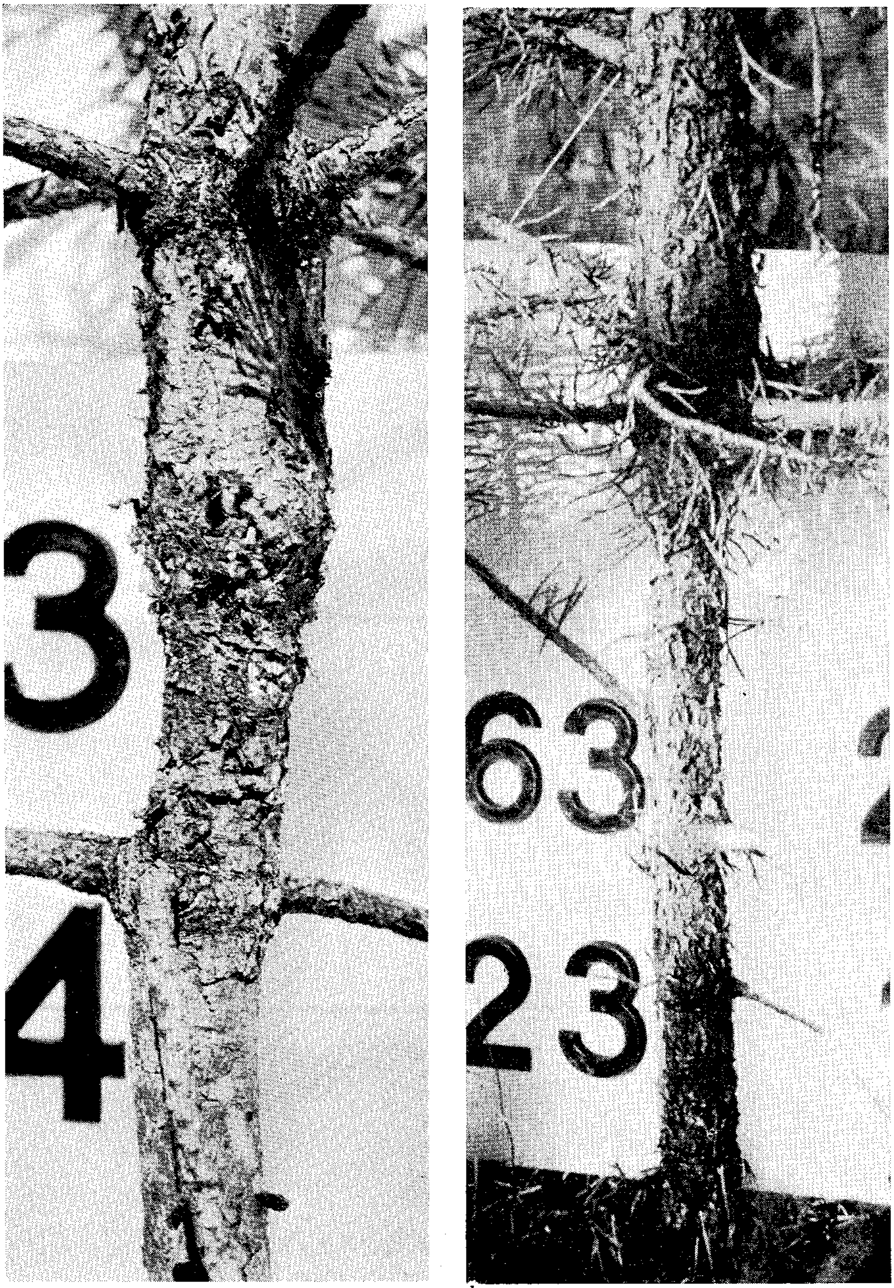
Fig. 1. Basal stem girdle of 1960/61, at ground surface. The damaged trees died in the autumn of 1962. The photographs were taken in September 1962.
a, experimental plantation 21, provenance 23;
b, experimental plantation 12, provenance 50;
c, experimental plantation 11, provenance 49.



a *b*

Fig. 2. Basal stem girdle of 1960/61, 40—50 cm above ground surface. The completely girdled trees lingered on until the autumn of 1963, owing to the survival of some living branches below the girdle:
a, experimental plantation 28, provenance 84;
b, experimental plantation 22, provenance 23.

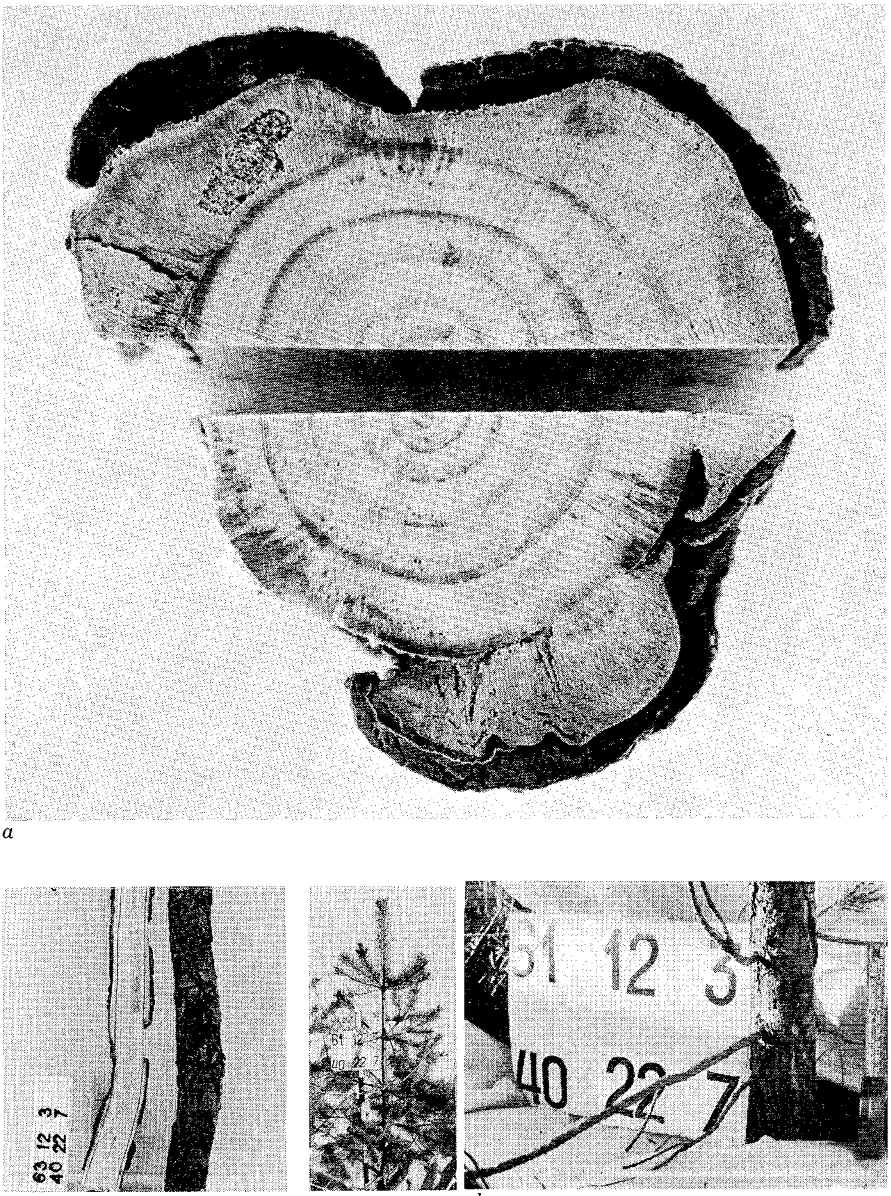


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Fig. 3. Basal stem girdle of 1960/61 and heavy frost canker:
a, transverse section at the centre of the frost canker;
b, longitudinal section of the portion affected by basal stem girdle;
c, short terminal and lateral shoots developed during the growing season of 1961;
d, the portion of the basal stem girdle.

The damaged tree died in the autumn of 1961. Photographs were taken: *a* and *b* in 1963; *c* and *d* in the autumn of 1961.

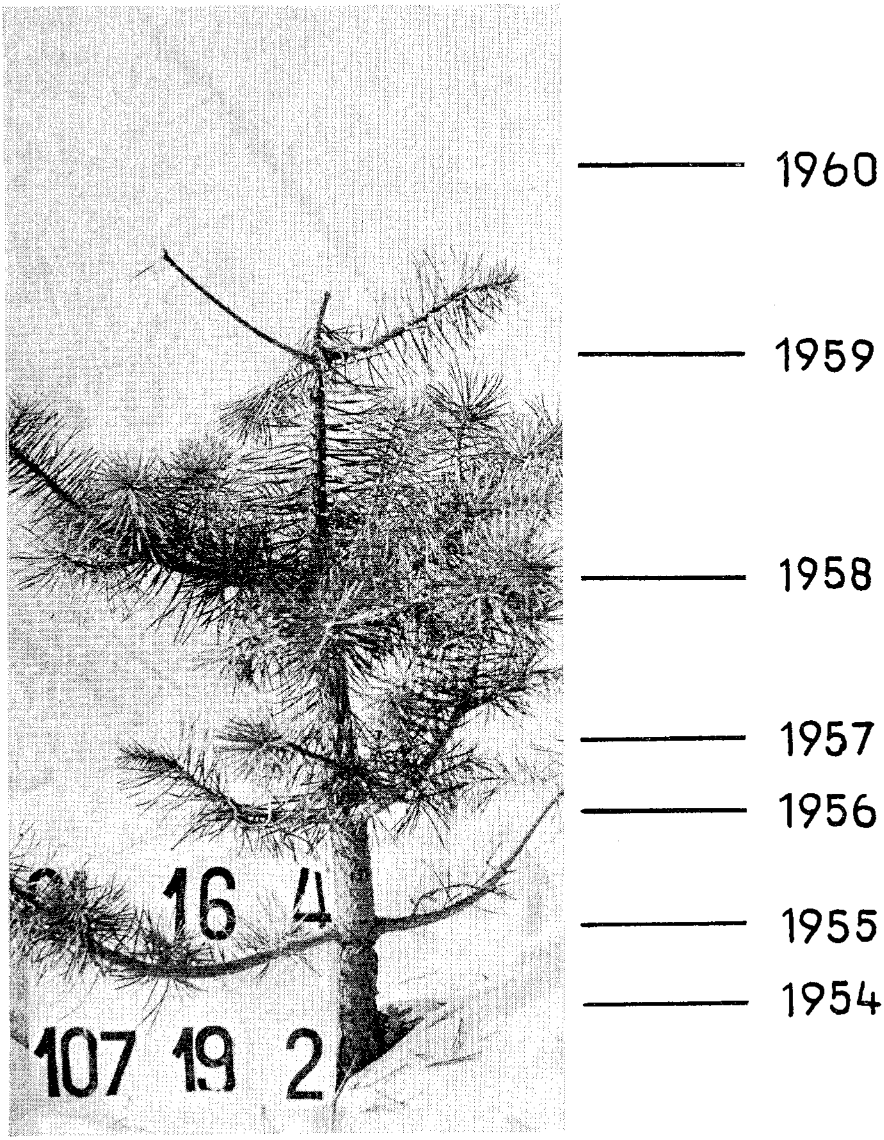

Fig. 4. Basal stem girdle of 1960/61 (at the height corresponding to the height of the tree in 1955) and dieback of the leader of 1960 during the winter 1960/61. The photograph was taken in September 1961.

cuous on afforestation and natural reproduction areas in the uplands of northern Sweden and other localities with similar climatic conditions. Plantations of high quality were wholly or partially laid waste on account of cold injury. (Norrlands Skogsvårdsförbunds exkursion till Lappland, Norrbottens län, 1961.) The unusual type of damage and its variable manifestation caused surprise, and attempts were made to explain the causes of this intricate phenomenon. Misinterpretations did not fail to crop up. In endeavouring to elucidate this phenomenon an unproportionally large role was attributed to secondary agents and other accessory factors.

Injury to Scots pine caused by temperatures below freezing point is not an unfamiliar phenomenon either in Sweden, or in other countries with similar climatic conditions. A detailed and systematic historical survey of cold damage lies outside the scope of this paper, yet it is not out of place to mention some kinds of cold injury and also the investigations connected with the problem under discussion.

Among different experiments dealing with cold damage to forest trees and plants, provenance experiments play an outstanding role. In Sweden provenance tests were started more than 60 years ago. During this period most valuable information on the sensibility of plants to cold injury in relation to the origin of seeds has been collected. The susceptibility of plants is clearly revealed when seeds are transferred from their natural habitat to areas with a more severe climate. Cold resistance is one of the aspects in the variability of physiological qualities that have been studied in Scots pine.

The different silvicultural values of provenances are closely connected with cold damage to plants. In this connection reference should be made to: SCHOTTE (1910, 1923), WIBECK (1912, 1913, 1929, 1930—1931), ENEROTH (1926—1927, 1928, 1930) and LANGLET (1929, 1934, 1936, 1945, 1952, 1959).

It should also be mentioned here that the problem of cold resistance has been touched upon in many papers on the provenances of Scots pine by authors outside Sweden (Ref.: LANGLET, 1936, 1938, 1959; KALELA, 1937).

In silvicultural practice in Sweden, different kinds of cold injury to Sctos pine have been observed. One of the most notorious examples is the extensive cold damage to Scots pine which took place in the year 1903 (ÖRTENBLAD, 1903; ANDERSSON, 1905).

There is an evident connection between the manifestation of cold damage to Scots pine in the year 1903 and the weather conditions prevailing at that time in Sweden. The summer of 1902, cool and rainy, was followed by an early cold wave but by a mild winter later; in the early spring of 1903 there was a period of warm weather and then a severe cold wave. Dieback of the shoots, plant tips and of the crowns occurred in Scots pine of different ages, and even in older trees on natural growth localities.

The cold damage of 1903 serves as an example of the manifestation of the damage comprising a large region, namely, the north of Sweden. The effect of the general weather conditions in this particular case is obvious. The variations of local climate in individual areas within the boundaries of the region exercise a modifying influence on the intensity of the cold damage, either strengthening or weakening it, subject to the topographic situation on the particular place of growth and the character of the ground surface.

In this paper attention will be focussed particularly on cold damage in the north of Sweden. However, it should be mentioned that the type of cold damage which occurred in 1903 was not the same as was observed in this region during the last decade and has nothing in common with basal stem girdle.

The effect of cold as a cause of injury to plants on a large scale has been registered also during other years (FRIES, 1918; SYLVÉN, 1924). However, cold injuries on frost localities occur rather frequently. Most often they take place in northern Sweden.

Of the different kinds of cold damage in the vegetative organs of Scots pine the most common are distortion and killing of living cells in needles, buds and shoots. Injury to needles results in partial or complete loss of foliage in seedlings, plants and young trees. The same may be said of injuries to buds. Part of them on terminal and lateral shoots may be killed. Injury to phloem, cambium and cambium rays, as well as other parenchymatous elements of tissues, results in dieback of shoots (Figs. 5 and 6) or total dieout of plants.

On the other hand, injury to old wood in Scots pine is considered a rare occurrence, but in many other coniferous species this type of damage is common and occurs in young stems (DAY, 1928). Cold damage to old wood in Scots pine has been mentioned in literature in connection with the phenomenal spring frosts in 1935 in England when "in one area a number of pines died in the autumn and were found to have been girdles at the base caused almost certainly by the May frost" (DAY and PEACE, 1946, p. 51). At the same time it is stated that "Scots pine is fundamentally resistant to late frosts regardless of its state of development" (ibid. p. 50). As regards the type of cold damage to Scots pine it is said that ". . . where damage was recorded it was usually very slight . . . and . . . damage was entirely confined to the side shoots." Using data obtained from extensive afforestation areas, DAY proposes to plant Scots pine and Norway spruce in frosty localities where other species are killed outright by cold injury. Severe injury by the June frost, which caused dieback of the top of pines, has occurred in Germany in frosty localities (DENGLER, 1910, 1932).

The state of the development of plants and the physiological processes connected with the seasonal changes play a decisive role in the occurrence of

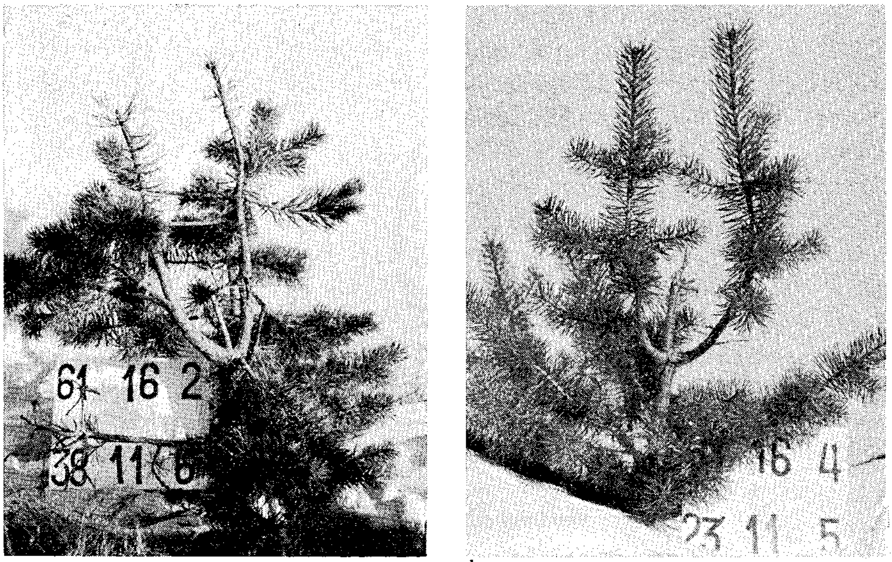

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Fig. 5. Dieback of top and forked stems:
a, killed leader of 1957 (during the winter of 1957/58) and killed leader of 1960 (during the winter of 1960/61);
b, killed leaders of 1956 and 1957 (during the winter of 1960/61). Experimental plantation 16, provenances 38 and 23. The photographs were taken in September 1961.

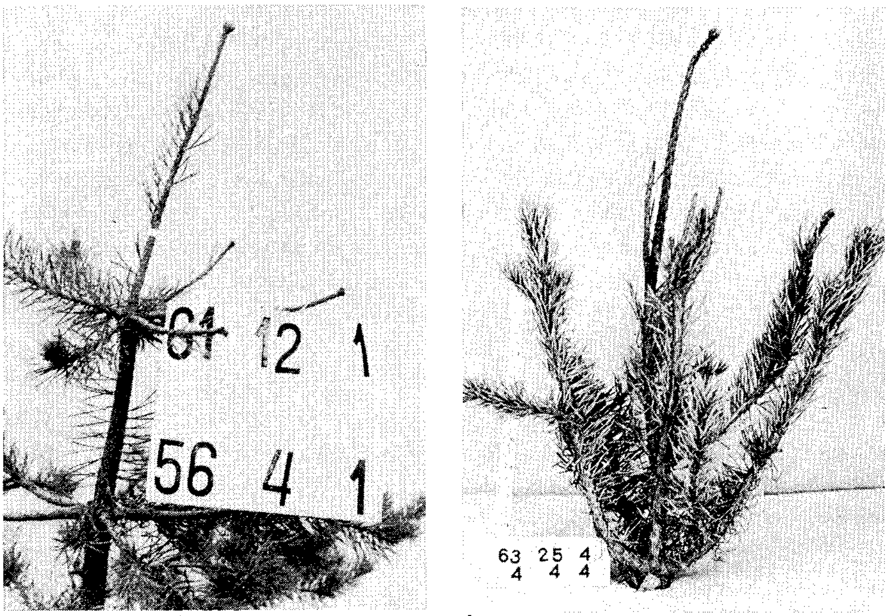

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Fig. 6. Dieback of top, killed leaders and lateral branches:
a, during the winter of 1960/61, experimental plantation 12, provenance 56;
b, during the severe spring frost of 1963, experimental plantation 25, provenance 4.

cold damage. It is believed that most cold damage appears during the growing season and is due to either late or early frosts. However, it should be stressed at the same time that cold injury may occur in any season (PARKER, 1963, p. 128). Cold injuries are usually classified depending on the season when they occur, for instance, damage by winter cold, by spring or late frost, and by early or autumn frost.

In Sweden cold injury can be observed in the seedlings and plants of Scots pine. Cold damage occurs during some years in nurseries and on plantations, but most of all on natural reproduction areas, in frost hollows, frost pockets and on flat heathland. At this stage of development of individuals the rate of losses is sometimes considerable. However, it should be emphasized that the type of damage might be described as slight. These injuries occur in young plants susceptible to cold during the growth season, in spring and autumn, and even in the middle of summer. The cause of this type of cold damage is due to advective and radiation frosts, which often arise simultaneously (DAY, 1946, p. 14 f.). The same kind of cold damage occurring during the growth season in the north of Sweden is also to be met with in countries with a similar climate. Although the effect of cold damage is plainly visible and conspicuous, it has not yet attracted the due attention of foresters in the north of Sweden.

The concealed injuries which occur not only to plants, but also to young trees, often remain quite unnoticed on frosty localities. Formation of abnormal wood and structural changes in both xylem and cortex elements may be perceived only when careful analysis of the damage is made. In the north of Sweden the most characteristic internal injuries are frost rings and bark rents. Plants and young trees having damage only of this kind usually survive. On the other hand, insect attacks on the weakened individuals and infection of the injured places by fungi can be fatal to most plants and trees injured by cold. In such cases the initial cause of death often remains unnoticed.

It has already been mentioned that cold damage to Scots pine in the north of Sweden which occurs during the growth season is of a comparatively slight character. In the natural growth places where spring and summer frosts have occurred, severe cold damage to old wood, that is, girdles at the stem base, is seldom met with on frost localities simultaneously with other, slighter types of injury. The author has not met with such damage, with the exception of some cases of severe dieback of the plant top, that is, girdling of the main stem in the upper part of the tree (Chap. 3.1.1.7). Thus, Scots pine shows a very high degree of hardiness in these environmental conditions, although extremely low temperatures occur during the growth season, in some cases falling several degrees below 0° C.

However, as regards the susceptibility of Scots pine to cold, mention should be made of the results obtained by DAY and PEACE (1934, pp. 16 and 52) in their experiments on the artificial production of frost damage in young trees. Scots pine proved to be surprisingly susceptible to winter cold and rather susceptible to early spring frosts. The origin of seeds in these experiments was not known and the authors are of the opinion that the origin of seeds may have played a considerable part in the production of cold damage.

Severe and extensive cold damage to old wood, that is, basal stem girdle, which is the subject of this paper, is identical with damage patterns described by Day (1928) in other species of conifers, but as regards the cause of cold damage there exists a great difference between the two cases. Basal stem girdle in the climatic conditions of the north of Sweden has another time of occurrence than that observed in England and Scotland, and also a different process of development. Basal stem girdle originates in late winter and early spring, when diurnal fluctuations coincide with the thawing of the snow and the development of ice crust.

The problem of the hardiness of Scots pine is rather paradoxical. During the extremely severe spring frosts in 1935 in England, and on similar occasions in the north of Sweden, Scots pine proved to be highly resistant to cold during the growth period, when plants are supposed to be susceptible to cold. But during the years of extreme climatic conditions many young trees were killed and some plantation areas were even destroyed in the north of Sweden before the growth period set in.

Undeniably, basal stem girdle is the most conspicuous type of damage. It occurs not only in plants, but also in young trees. It damages and kills plants and trees even with well-developed thick bark at the time when they are well-protected against environmental influences. Basal stem girdle may occur simultaneously with other types of cold damage in one and the same plant or tree, and in the same year. However, this principal type of damage has not yet been noticed in the north of Sweden. A preliminary report on this question was published in 1962 (Eiche), in which the damage was described as a "strangulation" phenomenon. The analysis of damage caused by basal stem girdle is continued in this paper. More extensive research material and a more thorough approach to the problem are made use of.

The data were obtained from a provenance experimental series with Scots pine which includes 30 experimental plantations comprising 36 ha laid out by the Department of Forest Genetics at the Royal College of Forestry during the period 1952—1955. Owing to the fact that each plant in the series was the object of individual attention, this specific type of damage did not pass unnoticed. Observations acquired on the experimental areas were checked by comparing them with the corresponding phenomena on the surrounding natural reproduction areas.

A great number of provenances of different origin played a prominent role in the analysis of the problem. There were marked differences in the resistance to cold between different provenances. The frequencies of damaged and killed plants were varied among the provenances tested. Differences were also observed in the intensity of the damage and in healing of the wounds in the injured individuals of different provenances. In addition, the manifestation of the damage showed certain deviations in different provenances.

Basal stem girdle was discovered by the author already in 1946 on experimental provenance plantations laid out by SCHOTTE and WIBECK in 1911. A limited number of badly-injured trees, which had not completely recovered from wounds, had survived and bore witness to old, severe cold damage. The trees belonged to provenances susceptible to cold.

After the long and severe winter of 1954/55 considerable frequencies of this type of damage were observed on experimental plantations laid out during 1952—1954. The plants were only four years old, and the external sign of damage was inconspicuous. It could easily be mistaken for another, and very common, type of damage, *i.e.*, dieback of the plant top. There were also other factors which hindered the analysis of the phenomenon. But in the following years characteristic basal stem girdle damage—the circular peeling off of the bark and the infiltration of resin into the xylem of the damaged place—could be perceived in the dead plants. The type of damage of 1954/55 was frequently found later on natural reproduction areas.

After the winter of 1960/61 extensive damage to ten-year-old trees suddenly appeared again. The further development of the experimental plantations was influenced by the severe damage of 1960/61. The effects of the damage were recorded every year and the data obtained comprised the period up to September 1964.

The analysis of cold damage is part of the plan of the experimental series with Scots pine. The death or survival of single individuals shows in general outline the ability of provenances to adapt themselves to the climatic conditions on experimental sites. At the same time the problem of cold damage—its occurrences and consequences—is closely connected with the practical aims in silviculture. However, from the point of view of silviculture, several other approaches are possible as regards cold and other weather factors influencing the afforestation of vast logged-off areas.

Only part of the research data accumulated from the year when the experimental provenance series were laid out have been made use of in this paper. This refers to the records obtained from the plantations, to the archive photos and to the histological analyses made in the laboratory. At the same time a lack is felt of some data on the subject, which as yet it has not been possible to collect. References to literature and to investigations upon similar phenomena fill the gap only partially. It is necessary to expand the boundaries of research work into the causes of basal stem girdle. Further, it is of utmost importance to investigate this type of damage in artificial, controlled laboratory conditions.

It would be most desirable to know more about the correlation between the meteorological factors on the one hand, and the origin of the damage on the other. The influence of the ecological factors on the origin of the damage, in its turn, gives rise to a desire for a deeper contact with the branches of biology dealing with cold and winter hardiness, hardening and dormancy in plants. The type of cold damage discussed in this paper is related to several branches of science, dealing with the problems of cold resistance, which are common for many countries.

Of all the abundant literature on cold damage in plants and on plant resistance to cold, the author would like to mention the work of those scientists who have essentially contributed to the analysis of the problem under discussion. (References are to be found in the literature cited.)

It is thanks to the British scientist W. R. DAY that the causes and the occurrence of the basal stem girdle have been examined and elucidated in several species of conifers in the climatic conditions of England and Scotland. His investigations also dealt with other types of cold damage and were carried out at the Department of Forestry, University of Oxford, during 1928—1961 in collaboration with T. R. PEACE, and during recent years with D. K. BARRETT. It is most gratifying to state that the results of these investigations can also be successfully applied to the analysis of cold damage in climatic conditions in Sweden. The problems under discussion have also been thoroughly examined by the American scientist J. SH. BOYCE in "*Forest Pathology*". It would be by no means superfluous to remark that in the manifestation of cold damage the scientists mentioned above closely analysed the importance not only of the role of the physiogenic, but also that of the pathogenic factors.

The review on "*Cold Resistance in Woody Plants*" by J. PARKER, Yale School of Forestry, New Haven, Connecticut, U.S.A., is of particular interest to the author, since it was published when this paper was being written.

Some time after 1940 the author of this paper had the opportunity of reading I. I. TUMANOV's work on "*Physiological Foundations of Winter Hardiness in Plants*" (in Russian). By studying the experimental work of I. I. TUMANOV and his collaborators, D. A. KRASAVCEV, P. A. GENKEL and others, at the K. A. Timirjasev's Institute of Plant Physiology, Academy of Science U.S.S.R., Moscow, it has been possible to avail oneself of the achievements of the Soviet scientists as regards the problems of plant cold hardiness. Mention should also be made of "*The Reports of the Conference on Physiology of Plant Hardiness, 3—7 March, 1959*" (in Russian) and to the "*Resolution of the*

Conference on Physiology of Plant Hardiness, Adopted March 7, 1959" (in Russian).

The fundamental monographs by J. LEVITT, University of Missouri, Columbia, on "*The Hardiness of Plants*" and on "*Frost, Drought and Heat Resistance*" have greatly helped the author in his search for finding references and clues to the problems connected with cold damage and plant resistance to cold.

A series of studies on frost-hardening processes and frost-hardiness of woody plants have been carried out during the recent decennium by A. SAKAI, at the Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan. The research work of this scientist, just as the investigations and experiments of the American and Soviet scientists, is directed towards the elucidation of biochemistry and biophysics of living cells and tissues in connection with cold hardiness in plants.

"*Ecological Studies on the Subalpine Zone with the View of Afforestation of Uplands*" (Mitt. der Forstl. Bundes-Versuchsanst., Mariabrunn, H. 59, 1961 and H. 60, 1963) comprise the works of W. TRANQUILLINI, H. AULITZKY, A. PISEK and other authors. These investigations deal with ecological problems similar to those in northern Sweden.

A. VEGIS has carried out extensive experiments on dormancy and the rest period in higher plants at the Institute of Physiological Botany in Uppsala. A. VEGIS's works on the above problems printed in the "*Encyclopedia of Physiology*" and in the "*Annual Review of Plant Physiology*" may be looked upon as comprehensive on the subject.

Investigations on the physiology of winter hardiness in relation to dormancy in woody plants is being carried out by L. I. SERGEJEV and his collaborators at the Institute of Biology, Ural branch of the Academy of Science, in the Soviet Union. In this connection "*Summary on Reports at the 2nd Ural Conference on Ecology and Physiology in Woody Plants, Ufa, 1965*" should also be mentioned.

From earlier investigations the classical works of B. LIDFORSS, at the University of Lund, Sweden, and of N. A. MAXIMOV, at the Forest Institute, Department of Plant Physiology, St. Petersburg and later at the K. A. Timirjasev's Institute of Plant Physiology, Academy of Science U.S.S.R., Moscow, deserve attention.

The investigations on mortality in plants caused by cold, and on plant resistance to cold, were carried out by the Swedish scientist Å. ÅKERMAN, at the Swedish Seed Association, Svalöv, continued there by G. ANDERSSON.

Of the investigations of several German scientists at the end of the 19th century and the beginning of the 20th, dealing with the problems of cold as the cause of damage and death in plants, those of R. HARTIG, at the University of Munich, and of A. WINKLER, University of Leipzig, are closely connected with the problems discussed in this paper. As far back as 1883 R. HARTIG described the occurrence of the basal stem girdle (Einschnürung) in transplants of silver fir and Norway spruce in nurseries, but was not sure as to the causes of its origin and was rather reserved in his conclusions.

Abbreviations used

BSG	basal stem girdle
CM	cumulative mortality
EP	experimental plantation
MS	meteorological station
PR	provenance
SMHI	Swedish Meteorological and Hydrological Institute
SYM	single-year mortality = mortality in single years

1. General information on experimental plantations

The experimental series with Scots pine was planned in 1948 by TIRÉN, GUSTAFSSON, LANGLET, EICHE.

When drawing up the plan for the new experimental series, experience and knowledge gained from a series of EPs laid out in 1911 by SCHOTTE (1923) and WIBECK, as well as from the international PR experiment series laid out by LANGLET in 1938, were taken into consideration. The new series was laid out during 1952—1955 by LANGLET, EICHE. This series comprises 30 EPs distributed over the whole country with a total area of 36 ha, of which 29 EPs occupy an area of 24 ha, and one an area of 12 ha (Figs. 7 and 8).

1.1. Provenance material tested in the experiments

The experimental series of 1952—1955 include 100 PRs, originating from natural growth localities of Scots pine.

Seed was procured during 1948—1950 by collecting cones from 3,100 standing individual trees in 90 populations. Between twenty-five to thirty trees were chosen from each population. Mother trees to represent the whole population were chosen at random. However, in some upland regions, as well as in northern regions, collection was made from all productive trees, and in some cases it appeared to be necessary to double the number of the trees in order to obtain the necessary quantity of seeds.

The experimental series of 1952—1955, as mentioned above, included 90 populations, representing a progeny of 2,200 individual trees. Eight of these 90 populations were supplemented by seed from bulk collections. A further ten populations were raised from bulk collections only, originating from Germany and the Netherlands (Fig. 7).

An archive consisting of photos, measurements, records, cones, needles, seed, samples and analyses testing the quality of seed was established. It contains all necessary data concerning individual trees and collected seeds.

Planting stock was raised in two nurseries, one in the province of Stockholm (φ: 59° 25′, λ: 18° 10′, H_s: 20 m) and the other in Västernorrland (φ: 63° 30′, λ: 16° 42′, H_s: 200 m). The sowing of seed from individual PRs and individual trees was carried out under uniform conditions in nurseries, in seed beds side by side in simple inventory. The data on the rate of seed germination in nursery conditions and on the growth of seedlings were obtained by minute and consistent recording.

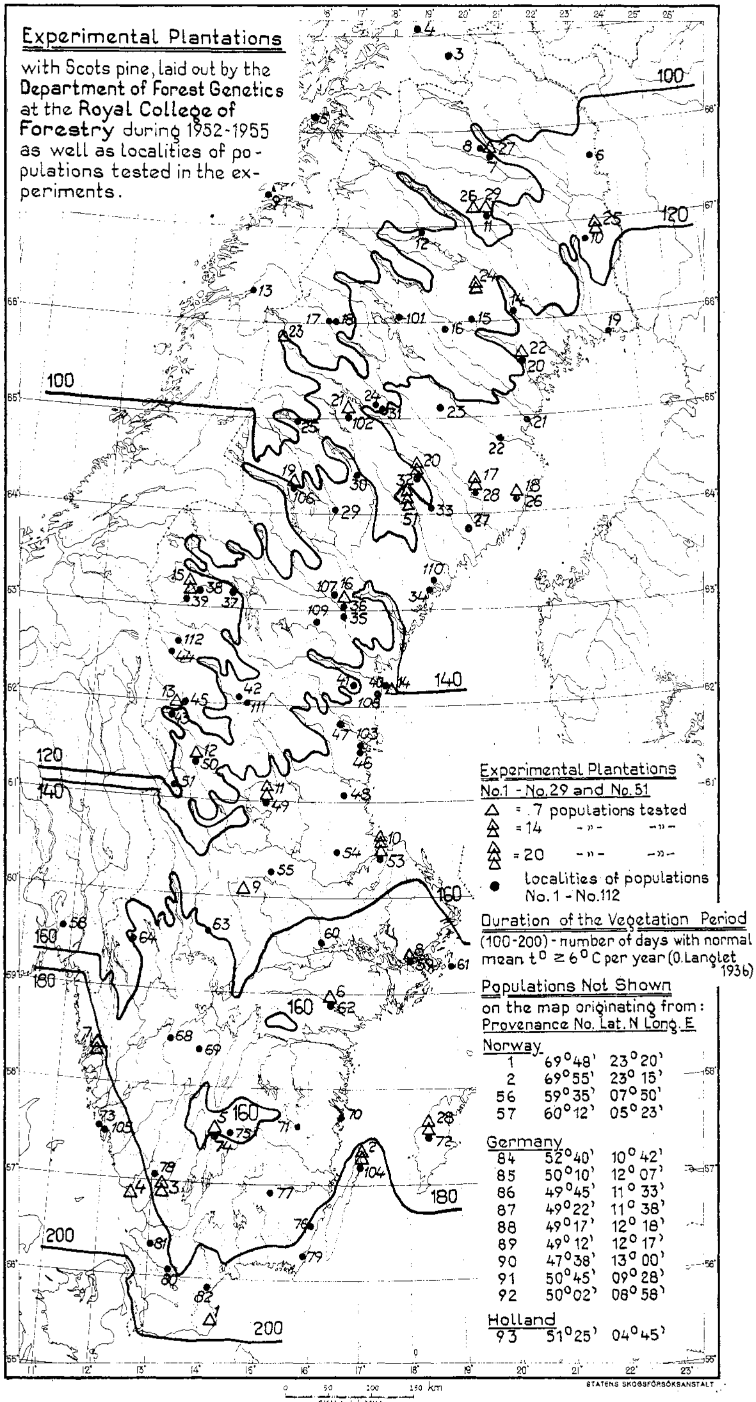


Fig. 7. EPs laid out during 1952—1955 (No. 1—29 and No. 51) and natural habitats of populations tested in the experiments (No. 1—112). Isolines (100, 120, 140, 160, 180 and 200) show the length of the growing season ("vegetation period").

1.2. Design, layout and tending of the experiments

On 29 EPs PR experiments were conducted in randomised blocks with restriction similar to YOUDEN square design and with 2×2 replications with a planting space of 2×2 metres and 1.25×1.25 metres respectively.

PRs in the EPs were chosen on the basis of a definite, adopted plan. On the EPs where seven PRs were represented their composition was as follows: a local PR, two standard PRs, which were also represented on all other EPs, and two plus two PRs, whose natural habitats lie to the north or to the south of the experimental locality respectively. In both cases, that is, both in the northern and in the southern variants, one of the PRs originates from a higher and the other from a lower altitude in comparison with the altitude of EP. Whenever it was possible to introduce standard PRs in the adopted design in such a way that two more PRs could be added, they were chosen from the same latitude where the locality of the EP was situated—one from the higher and the other from the lower altitude than the altitude of the EP (LANGLET, 1952).

As regards the transfer of the PRs from their natural habitat to the experimental site, the maximum accepted distance in the north of Sweden was 150 km in meridional direction and 100 m in vertical scale (LANGLET, 1945), with a few deviations on some occasions.

On EPs where the number of PRs was 2×7, the PRs were chosen according to the plan mentioned above, but the remaining seven PRs were taken from more remote habitats in relation to the locality of the EP, than in the case mentioned earlier. This gave the possibility of simultaneously testing PRs transferred from reasonable distances and from remote habitats.

The plantation space in two randomised blocks was 2×2 metres, in two other blocks 1.25×1.25 metres. Each PR plot in the blocks of the sparse plantation contained 50 plants and covered an area of 200 m^2, the plot size being 20×10 metres, whereas each plot on the dense plantation had an area of 125 m^2 and contained 80 plants, the plot size being 12.5×10.0 metres. Progenies of the individual trees were tested in randomised rows. In two blocks progenies of ten trees, and in two other blocks progenies of ten other mother trees from the same population were tested. Thus 13 plants in the experiment represent the progeny of one tree. This is a figure which can give some guidance in testing the hereditary characters of a tree. It should be mentioned that progeny from the same tree was also tested on other EPs. Each PR in the EP was represented by 50+50+80+80 = 260 plants.

In 1955 this experimental series was extended by an EP (Fig. 7, No. 51) with three randomised blocks, containing 20 PRs laid out on an area of 12 ha with a planting space of 2.5×2.5 metres. Each PR plot in the blocks covered an area of 50×37.5 = 1,875 m^2 and contained 20×15 = 300 plants. In each

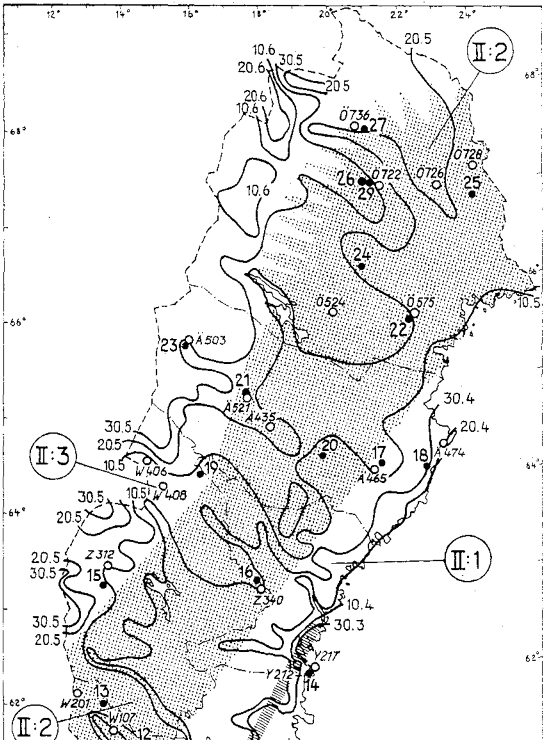


Fig. 8. EPs (No. 1—29, black dots), MSs (Table 1, circles) and isolines showing the date when snow melted in the spring of 1961, *e. g.* 20.4 = 20th April. Regions I and II, subregions II:1, II:2 and II:3 are described in Chaps. 2, 4 and 6.3.

block progenies of 20 trees were tested. Each mother tree in the experiment was represented by $15 \times 3 = 45$ plants.

It should be emphasized that the layout of the experiments was accompanied by certain difficulties. It was not easy to find a sufficiently large area with uniform edaphic conditions in the north of Sweden. It was easier to find the site for seven PRs with an area of 0.63 ha than a site for a double number of PRs with an area of 1.25 ha.

Preparation of the area for the EPs was made during the period 1952—1953. Careful scarifying was applied where necessary. Planting in open pits was carried out by using seedlings (2+0) and transplants (2+1 and 2+2). Up to 1955 losses were replaced by transplants from nurseries; later, reserve plants grown on the site of the experimental plot were used. Fencing of the EPs with the view of protecting them against the attacks of reindeer (*Rangifer tarandus*) appeared to be necessary on many EPs in the north of Sweden, and in southern and central Sweden similar protection was necessary against elk (*Alces alces alces*) and roe (*Capreolus capreolus*). Every autumn, on all EPs north of the river Dalälven, that is, practically in the whole of Norrland, seedlings and plants were sprayed to protect them against snow blight (*Phacidium infestans*), which causes injuries and plant death on a great scale in the north of Sweden. Weeding, eradication of insects, rats, mice and lemming, as well as other kinds of routine work, were carried out where necessary.

Observations and assessment of EPs were carried out every year, and in some cases even twice a year. Mortality and changes in plants were examined; where possible, factors causing them were stated. Thus each plant became a permanent experimental object.

PR tests (1952—1955) were extended by an analysis of populations, based on the same PRs and on individual trees. Observations were carried out in nurseries, hothouses and in the laboratory. The problems examined deal chiefly with chlorophyll mutations, the variation of anthocyanin pigmentation at juvenile stage and formation of Lammas shoots.

Grafting of pine populations, which together with their progeny constitute PR tests, was started in 1952 and has not yet been completed. A tree bank was established with the view of examining the characteristic traits of clones and of the genotypical characters of trees. Grafts were planted on the experimental field at Bogesund, near Stockholm, covering an area of 7 ha and containing about 1,400 clones.

2. Weather conditions during the years when plants suffered severe injury

2.1. Cold damage in connection with weather conditions

It has already been mentioned that extensive, heavy and intricate injuries appeared on the EPs after the long and severe winter of 1960/61. The high frequencies of these injuries occurred in the region which chiefly comprises the uplands of the north of Sweden (Norrland and the northern part of the province of Kopparberg, W). Outside this region damage occurred only sporadically. Within the boundaries of the region the variation of frequencies attained in some places a most striking expression. These two statements—the distribution of cold damage within a large region and the connection of the occurrence of the damage with the peculiar winter climate of 1960/61—will be verified in the chapters that follow.

Some types of injuries were caused by the direct effect of low temperatures. The dieback of the buds and of the tips of the plants is a characteristic example of this. Other types of damage originated owing to snow or ice crust, which mechanically, by its weight, had injured either the whole crown of the plant, some individual whorls of the branches, or some individual branch in a whorl. The cause of the principal type of damage, BSG, is most complicated. There is evidence which points to the combined effect of low temperatures and other elements of winter climate. The position of the damage along the stem of the tree varies. The level of damage above the surface of the ground shows that it is connected with the changes in the depth of the snow cover in late winter and early spring. Another type of damage, winter sunscald, is connected with the S or SW side of the tree. This circumstance leads to the conclusion that the causes of the damage are the extreme fluctuations of temperatures in the tissues of the tree, called forth by diurnal insolation and fall of temperature in early spring. The various types of damage are by no means confined to these examples. Only most characteristic and striking examples are mentioned here. However, these examples prove that it is necessary to apply meteorological aspects in the analysis of cold damage. At the same time the traditional approach of checking the origin of cold damage with weather records should be referred to.

When emphasizing the fundamental importance of weather conditions in analysing the manifestation of cold damage, it is necessary to mention those difficulties and hindrances which prevent the elucidation of the role played by

Table 1. Meteorological stations (MS) of the SMHI, whose observation data were used for characterizing the climatic conditions on experimental provenance plantations (EP).

				φ	λ	H_S
EP	BD	27	Kiruna, Kauppinen	67° 50′	20° 27′	360
MS	Ö	736	Kiruna flygplats	67° 49′	20° 20′	452
EP	BD	26	Gällivare, Linalombolo	67° 14′	20° 29′	470
EP	BD	29	Gällivare, Linalombolo	67° 14′	20° 29′	475
MS	Ö	722	Malmberget	67° 11′	20° 42′	393
EP	BD	25	Korpilombolo, Ohtanajärvi	66° 56′	23° 11′	200
MS	Ö	726	Kompelusvara	67° 4′	22° 20′	238
MS	Ö	728	Pajala	67° 12′	23° 25′	176
EP	BD	24	Kåbdalis, Rahaberget	66° 16′	19° 53′	440
MS	Ö	524	Suddesjaur	65° 54′	19° 6′	345
EP	BD	22	Älvsbyn, Asplövberg	65° 38′	21° 7′	60
MS	Ö	575	Älvsby skogsskola	65° 41′	21° 4′	40
EP	AC	23	Tärnaby, Snebacken	65° 43′	15° 6′	630
MS	Ä	503	Tärnaby	65° 43′	15° 18′	447
EP	AC	21	Långsjöby, Rönnhagen	65° 9′	16° 33′	465
MS	Ä	521	Långvattnet	65° 6′	16° 42′	420
EP	AC	20	Lycksele, Storberget	64° 33′	18° 15′	555
MS	Ä	435	Ulvoberg	64° 46′	17° 13′	520
EP	AC	17	Vindeln, Svartberget	64° 14′	19° 43′	200
MS	Ä	465	Kulbäcksliden	64° 12′	19° 34′	200
EP	AC	18	Robertsfors	64° 12′	20° 48′	50
MS	Ä	474	Lövånger	64° 22′	21° 20′	21
EP	Z	19	Harrsjön	64° 18′	15° 23′	360
MS	Z	406	Gäddede	64° 30′	14° 8′	318
MS	Z	408	Munsvattnet	64° 16′	14° 28′	520
EP	Z	15	Vallbogården	63° 10′	13° 4′	540
MS	Z	312	Åre	63° 24′	13° 6′	440
EP	Z	16	Bispgården, Torresjölandet	63° 8′	16° 39′	470
MS	Z	340	Fanbergstorp	63° 5′	16° 43′	290
EP	Y	14	Brämön	62° 12′	17° 42′	5
MS	Y	217	Brämö	62° 13′	17° 45′	17
MS	Y	212	Häljum	62° 16′	17° 22′	40
EP	W	13	Idre, Himmeråsen	61° 54′	12° 47′	765
MS	W	201	Grövelsjön	62° 6′	12° 19′	815
EP	W	12	Bunkris	61° 27′	13° 28′	575
MS	W	107	Särna	61° 41′	13° 7′	442
MS	W	128	Trängslet	61° 23′	13° 44′	425
EP	W	11	Orsa, Högståsen	61° 5′	14° 58′	365
MS	W	117	Mora	61° 1′	14° 31′	168
EP	W	9	Gravendal	60° 4′	14° 32′	335
MS	W	009	Lejen	60° 12′	14° 24′	340
MS	W	013	Skattlösberg	60° 11′	14° 44′	332
EP	C	10	Älvkarleby	60° 32′	17° 28′	25
MS	X	012	Gävle	60° 40′	17° 8′	11

Symbols used in Table 1:

	Province		Province
BD (= Ö for MS_S) ——	Norrbotten	X ——	Gävleborg
AC (= Ä for MS_S) ——	Västerbotten	C ——	Uppsala
Z ——	Jämtland	φ ——	North latitude
Y ——	Västernorrland	λ ——	East longitude from Greenwich
W ——	Kopparberg	H_S ——	Altitude in metres

weather factors. In the first place it should be stressed that no special meteorological observations, connected with the PR experiments discussed in this paper, were carried out. It was intended to furnish each EP with some kind of automatic meteorological equipment, registering weather conditions. It was impossible to carry out these plans on account of technical hindrances. The only information obtainable on weather conditions was procured from SMHI.

It should be emphasized that the available meteorological data are insufficient for the purpose of elucidating the relation between the cause of damage and its manifestation. Most of the MSs are situated in populated places where local climate is different from that in the woodlands, and often lie at a considerable distance from the EPs. The author's choice of the MSs fell on those which might best characterize weather conditions on the EPs under discussion (Table 1, Fig. 8). To some EPs it was possible to apply weather records from two neighbouring stations. The comparison between the meteorological data obtained simultaneously from two MSs gave a more reliable account of the weather conditions in a certain territory.

It is well known that many site factors can considerably modify the general climate even in a limited area. The topographical situation of the site, the microtopography on the EP and the surrounding vegetation are of importance when considering the origin of the damage. Site factors exercise a considerable influence on the piling up of snow in winter and on the accumulation of the cold air during frost spells in the growth period. When interpreting certain types of cold damage, reference will be made to site conditions on individual EPs.

However, weather conditions in the vast region where extensive severe damage occurred have certain features in common. From the available meteorological data that are closely connected with the cause of cold damage, diurnal fluctuations of air temperature and the nature of the snow cover best of all characterize the general climate of the region.

Data on air temperatures are shown on diagrams in Figs. 10—24. Diurnal maximum and minimum temperatures express the daily fluctuations of temperature and also the variation of temperature during the seasons of the year. A diagram on the depth of snow cover supplements the diagram on temperature. Both diagrams are synchronized. Their values refer to the same date. The amount of precipitation as well as mean air temperatures are given for a single month and are shown on the diagram above the horizontal axis. These values are supplemented in some diagrams by average values for the period 1930—1961. Each diagram comprises a time interval beginning in July and ending in June in the following year. Thus a year makes a complete annual cycle of the biological processes connected with cold hardiness in plants.

The summer season is connected with the growth processes in plants, while the hardening processes set in during the autumn. The physiological processes which take place in plants during these seasons follow each other in a certain sequence. It is a well-known fact that the degree of cold hardiness which plants attain in the autumn is decisive for their resistance to cold and other unfavourable weather conditions in winter and early spring. Nevertheless, frost can injure plants as early as in the summer or early autumn, when they are susceptible to cold. Sudden drops in temperature and severe cold waves in late autumn, before the plants become winter hardened, may be the cause of severe damage.

The appearance of BSG in Scots pine in 1960/61 is closely connected with the fluctuations of temperature and with the thawing of the snow in late winter and early spring of that year. Unfortunately, the available meteorological data characterizing those seasons are incomplete and this renders it difficult to estimate the damage fully.

With the advance of the spring season the physiological activity in plants increases and simultaneously their resistance to cold diminishes. Weather conditions during this season are characterized by intermittent warm and cold periods. Particularly destructive are periods when early warm spells are followed by cold waves. The spring frost of 1963 discussed here serves as an individual example of how cold damage, a typical case of the dieback of the plant top, and formation of abnormal wood occur.

It is important to note that the maximum and minimum temperatures supplied by MSs and expressed here in diagrams are screen temperatures and refer to standard level, *i.e.*, 150—180 cm above the ground. It is well known that actual differences between extreme diurnal temperatures in ground air zone, *i.e.*, 0—50 cm above the ground, are greater than those taken at standard level. According to data mentioned in literature on the subject (Tichomirov, 1963, p. 65) the difference between temperatures on standard level and in ground air zones can attain 40° C in arctic regions. In England during the May frosts of 1935 the maximum difference between minimum temperatures at both levels attained 6.5° C (Day and Peace, 1946). During radiation frosts the temperature in the ground air zone is considerably lower than at standard level, but on sunny days it is higher. Inversion of air temperature at both levels occurs in connection with its extreme diurnal fluctuation.

Heat absorption on a sunny day and loss of heat during the night owing to outgoing radiation when the air is clear and still, are dependent on the topography and on the surface of the ground. In this particular case the ground is covered by snow during that season of the year when BSG occurs. The depth and the structure of the snow cover, the physical qualities of the surface of the snow, albedo and the capacity of heat conductivity, together with the fluctuations of the temperature of the air, constitute the intricate climatic environment and take part in calling forth cold damage in the stems of the trees at the nearest level above the ground.

Meteorological observations furnish us only with information about the depth of snow cover. The data on snow cover are shown in diagrams for each day. The dynamics of snow cover are revealed both in the increase of its depth owing to precipitation, and in the diminishing of the depth of the snow cover. Of these two processes the most important is the thawing of the snow cover and its packing up. These phenomena are connected with the variations of air temperature, particularly during those days when diurnal maximum and minimum temperatures are above 0° C. Attention should be paid to extreme fluctuations of diurnal temperatures during the thawing periods of the snow in early spring.

Behind this outward facade, *i.e.*, the fluctuations of temperature and the alterations in the snow depth, important changes take place in the structure of the snow cover. These changes are closely connected with weather conditions, when shorter or longer thaw periods are followed by cold waves. During normal weather conditions the snow cover, on the other hand, preserves its porous structure until spring and protects against cold those parts of the plant lying under it. No meteorological data are available on the structure of the snow cover, with the exception of some records made by reporters from SMHI observation stations.

Valuable information on the qualities of the snow cover is supplied by A. Hamberg (1907) and H. E. Hamberg (1912). A. Hamberg gives an analysis of the weather conditions during a period of four years in the Sarek mountain region (north of latitude 67°). In these altitudes winter cold is, as a rule, continuous, and periods of thaw occur rarely and in odd years. In the coniferous forest zone (altitude lower than 550 m) snow forms a layer of uniform depth and melts away in May. On the mountain plateau, *i.e.*, in snow dune zones (altitude 550—1,850 m) the wind transports the snow and forms complicated, compact snow drifts and also influences the thawing of the snow.

The studies of H. E. Hamberg in 1910/11 comprise northern Sweden, but refer chiefly to the province of Norrbotten. During years of intermittent thawing periods in winter and spring, when snow melts interruptedly, a snow crust and an ice crust are formed. Thus the structure of the snow cover becomes most intricate, since several strata of ice crust, with layers of compact snow between them, are formed. Even in late winter, in the month of March, the wind thickens the snow cover with new compact layers of snow. During some years ice crust is formed directly on the ground already in October, when the first snow has partly melted away. On the elevated places of the ground surface the mass of wet snow remains on the ground in patches and it is here that the ice crust is formed. In the depressions of the ground, on the other hand, after the periods of thaw, the remaining part of the snow cover is thicker and here the ice crust is formed over the snow cover. When snow melts, its structure changes. The intermediate layers of snow disappear gradually and the ice layers melt together. The water resulting from the melting of the snow filters through the snow cover and is amassed above the ice crust on the ground. As regards the structure of the snow, considerable variations have been observed even on small areas.

Judging from the scarce information obtainable in literature, the packing up of the snow cover and the formation of ice crust is a well-known phenomenon not only in Scandinavia, but also in vast regions of northern Europe. In the arctic regions of the Soviet Union the accumulation of thick snow layers in the depressions of the ground is connected with the delayed thawing of the snow in late spring and summer and with the transformation of snow into ice (TICHOMIROV, 1963, p. 73). The negative effect of ice crust on the vegetation in other climatic regions of the Soviet Union is mentioned by GALACHOV (1959, p. 174). A new perspective on ice crust as an ecological factor causing cold damage is opened up by TUMANOV's investigations into winter cereals (1940, 1951, p. 46). Much attention has been devoted to this question and the necessity of further investigations has been stressed. (Ref.: Resolution of Conference on Physiology of Plant Hardiness, Adopted March 7, 1959, in Leningrad. Fiziologija rastenij, 8: 5, p. 644.)

The connection between the cold damage of 1960/61, on the one hand, and the fluctuations of temperature and the thaw period of snow, on the other hand, is evident. When examining the position of the damage on the stems, it is easy to reconstruct the level of the snow cover during the time damage occurred. Frequencies of injuries are often correlated to insignificant variations of the ground surface. Depressions in the surface of the earth, areas on the lee side etc., favour accumulation of snow and delay its melting in spring. It is important to note that sites with thick snow cover are not always identical with the sites in the microtopography of the ground surface, where cold air is amassed during radiation frosts. On natural reproduction areas high frequencies of BSG can be registered not only in hollows, but also on N and NE slopes, where the melting of the thick snow layer is delayed. A striking example is the manifestation of BSG on flat areas along narrow belts of snow-sheltering fences by the roadsides (Fig. 25).

The geographical aspect of the manifestation of cold damage is shown in Fig. 8. Isolines showing the date when snow cover melted in the spring of

1961 also express the gradient of the frequencies of the BSG on EPs. The isoline of April 20 draws an approximate demarcation line for the region where severe cold damage had occurred. Outside this region, approximately to the south of 61° N latitude, damage occurred only sporadically. Insignificant damage also occurred north of latitude 61° N, in the transition zone, along the Gulf of Bothnia. This conclusion was arrived at owing to the data on CM rate in plants obtained from EPs. EPs 9 (Fig. 36), 10 (Fig. 37), as well as 14, (Fig. 38) are situated outside the region of cold damage. EPs 11 (Fig. 39), 17 (Fig. 40) and 18 (Fig. 41), located in the transition zone, belong to the region of cold damage, although frequencies of damage and death-rates in plants are not particularly high here.

The uplands of northern Sweden constitute the region where the manifestation of BSG predominates. Isolines in Fig. 8 show the connection of this phenomenon with the delayed melting of snow cover in the spring of 1961. EPs 22 (Fig. 42), 12 (Fig. 43), 13 (Fig. 44), 16 (Fig. 45), 20 (Fig. 47), 21 (Fig. 48), 24 (Fig. 50), 25 (Fig. 51) as well as EPs 26 and 29 (Figs. 52 and 53) and EP 27 (Fig. 54) are characteristic examples of the severe cold damage of 1960/61.

Nevertheless, it would not be out of place to point to some exceptions. On EPs in mountain districts damage and mortality rates were not high. This refers to EPs 15 (Fig. 56), 19 (Fig. 57) and 23 (Fig. 58). One is inclined to think that several causes might explain these divergencies. General climatic conditions in these districts are less liable to thawing periods in winter. The microclimatic conditions of the site provide better protection against wind and exclude the accumulation and compression of the snow.

In connection with the occurrence of cold damage under discussion, attention should be paid to solar radiation as one of the weather factors which exercise considerable influence in late winter and early spring, when the soil is covered by snow and the air temperature is low. As an example of this should be mentioned the months of April and parts of the months of May in 1961 and 1962 (Figs. 13 and 14) in northern regions. The differences between diurnal extreme temperatures in the diagrams give indirect evidence of the frequencies of sunny days.

Although strong solar radiation during this season appears almost every year, presumably it exercises a negative influence only during certain years. Owing to the direct absorption of the solar radiation the temperature in the different parts of the plant in the middle of the day can be higher, for instance, 5° C and more, than the temperature of the air (Odin, 1964; Tichomirov, 1963). When insolation ceases the temperature falls rapidly. The sudden changes of temperatures and their considerable amplitudes cannot but affect harmfully the sensitive parts of the plants.

In 1962 a high mortality rate of plants injured during the preceding year was registered. This phenomenon should be considered as the direct effect of the BSG of the year 1961, irrespective of the weather conditions of 1962. At least in part of the plants a deterioration of the old, unhealed wounds was noticeable at the same time. The development of large frost canker from small canker (Figs. 64—66) must to a great extent be explained by the weather conditions in the spring of 1962. The more extensive dieback of the upper part of the crown, where cold injury and mechanical damage had occurred in the previous year, should be explained in the same way. It is well known that parts of the plant which have previously suffered cold injury or mechanical damage are most susceptible to cold (DAY, 1934).

It is undeniable that in the case of dieback of the crown an important role was played by the disturbances in the moisture balance of the injured trees during late winter. A more intensive dehydration in the injured parts of the trees is a well-known phenomenon (LEVITT, 1956, 1958).

However, new manifestations of cold injury caused by solar radiation and fluctuations of temperature in the late winter of 1962 were insignificant. They were limited to the browning of the foliage in young trees on the S and SW sides. On some sites bud-killing and bark injury were observed. The manifestation of damage was connected with the microtopography of the site.

Late spring frosts in 1962, which caused considerable damage in southern regions, had little effect in the north of Sweden.

New manifestations of cold damage occurred in 1963. At the same time the dying-back of trees damaged in 1960/61 proceeded as an inevitable result subsequent to severe BSG. The types of damage of 1960/61 and those of 1963 might, at first glance, seem identical. However, the injuries of 1963 were a typical case of dieback of the leading shoots. Their cause and manifestation were so evident that they might serve as a demonstration object. They occurred at the end of May and in June as a result of a cold wave, which set in after an early warm period in the beginning of May (Figs. 18—21). Most frequent were slight injuries, killed leaders, often in combination with killed lateral branches. There were also cases where the whole tree was injured beyond recovery. In frost localities damage was recorded even in trees of a height of 5 metres. Formation of abnormal wood, *i.e.*, of frost rings, complemented the types of damage mentioned above and gave evidence as to the time of its commencement and its character.

The most intense damage had occurred in the NW part of northern Sweden. The isoline, showing $+3^{\circ}$ C deviation of main air temperature in May from the normal (Fig. 9), marks the approximate limit of the distribution of the damage within the region in SE direction. The actual temperatures in the be-

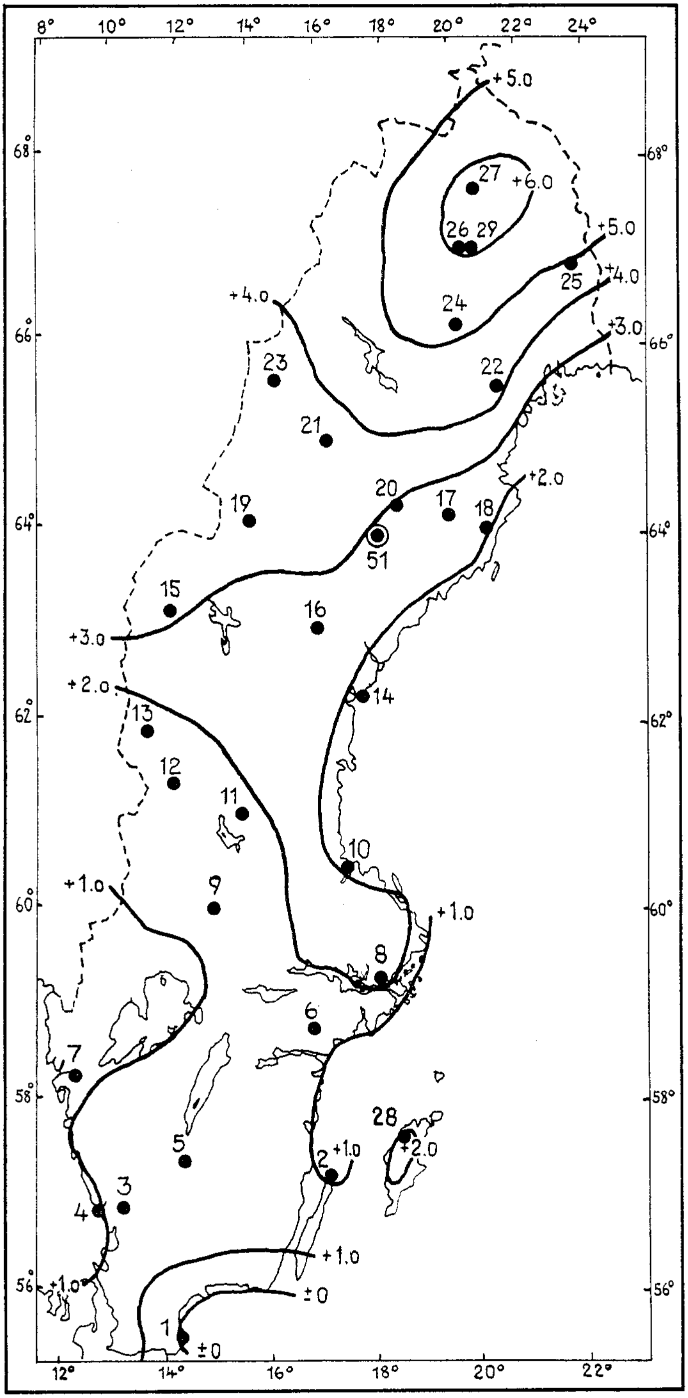


Fig. 9. EPs (No. 1—29 and No. 51) and isolines showing the deviation from the normal in monthly mean temperature, May 1963.

ginning of May were strikingly high (Figs. 18—21), which induced an early start of growth in trees.

Particular attention should be paid to a limited district in the province of Norrbotten, shown by +6° C isoline (Fig. 9). EP 27, situated in the district in which most frequent cases of frost injuries had occurred, serves as a representative example of this damage (Figs. 54 and 55, Table 18).

In the second half of July in 1964 new manifestations of cold damage, analogous to those of the preceding year, occurred. They were almost exclusively limited to frost localities and their frequencies were insignificant.

It is difficult to give a comprehensive answer to the question as to what extent the spring and summer frosts of 1963 and those of 1964 affected the trees damaged in 1960/61. In some of the trees, girdled and cankered in 1960/61, the healing of the wounds was so successful that after four growing seasons in the autumn of 1964 it was difficult to find outward signs of the damage. Simultaneously, in some of the damaged trees, frost canker developed further and the dying-back of the trees proceeded.

Concluding this report on cold damage in connection with weather conditions during 1960/61 and 1962—1964 it can be inferred that two principal types of damage are the most important. Firstly, BSG, which occurred in 1960/61 when trees on EPs were ten years old. High death-rates in trees and the extensive geographical distribution characterize this type of damage in Scots pine, which is rather unfamiliar. Secondly, the dieback of the top of the trees, that is, of the leading and lateral shoots, which occurred in 1961, 1963 and 1964. The age of plants on EPs was 10, 12 and 14 years respectively. The trees had already grown out of the dangerous air zone and death-rate in plants was insignificant, except on EP 27 (Fig. 55).

2.2. Weather in single years

For technical reasons, from all available meteorological data (Table 1) only 13 diagrams, elucidating weather conditions during single years from 1960 to 1963, and two diagrams from 1954/55, are used in this paper. They are chosen with the view of illustrating graphically weather factors connected with the occurrence of cold damage in single years. Naturally, a few diagrams do not embrace all possible variations of weather conditions prevailing at that time, but give only representative examples. Short elucidatory comments supplement the contents of the diagrams, showing weather conditions by means of curves month after month, in succession. Most attention is devoted to weather conditions during 1960/61.

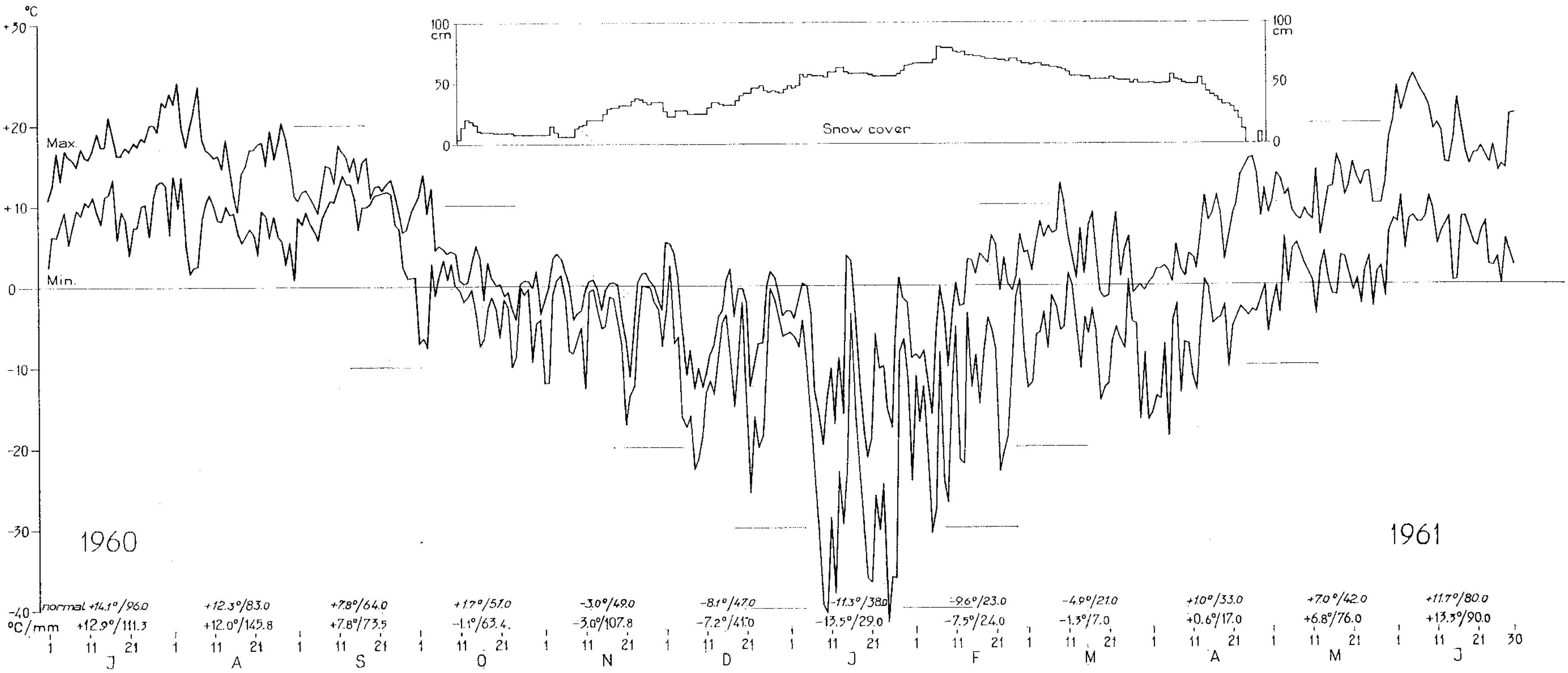


Fig. 10. Weather during 1960/61. MS W 107, Särna.

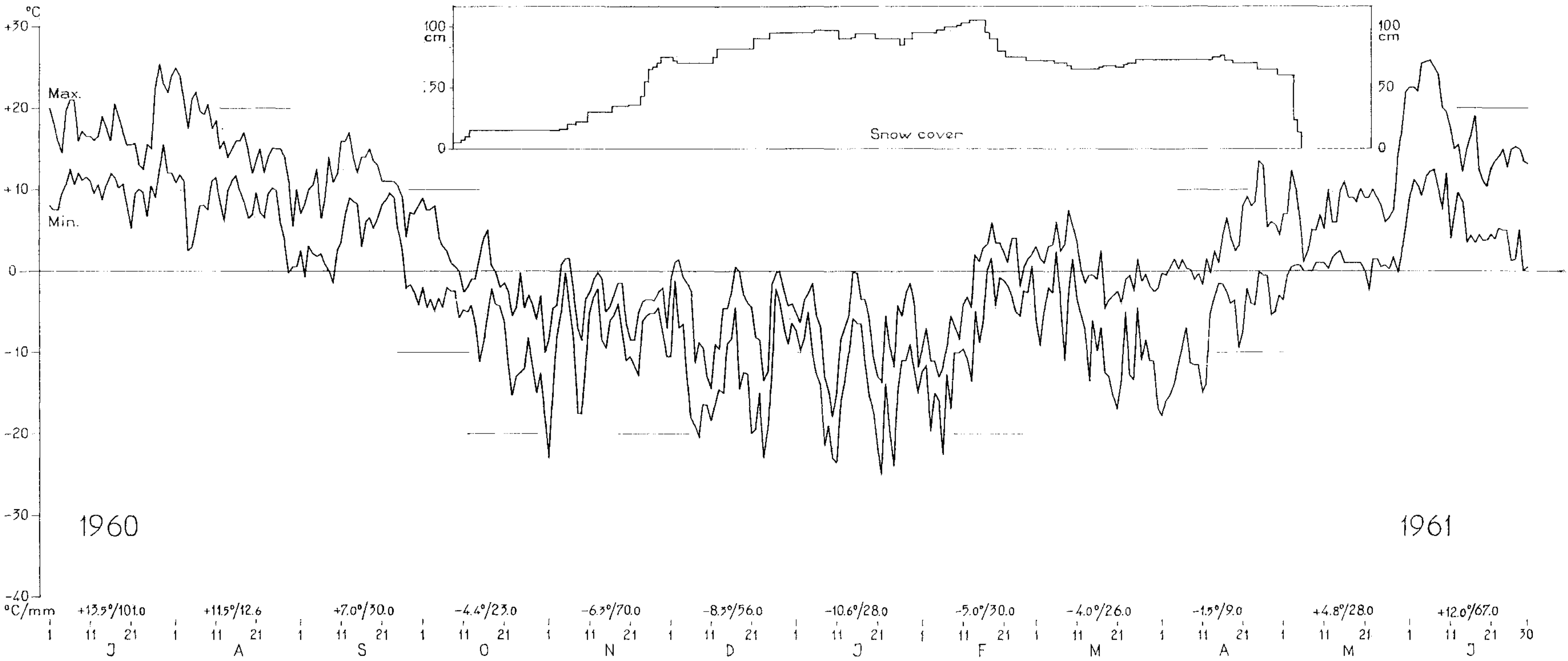


Fig. 11. Weather during 1960/61. MS Ä 435, Ulvoberg.

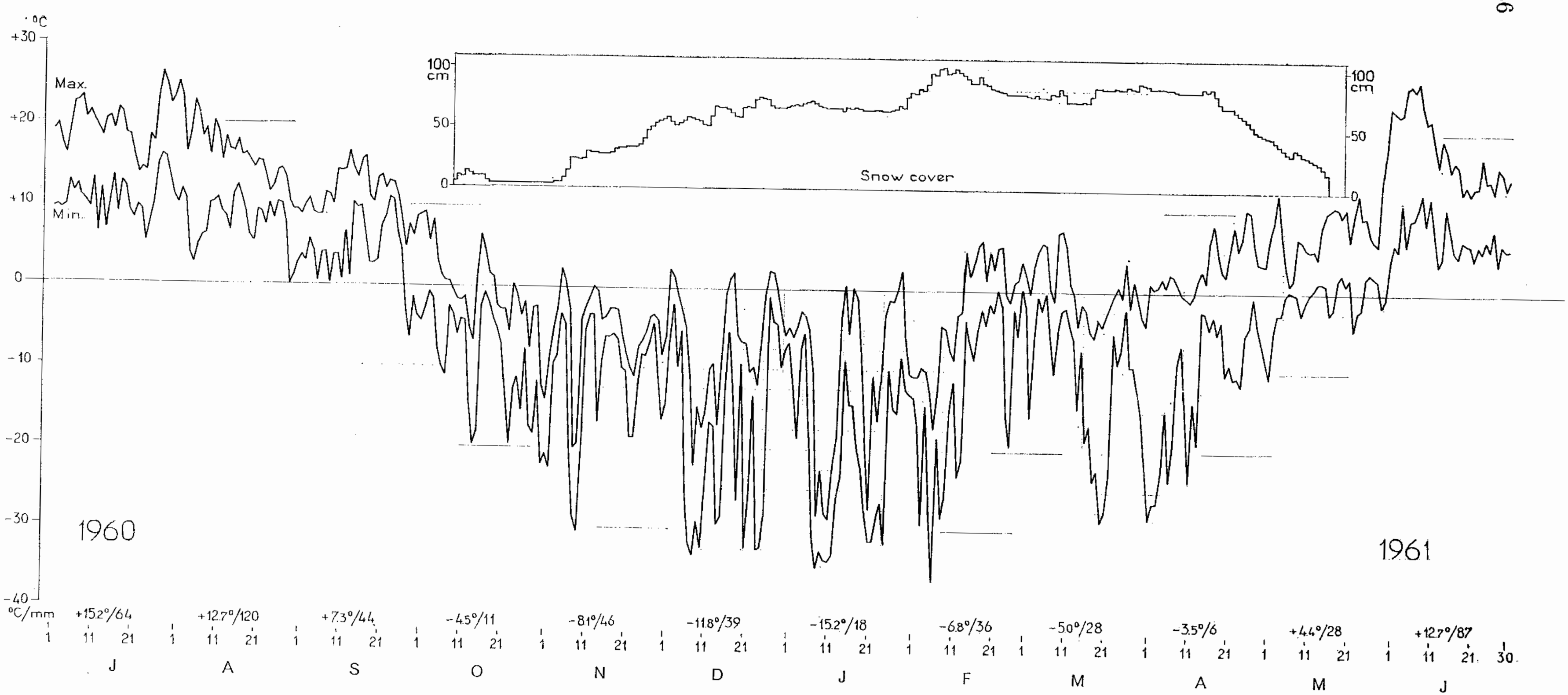


Fig. 12. Weather during 1960/61. MS Ö 524, Suddesjaur.

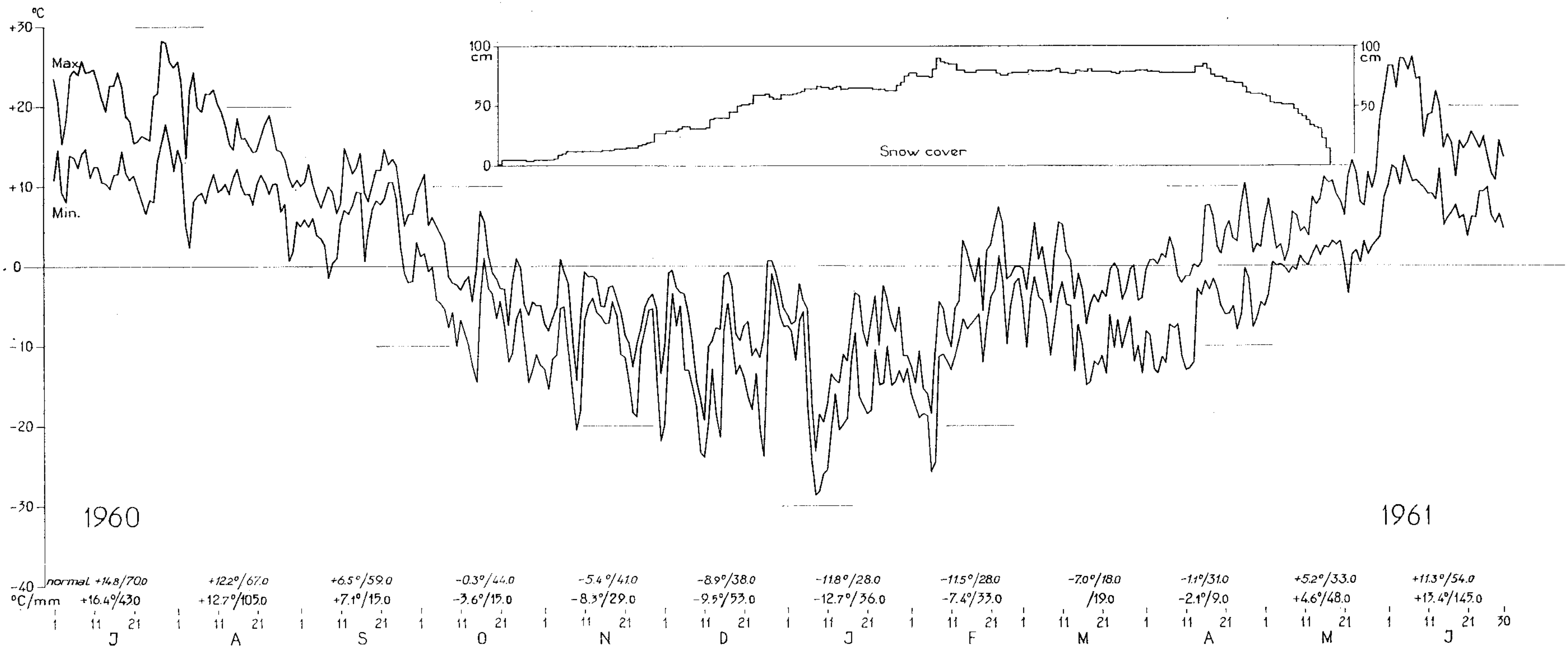


Fig. 13. Weather during 1960/61. MS Ö 726, Kompelusvara.

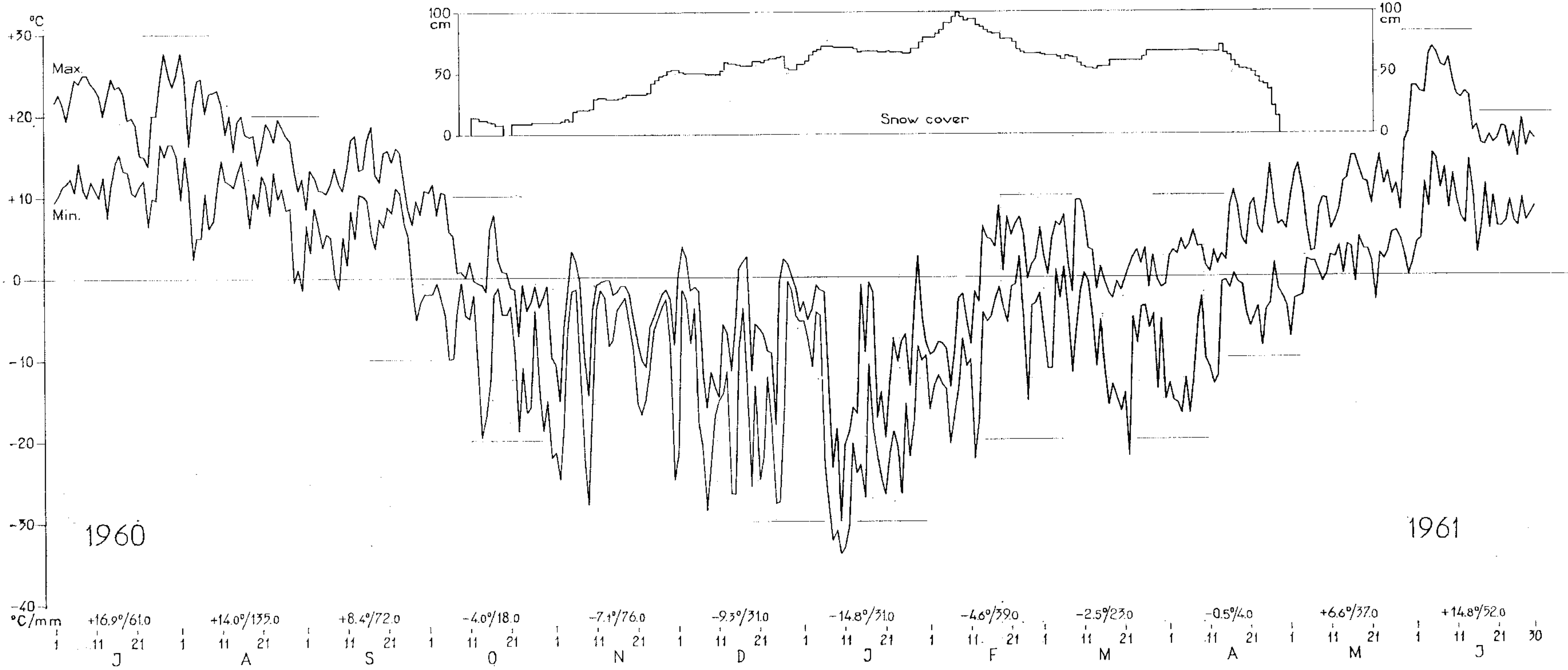


Fig. 14. Weather during 1960/61. MS Ö 575, Älvsby skogsskola.

Weather during 1960/61

Figs. 10—14. MSs: W 107, Ä 435, Ö 524, Ö 726, Ö 575, situated within the region of severe BSG

In the months of July and August air temperature was higher than normal. The thermal excess in Norrland was +2°—+3.5° C. Precipitation amounted to 150—160 % of the normal. ("Normal values of temperature and precipitation" are mean values for the period 1931—1960.) An exceptional position is held by a belt in the north of Norrbotten, on the site of EPs 25 and 27, where the summer was warm and sunny and precipitation normal.

September was somewhat warmer than normal, with a mean temperature from 1° to 2° higher than normal. Precipitation was approximately 70 % of the normal. The weather was cloudy, with insignificant differences in maximum and minimum temperatures from September 1st to 27th (Fig. 10); from September 11th to 27th (Fig. 13) and from September 21st to 27th (Figs. 11 and 12). This peculiar cool, "greenhouse" weather period was suddenly interrupted by a cold wave. In the NE part of the region the temperature dropped more gradually (Fig. 13).

In October the mean temperature was 2°—5° C lower than normal. Precipitation amounted to 60 % of the normal and in the NE part of the region to only 10 % of the normal.

In the southern part of the cold damage region the first snow, and rain mixed with snow, fell as early as the 5th of October. The formation of snow cover began on the 9th (Figs. 11 and 12), the 11th (Fig. 10) and the 21st of October respectively (Fig. 13). Snow fell in great quantities, but partly melted away between the 14th and the 18th of October (Figs. 10 and 12). When cold set in, the snow packed up by thaw and rain congealed and a possibility arose for the snow crust to be formed in different variations, often on ground which was not yet frozen.

In November cold and warm periods alternated intermittently. The mean temperature of this month did not differ considerably from the normal. The amount of precipitation in Norrland was 168 % of the normal. However, the amount of precipitation in the northern part of the province of Norrbotten reached only 46 % of the normal, but in the south of Norrland it rose at the same time to three times above the normal. The changes in the depth of the snow cover, caused by thaw, are shown in Figs. 10 and 11.

The mean temperature in December was normal, or somewhat higher than normal. Precipitation in Norrland was 128 % of the normal. It was reported that large quantities of snow impeded forest exploitation. The periods of thaw were similar to those in November.

In January an unusual spell of warm weather prevailed for a short time, beginning with January 15th, when the temperature rose suddenly and then fell abruptly (Fig. 10). During the thaw rain cleared the trees of snow (Reporter: Borgärdet, W). The temperature fluctuated considerably even in the second half of the month. The mean temperature in January was lower by 1°—2° C than normal. The depth of the snow cover increased at the beginning of the month. The snow cover was compact and granular (Reporter: Vinliden, AC). To all appearances the layers of ice crust had already been formed in November and December, and thaws in January, in their turn, made it more compact.

February began with cold spells, northerly winds and snowstorms, followed by a period rich in precipitation and hard south-westerly winds. About the middle of the month came a lengthy warm spell, interrupted in places by snowstorms and westerly and south-westerly winds. In clear weather considerable fluctuations in diurnal temperature were noticeable. In central Norrland the mean temperature of the month was 5°—6° C above the normal. Precipitation in the whole of Norrland was 116 % of the normal, at some places with a variation from 104 % to 139 %. In the beginning of the month the depth of the snow cover increased, but after snowstorms and during the thaw period the snow was packed up and covered with a glass-like hard ice crust (Reporters: Vinliden, AC; Duved, Z; Bölestrand, Z and other meteorological stations). During the thaw period sludge from the melting snow formed under the snow in a thick layer (Reporter: Kosa, Y). The rest of the snow cover consisted of frozen crusty snow under which the soil was not frozen (Reporter: Flatån, W). The meteorological accounts of the weather reporters supply valuable evidence, which compensates for the somewhat scarce data on the qualities of the snow.

In the beginning of March the unusual warm spell for this time of the year continued, with south-westerly and westerly winds. In the mountain regions frequent snowstorms with plenty of snow occurred. From the 12th of March a cold wave set in in northern Norrland, which expanded to the south. The cold wave, coming into contact with the moist air over southern Norrland, caused a snowfall on the 18th of March. The rest of the month was stormy, with low temperatures. Although a cold wave set in in the end of the month, the mean March temperature was higher by 2°—3.5° C than normal. The depth of the snow cover diminished in connection with the thaw. Snow was packed up, forming a hard ice crust. The accounts of several reporters give the same information with some variations. The ice crust in some places was so hard that a horse-drawn sledge loaded with lumber did not break it (Reporters: Vinliden, AC; Bredträsk, AC).

In April the cold wave continued with north-westerly winds. From the 14th to the 17th of April a cyclone from the west brought with it snow and was followed by a cold wave. Another dry and warm wave from the south resulted in a spell of warm weather. From April 23rd to 25th maximum recorded temperatures in southern Norrland were +19°—+22° C. Then came a cold wave from NE, moving to the south and causing a considerable fall in temperature. During the last 10—12 days of the month the temperature repeatedly fluctuated from +15° C to —10° C. On sunny days the fluctuations of diurnal temperatures were most conspicuous, and a rapid thawing of the snow cover was recorded.

The weather in May was mixed, with intermittent short spells of warm and cool weather. Rainy periods were followed by spells of dry, fine weather. The minimum recorded diurnal temperature was —3.5° C. In the north of Norrland snow cover melted away slowly and gradually (Reporter: Korpilombolo, BD).

In the beginning of June a spell of unusually warm and sunny weather was experienced. From the 10th to the 30th of the month the weather was unsettled. Light night frosts were recorded in Norrland. However, no new cases of cold damage were observed. The mean temperature in June in Norrland was 2.5° C above the average.

The diagrams discussed (Figs. 10—14) contain many common features as regards fluctuations of maximum and minimum temperatures and thaw

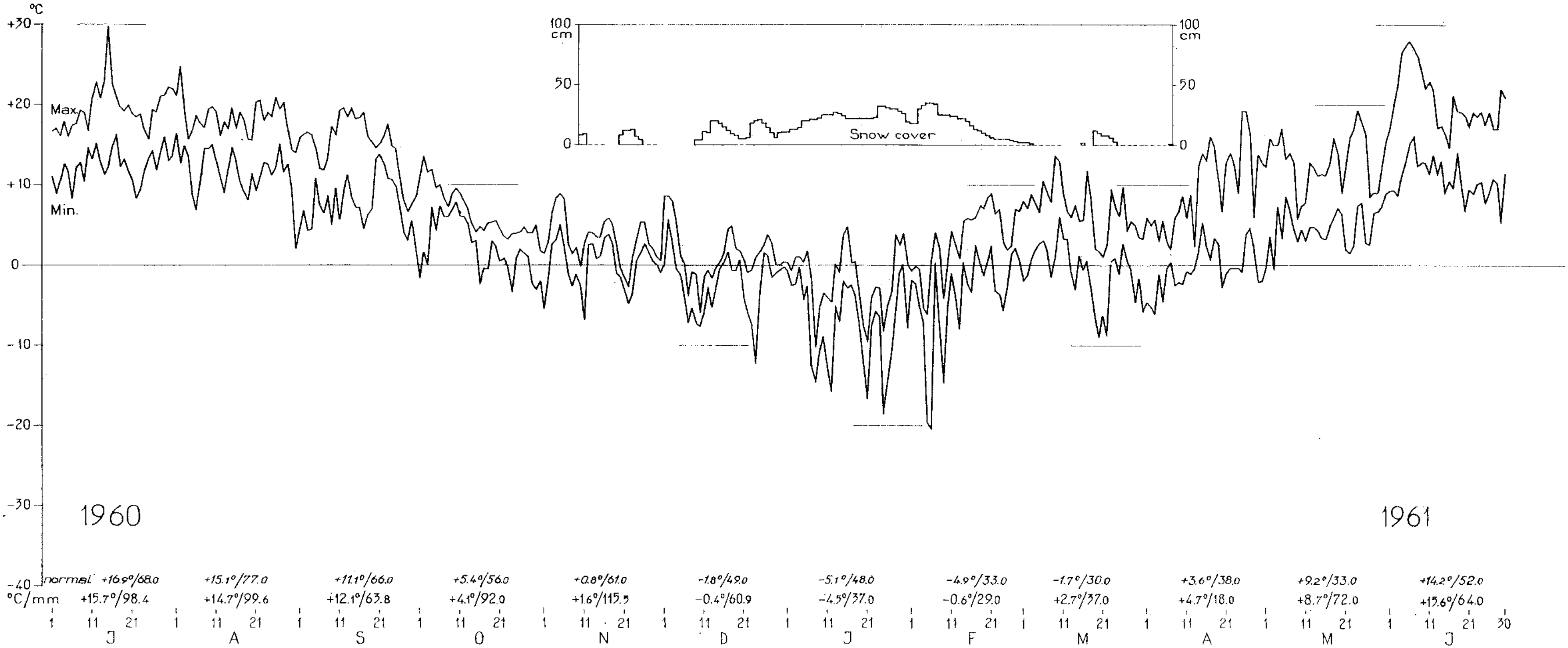


Fig. 15. Weather during 1960/61. MS X̄012, Gävle.

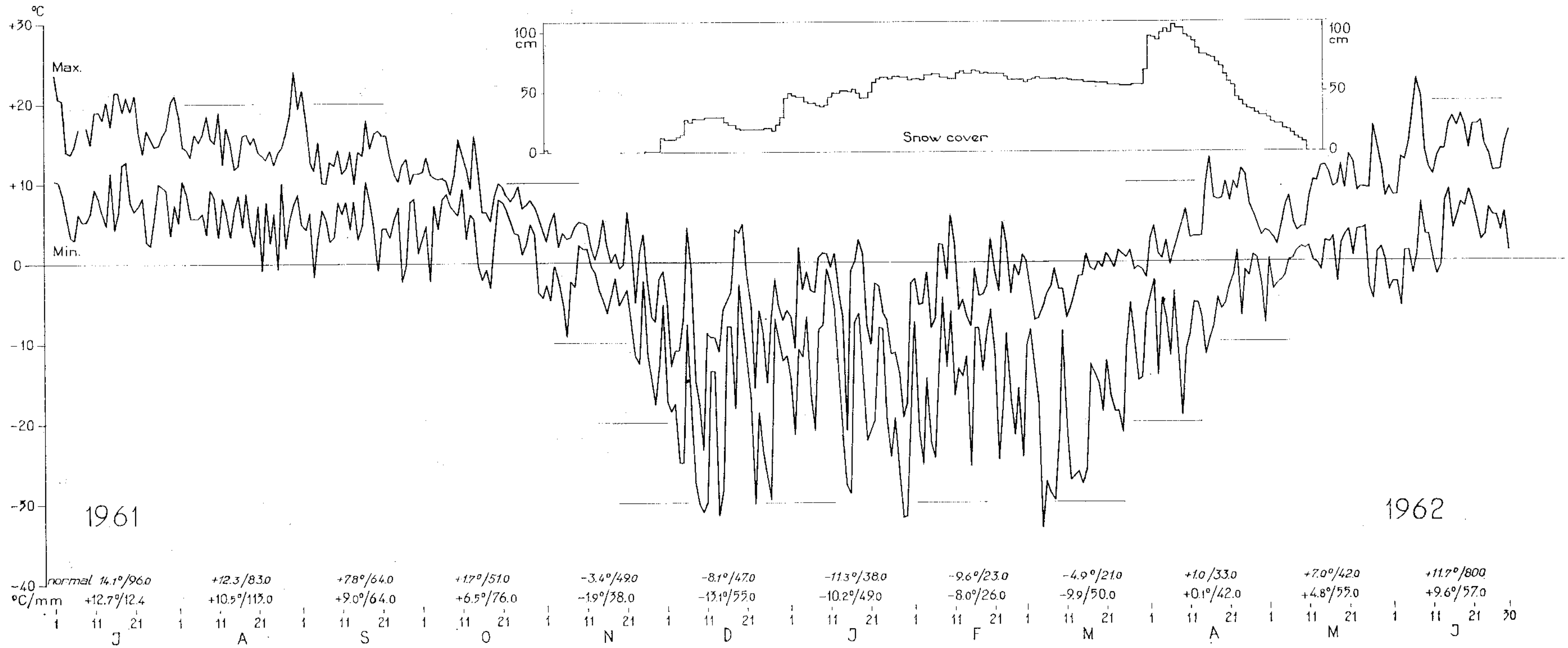


Fig. 16. Weather during 1961/62. MS W 107, Särna.

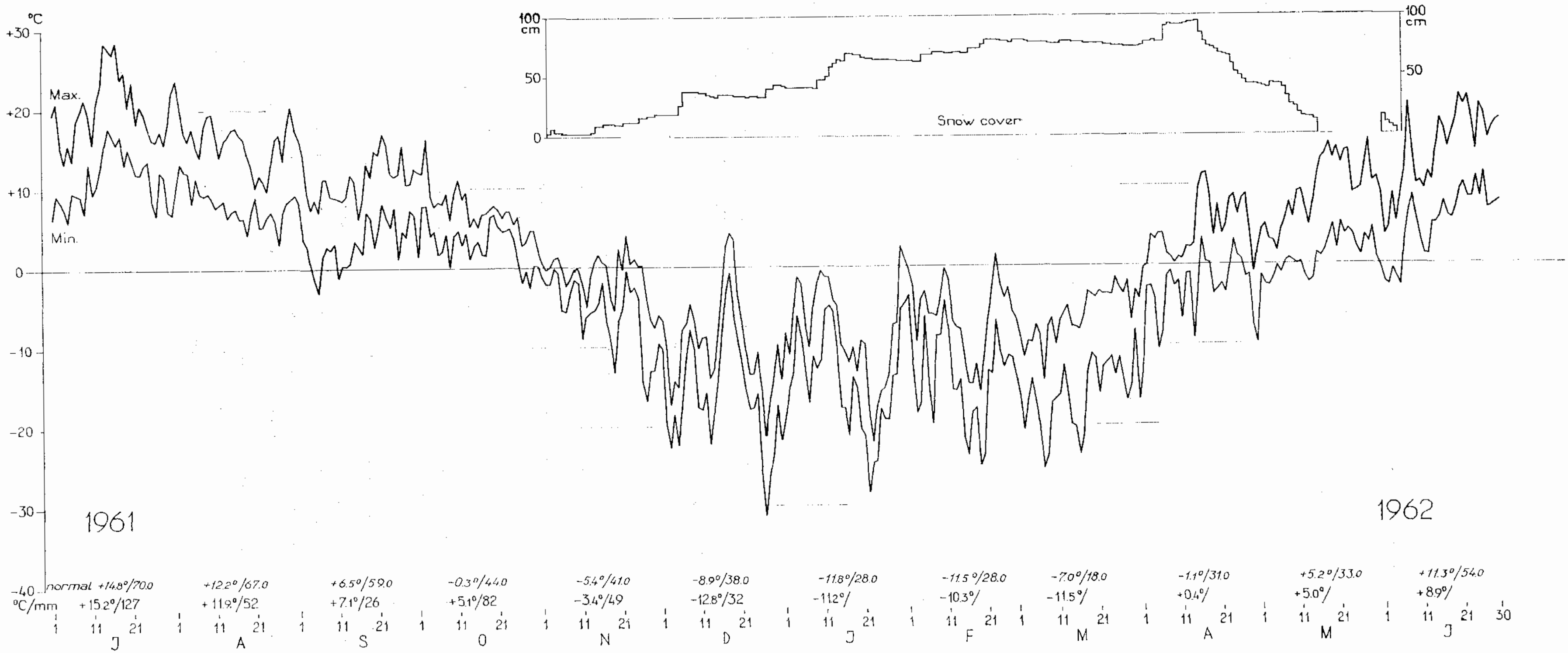


Fig. 17. Weather during 1961/62. MS Ö 726, Kompelusvara. (Data on the amount of monthly precipitation from January to June 1962, which are not shown in the diagram, are as follows: 40, 29, 2, 47, 57 and 41.)

periods, as well as regarding the changes of the depth of the snow cover. When summarizing the report on weather conditions during 1960/61, it should be definitely stressed that no new cases of cold damage occurred on the EPs after the snow had melted in the spring of 1961. From the 15th of May to the 20th of June that year mortality rates and injuries to plants were carefully examined. On some EPs the checking-up was made immediately after the snow had melted. Already at that time the fresh, open rents at the basal part of the stem and the high mortality rates in PRs susceptible to cold were striking. The characteristic traits of girdling and frost canker appeared only later in the autumn and the years to follow.

Fig. 15. MS X 012, situated outside the region of severe BSG

It is evident that the diagram on Fig. 15 differs from those on Figs. 10—14. The gradual fall of temperature in the autumn is conspicuous. The duration of snow cover was short, in fact not longer than three months. The depth of the snow cover was only half of that at other stations. However, the periods of thaw alternated even more frequently, but the minimum temperatures were not so low as on previous diagrams.

The few cases of the girdling of the main stem on EP 10 attract attention, since they appeared on two different levels above the ground surface. In some of the damaged trees the position of the girdle on the stem corresponded to the maximal depth of the snow cover. The damage probably occurred in connection with thaws in January and February (Fig. 15). On other trees the damage occurred on the ground level and probably in March. Damage of the latter kind was also observed in seedlings on natural reproduction areas in the vicinity of the EP 10 (Fig. 28). It should be mentioned that girdling of the main stem on a higher level above the ground surface is the only modification among this type of cold damage, which sporadically occurs in districts lying farther to the south of the region of severe cold damage of 1960/61.

Weather during 1961/62

Figs. 16 and 17. MSs: W 107 and Ö 726

It has already been mentioned that no new manifestations of severe cold damage were observed. The two diagrams (Figs. 16 and 17) are chosen to illustrate the differences in weather conditions between twelve months in 1961/62 and the preceding twelve months, when severe cold damage occurred (Figs. 10 and 13). MSs Särna, W and Kompelusvara, Ö (BD), whose weather records are made use of in the diagrams of the two corresponding years, are situated within the region of BSG of 1961 at its most remote points in a south to north direction. However, it should be stressed that the differences between the weather conditions during the two years under discussion were, according to the records supplied by other MSs, which geographically lie between the two stations mentioned above, similar to those shown in Figs. 16 and 17.

In the summer and autumn of 1961 (Figs. 16 and 17) the precipitation of rain was moderate. Temperature fell gradually until the winter season set in. This circumstance had a great and beneficial effect on the hardening processes which took place during this season. Snowfalls began as late as December (Fig.

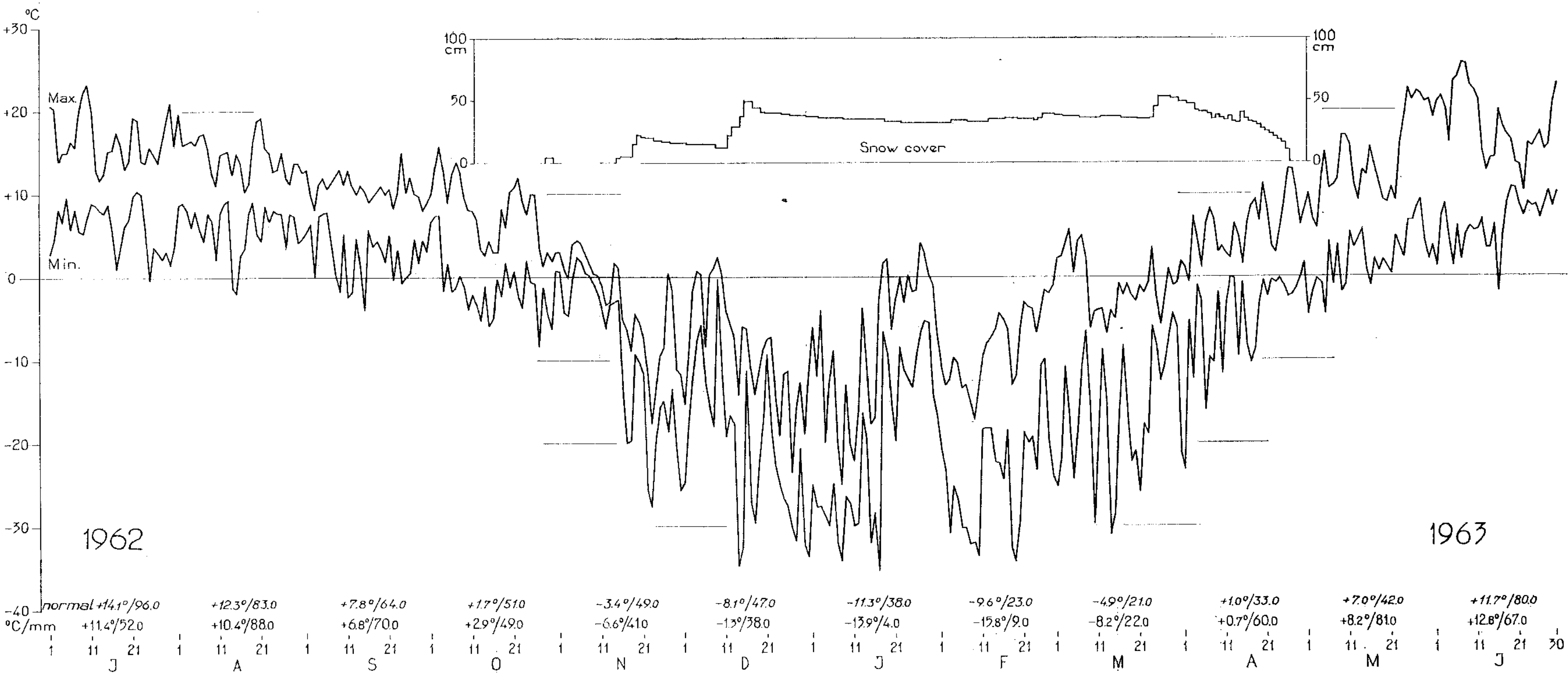


Fig. 18. Weather during 1962/63. MS W 107, Särna.

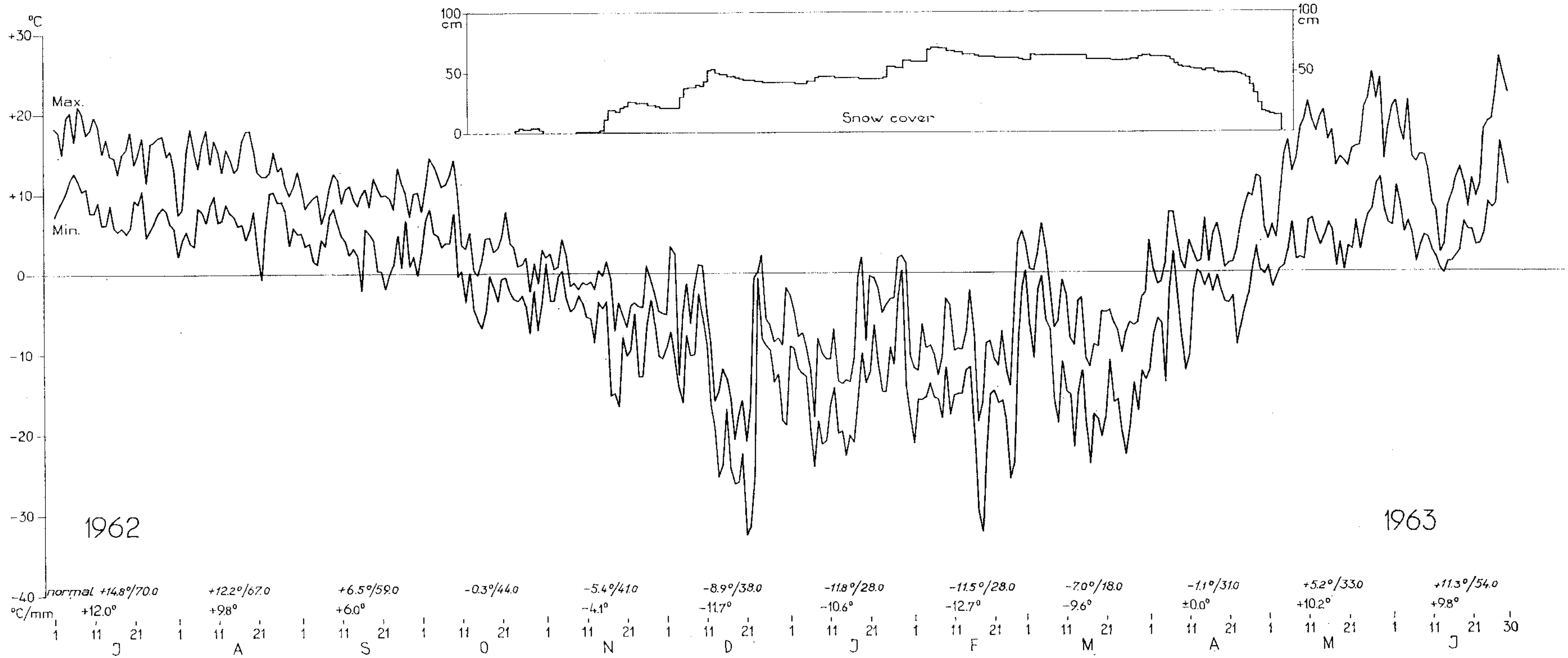


Fig. 19. Weather during 1962/63. MS Ö 726, Kompelusvara. (Data on the amount of monthly precipitation from July 1962 to June 1963, which are not shown in the diagram, are as follows: 64, 88, 76, 27, 40, 35, 20, 12, 8, 17, 36 and 80. Monthly mean temperature in October 1962 was +2.1°.)

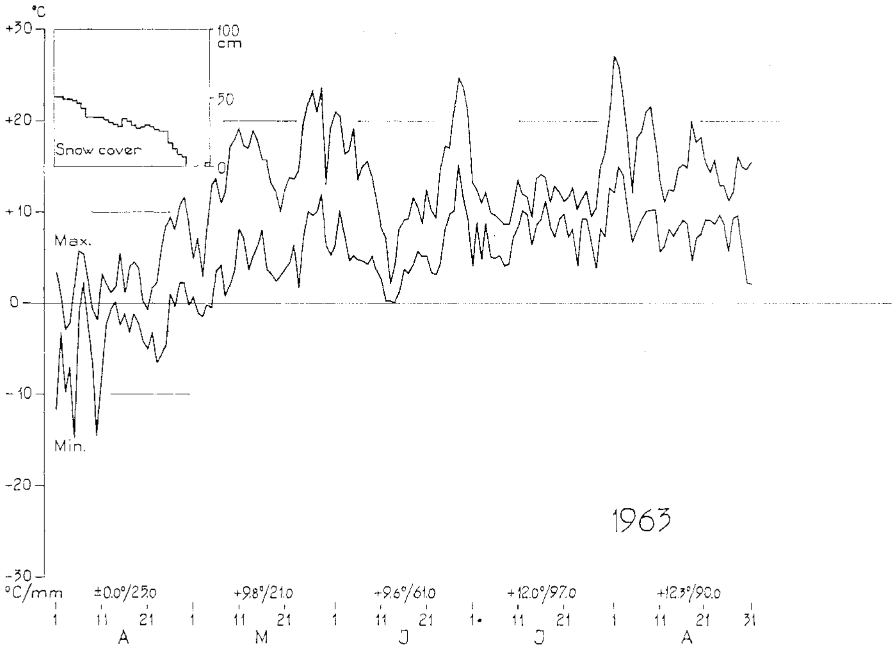


Fig. 20. Weather during spring and summer, 1963. MS Ö 722, Malmberget.

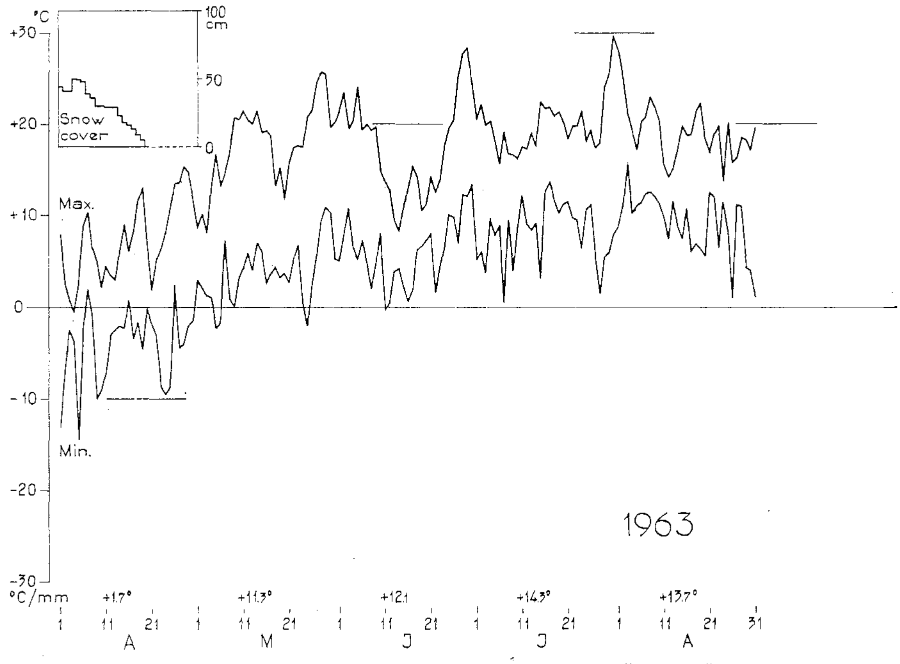


Fig. 21. Weather during spring and summer of 1963. MS Ö 575, Älvsby skogsskola. (Data on the amount of monthly precipitation from April to August 1963, which are not shown in the diagram, are as follows: 20, 26, 18, 48, and 93.)

16). There were no thawing periods during winter. Maximum temperatures above 0° C were recorded during a few days only. In their accounts reporters did not mention any formation of ice crust. Fluctuations of temperature began in April, when large quantities of fresh, loose snow fell. Thus, the composition of the snow cover was quite different from that of the preceding year. Solar radiation and slight cold injuries have already been mentioned in Chap. 2.1 of this paper.

Weather during 1962/63

Figs. 18—21. MSs: W 107, Ö 726, Ö 722 and Ö 575

Weather conditions in 1962/63 until May 1963 were almost similar to those in 1961/62. No new cases of the girdling of the main stem occurred, and according to the data furnished by the diagrams and to the accounts of the reporters, they could not be expected either, since the necessary prerequisites for their manifestation were lacking. However, in 1963 there were considerably more manifestations of cold damage caused by spring frosts than in other years. The causes of damage and its extent have been mentioned previously (Chap. 2.1, Fig. 9). The early spring of 1963 turned out to be exceptionally warm. The early wave of warm weather in May is shown on the diagrams in Figs. 18—21. In the region of cold damage in 1963 the mean temperature was considerably above the average and was the highest recorded for the past 100 years. It might seem that the minimum values of the temperature from the 11th to the 20th of June were not sufficiently low to cause cold injury to trees. Nevertheless, one might assume that the extreme values of temperatures below 0° C during frost periods on the EPs had been considerably lower than on the sites of the MSs, since some of the EPs are situated on frost localities. At the same time it should be mentioned that on EPs surrounded by forest stands, and thus protected against the wind, even the maximum values of temperatures during the warm wave were probably considerably higher than those recorded on the sites of the MSs.

Weather during 1959/60

Fig. 22. MS Ö 726

During this year neither severe girdling nor injuries of dieback of plant tips had been observed on the EPs. According to outside information, some BSG cases were observed on natural reproduction areas. The author, however, did not succeed in finding manifestations of cold damage which might have originated in 1959/60. Weather records shown on the diagram were obtained from Kompelusvara station, Ö 726, which is situated in the district where the above-mentioned possible cases of stem girdling might have occurred. However, the data on the diagram do not furnish convincing evidence in connection with the possibility of the manifestations of BSG in this year. On the other hand, the weather conditions in the early winter were such as might contribute to the formation of ice crust in connection with October and November thaws. The sudden fall of temperature in the middle of October, in its turn, was not favourable for the development of hardiness in plants. But no thaws occurred during the whole winter up to as late as the second half of March. In February and March of 1960 the author, during his stay in Norrland in the region under discussion, could observe that the snow cover in woodlands had reached a depth of 1.3 metres. The snow was unpacked and skiing was impeded by the loose composition of the snow. It is difficult to imagine that in connection with thawing in the second half of March, followed by a cold spell, the composition of the snow cover would have been similar to that of 1960/61. Another point of great importance is that the fluctuations of temperature during the period of thaw in April and May were very moderate.

Weather during 1954/55

Figs. 23 and 24. MSs: W 107 and Ö 524

It has already been mentioned that severe BSG occurred during this year. However, no attempts were made during that time to elucidate the geographical distribution of the damage. The diagrams (Figs. 23 and 24) illustrate weather conditions in the regions where such damage occurred. When comparing the two diagrams with the diagrams (Figs. 10 and 12) of the same MSs during 1960/61 several similarities might be established. Attention should be paid to thaws in October, November and December and to the fluctuations of the temperature in April during the period of thaw. During his stay in Norrland in October 1954 the author had the opportunity of observing the formation of the ground ice crust in some districts. The melting of the snow cover in the spring of 1955 was delayed, as was the case in 1961.

2.3. Extreme weather conditions causing severe cold damage in general

When summarizing the role of the weather factors in the manifestation of severe BSG, these factors should be approached from three different points:

1. Weather conditions during the hardening processes in plants before the occurrence of cold damage.
2. Weather conditions causing cold damage.
3. Weather conditions after the occurrence of cold damage and their influence, favourable or unfavourable, on the recovery of plants and healing of wounds.

With the view of concentrating attention on the most important part of the problem, the role of weather factors causing cold damage is approached in the first place.

The histological analysis of the BSG (Chap. 5.1.1) shows that its occurrence is connected with the death of cambium and phloem, or with the injuries in cortex elements. Damage round the stem occurs at different levels above the ground. The cause of this type of damage is the effect of low temperatures on living cells.

BSG occurs only when extreme weather conditions prevail. Moreover, to cause this type of damage the weather factors must exercise their influence on a limited area on the stem at a certain level above the ground. In some coni-

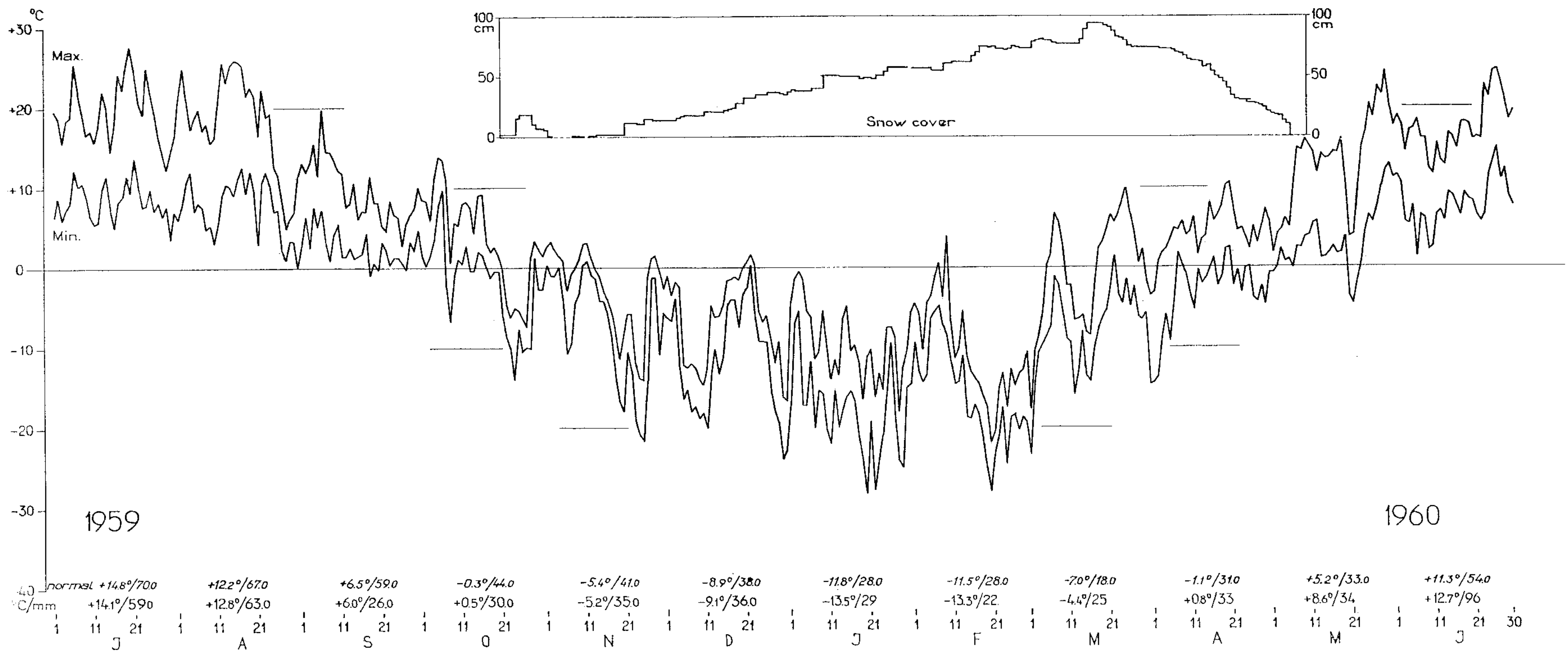


Fig. 22. Weather during 1959/60. MS Ö 726, Kompelusvara.

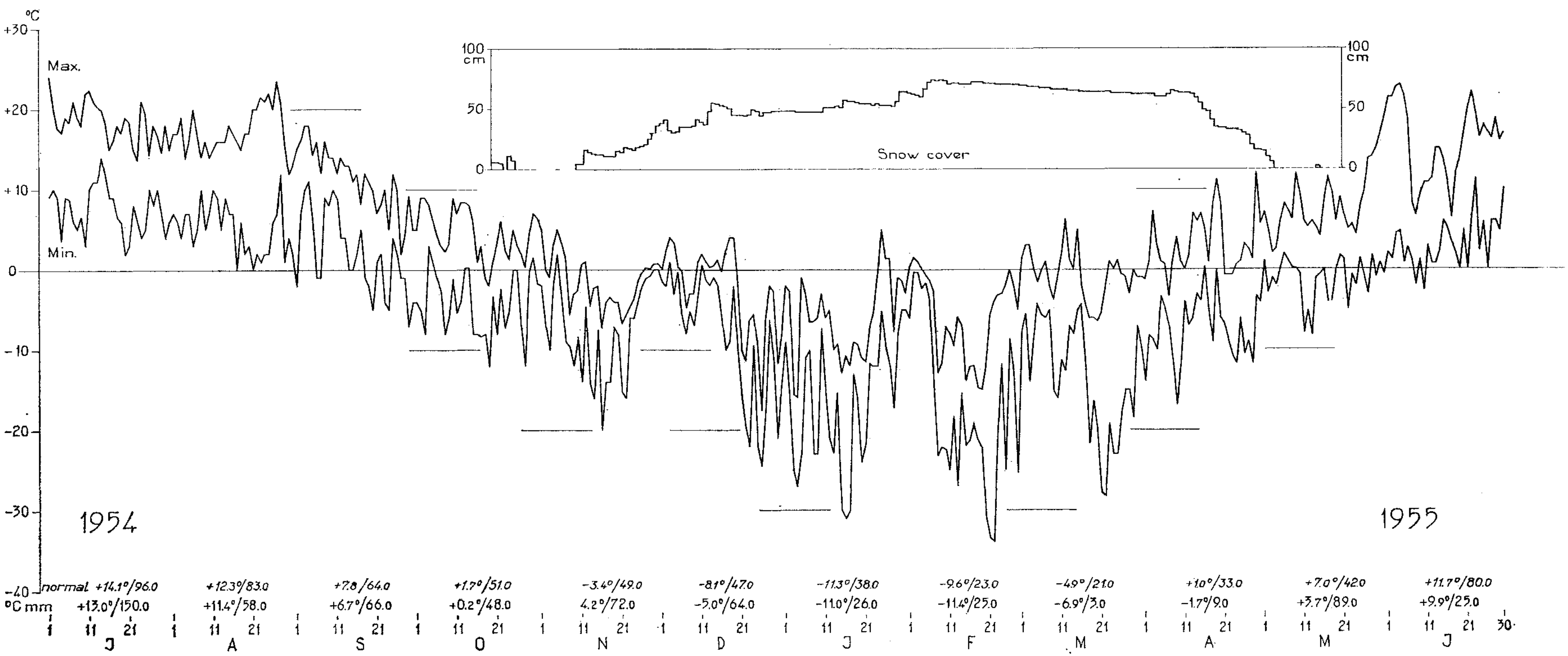


Fig. 23. Weather during 1954/55. MS W 107, Särna.

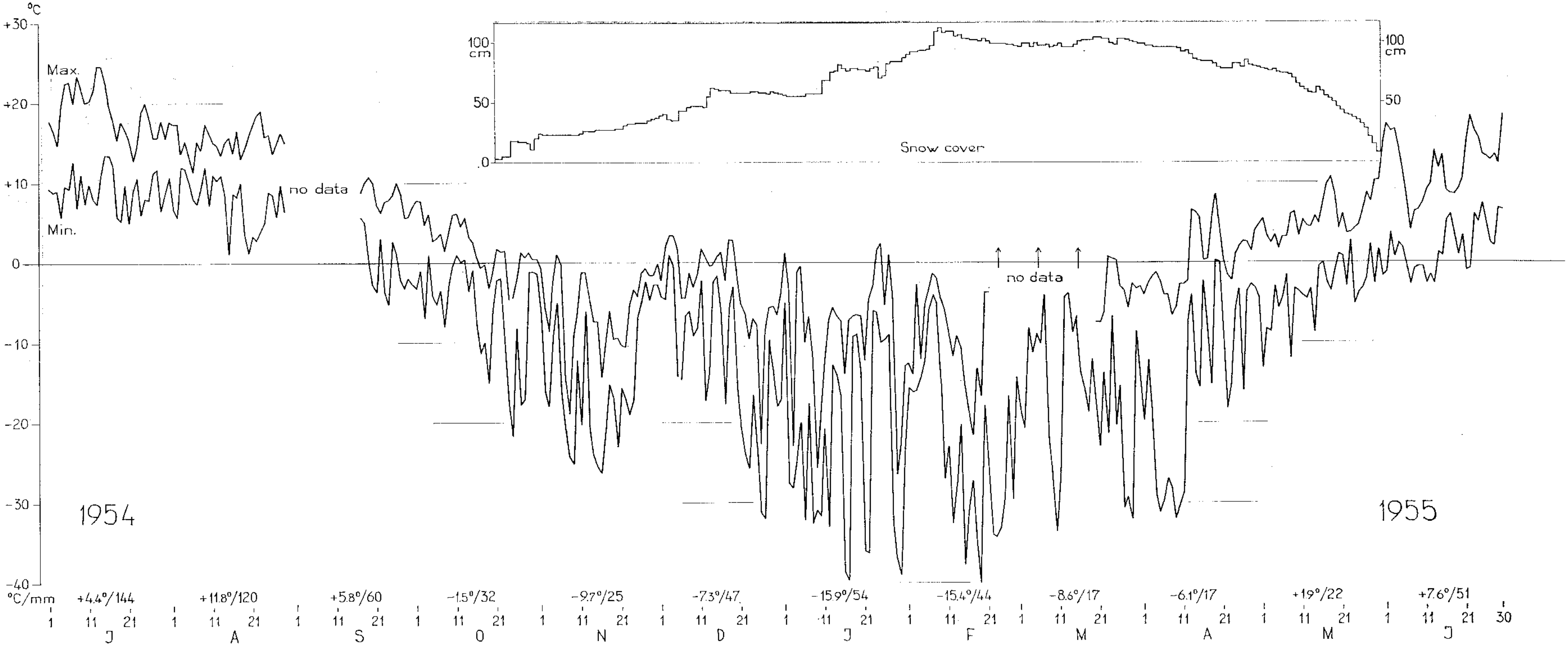


Fig. 24. Weather during 1954/55. MS Ö 524, Suddesjaur.

fers in England this type of damage occurred during spring frosts, after cambial activity had begun. Cold damage occurred most frequently on sites where the ground vegetation consisted of coarse grasses. The level of the damage on the stem above the ground coincided with the tip level of the grasses, that is, with that level in the ground air zone where extremely low temperatures were recorded during the frost period (the so-called grasses temperature) (DAY, 1928: DAY and PEACE, 1946).

BSG in Scots pine, the subject under discussion in this paper, occurs before the snow has melted and before the growth period sets in. Even in this case the decisive role in killing-off the living cells was played by the low temperatures. The effect of low temperatures is not single, but occurs repeatedly; in winter when periods of thaw and cold alternate, and in spring during the fluctuations of diurnal temperature when snow melts (Figs. 10—15, 21 and 22). Snow cover in the north of Sweden plays the same role as the canopy of grasses in England, that is, it determines the level of the BSG above the ground. However, the role played by the snow cover is much more important and intricate. Actually, it is packed snow which, during the period of thaw and with the infiltration of water from melted snow and subsequent freezing, is turned into a strata of ice and snow layers and, in extreme cases, into entire ice crust (H. E. HAMBERG, 1912).

During winters with normal temperature the snow cover remains unpacked up to as late as the end of April. Ice crust on snow appears only in late spring during fluctuations of diurnal temperature (A. HAMBERG, 1907). AGER (1964) in "*Studies on the Climate in North and Central Sweden*" gives mean values covering a ten-year period (1946/47—1955/56) on the qualities of the structure of the snow cover. The frequency of the type of snow cover, "Snow crest carrying a person", was below 10 % in March, and in April approximately 20 %. In some regions in Norrland such snow crust was formed as early as in December, January and February, but its frequencies were insignificant. It has to be remembered that the year 1954/55 with variable weather conditions and a striking manifestation of severe cold damage also belongs to the period mentioned above. However, mean values do not furnish any information on the question as to what extent the year 1954/55 differs from the other years during this period.

For those parts of the plant which lie under unpacked snow cover, the latter provides a good protection against low temperatures and their fluctuations. This kind of snow cover also protects trees against the action of wind. This protection is particularly decisive for vegetation in the north of Scandinavia at timberline (KIHLMAN, 1890). On the other hand, during those winters when snow is packed up and turns into an ice crust, it does not exercise any protective influence at all. Ice crust formed on the ground becomes most dangerous for the plants (TUMANOV, 1940, 1951, 1959; GALACHOV, 1959; TICHOMIROV, 1963).

Wind and thaw are principal agent factors which decide the character of snow (A. HAMBERG, 1907; H. E. HAMBERG, 1912). Most often one must reckon with the combined effect of these two factors upon the formation of the snow cover. However, during the years of severe cold damage the decisive role in the formation of packed snow is played by the thaw. The diminishing of the depth of the snow cover is functionally connected with the setting-in of thaw (Figs. 10—14, 23 and 24). Records of the MSs furnish us with information regarding the depth of snow and its dynamics. The accounts of the reporters give insight into the intricate and extreme forms of the changes in the characteristics of the snow cover.

The topography of the sites on which EPs are situated is varied. Some of the EPs were laid out on large clear-felled areas, which came into being recently in connection with modern logging methods. On these logged-off areas the wind can easily transport snow and pack it up. The variation of microtopography favours an uneven accumulation of snow with different characteristics, which make themselves felt during alternate periods of thaw and cold. We may assume that the formation of snow cover on logged-off areas takes place in circumstances which resemble those existing in the zone of snow dunes above the timberline, described by A. HAMBERG (1907). This is particularly true as regards EPs situated on high altitudes, that is, near the timberline.

In this connection it may be appropriate to emphasize that the EPs, which are situated on large logged-off areas, show a higher rate of plant mortality as a result of severe cold damage than other EPs. These are EPs 29 (Fig. 53), 26 (Fig. 52), 25 (Fig. 51), 24 (Fig. 50), 20 (Fig. 47), 16 (Fig. 45) and 12 (Fig. 43). However, EPs 12, 16, 20 and 25 differ from other EPs as regards their singular position in topography and the surrounding vegetation, consisting of thin stands, left intact after logging, which provide shelter against the wind, but at the same time favour the accumulation of considerable masses of snow.

It would be precipitate to draw the conclusion that snow is packed up exclusively by the wind and that the wind is the decisive factor in the production of severe cold damage. The manifestation of cold damage occurs in years with extreme climatic conditions. Of all available meteorological data, the fluctuations of the temperature and the periods of thaw in winter and spring mark the difference between the years when severe cold damage occurred and those with normal climatic conditions.

However, the problem of plant mortality on these EPs is most intricate. Attention should also be paid to other external factors which are different on

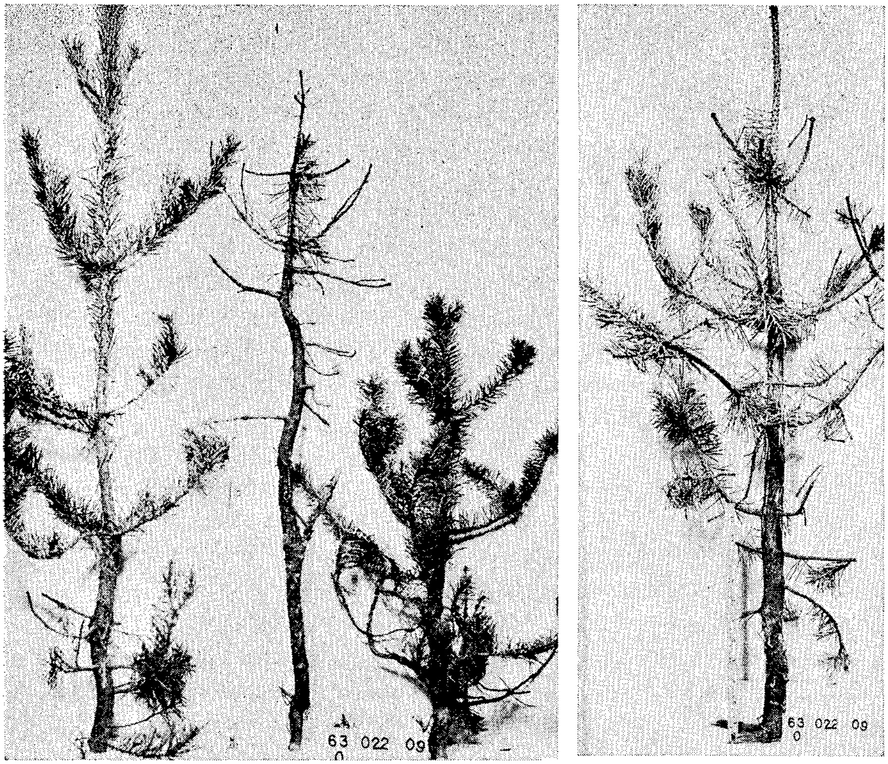


Fig. 25. Varying degrees of severity and varying length of the portion of BSG in trees along narrow belt of snow-shelteringfences by the roadside in the vicinity of Moskosel, in the province of Norrbotten.

each individual plantation. It should be remembered that site conditions which determine the accumulation of snow on EPs undergo certain changes in connection with the unequal density of plants on PR plots. PR plots with insignificant losses of plants, before the manifestation of severe cold damage, serve as shelters against snow in winter. The thick snow cover frequently piles up in the belt lying close to such plots, just as is the case in connection with snow-sheltering fences by the roadsides (Fig. 25).

It has been stressed in this paper that one of the weather factors exercising a decisive influence on the occurrence of severe cold damage is the length of time the snow cover and ice crust remain on the ground in spring. This refers to the manifestation of damage on EPs in connection with the variations in microtopography and uneven distribution of the snow, and this also refers to the geographical distribution of the cold damage (Chap. 2.1, Fig. 8).

Extreme weather conditions in 1960/61 were caused by cyclonic activity in the North Atlantic and in the north of Europe. In northern Sweden it brought about a variation of temperature and precipitation, which resulted in deviations from normal climate, particularly in winter and early spring, with alternating periods of thaw and cold. In summer and autumn, on the other hand, these differences were not equally represented in the region of severe cold damage. The sudden fall of temperature in October, which occurred in the southern (Fig. 10) and central part (Fig. 11) of the region was not so conspicuous in the northern part of the region (Figs. 12—14). It is true that in the different parts of the region differences existed in the intensity and modification of the cold damage. However, it would be hasty to assert that, on the basis of the differences of temperature in the autumn in the individual parts of the region, different hardening processes are alone responsible for the modifications in the types of the damage.

Weather conditions in 1960/61 (Figs. 10 and 12) and those in 1954/55 (Figs. 23 and 24) have some common characteristics, which were the cause of the occurrence of BSG in those years. The scope of the damage and its distribution were not gone into in 1955. In addition, information on the characteristics of the snow cover in 1954/55 is scarce.

When estimating the significance of extreme weather conditions as regards the occurrence of severe cold damage, available meteorological data, the accounts of the reporters, and literature dealing with allied problems were used. Nevertheless, these data provide only a small foothold for considerations regarding the kind of weather conditions when damage occurred. The weather diagrams which contain data on diurnal fluctuations of temperature and on the depth of the snow cover give indications, firstly, regarding the changes which might take place in the snow cover, and secondly, of the time of the possible occurrence of the cold damage. On the other hand, the accounts of the weather reporters give indications regarding the changes in the snow cover, and they also supply evidence regarding the extreme weather conditions requisite for the occurrence of cold damage. The analysis of the types of the damage and its modifications supply, in their turn, direct evidence on the relation existing between the cold damage and the weather factors.

3. Injury to plants and damage patterns

Of all the various kinds of damage occurring in plants in field experiments, only those injuries which manifested themselves on a large scale during 1960—1964, and which were caused by cold as a damaging factor, are discussed in this paper. At the same time injuries whose manifestation is connected with other hibernal climatic factors and which have a certain connection with cold are also touched upon here. Reservation should be made here as regards the manifold secondary phenomena, *e.g.*, the activity of fungi and insects, which usually follow the cold damage. Injuries caused by fungi and insects claim a special penetration into the question.

3.1. Damage patterns

Cold damage occurring in the above-ground part of the plants falls into two conspicuous groups of damage, namely, injury at the main stem and dieback of the plant top. The first group consists mainly of BSG injuries. Thus, such grouping of cold damage provides the possibility of analysing separately the two parts of the plant above ground which are most susceptible to cold damage. However, it should be added that in the following chapters cases of severe cold damage will be discussed where both types of damage merge, the result being the immediate death of the tree.

3.1.1. Injury of the main stem

Various modifications of this kind of damage appeared in 1960/61. It should be emphasized that the plants, that is, young trees, had at that time reached the age of ten years. In most of the trees thick bark had already been formed at those places where damage occurred, and the maximum diameter of injured trees was 6 cm at the base of the stem.

3.1.1.1. Basal stem girdle and frost canker

To most plant breeders the manifestation of this type of damage in Scots pine on such a large scale as occurred in 1960/61 is hardly known and often inconceivable. One of the most conspicuous manifestations of this type of damage is the constriction in the lower part of the damaged tree (Fig. 1). However, this indication, which originates in connection with the death of the cambium at the damaged place, appears earliest in the following growth

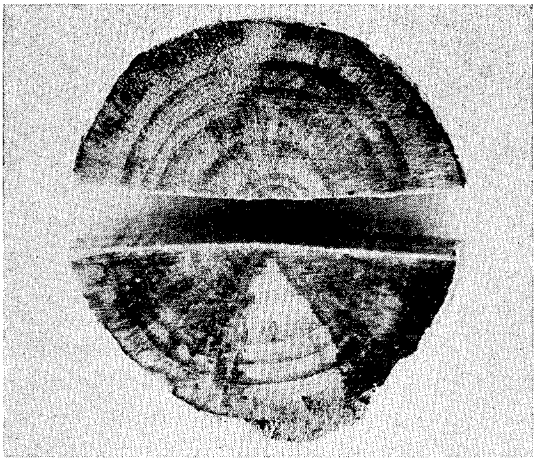
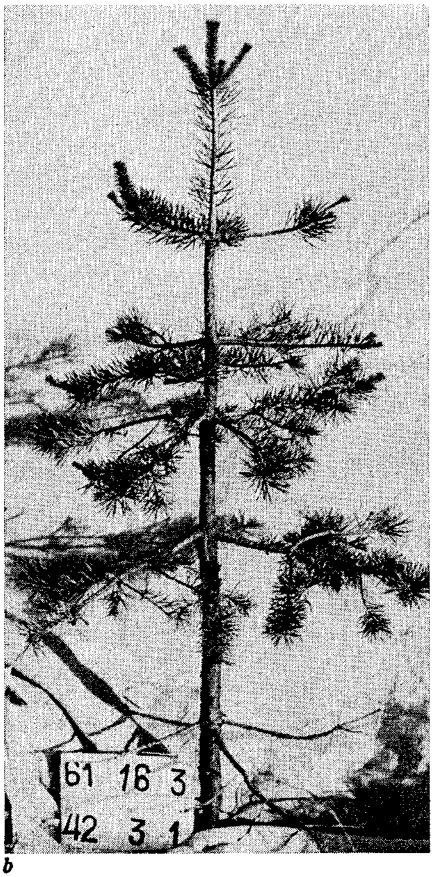


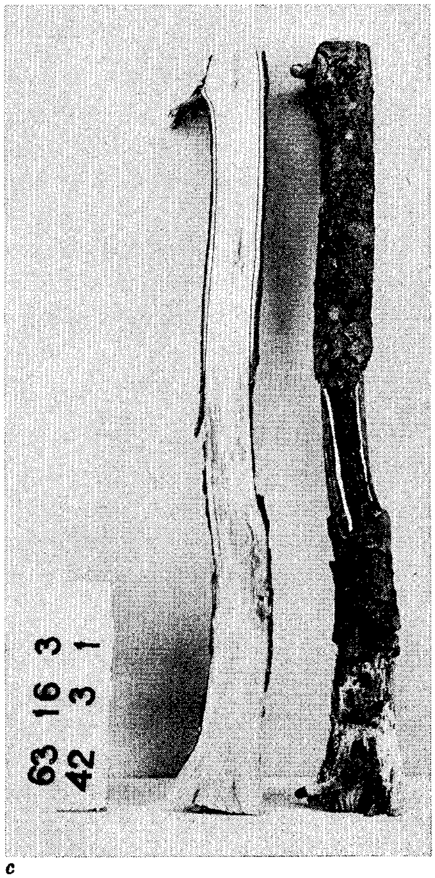
Fig. 26. BSG of 1960/61 encircles the stem leaving only a narrow string of cambium unimpaired (*a* and *c*).
a, transverse section at the centre of the frost canker showing a sector of unimpaired xylem with the thin annual ring of 1961.
b, swelling of the stem above the girdle; a short leader and short lateral shoots developed during the growing season of 1961.
c, longitudinal section of the portion affected by BSG. The damaged tree (EP 16, PR 42) died in the early spring of 1962.

a

The photographs were taken: *b* in September 1961; *a* and *c* in October 1963.



b

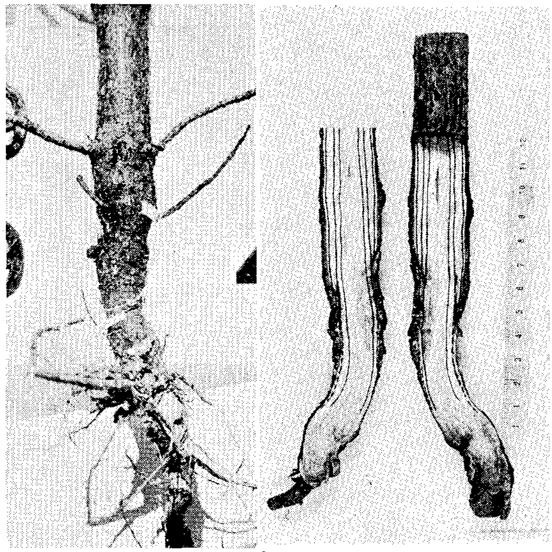


c

period, after the occurrence of the damage. No external signs of injury could be noticed in these trees in May, immediately after the melting of the snow. At the same time there were on the EPs damaged trees with other modifications of injury, with other external signs of damage. In August and September some callusing and characteristic swelling had appeared above the girdle (Fig. 26). The bark of the stem at the damaged section was ruptured owing to the development of the callus. The other external sign of the damaged trees was that the leading and lateral shoots of the recent year were shorter than the normal ones. These indications were so reliable that damaged trees could be easily discerned on the plantation area even in those cases when the girdled section was not easily noticeable. The length of the shoots varied from a few cm up to normal, and from the length of the shoot it was possible to estimate the degree of the injury. On the other hand, the yellowing or reddening of the needles and the debility of the crown manifested themd selves only in the severely injured trees (Fig. 4). In some of the injure-trees the green colour of the needles was even darker than in the undamaged trees.

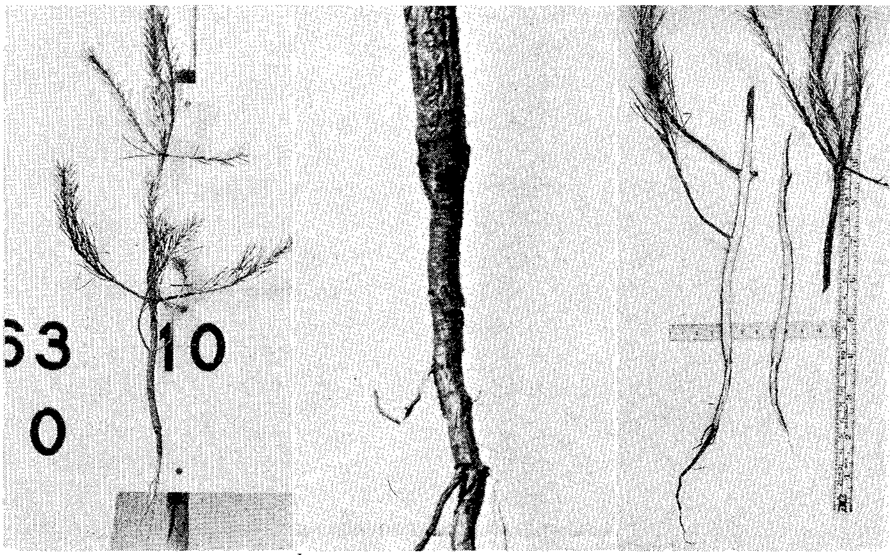
The injury of the stem was located at different levels above the ground. Most of the girdles had occurred almost on ground level (Fig. 1). However, on some occasions girdling had taken place at a height of 40—50 cm above the ground, and in exceptional cases at a level of 60 cm. Fig. 2 shows a case where a peculiar shape had been formed with a thin stem below the girdle and an unproportionally thick stem above it. That the tree had been able to grow further and that its root system could function during three growing seasons after the damage had occurred, might be explained by the fact that a few small living branches with foliage capable of assimilation had survived below the girdle. On those occasions where the damaged tree had some vigorous green branches left below the girdle, the difference between the thickness of the tree below and that above the constricted section was less conspicuous, and in some cases no difference could be noticed at all. In some cases the only difference which could be noticed was the constriction of the injured section.

Special attention should be devoted to those cases where the girdle had occurred immediately below the surface of the ground (Fig. 27). Damage had occurred in that section of the stem whose level corresponded to the hypocotyl and epicotyl of the ontogeny during the first year. In field experiments, when planting out, this section of the transplant not infrequently happens to come under the surface of the ground. It should be emphasized that on these occasions the root system, as well as the stem of the tree and its crown, are unimpaired. Even if such damage does not occur too often, it deserves attention and should not be confounded with other types of injury.



a b

Fig. 27. BSG of 1960/61 located immediately below the surface of the ground.
a, damaged portion of the stem,
b, longitudinal section of the damaged portion and of the root affected by black spots.
The photographs were taken in July 1962 when the damaged tree (EP 19, PR 42) was dying.



a b c

Fig. 28. BSG of 1960/61 located exactly at the ground surface level in a naturally regenerated plant in the vicinity of EP 10.
a, a five-year old damaged plant;
b, the portion of BSG with characteristic swelling above the girdle;
c, longitudinal section.
The damaged plant died in the autumn of 1962. The photographs were taken in May 1963.

On EPs BSG was discovered in trees of different diameter and height. Injured trees in each PR were to be found in all dimensions, with the exception of the thickest individuals. On natural reproduction areas in the vicinity of EPs injuries were recorded even in seedlings a few years old (Fig. 28). On the whole it might be said that damage occurred in plants at all ages, at the seedling stage and also in trees which had attained the age of 15 and even 20 years, and which sometimes reached a height of 3.5 metres and a diameter of 6 cm.

The death of the cambium, which caused girdling at the stem base, did not always occur uniformly round the whole stem. Often the cambium was killed at several separate patches in the girdle. The callus overgrowth at the edge of the wound and the development of frost canker began soon after the injury had occurred (Fig. 3). On those occasions when cambium was killed only at small separate patches the wound soon healed, and the injury remained unnoticed (Fig. 63). The great majority of damaged trees were only partially girdled, *i.e.*, only one side of the tree was injured (Fig. 64). In some cases only a narrow string of cambium in the girdle, uniting the lower and the upper part of the tree, remained unimpaired (Fig. 26). Nevertheless, such "navel string" helped the injured tree to survive one or two years longer.

The death of cambium was followed by the dieback of the living cells in the cambium rays as well as by the dieback of the epithelium cells in resin ducts. The subsequent infiltration of resin coloured the injured parts, and those lying close to them, brown or dark-brown. Another matter worth mentioning is that the colour of the whole xylem sector turned dark brown in the section of the stem where the death of cambium had occurred (Fig. 63). Cambium injuries and frost canker were often accompanied by a conspicuous frost ring, lying in the limit zone of the annual rings of 1960 and 1961.

Another point of importance is that the manifestation of damage was most variable, and only some of the cases were so definitely expressed as in Figs. 1, 2 and 26. The majority of injuries were different combinations of this kind of damage with other modifications described on the following pages. Often no swelling appeared above the girdle of the damaged trees, and the location of the injury as well as its character could be revealed only by cutting off the bark and determining the death of the cambium.

Owing to the death of the cambium and the callus overgrowth on damaged sections, the shape of the stem often changed its form in both the vertical and in the horizontal directions; for instance, the flattening and the crooking of the stem were often secondary consequences of the damage.

Girdling at the stem base is well known as one of the different kinds of cold damage in forest trees. The oldest references to this phenomenon are to be found in literature as early as 1883 in Germany, and deal with seedlings

a *b*

Fig. 29. BSG with resin flow and rents in the bark.
a, small rents filled with resin (EP 12, PR 40);
b, the damaged section is uniformly crusted over by resin flow (EP 25, PR 19).
The damaged trees died in the autumn of 1961 (b) and 1962 (a). Photographs were taken in July 1962.

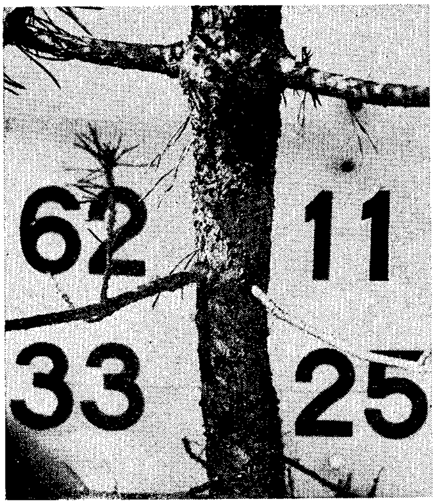


Fig. 30. BSG and *Dasyscypha fuscosanguinea* canker. Yellow apothecium cupules cover the portion of BSG (EP 11, PR 33). The damaged tree died in the autumn of 1962.
The photograph was take in July 1962.

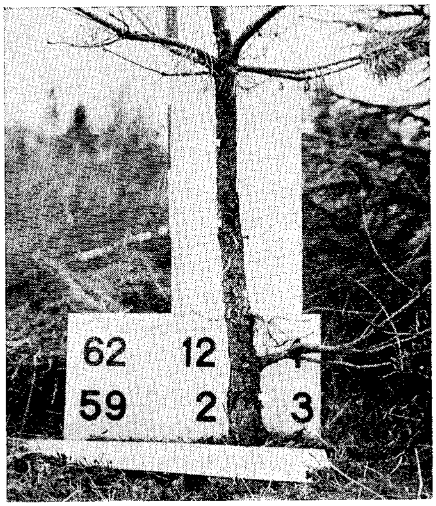


Fig. 31. Girdles of 1960/61 located at several levels. BSG and the dieback of the top merge in this tree. The damaged tree died in the early spring of 1961.
The photograph was taken in July 1962.

and transplants of Norway spruce and European silver fir (R. Hartig, 1883). Adetailed analysis of this type of cold damage in Douglas fir, Sitka spruce and other conifers was made by Day (1928 a, b; 1931), by Day and Peace (1937, 1946) in England, and by Boyce (1938, 1961) in U.S.A.

In Scots pine this type of cold damage was considered very rare, owing to a remarkable cold resistance characteristic for this species. In this paper the author wishes to provide evidence proving that BSG was the predominant type of injury in Scots pine in 1960/61. This type of damage in the four-year plants was already noticed and recorded as early as 1954 on the EPs and in the nursery near Stockholm, where the PR material was raised.

3.1.1.2. Basal stem girdle with resin flow and rents in the bark

This kind of damage differs from the one mentioned above in the first place by its external characteristics. The flow of resin from the damaged section is most conspicuous. Penetrating through small rents in the bark, resin flow reveals their texture (Fig. 29a). In most cases the damaged section is uniformly crusted over by resin flow (Fig. 29b). As regards the location of the girdle on the stem, as well as the age and size of the injured trees, this modification of damage does not differ from the one described in Chap 3.1.1.

Large cavities filled with resin were usually formed under the bark, wherever damage had occurred. These were located throughout the girdle, but more often they were to be found at the edge of the frost canker. Killed cambium either encircled the stem or appeared in patches where the overgrowth of callus then took place. However, the dissection of the damaged parts leads to the assumption that in many cases cortex tissues might have been killed by the cold in the first place and that dieback of the phloem and of the cambium occurred later, in the same or in the following year. Injured trees lingered on for two and sometimes four years before dying. The sections of the stem of the tree round the living branches lingered on longest.

Just these cases of damage should be given a histological and anatomical check at the time when damage occurs. No such analyses had been made. The dissections of the damaged parts of the tree, made in the second and third year after the occurrence of the damage, confirm the prevailing views on the subject (cf. Chap. 5.1.1). It is of interest that this kind of damage occurred most frequently in PRs fairly resistant to cold. On some plantations in the province of Norrbotten it was the predominant type of injury.

3.1.1.3. Basal stem girdle and fungus canker

It is not the purpose of this paper to make a study of the primary infection of plants by fungus diseases and of the development of fungus canker in the injured sections of the tree. In this investigation attention is paid to the infection by *Dasyscypha fuscosanguinea* which may occur in BSG caused by cold. The development of fungus canker after the infection can take place independently or simultaneously with the development of frost canker.

The emergence of *Dasyscypha fuscosanguinea* on the basal part of the stem and the connection of this disease with the manifestation of BSG is obvious. Fig. 30 shows the swelling of the stem which characterises the girdle, the rupturing of the bark, rents in the bark and, at the same time, the yellow apothecium cupules of the fungi. The position of the *D. fuscosanguinea* disease on the stem fully coincides with the different possible levels of the BSG above the ground. A fungus may form a complete circle, but often only one side of the stem is affected, just as is the case with BSG. Not only do the levels of the attack by fungi and those of BSG on the tree coincide, but also does the pattern, which may assume the form of a circle or appear in patches (Chaps. 3.1.1.1 and 3.1.1.2).

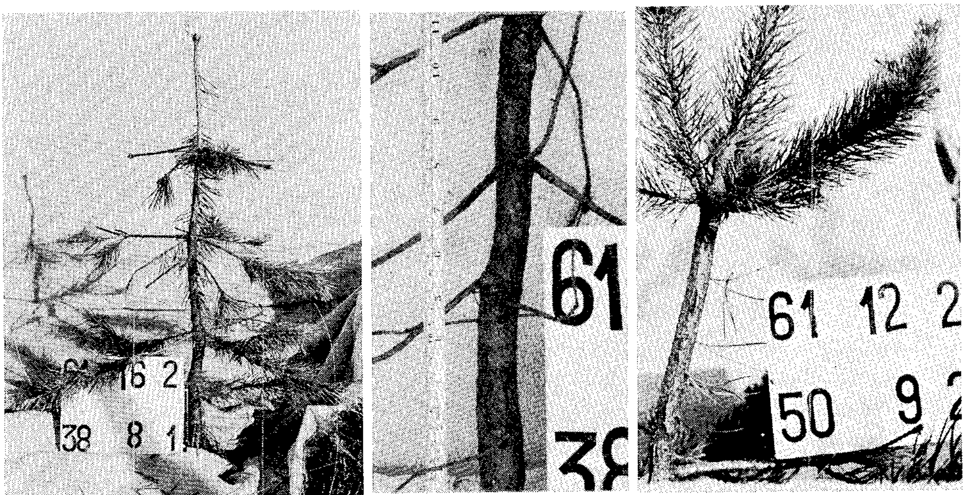
D. sanguinea disease is frequently met with in the north of Sweden (LAGERBERG, 1912). BJÖRKMAN (1957) draws attention to the frequent occurrence of *D. fuscosanguinea* in Scots pine in the north of Sweden on spaced out or thin plantations on trees two to three metres high, and associates this phenomenon with mechanical injuries. As regards the ecology of this fungus, it is known that it belongs to the so-called wound parasites. A primary factor must be at hand, which causes damage and rents in the bark of the tree and creates favourable preconditions for the infection. As a possible cause of the wounds in butt-swelling, BJÖRKMAN mentions the heavy frost heaving of the soil. According to BOYCE (1938, cit. DAY 1945, p. 4) *D. fuscosanguinea* disease and formation of fungus canker in U.S.A. are mostly restricted to high elevations or to poor sites.

In 1962 and 1963, that is, in the second and third year after the occurrence of severe cold damage *D. fuscosanguinea* appeared on the BSG on some of the injured trees. The disease was also recorded after the cold damage of 1955 and in a smaller degree after that of 1958. The manifestation of the disease a year or two after the occurrence of the severe cold damage is striking.

On the EPs trees are sometimes subject to root rot. However, injuries caused by *Fomes annosus* bear no relation to BSG caused by cold. In trees suffering from *Fomes annosus*, external signs in the section of butt-swelling are sufficiently manifest in order not to mistake them for BSG. It is true that a superfluous examination of the dying trees and particularly of the dieback of their crowns may, owing to a great similarity in both kinds of damage, lead to hasty conclusions. Luckily enough the region where the distribution of *Fomes annosus* occurs does not include the north of Sweden and only in a

a *b* *c*

Fig. 32. Sloughing of the bark.
a, circular sloughing on a tree (EP 11, PR 58);
b, circular sloughing on a naturally regenerated seedling (EP 17);
c, sloughing located only on one side of the tree (EP 12, PR 50). The damaged trees and the seedling died in the autumn of 1961. Photographed in October 1961 (*c*) and in July 1962 (*a* and *b*).



a *b* *c*

Fig. 33. Vertical lesions in the bark.
a and *b*, rents ran along the whole length of the stem on its SW side (EP 16, PR 38);
c, wounds located only on one section of the tree (EP 12, PR 50). The damaged trees died in the autumn of 1961 and 1962 respectively.
Photographed in September and October 1961.

small part of central Sweden does it coincide with the regional distribution of BSG.

3.1.1.4. Circular sloughing of the bark

The peeling off of the dead bark in the injured sections of the tree took place already in the first or the following year after the cold damage had occurred. Thus BSG, which otherwise may remain unnoticed, in dead trees becomes visible.

On the other hand, circular sloughing off of the living bark, which is being discussed here, occurs simultaneously with the occurrence of BSG. This probably takes place owing to some mechanical action of an external factor. The edge of the bark at the section where sloughing occurs is uneven (Fig. 32a), but in all other respects the damaged section resembles the artificial circular incision, that is, ring-barking. Owing to its fringy character this type of damage is easily distinguished from damage caused by rodents, which occurs in mountainous districts.

The sloughing of the bark takes place at the same level above the ground as does BSG, and occurs both in seedlings (Fig. 32b) and in trees up to the height of 4 metres. Not always does the sloughing occur round the whole stem. Very often it appears in patches (Fig. 32c). The wound in the section of the damage is usually deep enough to lay bare the xylem, but cases were recorded where the layer of cambium was intact.

The sloughing of the bark occurred in geographically limited districts in the provinces of Kopparberg and Västerbotten. Its manifestation was probably connected with conspicuous thawing periods, which occurred in these districts in the winter of 1961. The ice crust, which developed a disruptive action when the periods of thaw and cold alternated, may be considered as the cause of the damage.

3.1.1.5. Other kinds of lesions in the bark

In the spring of 1961 different kinds of fresh wounds, both shallow and deep, were recorded in trees. Contrary to the wounds mentioned in the previous chapter, which encircled the stem, these lesions ran in vertical directions, that is, in the direction of the stem. The character of these injuries was most complicated. Most injuries were caused by ice crust and at the same time had the characteristics of damage by cold. In some of the trees such vertical wounds ran along the whole length of the stem (Fig. 33b), but in some cases they appeared only in individual sections (Fig. 33c). These lesions bore a striking resemblance to the winter sunscald wounds (Filewicz and Modlibowska, 1955) which, as is well known, are rather rare in Scots pine.

In most cases wounds occurred on the south-west side, but they were also spread over a wider circumference from the south-east to west sides. Some of these lesions might have resulted from ice coatings (POMERLEAU, 1944; PARKER, 1963, p. 147; SCHNELLE, 1963, p. 397). The lesions so caused predominated on the west and north-west sides of the trees.

These injuries were most prominent in the PRs susceptible to cold and they were not sufficiently serious by themselves to cause the death of the tree. However, on injured trees severe BSG occurred simultaneously with lesions, and this decided the fate of the tree. The open lesions in the bark, in their turn, provided a favourable ground for new cold injuries and infection by fungi in the following years.

3.1.1.6. Mining damage by bark beetles

The colonisation by insects of trees damaged by severe cold was already recorded in the summer of 1962. The gallery system under the bark and the exit holes of the *Hylastes ater* beetles, as well as the beetles themselves, were observed first of all in the BSG on dead or dying areas of the stem. In the third summer after the occurrence of the damage, *i.e.*, in 1963, damaged trees were to a great extent infested by *Pissodes* weevils. The gallery system had been built in the section of the girdle and was limited chiefly to the last two annual rings, that is, to those rings which were formed after the damage had occurred (Figs. 3 and 64). Larvae, found in tunnels, were those of *Pissodes notatus*, but attacks by other bark-beetles were also observed.

The infestation of the cold-damaged trees by *Pissodes* weevils in the sections of the BSG, is a proof that cold is the primary cause of the damage. In uninjured trees no such insect attacks were found. However, damage by *Pissodes* weevils can by no means be regarded as insignificant. When examining the injured trees, one was under the impression that at least some of the cankered trees would have survived if no insect attacks, which radically decided the fate of the injured trees, had occurred.

Observations made by the author on insect infestation in cold-injured trees, and views expressed in this paper, correspond to the conclusions arrived at by DAY (1928, 1945), CHRYSTAL (1928) and BOYCE (1961).

3.1.1.7. Girdling of the main stem in the upper part of the tree

Girdling of the leading shoots caused by cold is a well-known kind of injury in most of the conifers. In fact, this kind of damage belongs rather to the next type (Chap. 3.1.2), that is, the dieback of the top of the plant. The cause of the injury is clearly ascertained by DAY and PEACE (1934) and DAY and BARRETT (1962) by experimental production of injuries by freezing. On these occasions the girdle of dead bark and dead cambium completely encircle the lower part of the last year's shoot. However, the girdle is often located at the whorl of the lateral branches or at the lower part of two-year, three-year, and sometimes even older, shoots.

This kind of cold damage differs from the BSG by its location above the ground as well as by its origin. In trees suffering from it the upper part of the tree above the girdle usually dies simultaneously with the occurrence of the damage, or shortly after it has taken place.

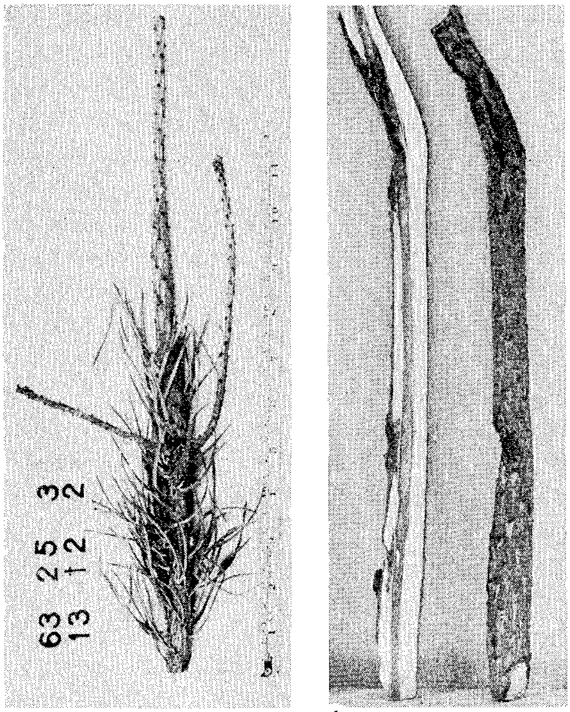
On EPs, girdling of the shoots at the main stem was recorded during several years. In 1958, and on some EPs also in 1959, this was the main type of damage. In most cases the location of the damage was limited to the top of the tree, and defects of the stem occurred (forked stems, posthorn bends and tortuous bends) when, instead of killed leaders, compensatory shoots developed (Fig. 5). In 1958 and 1959 the plants had not yet grown out from the dangerous ground air zone. During the periods of cold waves, not only the tops of the plants, but also the plants themselves, were killed. The frequencies of losses in plants belonging to PRs susceptible to cold were rather considerable (Chap. 4.2). This kind of damage was recorded again after the cold winter of 1961 and after the cold spell in the spring of 1963.

3.1.2. Dieback of the top of the plants and of the crown of the tree

Injuries caused by cold in the top of the plants and in the crown of the young trees may be of different character. Injuries of variable degrees of intensity were recorded from the time of the layout of the experiment until 1964 in plants of different ages, during single years and in all seasons. The scope of the subject does not permit the penetration into all kinds of injuries in detail. Only the most frequent types of damage are taken up for discussion here.

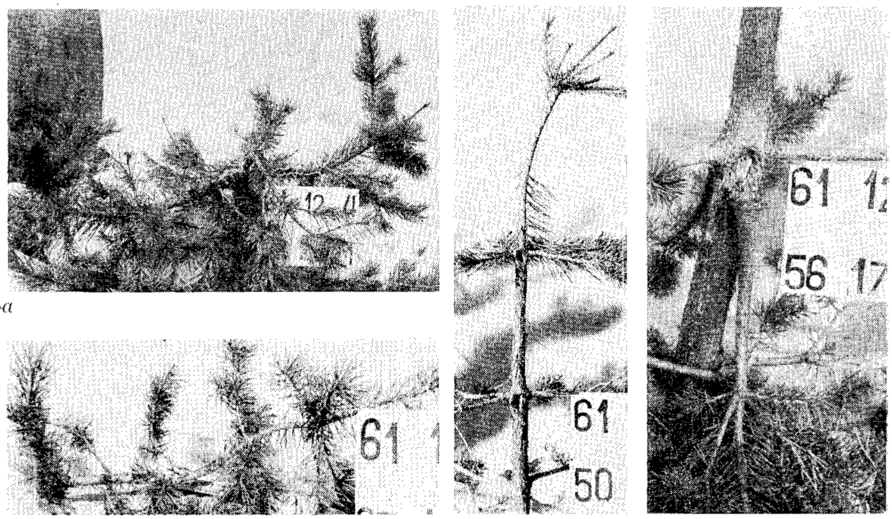
It has already been mentioned that, next to the basal stem section, the top of the plant is the part of the plant above the ground that is most susceptible to cold (Day, 1931; Kraevoj *et al.*, 1961). The amount of injuries is most frequent in the top of the plant. However, in young trees with a developed crown, injuries can manifest themselves simultaneously also in the lower part of the crown.

The characteristic external and internal signs of injury to pine are summarised by Day (1945, pp. 7f. and 1961, p. 150). On the basis of the data obtained from experimental freezing of plants, Day and Barrett (1962, p. 38) showed clearly these types of injury on the diagram. The objects of investigation in Day's experiments were Corsican pine and Black pine respectively. Analogy between cold damage in these species and the injuries



a *b*

Fig. 34. Dieback of top during the severe spring frost of 1963.
a, girdle located at the whorl of the lateral branches (EP 25, PR 13);
b, in some patches all living tissues were killed and the medula was injured (EP 25, PR 19).
Photographed in October 1963.



a *b* *c* *d*

Fig. 35. Distortion of the stem by snow.
a, split stem (EP 12, PR 50);
b, stem bent and broken at the base (EP 16, PR 23);
c, upper part of the tree bent and frozen; in different whorls several branches were pulled out of the stem (EP 12, PR 50);
d, several branches were pulled out of the stem (EP 12, PRs 50 and 56). Trees *a* and *c* died in the autumn of 1961, trees *b* and *d* survived.
Photographed in September 1961.

recorded in PR experiments in the north of Sweden in Scots pine is striking indeed.

Killed terminal buds are the most frequent kind of injury; simultaneously the adjacent part of the leader is also killed. The length of the section killed by cold can be less than 0.5 cm, but it can also be the whole of the previous year's shoot (Fig. 6).

The injury of the section affected by cold can manifest itself in many different ways. Often only cambium is injured. It appears in longitudinal dissections as a narrow brown line between xylem and unimpaired cortex. It can happen that only the outer part of the cortex is injured and that the dead tissue does not extend through to cambium. Injury to bark may occur in local centres as smaller or larger patches. In some patches all living tissues are killed and the inner part of the stem, the medula, is injured (Fig. 34).

The most severe type of injury is when dead bark and dead cambium encircle the stem (Chap. 3.1.1.7). It is of interest that girdling can occur not only on the main stem, but also on branches and twigs.

Discolouration of the needles appears on the injured parts of the crown and they turn brown or red. However, injury to needles can occur independently of other kinds of damage. Such needle damage manifested itself in the late winter of 1962 and in the summer of 1964 (in the second half of July).

When comparing the cases of dieback of the top during the three years (severe winter cold damage of 1961, some cases of cold injury in 1962 and extensive late frost damage of 1963), one can say that they hardly show any external differences. On all occasions injury occurred before flushing took place. Only in exceptional cases (see Chap. 4.2, EP 27) in 1963 did the damage take place before and during the flushing, and newly developed shoots were killed by late spring frosts.

As regards injuries by autumn frost, it is hardly possible to come to any definite conclusions. Such injuries were manifested frequently in 1954 among PRs susceptible to cold, but there is no evidence that they might have occurred during 1961—1963.

Spring cold injuries in Scots pine in May and June are well known (HOFFMANN, 1895; DENGLER, 1910, 1932; STAUDACHER, 1924).

Differences between damage by cold in winter and in spring are revealed in internal signs. Formation of frost ring and abnormal wood bears witness to the time when damage occurred. When sectioning plants and young trees both in longitudinal and transverse sections, those internal cold damage signs which otherwise would have remained concealed become visible. This particularly refers to PRs susceptible to cold.

3.1.3. Distortion of the stem and crown by snow

Of all the different kinds of damage caused by the weight of the snow upon individual parts of the tree, only damage connected with severe cold injury to trees in 1960/61 is taken up for consideration here. In this connection damage by snow is of twofold interest. The bending force of the snow can injure young trees mechanically beyond recovery, and it can also result in wounds in the crown and on the stem, which later become liable to cold injury and fungus diseases.

Damage by snow can be divided into two groups, according to the nature of the injury.

1. A plant or a tree may be bent by the weight of the snow amassed on the crown. In such a case, either the whole tree can be partially bent down, it can be completely pressed down to the ground, or it can be bent in the upper part only (Fig. 4). Stems and leaders can be fractured or broken at the bend (Fig. 35b).

2. Owing to the packing up of the snow, the frozen-in branches of the crown are pulled down. Sometimes either individual or several branches are pulled out of the stem at the whorl, leaving an open wound (Fig. 35c and d). In extreme cases the stem is split along the whole length of the tree (Fig. 35a). Often deformation and buckling of the stem in different directions occur in the same individual.

Damage by snow has been recorded in the north of Sweden (Holmerz and Örtenblad, 1886) and in individual years in central Sweden (Mattson-Mårn, 1922). The recorded types of damage correspond to a great extent to those described by Boerker (1914) in the U.S.A.

Of the injuries belonging to the first group, bends in the upper part of the stem were the most frequent. In the part of the stem below the bend, no deformation was observed in the injured trees. Damage was probably caused by the snowstorms which raged in February and March of 1961, that is, at the time when stems were embedded in deep and packed-up snow and only the crown of the tree above the snow cover was subjected to deformation by snowstorms. On the other hand, in 1961 trees were seldom bent at the base and pressed to the ground, which can probably be explained by the fact that in November of 1960 no storms, characteristic for this season, occurred (Meteorol. årsbok, 1960). However, the bending of the trees by snowstorms was observed in other years, *e.g.*, in 1954.

The other kind of severe damage by snow in 1961 was caused by heavy packing of the frozen snow cover. The wounds from those branches which had been pulled out by snow were healed over in the ensuing years. On the other hand, damage by snow in the small trees resulted in the dieback of the plant top and even in losses of plants.

It may be of interest if mention is made of the peculiarities in the structure of wood which arise in trees under the influence of the bending force of the snow. Formation of uneven wood fibres on the opposite side of the stem in the corresponding section of the bend has been dealt with in Scandinavia (Mork, 1946). The growth stress of stems and formation of reaction wood in young trees are well-known phenomena (Metzger; 1908; Jacobs, 1945; Sinnott, 1952; Wardrop, 1958; Senefield and Wardrop, 1962). Any small bend of the tree results in the formation of a brown or reddish-brown reaction wood in the corresponding sections of the tree. But, strange as it may seem, internal cold damage may occur at the same time in the same plants and young trees. The formation of abnormal reddish brown wood and frost rings may cause confusion with reaction wood, mentioned above, when longitudinal sections of the trees in question are examined. However, the anatomical and histological differences are most conspicuous when the formation of the wood in both cases is examined.

3.2. Relationship between different kinds of injury to plants

Several kinds of damage can manifest themselves in one and the same tree. This is clearly shown in Fig. 4, in which particular case the most severe kind of damage was BSG. It caused debility of the crown, discolouration of needles, defoliation and, at last, the death of the tree, which in this concrete case occurred in the late summer of the following year, after the occurrence of the damage. Dieback of the top of the plant (Chap. 3.1.2) is here an independent case of cold damage, which manifested itself in connection with the girdling of the main stem in the upper part of the tree (Chap. 3.1.1.7). In this particular case the cumulative effect of two different kinds of severe cold damage was clearly disclosed.

The relationship between the two main types of cold damage, namely, BSG and the dieback of the plant top, is rather intricate. Trees suffering from severe BSG, as well as heavily cankered trees, die after lingering on a shorter or a longer time, irrespective of the dieback of the top of the plant. This can be seen by comparing Fig. 4 with Fig. 26. However, in those cases where only the top of the tree was damaged, but no BSG had occurred, compensatory shoots developed in the ensuing years, the stem of the tree became more or less deformed, height growth was delayed and the whole habitus of the tree was permanently altered.

The most severe cases were, however, those where BSG had occurred at several levels in the part of the tree up to approximately 50 cm above ground surface. Frequently the whole upper part of the tree was at the same time severely affected and cambium was killed (Fig. 31). Both types of damage, BSG and the dieback of the top, merged in such trees. The whole stem of the tree was damaged by cold from the tip of the plant to the ground surface. The result of this damage was the immediate death of the tree. On the EPs in the spring of 1961, soon after the snow had melted, such trees did not show any signs of life. High death-rates in PRs susceptible to cold were already recorded in spring (Chap. 4.2 and 4.3). The causes of violent death were the two types of severe cold damage mentioned above.

In Fig. 4 the tree suffering from cold damage had also been affected by the mechanical action of the snow; it was bent in the upper part (Chap. 3.1.3). In the same tree attacks by *Pissodes* weevils (Chap. 3.1.1.6) were recorded in the basal stem section. It might be assumed that infection by saprophyte fungi would also have been found if the necessary examination had been made.

Summarizing, it can be stated that the winter cold of 1960/61 has on these occasions been of primary importance, and that the several types of damage by cold discussed above are closely connected with one another. When comparing different kinds of damage which manifest themselves in single trees, one notices a definite relationship between them. In the first place this can be said of BSG (Chap. 3.1.1.1) and other kinds of damage which were consistently manifested in the basal part of the stem (Chaps. 3.1.1.2; 3.1.1.3; 3.1.1.4). Of these, the most difficult to discern were the ruptures in the bark, which provided favourable conditions for infection by fungus diseases, which latter were then followed by fungus canker (Chap. 3.1.1.3). Next to the ruptures, and more serious and significant, is the girdle with resin flow (Chap. 3.1.1.2), where cortex tissues, and probably partly cambium, are also affected. The most severe kind of damage is BSG, where cambium is killed and frost canker develops. Circular sloughing of the bark (Chap. 3.1.1.4), on the other hand, is that kind of damage which manifests itself either quite independently or together with other kinds of damage. This mechanical kind of damage gives proof of the impetus of those external forces which work on the basal part of the stem. In this connection it is relevant to mention those processes which are associated with alternate thawing and freezing of the snow and with the packing of the snow cover. Circular sloughing of the bark or peeling off of the patches of bark can be explained by the fact that ice crust freezes to the bark and develops a hauling force, when snow cover packs down. However, this is only one of several physical actions (Chap. 5.1.2) in the sphere of ice crust which are connected with the processes causing cold damage in the basal part of the stem.

The manifestation of BSG and high death-rate of plants on EPs 20 and 24, and partly also on EPs 12, 16, 26 and 29 (see Chap. 4.2), coincides with damage to trees by snow. It is on these EPs that branches were often pulled out of the main stem, and the upper parts of the trees were fractured. In

Chap. 3.1.3 it has already been mentioned that this kind of damage intensified the dieback of the top of the plant. Nevertheless, it is clear that this kind of snow damage has nothing in common with BSG. When damage by snow occurred to the top of the trees, the stems of the trees had frozen in into the snow cover, reaching a depth of 1 metre. Neither the weight of the snow nor the influence of the wind could at that time affect the basal part of the stem. Consequently no bends, breaks or fractures were recorded there.

However, if the manifestation of both kinds of damage, *i.e.*, BSG and the damage by snow in the upper part of the crown, takes place in the same tree, it can be explained by the heavy packing of the snow cover and the development of the ice crust on the sites of these EPs. Such packed snow cover and ice crust in the first place damaged mechanically the top of the tree, presumably in January or February, and then two months later ice crust and fluctuations of the temperature, in their turn, caused severe cold damage at the basal part of the stem.

On some EPs (15 and 23) situated in mountain districts, damage by snow was either insignificant or did not occur at all. Even the manifestation of severe cold damage was rare (Chap. 4.2). However, damage by snow and damage by cold did not always coincide. BSG occurred even when no snow damage took place (EP 13). There is hardly any reason to expect any connection between these two kinds of damage. Each of them has a different time of occurrence and takes place in circumstances when the qualities of the snow have already changed. The question is taken up for discussion here only with the view of showing the role played by the snow cover when damage occurs.

4. Mortality rates in plants among provenances

4.1. Biological and statistical concepts on death in plants

The concept of death and the setting in of death in individuals, plants and young trees, might seem a simple problem. A tree is dead when it does not show any sign of life. However, in field experiments difficulties often arise in this connection. This refers particularly to individuals damaged by cold. When annual check-up of the EPs was made, some trees were recorded as dead on the basis of external signs. Nevertheless, corrections had to be made already in the following year, when discarded trees developed adventitious shoots from the lower whorls of branches or from short shoots. Capacity to develop adventitious shoots is particularly characteristic for PRs originating from northern regions and from high altitudes. As a rule, new shoots which sprout from local, living centres in the main stem of a tree, whose remaining parts are dead, are very weak. Most often they perish in the ensuing years. On the other hand, new shoots, which develop from the uninjured basal part of the stem, which has remained intact, may be permanent, and compensate for the killed upper part of the plant; but they, in their turn, can be damaged by cold in the years to come.

Permanent, adventitious shoots in individuals damaged by cold are considered to be symptomatic of the capacity of a particular tree to survive. Individuals capable of rejuvenation were not included in the death-rate records, although they might have been registered as dead immediately after the occurrence of severe cold damage. Still, if short-termed and insignificant shoots appeared, they were ignored and no corrections were made in the initial record of the death of the plant.

In the case of BSG it was difficult, immediately after the occurrence of damage, to distinguish between unimpaired individuals and those injured by cold, and during the ensuing year to distinguish between living and dead individuals. In the spring of 1961 the majority of the injured trees did not show any external signs of damage. Such signs appeared only in the summer of the same year. Some of the trees died in the autumn, some in the spring of 1962, and some even later. But some of the plants lingered on until the autumn of 1964 and were neither dead nor alive.

It is evident that production of cold damage and the death of the damaged individuals are two different phenomena. These two phenomena seldom occur simultaneously. This fact must be taken into consideration when statistical data on death-rate in plants in single years is interpreted. (See the graphical representation of these data in Chap. 4.2.) The frequency of dead individuals in single years can be caused by cold damage which has occurred in either the same year, in the preceding year, or two to four years earlier. This is clearly shown in the case of cold damage which occurred in 1961.

Much attention was devoted to consistent examination of individual plants. Field records were made during each growing season, sometimes even twice, except in 1960, when plantations were not examined during that season. The same applies to the EP 20 in 1957 and to the EPs 10 and 14 in some years. In 1960 the values lacking were compensated by minute distribution of dead trees into two groups (those killed in 1959/60 and those which died in 1960/61) according to assessment records of 1961. Luckily, frequencies of dead individuals in 1959/60 were insignificant. It was possible by external signs to distinguish dead trees from the trees injured in the winter of 1961, which subsequently died in the spring of the same year. The majority of individuals injured in the winter of 1961 died after the spring assessment of 1961.

Records obtained in field assessments were put into a system which enabled minute observation of each individual from year to year. Each replaced plant was registered in the same way as were original plants. However, in statistical records on death-rates only original plants were taken into account. This was done with the view of eliminating many and various influences on death-rates in plants, which crop up owing to the uneven scale of replacement losses in different PRs in different years.

The frequencies of dead individuals are calculated separately for each PR and for each year. These are average values obtained from four replications and refer to the whole EP. Complete estimation of statistical data has not yet been made. The variation of death-rates within the population due to the variable resistance to cold in progeny of individual trees has not been calculated at all. Since PR experiments are at the same time progeny tests of individual trees, the data on plant mortality are of particular interest. The statistical evaluation of these biological qualities is postponed until later. However, it is of interest to note that in some populations progeny of individual trees reveal a different hardiness to cold.

Death rates of different PRs are expressed graphically by time-age-mortality curves in diagrams. Two different modes of expressing death-rates have been used in this paper: 1. CM rates in plants and 2. SYM rates in plants. Both diagrams with their different modes of expressing death-rates complement each other.

CM rates are calculated on the basis of the cumulative number of dead individuals, year after year, in four replications for each PR on each EP.

These figures are expressed in percentages of 260, that is, from the number of the plants in each PR at the time of lay-out, in four replications (50+80+50 +80 = 260). On the other hand, frequencies of losses in plants in single years are calculated on the basis of the number of trees killed in a single year and expressed in percentages of the number of living trees for each PR in the EP during the previous year.

CM curves in the diagrams show the adaptation result of each individual PR on the experimental site, as well as differences among PRs or the traits they have in common. The curves clearly display quantitatively the result of the adaptation for survival for each EP at a definite age of development in successive calendar years.

However, certain disadvantages are connected with the use of CM curves. In the first place, each case of unforeseen chance losses in plants on EPs during the first years changes the position of the CM curves in relation to a normal one, *i.e.*, from the one which a certain PR would have had, had its survival depended only upon its endogenous sensibility to cold. Although a CM curve, in its further development, gives sufficiently valid evidence of the hardiness of PR to cold, the position of a curve above the horizontal axis in the diagram, in the cases mentioned above, does not show the real ability of a PR to adapt itself. The following PRs and EPs illustrate what has been said above: EP 21, PR 102, Fig. 48 A; EP 25, PR 101, Fig. 51 A; EP 13, PR 10, Fig. 44 A.

The graphical representation of losses in plants in single years by means of CM curves does not show the change of the direction of these curves to full advantage. These disadvantages are eliminated by the death-rate curves of the second type, that is, curves containing SYM rates. The initial chance losses in plants do not influence the position of the PR curves in the years to follow. The position of the curves shows the relationship between the PRs and their susceptibility to cold in single years. But these curves do not show the result of adaptation of PRs in the same way as it is seen on CM diagrams.

Death-rate values are consistently calculated individually from each PR replication on all EPs. However, only two representative EPs (16, Fig. 46 and 21, Fig. 49) were chosen to illustrate the variation of death-rates in four replications. EP 16 stands out among the others by reason of its high variation of death-rates in replications. This variation is particularly noticeable in PRs susceptible to cold. Each minute divergence of ground surface level between replications increases the variation of death-rates. On the other hand, EP 21 has a moderate death-rate variation. It should be stressed that replication death-rate curves do not differ essentially. Deviation of death-rate curves in each replication from PR mean values is expressed graphically.

Data on death-rates in plants among PRs on EPs are supplemented by tree height measurements. On EP 11 only arithmetical mean values of the heights were obtained, but on EPs 9, 10, 12, 16, 20, 21 and 25 both mean values and standard error values for each PR were taken. In this connection the heights supply us with information on the height growth in different PRs. It is undeniable that the tree growth is closely connected with the occurrence of cold damage. EPs on which tree height measurements were made are located in different parts of northern Sweden (Figs. 7 and 8). On the basis of these data certain conjectures can be made regarding the size of the trees even on all other EPs.

However, the statistical data on tree heights are by no means exhaustive, and they claim neither to supply a complete information on the variation of height growth in different PRs, nor to give a significative answer as to the fitness of PRs to the experimental sites.

4.2. Single experimental plantations

A concise commentary on diagrams and a short account of the characteristics regarding site conditions for each of the 20 EPs are given below. Diagrams containing CM curves are designated by A, for instance: Fig. 21 A. Diagrams showing SYM rates are designated by B, retaining the same number for the figure, for instance: Fig. 21 B. The latter kind of diagrams are lacking for EPs 10 and 14 as no records were made during some single years. The PR curves in the diagrams are designated by the same figures as corresponding PRs in tables and on maps.

Data on the origin of PRs, and on CM rates in plants, as well as data on the tree height, are contained in the corresponding table for each EP. The transfer distance of PRs from their natural habitat to the EP site is shown in the tables. CM rates from 1960 to 1964, that is, death-rates comprising chiefly losses in plants caused by BSG of 1960/61, as well as CM rates from 1956 to 1964, are also included in the tables.

Symbols in tables

PR: No. —Number of PR, see Fig. 7.
φ —North latitude.
λ —East longitude from Greenwich.
H_s —Altitude above the sea level in m.
Y —Length of growing season.
Locality—Province, nearest populated place,

Transfer of PR: φ — distance in meridional direction from the natural habitat of the PR to the site of EP in km, in northerly direction (+), in southerly direction (—).

H_s —Distance in vertical direction in m, upward (+), downward (—).

Y —Shortening (—) or the lenghthening (+) of the growing season.

R: Relative values of the CM rates of 1964 in different PRs (R of local PR = 100).

Living trees: N — % — Total number and % of the number of plants in the year the experiment was laid out.

n — (%) — Number of trees with crown intact and % of N number. These trees were measured and the data obtained were used for the estimation of $\bar{h}$.

n_1 — (%) — Injured, bent, topless trees and % of N number.

$\bar{h}$ — Mean height in cm.

Distribution of experimental plantations

On the basis of the differences in death-rate values recorded after 1960/61 in EPs, it seemed appropriate to divide the EPs into four groups in order to elucidate the problem of the BSG. Weather conditions in 1960/61 were also taken into account when EPs were grouped as follows:

I. EPs (9, 10 and 14) located *outside* the region of severe cold damage.

II. EPs *within* the region of severe cold damage.
   1. EPs (11, 17 and 18) in the transition zone, where moderate cold damage occurred in 1960/61.
   2. EPs (12, 13, 16, 20, 21, 22, 24, 25, 26, 29 and 27) where extensive cold damage occurred in 1960/61.
   3. EPs in mountain districts (15, 19 and 23) where moderate cold damage occurred in 1960/61.

Experimental plantations located outside the region of severe cold damage of 1960/61 (Region I)

Experimental plantation 9. Fig. 36 A and B. Table 2

The site of the EP occupies a small area, formerly used for agricultural purposes. Here the surface of the country is rolling and broken, and the site is surrounded by woodland and swamps. The most unfavourable factor on the site is the vigorous ground vegetation. Losses in plants in the summer of 1954 were considerable, which resulted in high death-rate values in 1955. The position of CM curves is therefore very high already in the initial section. The position of the curves was not influenced by physiogenic factors during the first year and was influenced only very slightly in subsequent years.

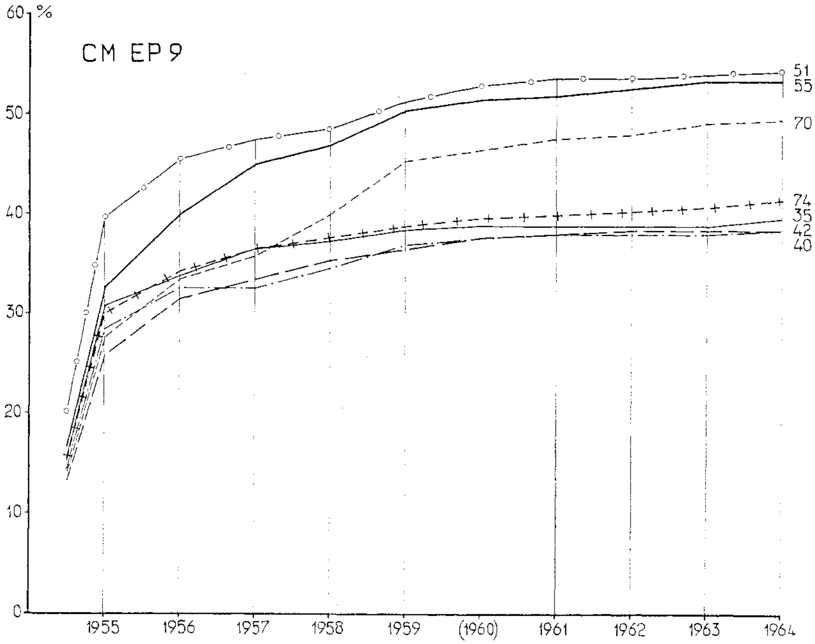


Fig. 36 A. CM of 7 PRs in EP 9 (see Table 2).

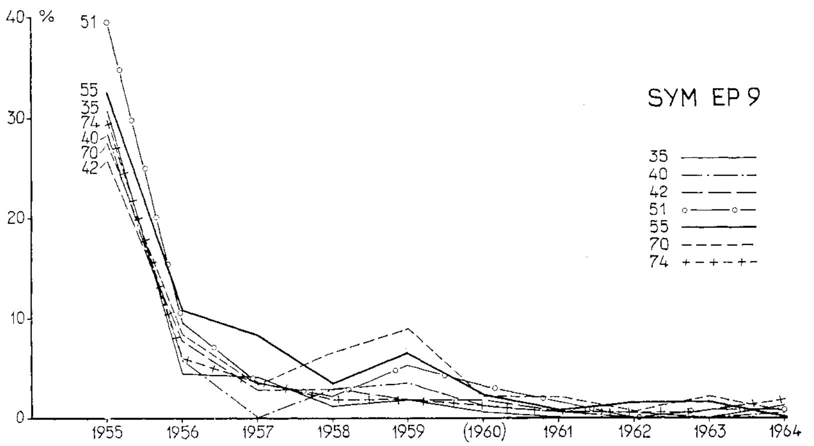


Fig. 36 B. SYM of 7 PRs in EP 9 (see Table 2).

Table 2. Experimental plantation 9. Kopparberg, Gravendal. φ: 60° 04′, λ: 14° 32′, H_s: 335, Y: 145.

No.	PR φ	PR λ	PR H_s	PR Locality	PR Y	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1962 N %	Living trees 1962 n (%)	Living trees 1962 n_1 (%)	Living trees 1962 $\bar{h}$ 1962
35	62° 59′	16° 39′	92	Jämtland, Bispfors, Stadsforsen	141	—325	+243	+ 4	39.62	74.1	5.77	0.77	159 *61.15*	152 *95.60*	7 *4.40*	199.38 ± 4.84
40	62° 12′	17° 42′	5	Västernorrland, Brämön, Sanna	150	—237	+330	— 5	38.46	71.9	5.77	0.77	161 *61.92*	157 *97.52*	4 *2.48*	177.23 ± 4.40
42	62° 03′	14° 19′	385	Jämtland, Sveg, Malmbäcken	132	—221	— 50	+13	38.46	71.9	6.92	0.77	160 *61.54*	157 *98.12*	3 *1.88*	210.20 ± 5.00
51	61° 09′	13° 00′	720	Kopparberg, Sälen, Hundfjället	120	—121	—385	+25	54.47	101.9	8.94	1.55	119 *46.30*	119 *100.00*	—	175.25 ± 5.49
55	60° 16′	15° 06′	325	Kopparberg, Grangärde	145	— 22	+ 10	—	53.46	100.0	13.46	1.92	123 *47.31*	115 *93.50*	8 *6.50*	186.23 ± 5.07
70	57° 46′	16° 39′	20	Kalmar, Västervik	175	+256	+315	—30	49.62	92.8	16.16	3.08	135 *51.92*	116 *85.93*	19 *14.07*	170.51 ± 5.05
74	57° 36′	14° 13′	225	Jönköping, Eckersholm	165	+275	+110	—20	41.54	77.7	7.31	1.92	155 *59.62*	139 *89.68*	16 *10.32*	198.84 ± 5.17

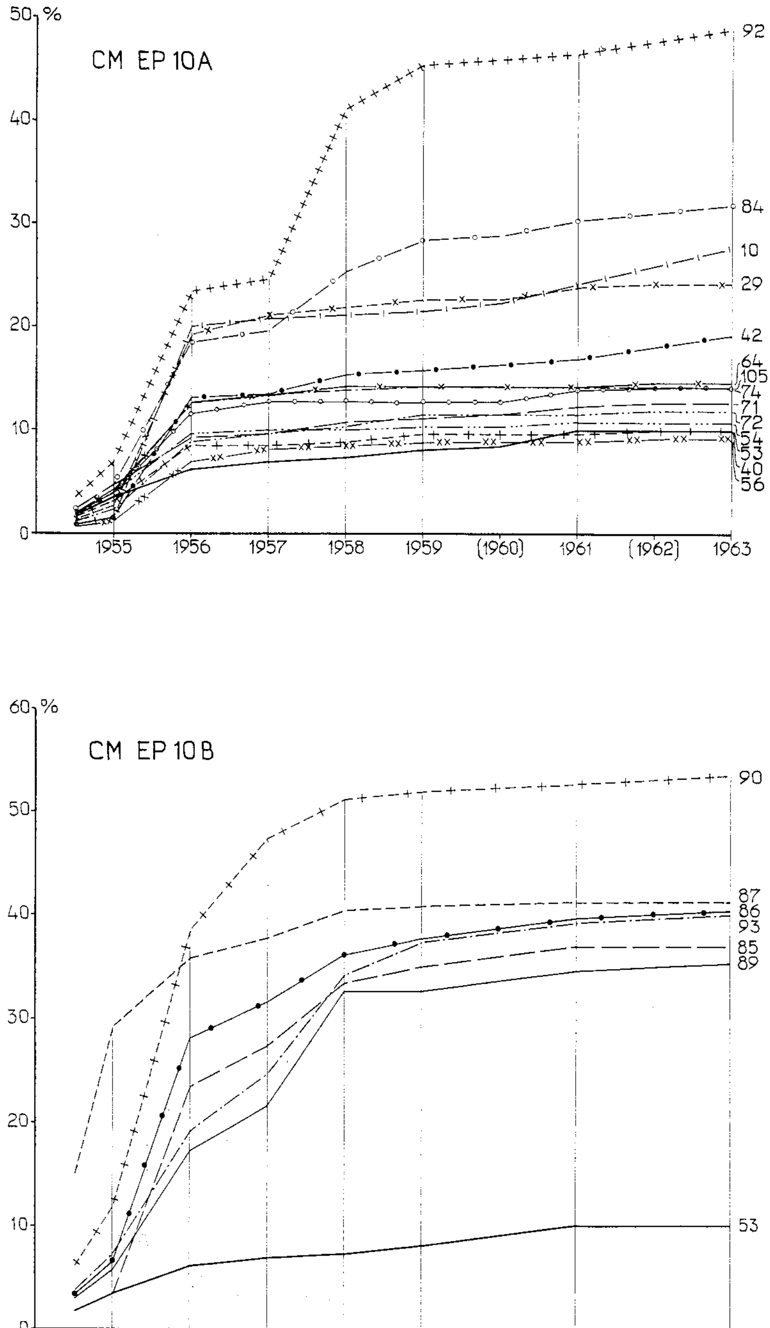


Fig. 37. A I and A II. CM of 14+7 PRs in EP 10 field A and EP 10 field B (see Table 3).

Table 3. Experimental plantation 10. Uppsala, Älvkarleby. φ: 60° 32′, λ: 17° 28′, H_s: 25, Y: 159.

Field A

	PR					Transfer of PR			CM 1963		Diff. CM		Living trees 1963			
No.	φ	λ	H_s	Y	Locality	φ km	H_s m	Y	%	R	1963—1956 %	1963—1960 %	N %	n (%)	n_1 (%)	$\bar{h}$ 1962
10	66° 56′	23° 11′	200	113	Norrbotten, Korpilombolo, Ohtanajärvi	—712	—175	+46	27.69	276.9	7.69	5.38	188 *72.31*	187 *99.47*	1 *0.53*	120.99 ± 13.01
29	64° 02′	16° 16′	250	127	Västernorrland, Hoting	—390	—225	+32	24.23	242.3	5.00	1.15	197 *72.31*	191 *96.95*	6 *3.05*	177.18 ± 13.01
40	62° 12′	17° 42′	5	150	Västernorrland, Brämön, Sanna	—186	+ 20	+ 9	10.00	100.0	1.54	0.38	234 *90.00*	229 *97.86*	5 *2.14*	181.85 ± 13.01
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	—169	—360	+27	19.23	192.3	6.15	3.08	210 *80.77*	205 *97.62*	5 *2.38*	191.90 ± 13.01
53	60° 32′	17° 28′	25	159	Uppsala, Älvkarleby	—	—	—	10.00	100.0	3.85	1.54	234 *90.00*	232 *99.15*	2 *0.85*	227.69 ± 13.01
54	60° 26′	16° 23′	150	153	Gävleborg, Kratten, Skogsvårdsgård	+ 11	—125	+ 6	10.77	107.7	1.15	0.39	232 *89.23*	232 *100.00*	—	211.50 ± 13.01
56	59° 35′	07° 50′	550	137	Norway, Vinje, Prästgården	+106	—525	+22	9.23	92.3	2.31	0.38	236 *90.77*	236 *100.00*	—	169.10 ± 13.01
64	59° 25′	12° 22′	250	154	Värmland, Årjäng, Höghult	+124	—225	+ 5	14.62	146.2	1.93	0.39	222 *85.38*	221 *99.55*	1 *0.45*	207.19 ± 13.01
71	57° 41′	15° 50′	155	169	Kalmar, Vimmerby	+317	—130	—10	12.69	126.9	3.46	1.15	227 *87.31*	220 *96.92*	7 *3.08*	208.63 ± 13.01
72	57° 39′	18° 21′	70	173	Gotland, Visby, Skogsholm	+321	— 45	—14	11.92	119.2	3.07	0.38	229 *88.08*	221 *96.50*	8 *3.50*	185.63 ± 13.01
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+326	—200	— 6	14.23	142.3	1.54	0	224 *85.77*	220 *98.21*	4 *1.79*	223.22 ± 13.01
84	52° 40′	10° 42′	100	201	Germany, Niedersachsen, Kassebeck	+876	— 75	—42	31.92	319.2	13.46	3.07	177 *68.08*	162 *91.53*	15 *8.47*	193.07 ± 13.01
92	50° 02′	08° 58′	125	215	Germany, Hessen, Seligenstadt	+1169	—100	—56	48.85	488.5	25.39	3.08	133 *51.15*	112 *84.21*	21 *15.79*	174.94 ± 13.01
105	57° 30′	11° 55′	10	177	Halland, Kungsbacka, Särö	+338	+ 15	—18	14.23	142.3	2.69	1.54	223 *85.77*	218 *97.76*	5 *2.24*	180.85 ± 13.01

Field B

No.	PR: φ	PR: λ	PR: H_s	PR: Y	Transfer of PR: φ km	Transfer of PR: H_s m	Transfer of PR: Y	CM 1963: %	CM 1963: R	Diff. CM: 1963—1956 %	Diff. CM: 1963—1960 %	Living trees 1963: N %	Living trees 1963: n (%)	Living trees 1963: n_1 (%)	Living trees 1963: $\overline{h}$ 1962
	Locality														
53	60° 32′	17° 28′	25	159	—	—	—	17.69	100.0	7.31	2.31	214	211	3	208.36 ± 12.16
	Uppsala, Älvkarleby											*82.31*	*98.60*	*1.40*	
85	50° 10′	12° 07′	550	190	+1154	— 525	—31	36.92	208.7	13.46	1.54	164	158	6	207.72 ± 12.16
	Germany, Bayern, Selb											*63.08*	*96.35*	*3.65*	
86	49° 45′	11° 33′	450	198	+1200	— 425	—39	40.38	228.3	12.30	1.92	155	147	8	194.39 ± 12.16
	Germany, Oberfr.-Bayern, Pegwitz											*59.62*	*94.84*	*5.16*	
87	49° 22′	11° 38′	500	198	+1243	— 475	—39	41.15	232.6	5.38	0.38	153	148	5	226.32 ± 12.16
	Germany, Oberpfalz-Bayern, Pfaffenhofen											*58.85*	*96.73*	*3.27*	
89	49° 12′	12° 17′	368	206	+1261	— 343	—47	35.38	200.0	18.07	2.69	168	157	11	213.82 ± 12.16
	Germany, Bayern, Nittenau											*64.62*	*93.45*	*6.55*	
90	47° 38′	13° 00′	1050	176	+1436	—1025	—17	53.46	302.2	15.00	1.15	121	120	1	96.37 ± 12.16
	Germany, Hochgeb.-Oberbayern, Berchtesgaden											*46.54*	*99.17*	*0.83*	
93	51° 35′	04° 45′	10	212	+ 996	+ 15	—53	40.00	226.1	20.77	1.92	156	150	6	203.76 ± 12.16
	Holland, Breda, Mastbosch											*60.00*	*96.16*	*3.84*	

Fig. 38 A. CM of seven PRs in EP 14 (see Table 4).

As regards frequencies of losses in plants in single years, the following may be said. In 1959 losses in plants were caused by winter cold and spring frosts, and in 1963 by rodents. Only a few plants with BSG from 1961 were found on this EP. Such damage was also occasionally found in neighbouring natural reproduction areas.

Experimental plantation 10. Fig. 37 A I (Field A) and A II (Field B). Table 3

This EP is located in the coastal region of the Gulf of Bothnia in flat country, and is surrounded by pine woods. During some of the initial years vigorous ground vegetation influenced the development of the EP. Heavy losses of plants occurred during the exceptionally dry summer of 1955, which was reflected in high death-rates in 1956. During each of the years following 1956, plant mortality was negligible among most of the Swedish PRs which, on the whole, did not differ from the local PR. The weather conditions prevailing in 1960/61 did not influence plant mortality. BSG was recorded only in 15 trees on the whole EP. Winter cold and late frosts in 1958 caused losses in plants in German PRs susceptible to cold. In PRs 10, 42 and 90 during the years following 1959 the only losses were those caused by roe, *Capreolus capreolus*.

Table 4. Experimental plantation 14. Västernorrland, Brämön. φ: 62° 12′, λ: 17° 42′, H_s: 5, Y: 150.

No.	PR φ	PR λ	PR H_s	PR Y	PR Locality	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1964 N %
21	64° 57′	21° 11′	20	133	Västerbotten, Byske	— 306	— 15	+ 17	19.62	116.0	0.77	0.39	209 *80.38*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	— 326	— 300	+ 32	4.62	27.3	0.77	0.77	248 *95.38*
40	62° 12′	17° 42′	5	150	Västernorrland, Brämön, Sanna	—	—	—	16.92	100.0	1.92	1.92	216 *83.08*
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+ 17	—380	+18	35.38	209.1	1.53	0.38	168 *64.62*
56	59° 35′	07° 50′	550	137	Norway, Vinje, Prästgården	+291	—545	+13	28.46	168.2	1.15	1.15	186 *71.54*
61	59° 17′	18° 55′	10	167	Stockholm, Sandhamn	+325	— 5	—17	26.92	159.1	3.46	2.30	190 *73.08*
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+512	—220	—15	36.92	218.2	1.15	0.77	164 *63.08*

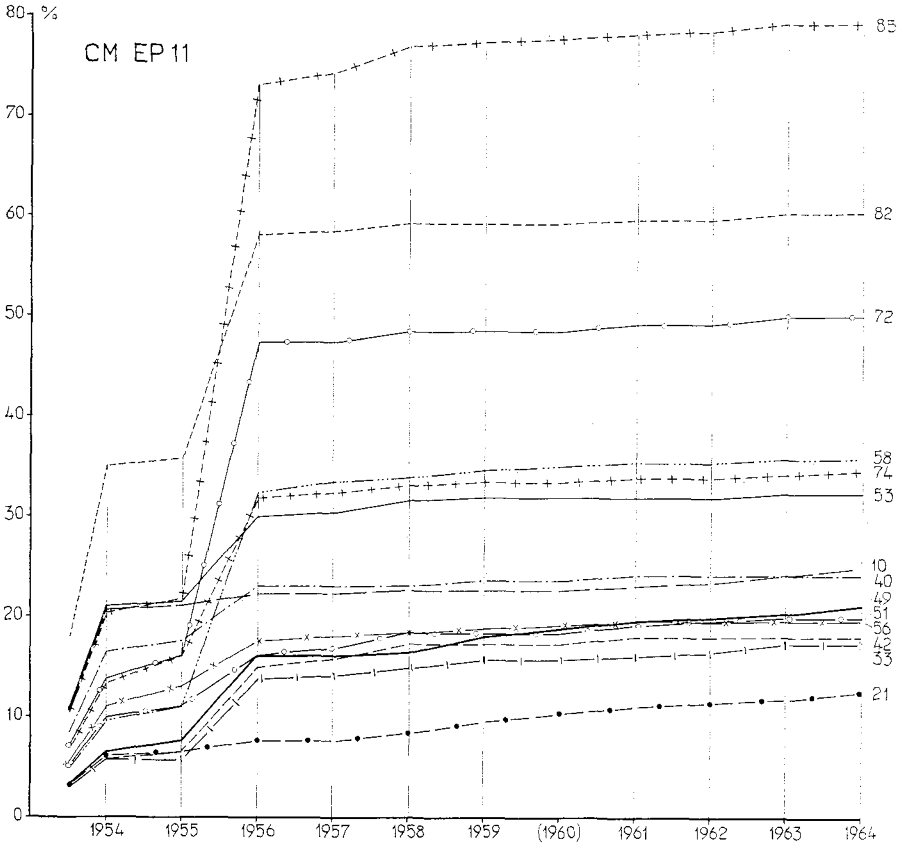


Fig. 39 A. CM of 14 PRs in EP 11 (see Table 5).

Experimental plantation 14. Fig. 38 A. Table 4

This EP is located on the island of Brämön in the Gulf of Bothnia and is surrounded by pine woods.

Losses in plants up to 1955 were caused by the attacks of *Hylobies abietis* and by the periods of drought in the spring of 1953 and 1954. The drought of 1955 was the only cause of the increase of CM rates in 1956. A certain increase in curves was also noticeable in 1958. Of all the types of cold damage only the manifestation of BSG was recorded in 1961. This resulted in an insignificant change in the trend of the direction of the curves. Death-rates in plants in connection with the damage of 1961 were inconsiderable. This EP lies outside the region of severe cold damage (Chap. 2.1).

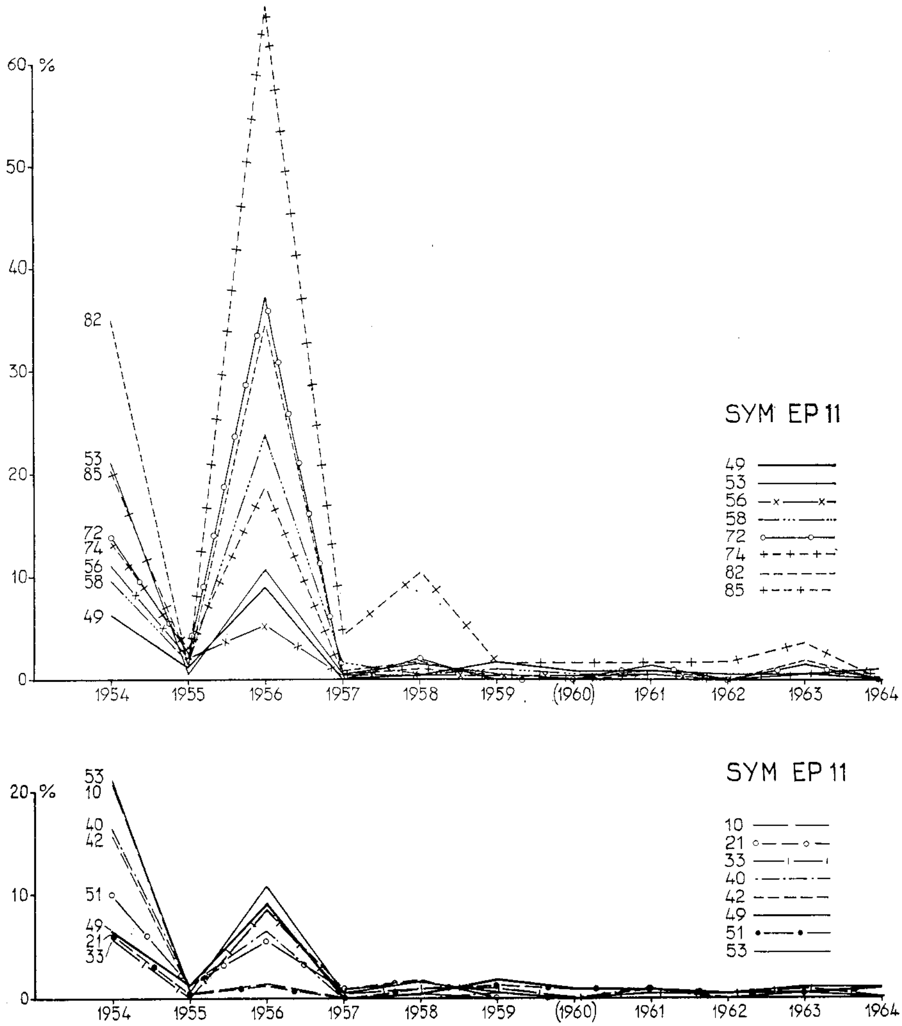


Fig. 39 B I and B II. SYM of 14 PRs in EP 11 (see Table 5).

Plantations where moderate cold damage occurred in 1961 (Subregion II:1)

Experimental plantation 11. Figs. 39 A, BI and B. Table 5

Mixed spruce and pine forest enclose the site, which is located on a flat plateau.

Severe snowstorms raged here in the October of 1954 and deep snow covered the crowns of the trees on the EP in the winter of 1961/62, without

Table 5. Experimental plantation 11. Kopparberg, Orsa, Högståsen. φ**: 61° 05′,** λ**: 14° 58′,** H_s**: 365, Y: 138.**

No.	PR: φ	PR: λ	PR: H_s	PR: Y	PR: Locality	Transfer of PR: φ km	Transfer of PR: H_s m	Transfer of PR: Y	CM 1964: %	CM 1964: R	Diff. CM: 1964—1956 %	Diff. CM: 1964—1960 %	Living trees 1963: N	Living trees 1963: %	Living trees 1963: $\overline{(h)}$ 1961
10	66° 56′	23° 11′	200	114	Norrbotten, Korpilombolo, Ohtanajärvi	—651	+165	+24	25.00	118.2	2.69	2.31	197	*75.77*	120
21	64° 57′	21° 11′	20	133	Västerbotten, Byske	—430	+345	+5	12.69	60.0	5.00	2.31	229	*88.08*	146
33	64° 08′	18° 39′	475	115	Västerbotten, Örträsk, Höglunda	—339	—110	+23	17.31	81.8	3.46	1.54	215	*82.69*	134
40	62° 12′	17° 42′	5	150	Västernorrland, Brämön, Sanna	—124	+360	—12	24.23	114.6	1.15	0.77	197	*75.77*	145
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	—108	—20	+6	18.08	85.5	3.08	0.77	213	*81.92*	158
49	61° 05′	14° 58′	365	138	Kopparberg, Orsa, Högståsen	—	—	—	21.15	100.0	5.00	2.30	207	*79.62*	157
51	61° 09′	13° 00′	720	120	Kopparberg, Sälen, Hundfjället	—7	—355	+18	20.00	94.6	3.85	1.54	208	*80.00*	140
53	60° 32′	17° 33′	35	159	Uppsala, Älvkarleby	+61	+330	—21	32.31	152.8	2.31	0.39	176	*67.69*	160
56	59° 35′	07° 50′	550	137	Norway, Vinje, Prästgården	+167	—185	+1	19.62	92.8	1.93	0.39	218	*83.85*	155
58	59° 40′	10° 40′	80	161	Norway, Ås, Sånes	+158	+285	—23	35.77	169.1	3.46	0.77	167	*64.23*	145
72	57° 39′	18° 21′	70	173	Gotland, Visby, Skogaholm	+382	+295	—35	50.00	236.4	2.69	1.54	130	*50.00*	125
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+388	+140	—27	34.62	163.7	2.70	1.16	171	*65.77*	148
82	55° 51′	14° 01′	30	186	Kristianstad, Vittskövle	+582	+335	—48	60.38	285.5	2.30	1.15	103	*39.62*	147
85	50° 10′	12° 07′	550	190	Germany, Bayern, Selb	+1205	—185	—52	79.23	374.6	6.15	1.54	53	*20.38*	136

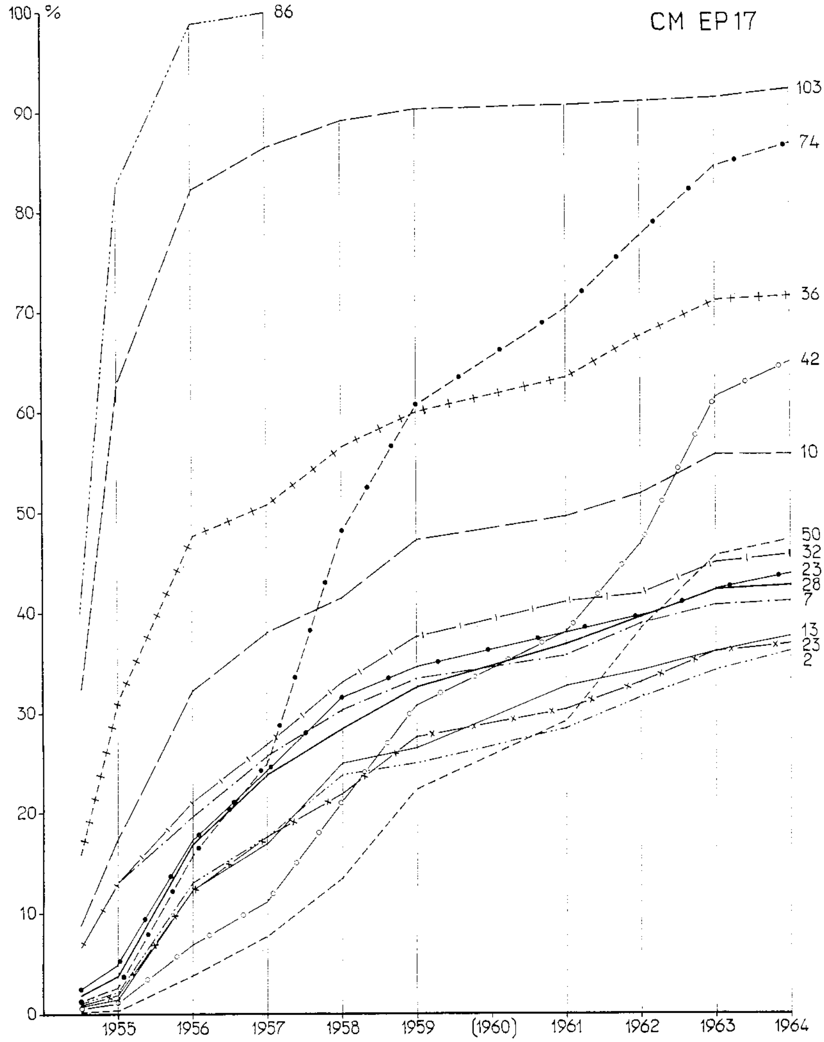


Fig. 40 A. CM of 14 PRs in EP 17 (see Table 6).

causing any considerable damage. As regards losses in plants in single years the following may be said. In PRs 82 and 85 cold damage which occurred in the spring of 1953 resulted in moderate death-rates in plants, and some losses in plants were also due to the attacks of *Hylobies abietis* in the spring of 1953. No cold damage occurred during the severe winter of 1954/55. The high death-rate values in 1956 were the result of the protracted drought in the summer of 1955. Death-rate values clearly elucidate the variable sensibility

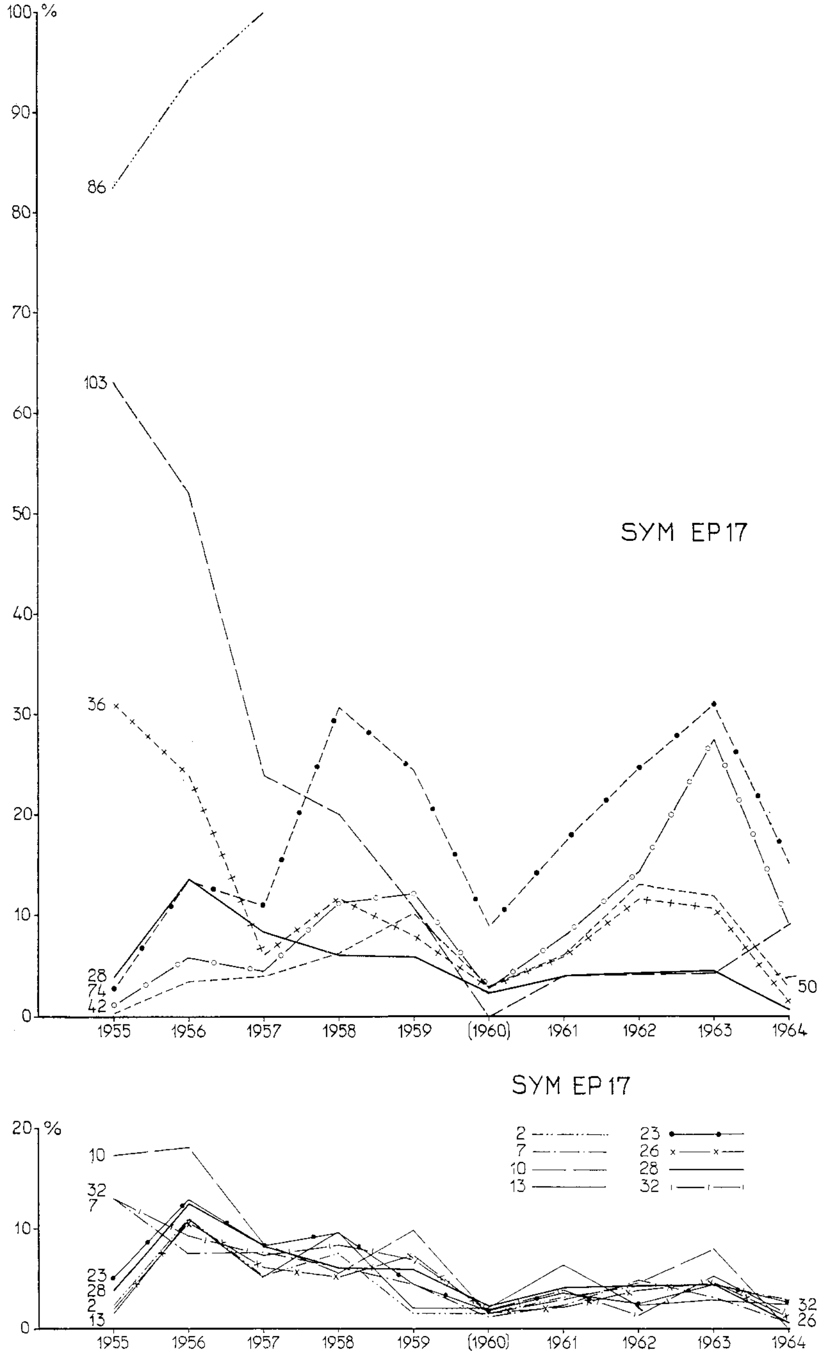


Fig. 40 B I and B II. SYM of 14 PRs in EP 17 (see Table 6).

Table 6. Experimental plantation 17. Västerbotten, Vindeln, Svartberget. φ: 64° 14′, λ: 19° 43′, H_s: 200, Y: 128.

	PR					Transfer of PR			CM 1964		Diff. CM		Living trees 1964	
No.	φ	λ	H_s	Y	Locality	φ km	H_s m	Y	%	R	1964—1956 %	1964—1960 %	N	%
2	69° 55′	23° 15′	20	104	Norway, Alta, Aronäs	—633	+180	+24	36.15	84.7	23.07	10.00	166	*63.85*
7	67° 51′	20° 27′	355	100	Norrbotten, Kiruna, Kauppinen	—403	—155	+28	41.15	96.4	21.53	6.92	153	*58.85*
10	66° 53′	23° 03′	175	114	Norrbotten, Korpilombolo, Smedberg	—295	+ 25	+14	55.77	130.6	23.46	7.69	115	*44.23*
13	66° 18′	14° 10′	75	123	Norway, Mo i Rana, Båsmo	—230	+125	+ 5	37.69	88.3	25.39	9.61	162	*62.31*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	—100	—105	+10	43.85	102.7	26.55	8.07	146	*56.15*
26	64° 12′	20° 48′	50	136	Västerbotten, Robertsfors	+ 4	+150	— 8	36.92	86.5	24.61	8.08	164	*63.08*
28	64° 14′	19° 43′	200	128	Västerbotten, Vindeln, Svartberget	—	—	—	42.69	100.0	25.77	8.46	149	*57.31*
32	64° 34′	18° 15′	555	109	Västerbotten, Lycksele, Tallträsk, Storberget	— 37	—355	+19	45.77	107.2	24.62	6.93	141	*54.23*
36	63° 02′	16° 39′	200	134	Jämtland, Bispfors	+134	—	— 6	71.54	167.6	23.85	10.39	74	*28.46*
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+243	—185	— 4	65.00	152.3	58.08	32.30	91	*35.00*
50	61° 27′	13° 28′	550	127	Kopparberg, Bunkris	+310	—350	+ 1	47.31	110.8	43.46	22.70	137	*52.69*
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+738	— 25	—37	86.92	203.6	71.15	22.69	34	*13.08*
86	49° 45′	11° 33′	450	198	Germany, Oberfr.-Bayern, Pegnitz	+1612	—250	—70	100.0	234.2	1.15	—	—	
103	61° 28′	17° 08′	5	154	Gävleborg, Långvind	+308	+195	—26	92.31	216.2	10.00	1.93	20	*7.69*

of PRs to drought. The most susceptible to drought appeared to be southern PRs 85, 82 and 72, whereas the northern and upland PRs 10, 21 and 51 were more hardy. This proves once again the well-known fact that the resistance of PRs to drought and their resistance to cold are similar.

PR 85 (Germany) and other sensitive PRs suffered from cold in the winter of 1958 and 1961. The acceleration in death-rates in 1963 was due to the BSG of 1961. No dieback of the plant tops was registered on this EP. However, on the whole the death-rate in plants after 1956 was negligible.

The CM diagram shows how consistently the position of PR curves changed after 1956, that is, after the drought of 1955 and after the chance agents of the initial years ceased to influence the adaptation of PRs. PRs 21, 10, 40, 53 and 82 clearly illustrate this fact.

Experimental plantation 17. Figs. 40 A, B I and B II. Table 6

The site of the EP is surrounded by pine forest. It is located in flat country, where spring and summer frosts occur frequently. Plant growth was unfavourably influenced by heavy heaving of plants in spring. Of all EPs only this one has such site characteristics. Losses of plants due to their heaving were considerable in 1955 and 1957, but even during other years the death-rate was influenced in this manner.

The cause of the high death-rate of 1956 was the summer drought of 1955. The winter cold and spring frost of 1958 and 1959 killed many plants, which resulted in high death-rates, particularly among sensitive PRs. BSG was manifested conspicuously after 1961 and was the cause of death in plants from 1961 to 1964. Here the grade of susceptibility to cold in different PRs stands out conspicuously. PR 103 makes an exception, since 82% of the plants perished already in 1956. However, the plants that survived showed a greater resistance to cold during the following years. A similar trend, which will be discussed later, was noticeable in other PRs on EPs.

PR 86 (Germany) perished completely during the second and the third initial years. In the diagrams CM rate curves of PRs 42, 50 and 74 differ from the others. The plants of these PRs were grown in a nursery in the province of Stockholm and were more vigorous than the plants belonging to other PRs grown in a nursery in the province of Västernorrland (Chap. 1.1). However, these vigorous plants showed greater hardiness to cold only during some initial years, but not later. The CM curves changed their direction already in 1958, and particularly in 1961. It should be stressed that PRs with more vigorous plants showed this particular tendency also on other EPs, where plants were supplied from different nurseries.

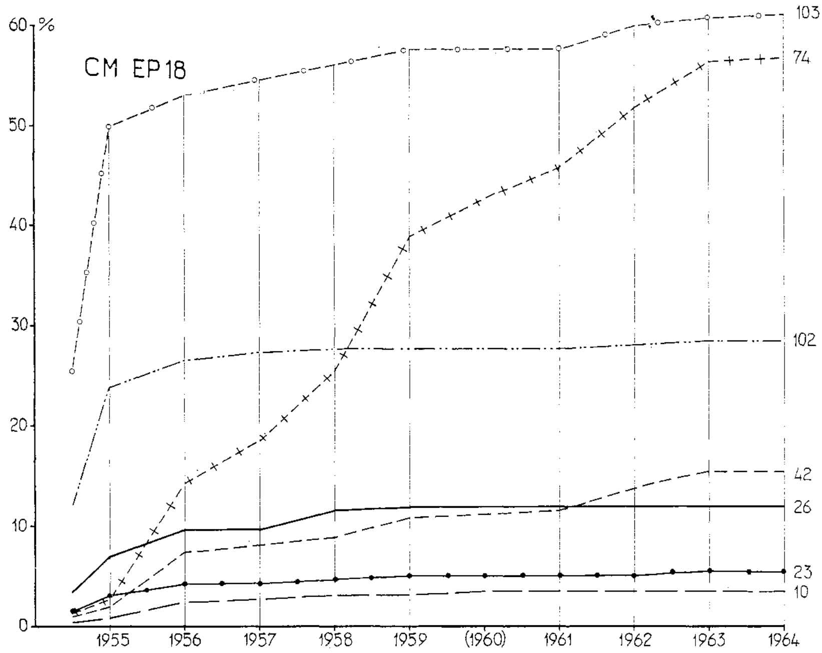


Fig. 41 A. CM of 7 PRs in EP 18 (see Table 7).

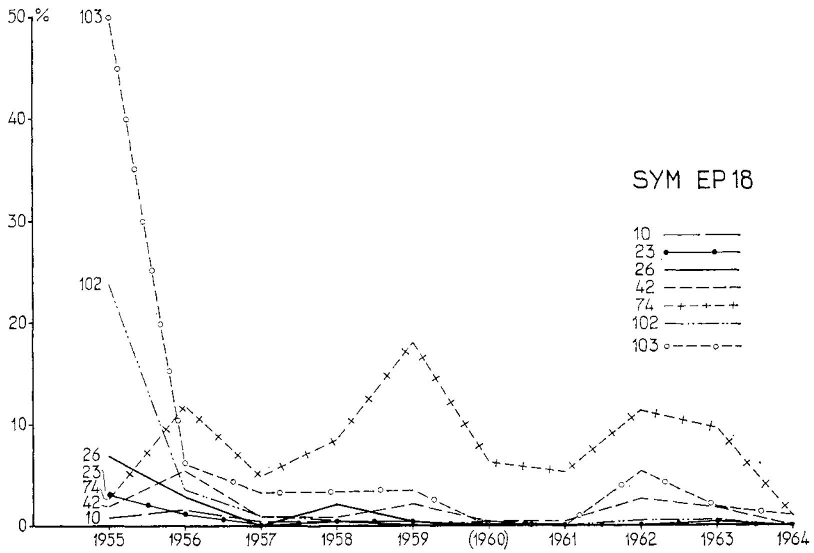


Fig. 41 B. SYM of 7 PRs in EP 18 (see Table 7).

Table 7. Experimental plantation 18. Västerbotten, Robertsfors. φ: 64° 12′, λ: 20° 48′, H_s: 50, Y: 136.

No.	PR φ	PR λ	PR H_s	PR Y	PR Locality	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1964 N %
10	66° 50′	23° 09′	185	114	Norrbotten, Korpilombolo	—293	—135	+22	3.46	29.0	1.15	0	251 *96.54*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	—104	—255	+18	5.38	45.1	1.15	0.38	246 *94.62*
26	64° 12′	20° 48′	50	136	Västerbotten, Robertsfors	—	—	—	11.92	100.0	2.30	0	229 *88.03*
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+239	—335	+ 4	15.38	129.0	8.09	4.23	220 *84.62*
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+735	—175	—29	56.92	477.5	42.69	4.23	112 *43.08*
102	65° 08′	16° 32′	450	111	Västerbotten, Långsjöby, Rönnhagen	—104	—400	+25	28.46	238.8	1.92	0.77	186 *71.54*
103	61° 28′	17° 08′	5	154	Göteborg, Långvind	+304	+ 45	—18	61.15	513.0	8.07	3.46	101 *38.85*

Experimental plantation 18. Fig. 41 A and B. Table 7

This EP is situated on a woodland plain in the coastal district of the Gulf of Bothnia.

Frequencies of losses in plants in the summer of 1954 were great among PRs 103 and 102, which is seen from the death-rates of 1955. Losses were caused due the deterioration of the quality of plants during transportation from the nursery to the EP site, but possibly the inbreeding depression was the primary cause. Beginning with 1955 the influence of chance agents disappears and the trend of the CM curves expresses the adaptation for survival of these PRs. In this connection PR 102 is similar to PRs 23 and 10, while PR 103 is similar to PR 42, which is clearly seen when comparing the SYM rates in these PRs.

Death-rates in single years were manifested as follows: The cause of high values in death-rates in 1956 was the summer drought of 1955 and also, to a certain extent, the spring frosts of 1956. It was almost impossible to distinguish the cause of death in dead individuals. The winter cold and spring frost of 1958 and 1959 were the cause of increased death-rates during these years. Cold damage of 1960/61 resulted in comparatively high death-rate values in 1962 and 1963. The only type of damage in this case was BSG. The consequences of this damage ceased in 1964. It is of interest to note that spring frost injuries of 1963 occurred only seldom on this EP and frost did not cause dieback of the trees cankered in 1961.

Experimental plantations where extensive cold damage occurred in 1960/61 (Subregion II:2)

Experimental plantation 22. Fig. 42 A and B. Table 8

The above EP is located in the coastal district of the Gulf of Bothnia on a gentle SE slope and is surrounded by spruce forest. The site of the EP is a frost locality.

In 1955 death-rates in plants were the result of the autumn frost of 1954 and of the cold during the winter of 1954/55 (PRs 47 and 34). The drought of 1955 was of no consequence as regards losses, but on the other hand, the spring frosts of 1956 influenced the death-rate values of PRs 47 and 34 in 1956.

The death-rate among sensitive PRs was due to spring frost and winter cold in 1958 and 1959. The winter cold of 1960/61 was the cause of high death-rates among several PRs, mostly among those susceptible to cold. Damage was manifested exclusively as BSG.

In PRs 47 and 34 the severe spring frosts of 1963 killed those plants which

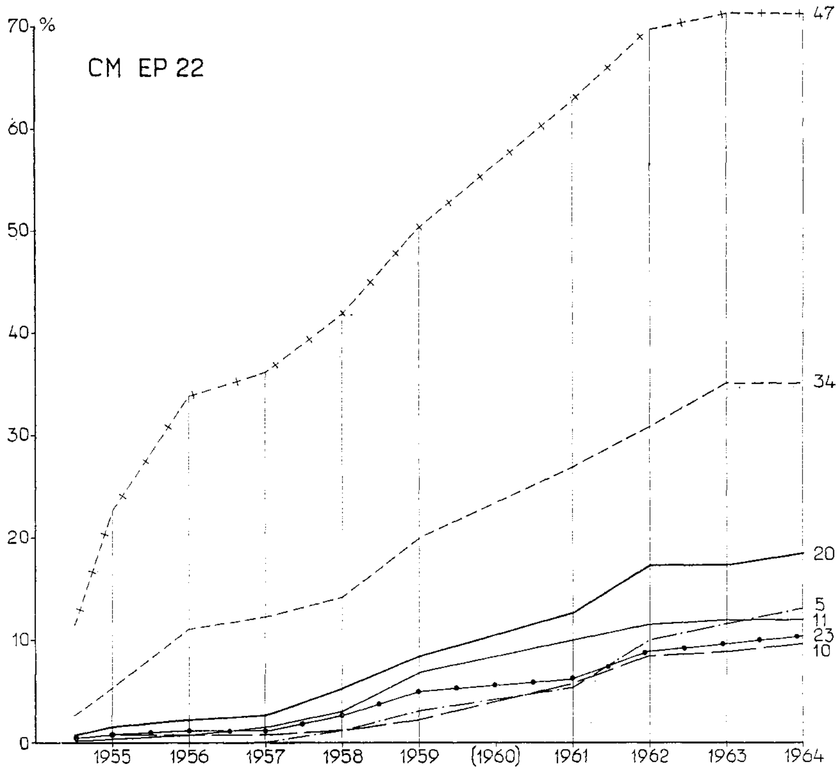


Fig. 42 A. CM of 7 PRs in EP 22 (see Table 8).

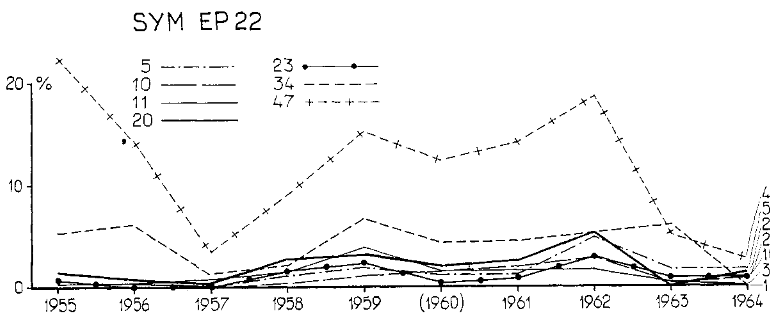


Fig. 42 B. SYM of 7 PRs in EP 22 (see Table 8).

Table 8. Experimental plantation 22. Norrbotten, Älvsbyn, Asplövberg. φ: 65° 38′, λ: 21° 07′, H_s: 60, Y: 127.

No.	PR φ	PR λ	PR H_s	PR Y	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1964 N / %
5	68° 11′	15° 35′	10	115	—284	+ 50	+12	13.08	70.9	13.08	8.85	226
	Norway, Tranöy											*86.92*
10	66° 50′	23° 09′	185	114	—134	— 125	+13	9.62	52.1	8.85	5.77	235
	Norrbotten, Korpilombolo											*90.38*
11	67° 09′	20° 49′	330	105	—169	—270	+22	11.92	64.6	11.15	3.46	229
	Norrbotten, Gällivare											*88.08*
20	65° 38′	21° 07′	75	127	—	— 15	—	18.46	100.0	16.15	8.08	212
	Norrbotten, Älvsbyn, Asplövberg											*81.54*
23	65° 08′	18° 53′	305	118	+ 56	—245	+ 9	10.38	56.2	9.23	5.00	233
	Västerbotten, Malå, Strömfors											*89.62*
34	63° 15′	18° 47′	8	144	+265	+ 52	—17	35.00	189.6	23.85	11.54	169
	Västernorrland, Örnsköldsvik, Alfredshem											*65.00*
47	61° 49′	15° 46′	155	145	+425	— 95	—18	71.92	389.6	38.07	15.38	73
	Jämtland, Färila, Korskrogen											*28.08*

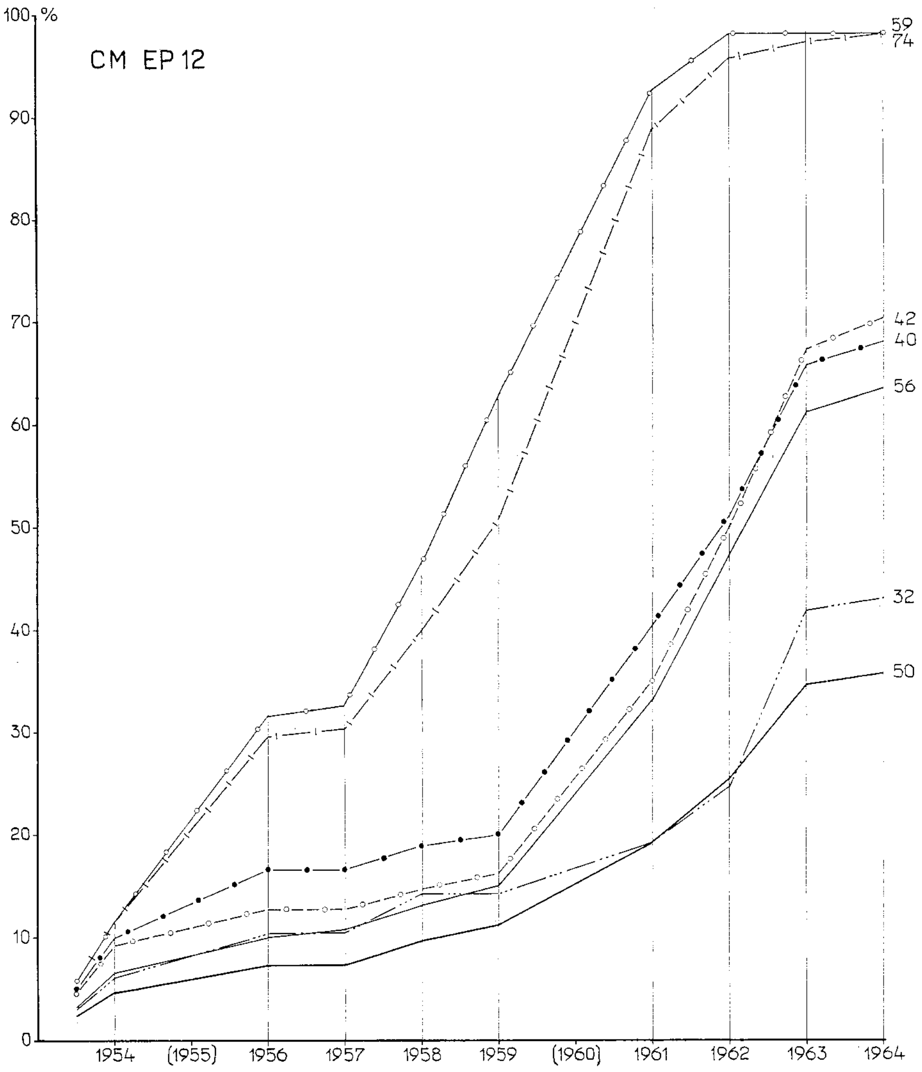


Fig. 43 A. CM of 7 PRs in EP 12 (see Table 9).

were already damaged and, having been checked in their development, had remained in the ground air zone. The frequencies of frost injuries among other PRs were rather great. However, damage was limited to the dieback of the leaders and lateral branches and did not influence death-rates in plants. Plants in these PRs had grown away from the dangerous ground air zone.

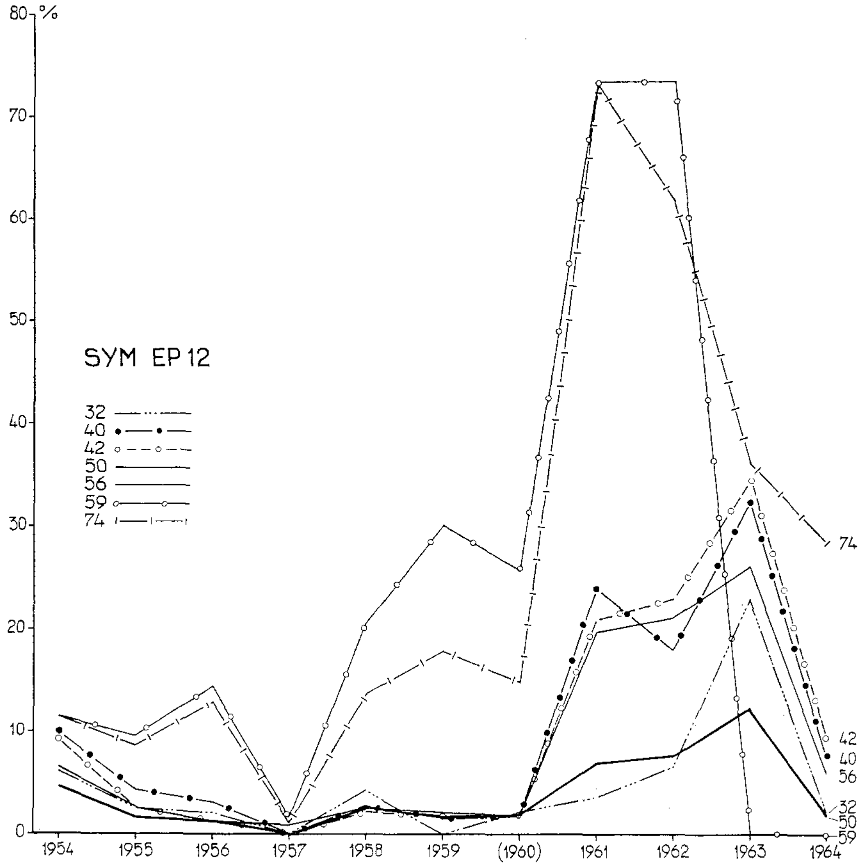


Fig. 43 B. SYM of 7 PRs in EP 12 (see Table 9).

Experimental plantation 12. Fig. 43 A and B. Table 9

This EP is located on an upland plateau. To the west from the site of the EP rises a narrow ridge of a hill, which protects EP from westerly winds, but at the same time acts as a snow shelter and influences an uneven distribution of snow on the EP area. The undulating ground surface increases in its turn the variation in the depth of the snow cover. This EP is one of those which, after a successful start, was most promising. However, the situation changed radically after the winter of 1960/61.

It should be noted that no chance agents influenced death-rates on this EP. On both diagrams death-rate curves show the same PR arrangement in 1954 as in 1963 and 1964. This arrangement shows differences in susceptibility

Table 9. Experimental plantation 12. Kopparberg, Bunkris. φ: 61° 27′, λ: 13° 28′, H_s: 575, Y: 125.

No.	PR φ	PR λ / Locality	PR H_s	PR Y	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1961 N %	Living trees 1961 n (%)	Living trees 1961 n_1 (%)	Living trees 1961 $\overline{h}$
32	64° 34′	18° 15′	510	111	—347	+ 65	+14	43.08	120.4	32.70	16.93	210	209	1	123.9 ± 2.44
	Västerbotten, Lycksele, Storberget											*80.77*	*99.52*	*0.48*	
40	62° 12′	17° 42′	5	150	— 83	+570	—25	68.08	190.3	51.54	46.54	155	145	10	127.7 ± 3.22
	Västernorrland, Brämön, Sanna											*59.62*	*93.55*	*6.45*	
42	62° 03′	14° 19′	385	132	— 67	+190	— 7	70.38	196.8	57.69	52.69	169	151	18	132.8 ± 3.12
	Jämtland, Sveg, Malmbäcken											*65.00*	*89.35*	*10.65*	
50	61° 27′	13° 28′	550	127	—	+ 25	— 2	35.77	100.0	28.46	22.69	210	205	5	159.6 ± 2.68
	Kopparberg, Bunkris											*80.77*	*97.62*	*2.38*	
56	59° 35′	07° 50′	550	137	+208	+ 25	—12	63.46	177.4	53.46	46.92	174	155	19	129.6 ± 3.03
	Norway, Vinje, Prästgården											*66.92*	*89.08*	*10.92*	
59	59° 24′	18° 12′	32	165	+228	+543	—40	98.08	274.2	66.54	25.86	19	9	10	158.2 ± 19.46
	Stockholm, Bogesund, Sandvreten											*7.31*	*47.37*	*52.63*	
74	57° 36′	14° 13′	225	165	+429	+350	—40	98.0	274.2	68.46	40.00	29	22	7	134.2 ± 7.04
	Jönköping, Eckersholm											*11.15*	*75.86*	*24.14*	

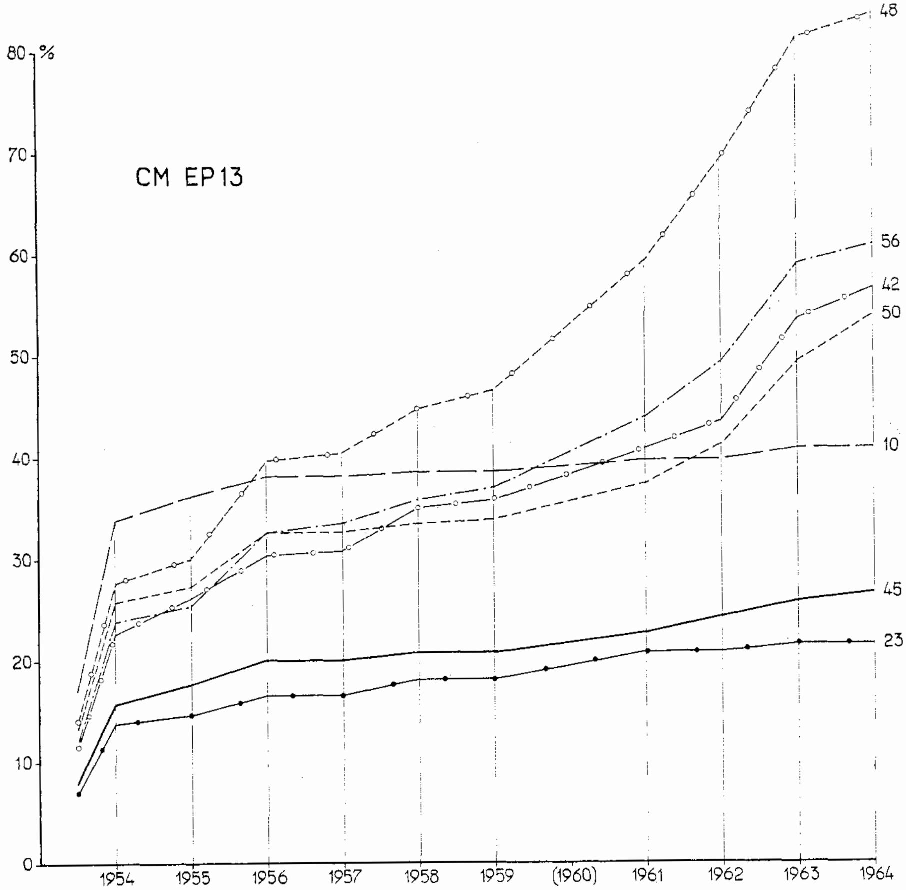


Fig. 44 A. CM of 7 PRs in EP 13 (see Table 10).

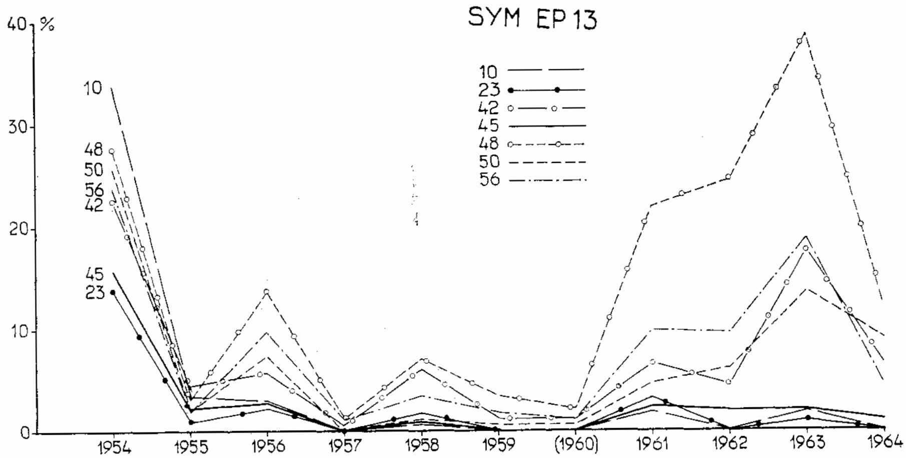


Fig. 44 B. SYM of 7 PRs in EP 13 (see Table 10).

Table 10. Experimental plantation 13. Kopparberg, Idre, Himmeråsen. φ: 61° 54′, λ: 12° 47′, H_s: 765, Y: 113.

No.	PR φ	PR λ	PR H_s	PR Y	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1964 N %
	Locality											
10	66° 56′	23° 11′	200	113	—560	+565	—	40.77	153.6	2.69	2.31	154 *59.23*
	Norrbotten, Korpilombolo, Ohtanajärvi											
23	65° 08′	18° 53′	305	118	—360	+460	— 5	21.54	81.2	5.00	3.46	204 *78.46*
	Västerbotten, Malå, Strömfors											
42	62° 03′	14° 19′	385	132	— 17	+380	—19	56.54	213.0	26.15	20.00	113 *43.46*
	Jämtland, Sveg, Malmbäcken											
45	61° 54′	12° 51′	850	109	—	— 85	+ 4	26.54	100.0	6.54	5.77	191 *73.46*
	Kopparberg, Grängesåsvallen, Städjan											
48	61° 08′	16° 31′	150	149	+ 85	+615	—36	83.46	314.5	43.84	25.77	43 *16.54*
	Gävleborg, Kilafors, Hemstanäs											
50	61° 27′	13° 28′	550	127	+ 50	+215	—14	53.85	202.9	21.16	19.62	120 *46.15*
	Kopparberg, Bunkris											
56	59° 35′	07° 50′	550	137	+258	+215	—24	60.77	229.0	28.08	23.08	102 *39.23*
	Norway, Vinje, Prästgården											

of PRs to cold. SYM rates reveal a consistent repetition of PR arrangement during all years. As regards SYM rates it might be said that the death-rates of 1956 were caused by the drought of 1955 and by the cold winter in 1954/55. BSG was recorded in some plants. The cause of death-rates in 1958 and 1959 was the winter cold of 1958 and possibly the spring frost of 1959.

However, principal losses in plants occurred after 1960/61, when all types of damage were manifested (Chap. 3.1). BSG dominated, and also decided the fate of the trees. Two of seven PRs, local PR 50 and PR 32, were only slightly damaged and had a similar CM rate. However, it would be too precipitous to conclude that the resistance to cold of these two PRs was identical. When comparing the two PRs, it should be mentioned that the tree growth in PR 32 was slower than in PR 50. On account of the small size of the trees and their thinner bark, PR 32 was more liable to BSG. On the other hand, PR 50 had greater chances to escape damage owing to the greater size of the trees. PRs 40, 42 and 56 suffered heavily, but there are no significative differences between them. In PRs 39 and 79 only a few individuals survived until the autumn of 1964. Actually the effect of cold damage ceased in 1964, which is reflected in death-rate curves. The reasons for the negative excess of death-rates in 1962 can be explained technically; dead individuals recorded in the autumn of 1961 were added to the number of individuals which had perished in the spring of 1961, thus increasing death-rate values in 1961.

Experimental plantation 13. Fig. 44 A and B. Table 10

The above EP is situated on an upland plateau, not far from the timberline, on a vast deforested area, which was formed after repeated wood fires. It is protected against north-westerly and westerly winds by the hill known as Himeråsen. The site of the plantation is surrounded by areas of heath and moorland, on which pine clusters grow here and there. Edaphic conditions are characterized by a raw humus, which covers the upper layer of the podsolised soil. Under such circumstances the growth of the trees was slow and only in exceptional cases did their height exceed 1 metre in 1961.

Death-rates in plants in 1954 show the variable susceptibility of the PRs to cold. However, the PR arrangement was influenced by the attacks of *Hylobies abietis* and by the summer drought of 1953. The winter cold of 1954/55 had no effect on the EP.

Positive excesses stand out clearly in SYM rate curves representing all PRs in 1956, 1958, and 1961—1963. With insignificant exceptions, the PR arrangement remained unchanged during all these years. High frequencies of losses in plants during these years were caused by the same factors as on EP 12 (See EP 12). Death-rate in plants in 1956 was the result of the drought

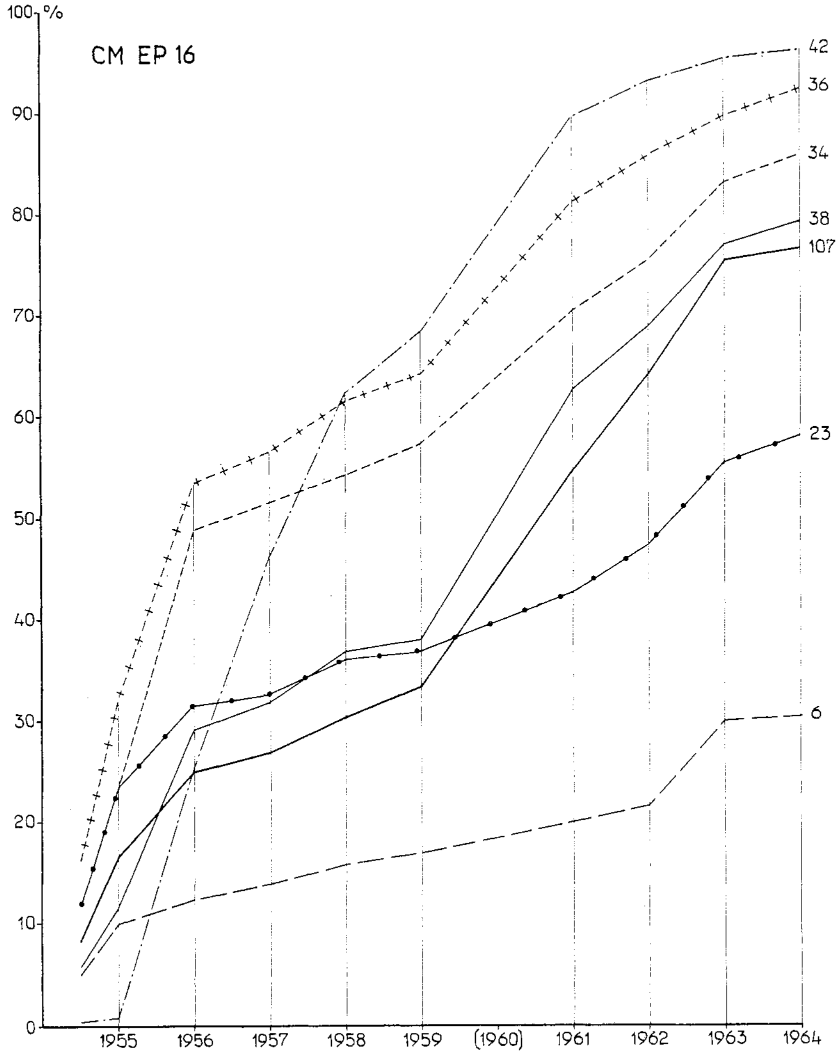


Fig. 45 A. CM of 7 PRs in EP 16 (see Table 11).

of 1955 and possibly also of the spring frost of 1956. Losses in plants in 1958 were caused by winter cold and the spring frost. It is of interest to note that effects of the cold damage of 1958 were manifested in high death-rates also in 1959.

From 1961 to 1963 all PRs, and particularly those susceptible to cold, had definitely high death-rates. SYM rates during these years were even higher than in 1954, that is, higher than during the first year after the EP had been

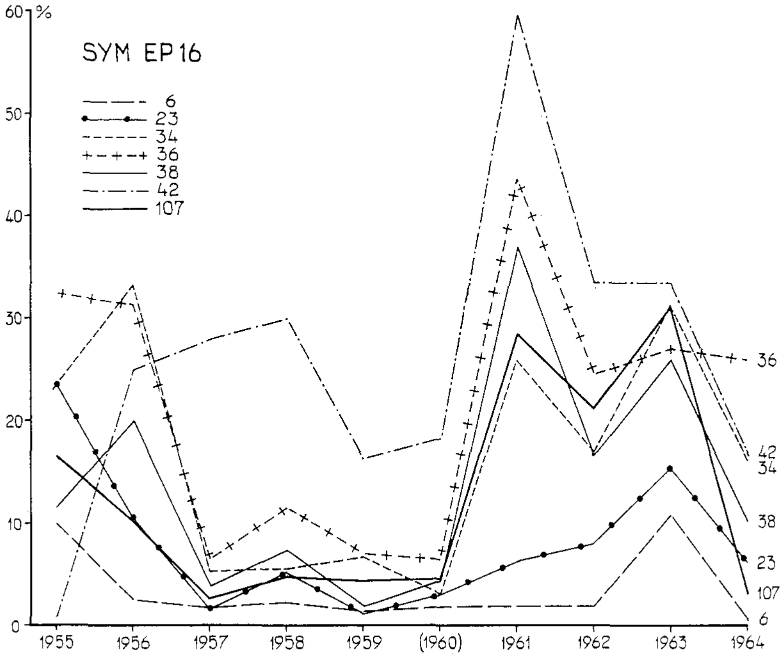


Fig. 45 B. SYM of 7 PRs in EP 16 (see Table 11).

laid out. The effects of cold damage of the 1960/61 winter are clearly seen. However, they ceased almost completely in 1964. Among all types of cold damage in 1961 only BSG was manifested. The position of the damage was exclusively at the butt of the tree. It should be mentioned that SYM rates show two positive excesses, in 1961 and in 1963, and one negative excess in 1962. This phenomenon can be explained by the severe spring frosts of 1963, which caused dieback of the plant top (Chap. 3.1.2) as well as the death of girdled and heavily cankered trees.

When comparing the CM curves (Fig. 44 A), it may be said that PRs 10, 23 and 45 show a great similarity. The same applies to PRs 42, 50 and 56; they do not reveal any significative differences, but the coastal PR 48 was badly damaged.

Experimental plantation 16. Fig. 45 A and B and Fig. 46. Table 11

The EP is situated on the top of an uneven and undulating hill. The ground surface of the EP area is also slightly undulating. The site is exposed to north-westerly and easterly winds. Topography and small scattered spruce and pine stands which surround the EP promote uneven piling up of the

Table 11. Experimental plantation 16. Jämtland, Bispgården, Torresjölandet. φ: 63° 08′, λ: 16° 39′, H_s: 470, Y: 121.

No.	PR φ	PR λ	PR H_s	PR Y	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1961 N %	Living trees 1961 n (%)	Living trees 1961 n_1 (%)	Living trees 1961 $\bar{h}$ 1961
6	67° 45′	23° 22′	225	107	—514	+245	+14	30.38	39.7	18.07	11.92	208	200	8	58.4 ± 1.65
	Norrbotten, Kitkiöjoki											*80.00*	*96.15*	*3.85*	
23	65° 08′	18° 53′	305	118	—223	+165	+ 3	58.08	75.9	26.54	19.23	149	144	5	66.9 ± 1.77
	Västerbotten, Malå, Strömfors											*57.31*	*96.64*	*3.36*	
34	63° 15′	18° 47′	8	144	— 13	+462	—23	85.77	112.1	36.92	25.77	77	66	11	48.8 ± 2.24
	Västernorrland, Örnsköldsvik, Alfredshem											*29.62*	*85.71*	*14.29*	
36	63° 02′	16° 39′	200	134	+ 11	+270	—13	92.31	120.6	38.85	25.77	49	31	18	42.2 ± 2.26
	Jämtland, Bispfors											*18.85*	*63.28*	*36.72*	
38	63° 10′	13° 04′	540	117	— 4	— 70	+ 4	79.23	103.5	50.00	38.46	97	67	30	47.6 ± 2.49
	Jämtland, Vallbogården											*37.31*	*69.07*	*30.93*	
42	62° 03′	14° 19′	385	132	+121	+ 85	—11	96.15	125.6	70.77	21.92	27	18	9	70.8 ± 7.92
	Jämtland, Sveg, Malmbäcken											*10.38*	*66.67*	*33.33*	
107	63° 08′	16° 39′	455	122	—	+ 15	— 1	76.54	100.0	51.54	40.00	118	89	29	58.0 ± 1.93
	Jämtland, Bispfors, Torresjölandet											*45.39*	*75.42*	*24.58*	

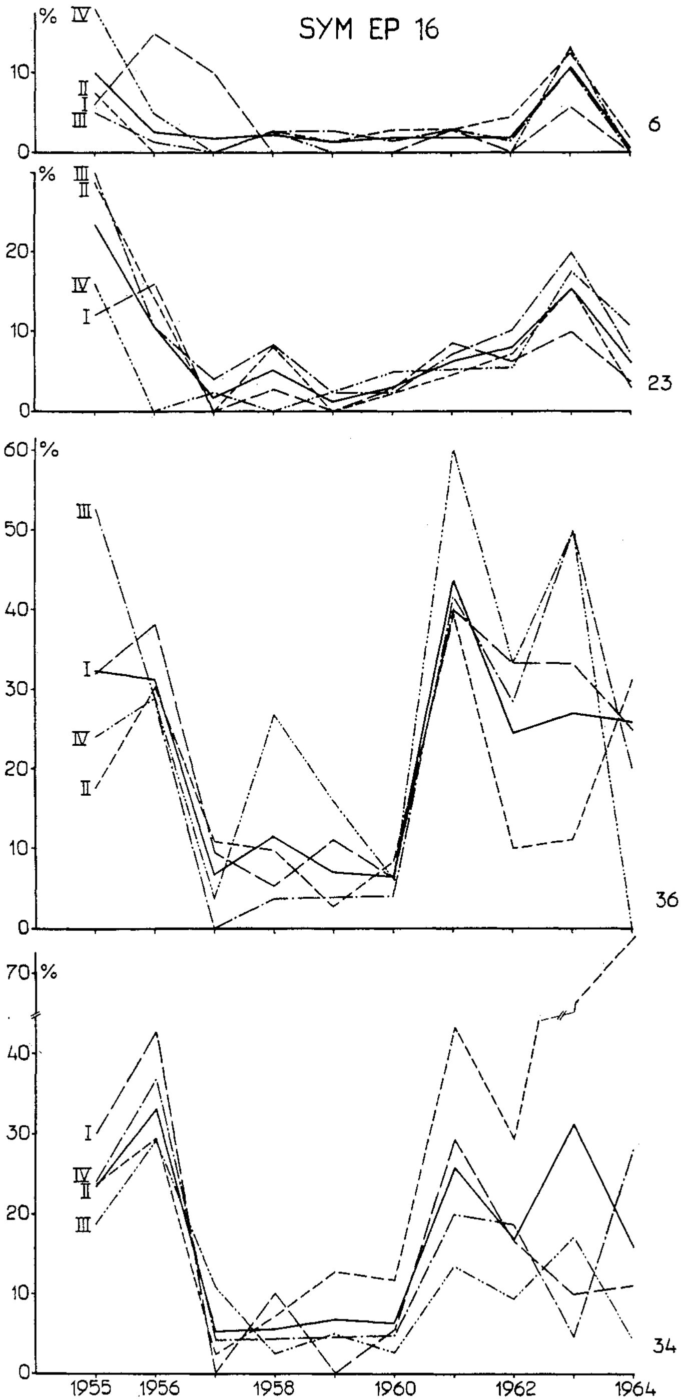


Fig.46. Variation of SYM rates in four replications of PRs 6, 23, 36, 34, 38, 42 and 107 (see Table 11) as well as mean SYM values of each PR in EP 16.

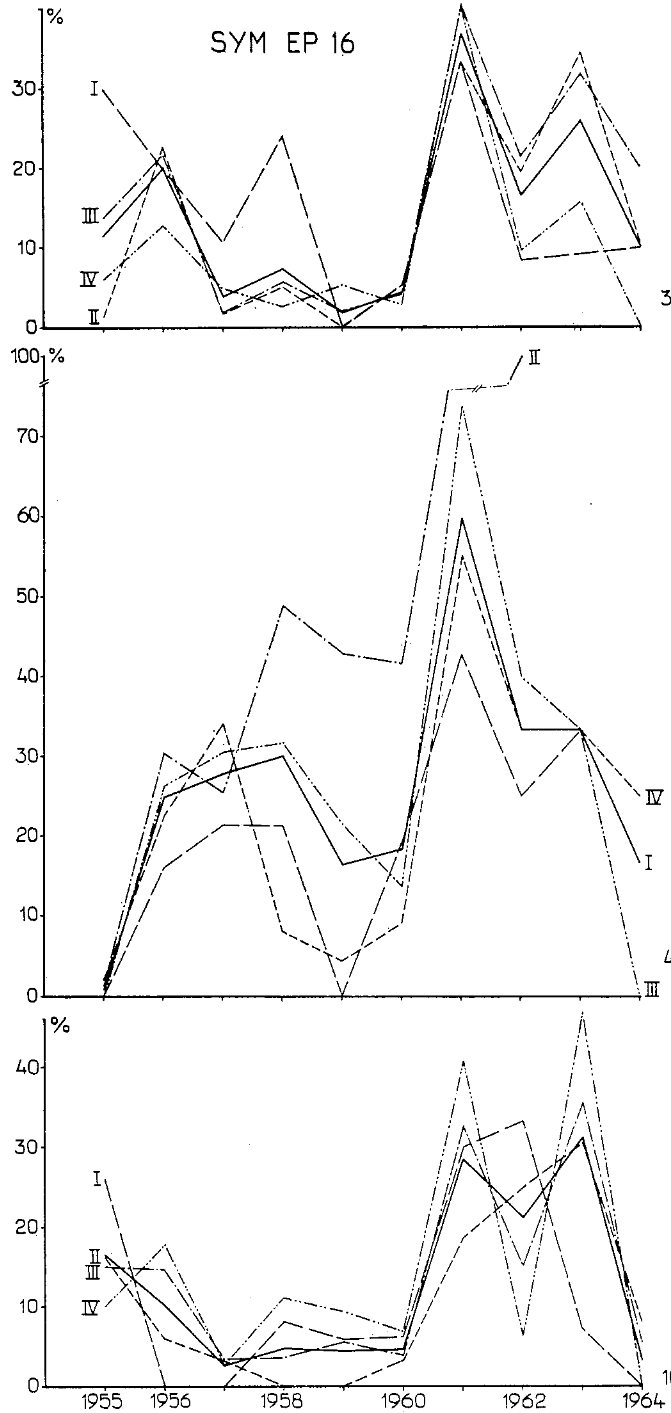


Fig. 46, see p. 108.

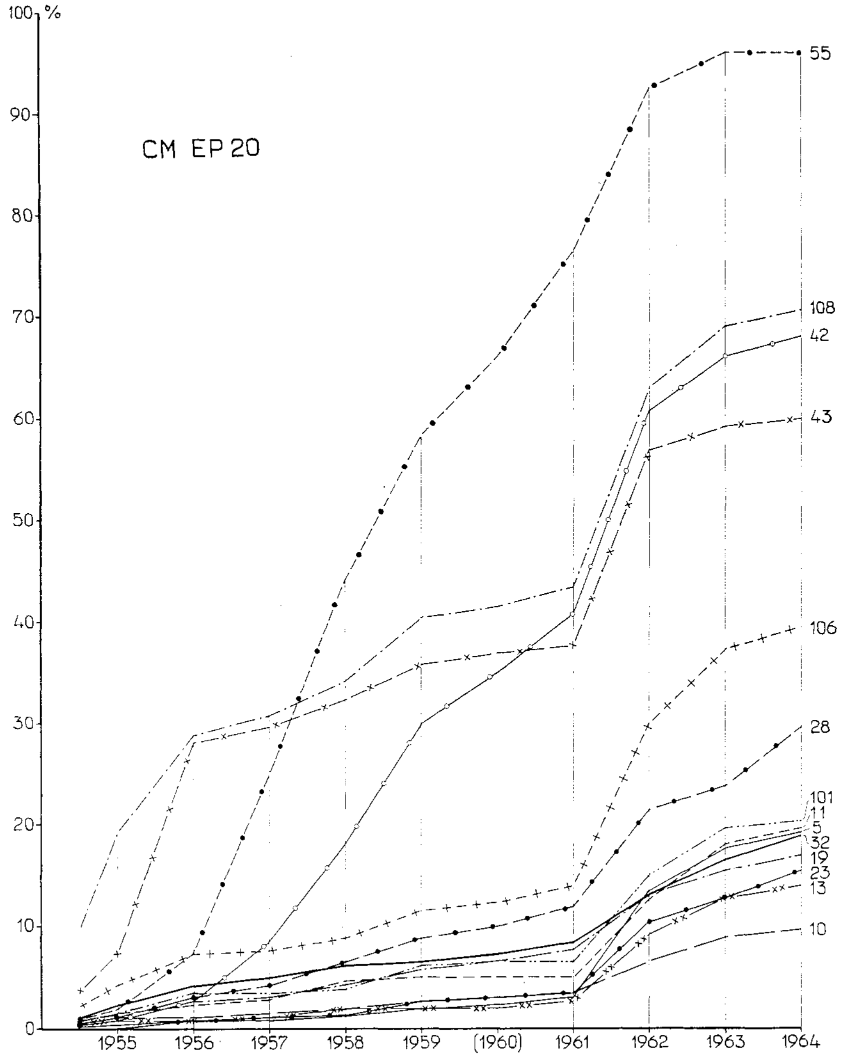


Fig. 47 A. CM of 14 PRs in EP 20 (see Table 12).

snow on the EP area. Insignificant depressions in the ground surface on the EP area, in their turn, contribute to the accumulation of cold air during radiation frosts. This encourages the possibility of the production of cold damage in PRs susceptible to cold. In comparison with other EPs, losses in trees on this EP were most conspicuous.

In 1913 the site of the present EP occupied a clear-felled area, which was

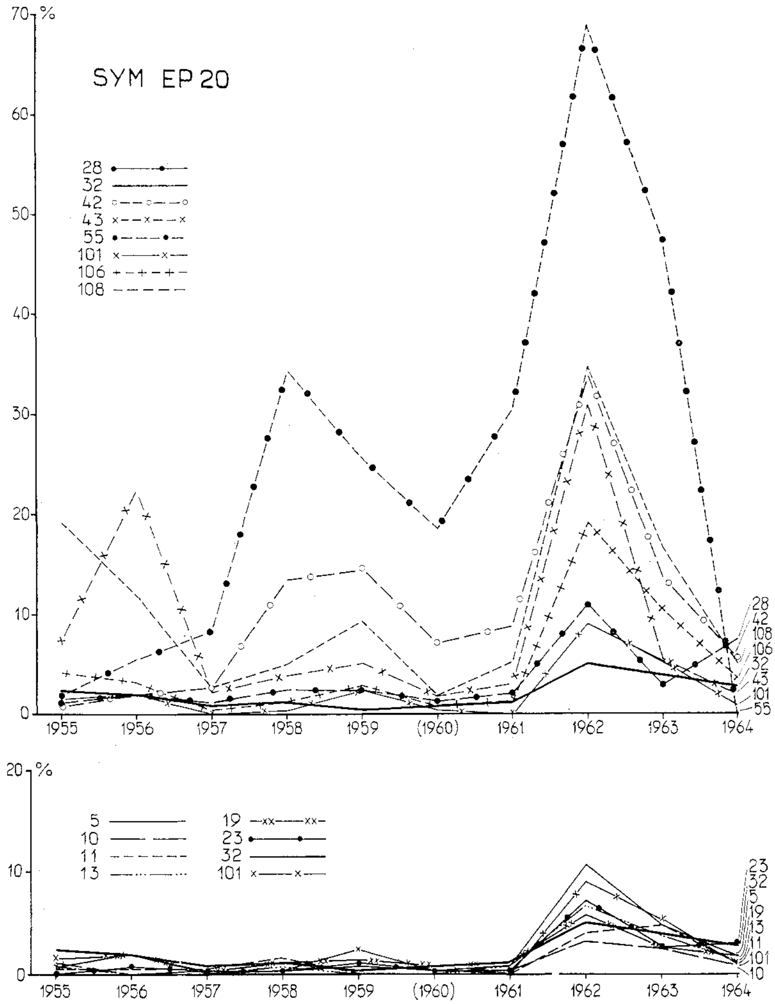


Fig. 47 B. SYM of 14 PRs in EP 20 (See Table 12).

successfully afforested in 1917. However, this plantation perished completely, probably after the severe winter of 1928. In later years repeated afforestation attempts gave poor results. After the winter of 1960/61 the same thing happened to EP 16.

Differences in CM curves are clearly expressed. The curve of PR 42 differs from other curves up to 1958, because stronger plants from the nursery in the province of Stockholm had been used. Beginning with 1958 the position of all curves shows the differences between PRs as regards their susceptibility to cold. After the cold damage of 1960/61 the change in direction of the curves is most conspicuous.

In 1964 CM rate was 77 % in the local PR 107; 79 % in PR 38; 92 % in both PRs 36 and 42. Northern PRs 6 and 23 had suffered least and their CM rates were 30 % and 58 % respectively. The mean height of the trees in these two PRs was greater than in other PRs.

SYM rates are as follows: In 1955 their values were made up of individuals whose mortality was caused by different agents, such as the uneven quality of plants in different PRs in the spring of 1954, the autumn frosts of 1954, BSG and dieback of the plant top in 1955. The high death-rates of 1956 were the result of the drought in the summer of 1955, of the die-out of plants caused by BSG in 1955 and of spring frost injuries in 1956. In 1958 the causes of death in plants were winter cold and spring frost. From 1961 to 1964 death-rate was caused by the severe cold damage of 1960/61. All types of injuries were recorded on this EP. However, in trees which had reached the age of 10—14 years, BSG proved to be the only cause of death (Figs. 4 and 26). In 1964 death-rate values diminished. In 1961 and 1963 they showed positive excess, and in 1962 negative excess. Technical causes partly account for this. In the spring of 1961, when killed individuals were recorded, the plants which had been registered as dead in the August and September check-up were also added to their values.

The positive excess of the death-rates in 1963 might be explained by the accelerated dieback of girdled and cankered individuals, due to the severe spring frosts of 1963. This tendency was most conspicuous in northern PRs and was observed also on other EPs. On EP 16 the variation of the frequencies of losses among PRs in four replications (Fig. 46) is considerable, which is particularly true as regards PRs susceptible to cold. This might be explained by the different site conditions of the replications, as well as by the insignificant number of trees which had survived. The deviation in the death-rate of replications from the mean values of the PRs, however, is not of such a nature as to influence the conclusions arrived at in the PR experiment.

Experimental plantation 20. Figs. 47 A, B I and B II. Table 12

The EP is situated on the top of Storberget hill, with undulating surface. The site of the EP is mainly exposed to westerly and south-easterly winds. Both its topography and small adjacent spruce stands induce uneven accumulation of snow. To the east of the EP lies a swampy valley, where cold air amasses during frost periods. The depth of snow cover in the winter of 1960/61 can be ascertained by the position of the girdle on the stems of the trees. The excessive piling up of the snow on the lee-side in one of the replication corners

Table 12. Experimental plantation 20. Västerbotten, Lycksele, Storberget. φ: 64° 33′, λ: 18° 15′, H_s: 555, Y: 109.

No.	PR: φ	λ	H_s	Y	Transfer of PR: φ km	H_s m	Y	CM 1964: %	R	Diff. CM: 1964—1956 %	1964—1960 %	Living trees 1963: N %	n (%)	n_1 (%)	$\bar{h}$ 1961	$\bar{h}$ 1962	$\bar{h}$ 1963
5	68° 11′	15° 35′	10	115	—404	+545	— 6	19.23	102.0	18.46	16.92	214	194	20	59.80 ± 1.28	73.77 ± 1.53	84.01 ± 1.66
	Norway, Tranöy											*82.31*	*90.65*	*9.35*			
10	66° 53′	23° 03′	175	114	—260	+380	— 5	9.62	51.0	8.47	6.54	237	221	16	80.66 ± 1.32	97.93 ± 1.57	111.99 ± 1.72
	Norrbotten, Korpilombolo, Smedberg											*91.15*	*93.25*	*6.75*			
11	67° 14′	20° 29′	470	98	—299	+ 85	+11	12.78	104.1	10.47	9.45	213	205	8	80.33 ± 1.50	96.85 ± 1.75	110.38 ± 1.92
	Norrbotten, Gällivare, Linalombolo											*81.02*	*96.24*	*3.76*			
13	66° 18′	14° 10′	75	123	—195	+480	—14	13.85	73.5	13.08	11.93	227	212	15	77.48 ± 1.45	93.59 ± 1.69	105.96 ± 1.80
	Norway, Mo i Rana, Båsmo											*87.31*	*93.39*	*6.61*			
19	65° 50′	23° 18′	30	128	—143	+525	—19	16.92	89.8	14.23	10.38	220	206	14	87.81 ± 1.65	105.93 ± 1.94	119.66 ± 2.13
	Norrbotten, Kalix, Mörtträsk											*84.62*	*93.64*	*6.36*			
23	65° 08′	18° 53′	305	118	— 65	+250	— 9	15.38	81.6	14.61	12.30	227	206	21	92.17 ± 1.49	110.89 ± 1.71	124.89 ± 1.86
	Västerbotten, Malå, Strömfors											*87.31*	*90.75*	*9.25*			
28	64° 14′	19° 43′	200	128	+ 35	+355	—19	29.62	157.1	26.54	19.62	198	177	21	81.79 ± 1.88	100.63 ± 2.14	115.10 ± 2.33
	Västerbotten, Vindeln, Svartberget											*76.15*	*89.39*	*10.61*			
32	64° 34′	18° 15′	525	110	— 2	+ 30	— 1	18.84	100.0	14.61	11.53	217	206	11	76.33 ± 1.50	94.71 ± 1.78	107.98 ± 1.93
	Västerbotten, Lycksele, Storberget											*83.46*	*94.93*	*5.07*			
42	62° 03′	14° 19′	385	132	+278	+170	—23	68.08	361.2	65.39	33.08	88	77	11	101.44 ± 3.03	120.18 ± 3.58	133.71 ± 3.90
	Jämtland, Sveg, Malmbäcken											*33.85*	*87.50*	*12.50*			
43	61° 53′	12° 44′	550	124	+297	+ 5	—15	60.00	318.4	31.92	23.08	106	100	6	62.98 ± 2.47	79.54 ± 2.88	91.41 ± 3.15
	Kopparberg, Idre											*40.77*	*94.34*	*5.66*			
55	60° 16′	15° 06′	325	145	+477	+230	—36	96.15	510.2	88.84	30.00	10	9	1	61.89 ± 9.15	77.44 ± 11.95	88.44 ± 12.74
	Kopparberg, Grangärde											*3.85*	*90.00*	*10.00*			
101	66° 03′	17° 57′	460	105	—167	+ 95	+ 4	20.38	108.2	16.92	13.84	209	196	13	72.72 ± 1.60	89.49 ± 1.81	102.91 ± 1.95
	Norrbotten, Arjeplog											*80.38*	*93.78*	*6.22*			
106	64° 18′	15° 23′	360	120	+ 28	+195	—11	39.62	210.2	32.31	27.31	163	147	16	77.50 ± 1.86	94.67 ± 2.22	108.09 ± 2.48
	Jämtland, Harrsjön											*62.69*	*90.18*	*9.82*			
108	62° 10′	17° 27′	5	150	+265	+550	—41	70.77	375.5	41.92	29.23	80	70	10	57.20 ± 1.87	71.26 ± 2.16	81.39 ± 2.33
	Västernorrland, Galtström											*31.77*	*87.50*	*12.50*			

of the EP caused heavy losses in plants in the hardy northern PR 11. The coincidence of BSG with the piling up of the snow on the EP is most striking.

At the outset the EP was a success, and in October 1954 only 3 % average losses in plants were recorded. No chance losses in plants occurred and time-mortality curves consistently show different resistance of PRs to cold. Up to 1957 PRs 42 and 55 greatly differed from the others, as strong transplants from the nursery in the province of Stockholm had been planted, whereas plants of other PRs had been grown in the province of Västernorrland, in northern climatic conditions. However, already in 1957 the direction of the PR curves 42 and 55 changed and in the following years they occupied the position among the curves of the other PRs which corresponded to their susceptibility to cold. Up to 1961 the CM rates for all northern PRs, including local PR 32 as well as PRs 23 and 106, were negligible. But, from the very beginning, the position of the curves of the southern PRs 43 and 108 were different. The direction of all PR curves changed suddenly in 1961, in connection with the occurrence of severe cold damage, when trees on the EP were 10 years old. BSG was the principal type of injury responsible for the death of trees. However, other types of cold damage were also represented. Damage by snow in the upper part of the crowns of the trees showed great frequencies. The position of the damage by snow above the ground level coincided with the maximal depth of the snow cover in the winter of 1960/61 (Chap. 3.1.3).

Up to 1961 SYM rates in all northern PRs as well as in the local PR 32 (Fig. 47 B I) were insignificant. For all PRs without exception, the BSG of 1961 was the cause of positive excess which reached its culmination in 1962 in the SYM rate curves. In 1964 SYM rates obtained almost the same values which the PRs had in 1961. However, BSG occurred in non-hardy PRs 43 and 108 (Fig. 47 B II) already in 1955, causing high frequencies of losses in 1956. The summer drought of 1955 did not affect the EP in any way. The weather conditions in the winter of 1958 caused new injuries, resulting in accelerated death-rate values in 1958 and 1959. Already in June of 1961 killed trees in PRs susceptible to cold were recorded, due to the combined effect of BSG and dieback of the plant top.

In October 1964 it was possible to ascertain that the dieback of trees caused by BSG had ceased. All PRs susceptible to cold had greatly suffered. CM rates in PR 55 were 96 %, in PRs 42, 43 and 108 from 60 % to 70 %, in PRs 28 and 106 from 30 % to 40 %, but in hardy PRs mortality rates were only from 10 % to 20 %. The healing of wounds and recovery of the damaged trees proceeded successfully, and on some of the cankered trees no external signs of damage could be noticed. Evidently the spring frosts of 1963 had no retarding effect on the recovery of injured trees.

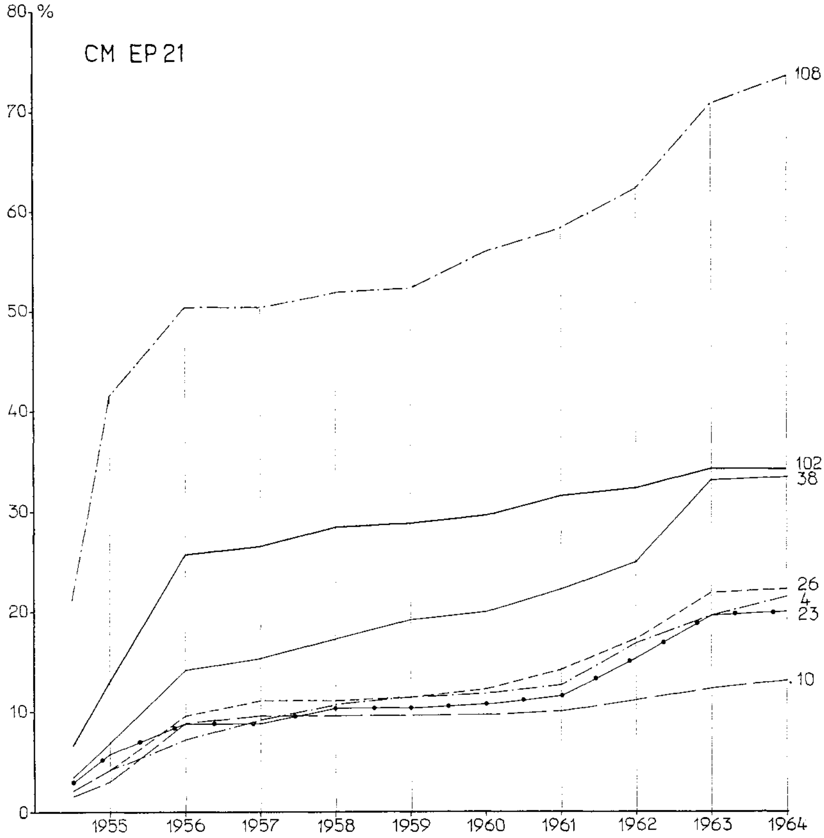


Fig. 48 A. CM of 7 PRs in EP 21 (see Table 13).

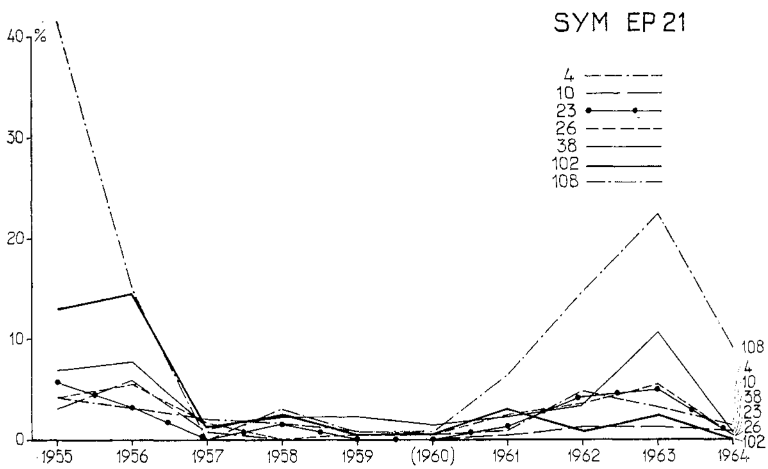


Fig. 48 B. SYM of 7 PRs in EP 21 (see Table 13).

Table 13. Experimental plantation 21. Västerbotten, Långsjöby, Rönnhagen. φ: 65° 09′, λ: 16° 33′, H_s: 465, Y: 110.

PR					Transfer of PR			CM 1964		Diff. CM		Living trees 1963					
No.	φ	λ	H_s	Y	φ km	H_s m	Y	%	R	1964—1956 %	1964—1960 %	N %	n (%)	n_1 (%)	$\bar{h}$ 1961	$\bar{h}$ 1962	$\bar{h}$ 1963
	Locality																
4	69° 07′	18° 35′	100	105	—441	+365	+ 5	21.54	62.9	14.23	9.62	209	202	7	79.42 ± 1.82	96.89 ± 2.18	109.01 ± 2.46
	Norway, Målselv, Moen											*80.38*	*96.65*	*3.35*			
10	66° 50′	23° 09′	185	114	—187	+280	— 4	13.08	38.2	4.23	3.46	228	226	2	82.90 ± 1.70	102.08 ± 2.01	115.58 ± 2.29
	Norrbotten, Korpilombolo											*87.69*	*99.12*	*0.88*			
23	65° 08′	18° 53′	305	118	+ 2	+160	— 8	20.00	58.4	11.15	9.23	209	205	4	92.33 ± 1.79	114.28 ± 2.14	130.25 ± 2.43
	Västerbotten, Malå, Strömfors											*80.38*	*98.09*	*1.91*			
26	64° 12′	20° 48′	50	136	+106	+415	—26	22.31	65.2	12.69	10.00	203	199	4	101.89 ± 1.82	124.50 ± 2.16	139.89 ± 2.38
	Västerbotten, Robertsfors											*78.08*	*98.03*	*1.97*			
38	63° 10′	13° 04′	540	117	+221	— 75	— 7	33.46	97.8	19.23	13.46	174	163	11	87.34 ± 2.34	108.05 ± 2.80	122.94 ± 3.19
	Jämtland, Vallbogården											*66.92*	*93.68*	*6.32*			
102	65° 08′	16° 32′	450	111	+ 2	+ 15	— 1	34.23	100.0	8.46	4.61	171	168	3	79.89 ± 1.93	100.99 ± 2.32	115.29 ± 2.63
	Västerbotten, Långsjöby, Rönnhagen											*65.77*	*98.25*	*1.75*			
108	62° 10′	17° 27′	5	150	+332	+460	—40	73.46	214.6	23.08	20.00	76	58	18	75.38 ± 3.23	95.88 ± 3.90	108.43 ± 4.38
	Västernorrland, Galtström											*29.23*	*78.94*	*21.06*			

Experimental plantation 21. Fig. 48 A and B and Fig. 49. Table 13

The site of the EP occupies a slight southerly slope on a broken upland plateau. Topography, neighbouring pine afforestations and spruce stands promote the piling up of the snow on the EP area. The EP was a success from the very beginning, and later its development was most satisfactory. During the first years local PR 102 made an exception, due to the fact that the transplants had been weak. Therefore the position of the CM curve of this PR (Fig. 48 A) does not reflect its hardiness. Actually, local PR 102 has more in common with northern PRs 10 and 23 than with the others. This is clearly seen in Fig. 48 B, when SYM rates are compared.

In 1955 frequencies of losses in plants were very high for the coastland PR 108 and rather high for the local PR 102, mentioned above. The cold damage of 1955 and the summer drought of the same year, as well as the spring frosts of 1956, caused losses in plants in 1956. In most cases it was almost impossible to distinguish between the three causes of mortality in plants. The cold of 1958 resulted in insignificant frequencies of losses in plants in all PRs. During the period 1961 to 1964 the BSG of 1961 was the only cause of losses in plants. SYM rates culminated in 1963. However, in some PRs there were two positive excesses in 1961 and 1963. Probably the severe spring frosts of 1963 intensified the dieback of the trees girdled and heavily cankered in 1961. This would explain both the culmination of SYM rates in 1963 and the second positive excess in 1963.

On this EP, just as on all other EPs in mountain districts, BSG occurred close to the ground surface (Fig. 1).

Fig. 49 shows the variation of losses in the PRs in four replications. The deviation of these values from PR mean values is insignificant and it is also insignificant in PRs susceptible to cold. In this connection EP 21, with its moderate variation of CM rates in PR replications, differs from EP 16 (Fig. 46).

Experimental plantation 24. Fig. 50 A and B. Table 14

The site of the EP occupies an elevated position on a large logged-off area, which is part of a vast, high plateau. The EP is exposed to winds coming from all directions. Only a small cluster of pines and spruce grows south-east of the EP.

The development of the EP in the initial years was satisfactory and no chance factors caused any losses in plants. During the first year an insignificant deviation of CM curves was noticed in PR 42 and in PR 101, which substitutes the local PR on this EP. The transplants of PR 42 came from the nursery in the province of Stockholm and were stronger than other specimens.

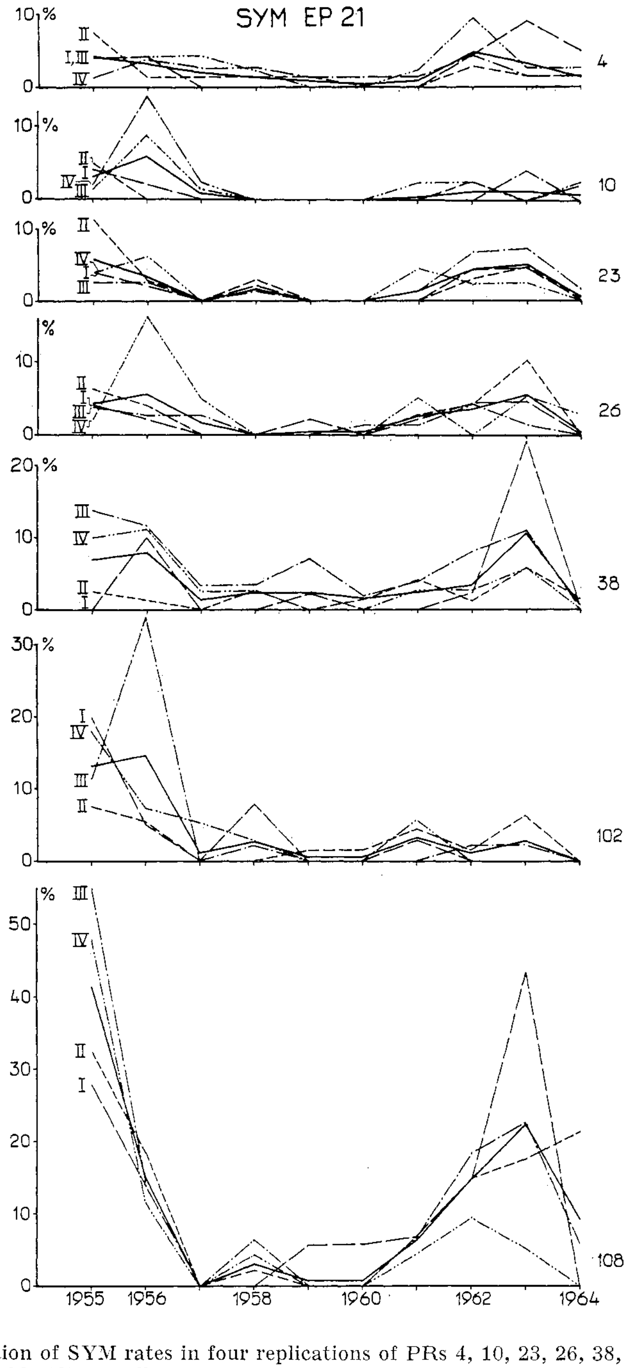


Fig. 49. Variation of SYM rates in four replications of PRs 4, 10, 23, 26, 38, 102 and 108 (see Table 13) as well as mean SYM values of each PR in EP 21.

The position of the CM curve of the PR 101 differs from that of other hardy PRs on account of a weaker development of plants during initial years. The deviation in the position of the curves of these two PRs disappeared as early as 1955 and 1957 respectively. Fig. 50 A and Table 14 show that in 1964 the CM rate in the northern PR 7, originating from the Kiruna district, was 12 %. PR 42 perished completely, and in PR 101 losses reached 37 %. The CM curves clearly show the different adaptation capacity of PRs.

EP 24 had suffered heavily and its CM rates for 1964 resemble those of EP 16. The results of the experiment distinctly show the difficulties which arise in the districts close to the Arctic Circle when afforestation is carried out under site conditions similar to those prevailing on EP 24. On the afforestation areas surrounding the EP, great losses occurred in 1953 and earlier. After 1955 only a few trees remained alive.

Time-mortality curves which express SYM rates (Fig. 50 B), however, conspicuously show the culmination cycles, which are repeated in wave-like movements in all PRs with a definite spacing on the scale.

The first peak of SYM rates occurs in the first year of the EP and is expressed by the death-rates of 1955. The causes of death in plants in PRs 34, 38, and 42 are the early frosts in August of 1954, the BSG, and the dieback of the plant tops in 1955. The summer drought of 1955 and the spring frosts of 1956 did not affect the EP in the least. This explains the truncated shape of the curves after 1955.

In 1958 and 1959 the second culmination in the SYM rate curves took place. Unfortunately, it was not possible to devote more time to the analysis of cold damage at that time. It is impossible to ascertain definitely if losses in plants in 1959 were due to the cold damage of that year, or if they were the result of cold damage caused in the preceding year (1958). No BSG occurred at that time, but the girdling of the main stem in the upper part of the plants was manifested (Chap. 3.1.1.7). Internal injuries in plants, that is, frost rings in the inner part of the summer wood adjacent to the annual ring of 1957, were recorded.

The third culmination in the SYM rates refers to the period 1961—1963. After 1960/61 all types of damage were manifested on the EP, although trees perished almost exclusively on account of BSG, which occurred close to the ground. On this EP high frequencies of damage by snow were also recorded. Injury occurred in the upper part of the crowns (Chap. 3.1.3). Frequencies of losses increased already in 1961. They rose and were particularly high in 1962 and 1963. There is every reason to assume that the spring frosts of 1963 influenced the dieback of girdled and heavily cankered trees. In April of 1962 sudden fluctuations of diurnal temperature due to strong solar radiation caused injuries in the parts of the trees above the snow level. In 1964 fre-

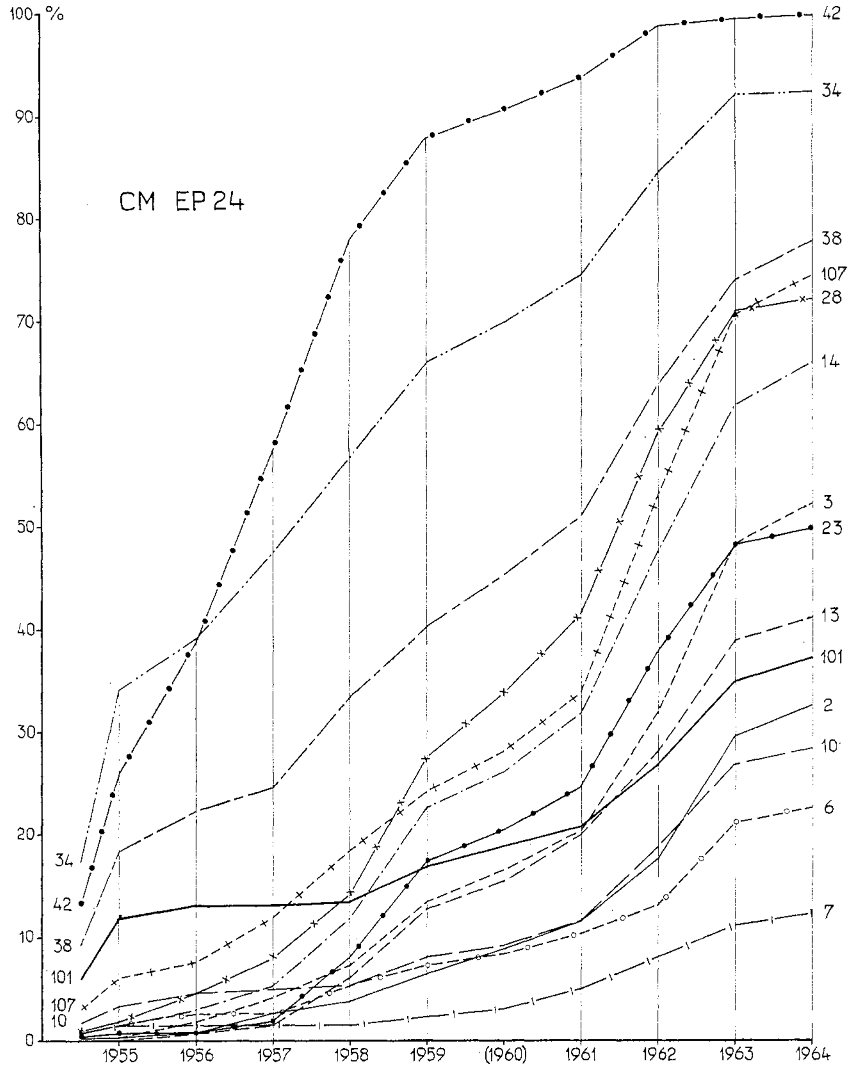


Fig. 50 A. CM of 14 PRs in EP 24 (see Table 14).

quencies of losses were low and the third cycle of years with high SYM rates was already completed. However, the healing of wounds and recovery of damaged trees did not proceed successfully, as was the case on EP 20. Northern PRs 7, 6, 10 and PR 101, which had suffered least, were in good condition.

The results obtained from this EP are convincing and furnish grounds for

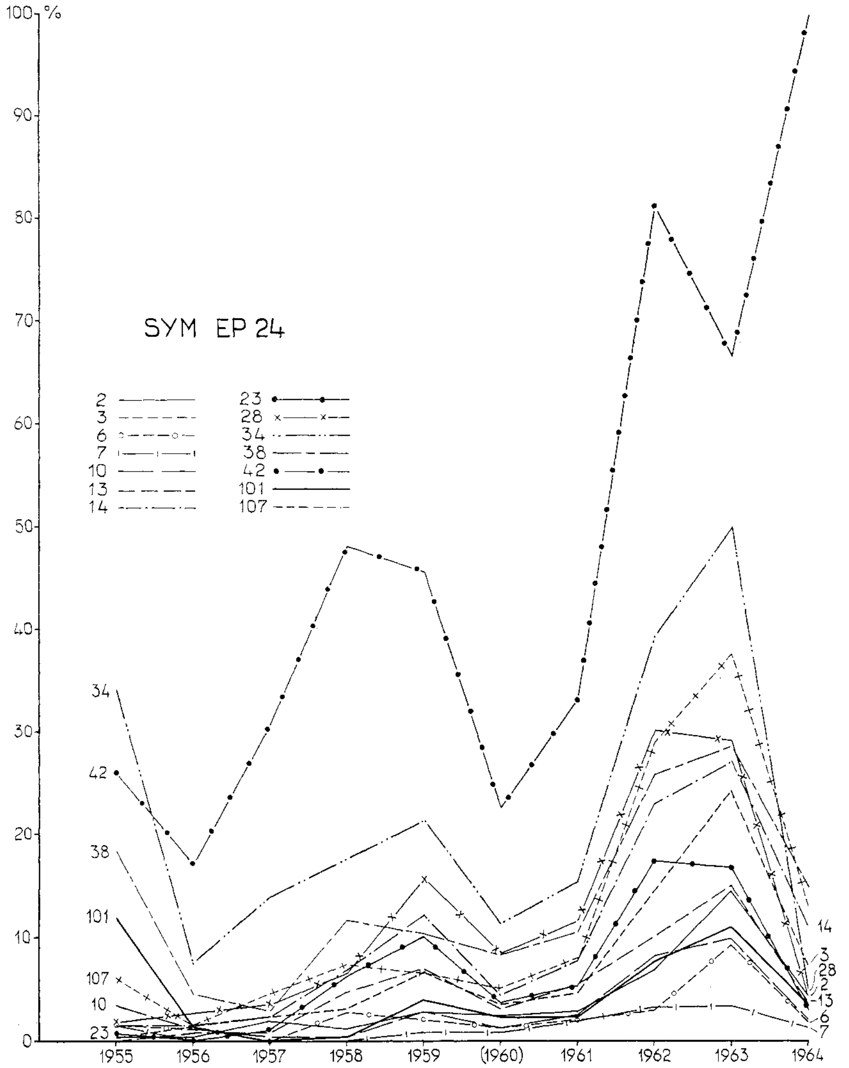


Fig. 50 B. SYM of 14 PRs in EP 24 (see Table 14).

the conclusions which might be applied when afforestation is carried out on areas with similar site conditions.

Experimental plantation 25. Figs. 51 A, B I and B II. Table 15

The site of the EP is in flat country north of the Gulf of Bothnia and is surrounded by swampy areas and sparse pine stands. It is exposed to westerly

Table 14. Experimental plantation 24. Norrbotten, Kåbdalis, Rahaberget. φ: 66° 16′, λ: 19° 53′, H_s: 440, Y: 105.

	PR					Transfer of PR			CM 1964		Diff. CM		Living trees 1964	
No.	φ	λ	H_s	Y	Locality	φ km	H_s m	Y	%	R	1964–1956 %	1964–1960 %	N	%
2	69° 55′	23° 15′	20	104	Norway, Alta, Aronäs	—406	+420	+ 1	32.69	87.6	31.92	23.84	175	*67.31*
3	68° 47′	19° 30′	250	100	Norway, Målselv, Dividalen	—280	+190	+ 5	52.31	140.2	50.39	35.77	124	*47.69*
6	67° 45′	23° 22′	225	107	Norrbotten, Kitkiöjoki	—165	+215	— 2	22.69	60.8	20.00	14.23	201	*77.31*
7	67° 51′	20° 27′	355	100	Norrbotten, Kiruna, Kauppinen	—176	+ 85	+ 5	12.31	33.0	10.77	9.23	228	*87.69*
10	66° 53′	23° 03′	175	114	Norrbotten, Korpilombolo, Smedberg	— 69	+265	— 9	28.46	76.3	23.84	19.23	186	*71.54*
13	66° 18′	14° 10′	75	123	Norway, Mo i Rana, Båsmo	— 4	+365	—18	41.31	110.3	40.54	25.87	152	*58.69*
14	66° 05′	20° 45′	130	121	Norrbotten, Spikseleå	+ 20	+310	—16	66.15	177.3	63.07	40.00	88	*33.85*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	+126	+135	—13	49.81	133.0	49.04	29.35	130	*50.19*
28	64° 14′	19° 43′	200	128	Västerbotten, Vindeln, Svartberget	+226	+240	—23	72.31	193.8	67.69	38.47	72	*27.69*
34	63° 15′	18° 47′	8	144	Västernorrland, Örnsköldsvik, Alfredshem	+336	+432	—39	92.69	248.5	53.46	22.69	19	*7.31*
38	63° 10′	13° 04′	540	117	Jämtland, Vallbogården	+345	—100	—12	78.08	209.3	55.77	32.70	57	*21.92*
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+469	+ 55	—27	100.00	268.0	61.15	9.23	0	
101	66° 03′	17° 57′	460	105	Norrbotten, Arjeplog	+ 24	— 20	—	37.31	100.0	24.23	18.46	163	*62.69*
107	63° 08′	16° 39′	455	122	Jämtland, Bispfors, Torresjölandet	+349	— 15	—17	74.62	200.0	66.93	46.54	66	*25.38*

Table 15. Experimental plantation 25. Norrbotten, Korpilombolo, Ohtanajärvi. φ: 66° 56′, λ: 23° 11′, H_s: 200, Y: 113.

No.	PR φ	PR λ	PR H_s	PR Y	Locality	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1963 N %	n (%)	n_1 (%)	$\bar{h}$ 1961	$\bar{h}$ 1962	$\bar{h}$ 1963
3	68° 47′	19° 30′	250	100	Norway, Målselv, Dividalen	— 206	— 50	+13	37.31	176.4	33.85	20.39	172 *66.15*	163 *94.76*	9 *5.24*	82.47 ± 1.76	102.79 ± 2.18	115.85 ± 2.42
4	69° 07′	18° 35′	100	105	Norway, Målselv, Moen, Olberg	— 243	+100	+ 8	19.23	90.9	12.31	5.38	212 *81.54*	206 *97.17*	6 *2.83*	95.24 ± 1.62	118.54 ± 2.01	132.51 ± 2.24
10	66° 50′	23° 09′	185	114	Norrbotten, Korpilombolo	+ 11	+ 15	— 1	21.15	100.0	14.23	6.92	206 *79.23*	197 *95.63*	9 *4.37*	92.46 ± 1.65	117.53 ± 1.94	133.39 ± 2.13
11	67° 09′	20° 49′	330	105	Norrbotten, Gällivare	— 24	—130	+ 8	19.23	90.9	13.46	5.77	215 *82.69*	209 *97.21*	6 *2.79*	89.66 ± 1.68	114.28 ± 2.04	130.57 ± 2.24
13	66° 18′	14° 10′	75	123	Norway, Mo i Rana, Båsmo	+ 70	+125	—10	31.92	150.9	26.15	17.30	184 *70.77*	168 *91.30*	16 *8.70*	93.43 ± 1.82	116.19 ± 2.17	129.86 ± 2.39
19	65° 50′	23° 18′	30	128	Norrbotten, Kalix, Mörtträsk	+ 122	+170	—15	20.77	98.2	16.92	8.85	210 *80.77*	203 *96.67*	7 *3.33*	108.15 ± 1.91	135.15 ± 2.17	152.21 ± 2.38
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	+ 200	—105	— 5	38.85	183.6	30.77	15.39	168 *64.62*	161 *95.83*	7 *4.17*	88.07 ± 2.09	110.53 ± 2.37	125.01 ± 2.62
26	64° 12′	20° 48′	50	136	Västerbotten, Robertsfors	+ 304	+150	—23	48.46	229.1	42.31	26.15	143 *55.00*	131 *91.61*	12 *8.39*	94.60 ± 2.14	116.48 ± 2.55	128.89 ± 2.85
36	63° 02′	16° 39′	200	134	Jämtland, Bispfors	+ 434	—	—21	90.00	425.5	61.54	20.77	26 *10.00*	24 *92.31*	2 *7.69*	80.48 ± 4.51	104.50 ± 4.66	117.42 ± 5.80
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+ 543	—185	—19	100.00	472.7	63.08	5.38	2 *0.77*	2 *100.00*	—	(99.00 ± 33.00)	(132.00 ± 17.00)	—
50	61° 27′	13° 28′	550	127	Kopparberg, Bunkris	+ 610	—350	—14	94.62	447.3	70.00	15.39	16 *6.15*	14 *87.50*	2 *12.50*	103.79 ± 5.25	126.50 ± 5.24	137.54 ± 6.06
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+1039	— 25	—52	100.00	472.7	30.77	—	—	—	—	—	—	—
101	66° 03′	17° 57′	460	105	Norrbotten, Arjeplog	+ 98	—260	+ 8	36.92	174.5	13.84	6.92	174 *66.92*	164 *94.25*	10 *5.75*	84.96 ± 1.87	109.16 ± 2.20	124.27 ± 2.42
103	61° 28′	17° 08′	5	154	Gävleborg, Långvind	+ 608	+195	—41	98.85	467.3	38.62	8.08	4 *1.54*	4 *100.00*	—	71.00 ± 9.77	92.75 ± 9.79	103.00 ± 8.20

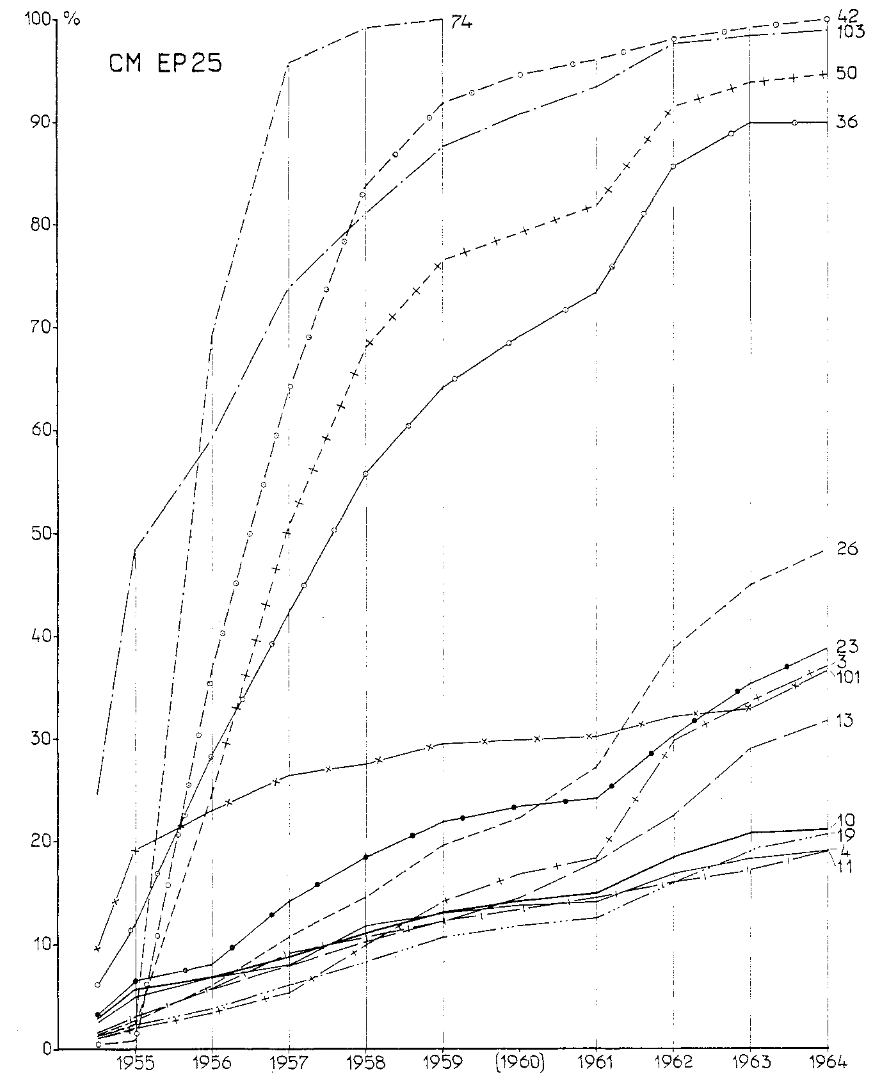


Fig. 51 A. CM of 14 PRs in EP 25 (see Table 15).

and south-westerly winds, and piling up of the snow is most common here. The EP area is also a frost locality.

The development of the EP was not retarded by any chance factors, with the exception of PR 101, where the transplants were weak during the first years. That is why the position of the CM curves of PR 101 differs from that of other hardy PRs (for instance, 10 and 19) which, as regards susceptibility

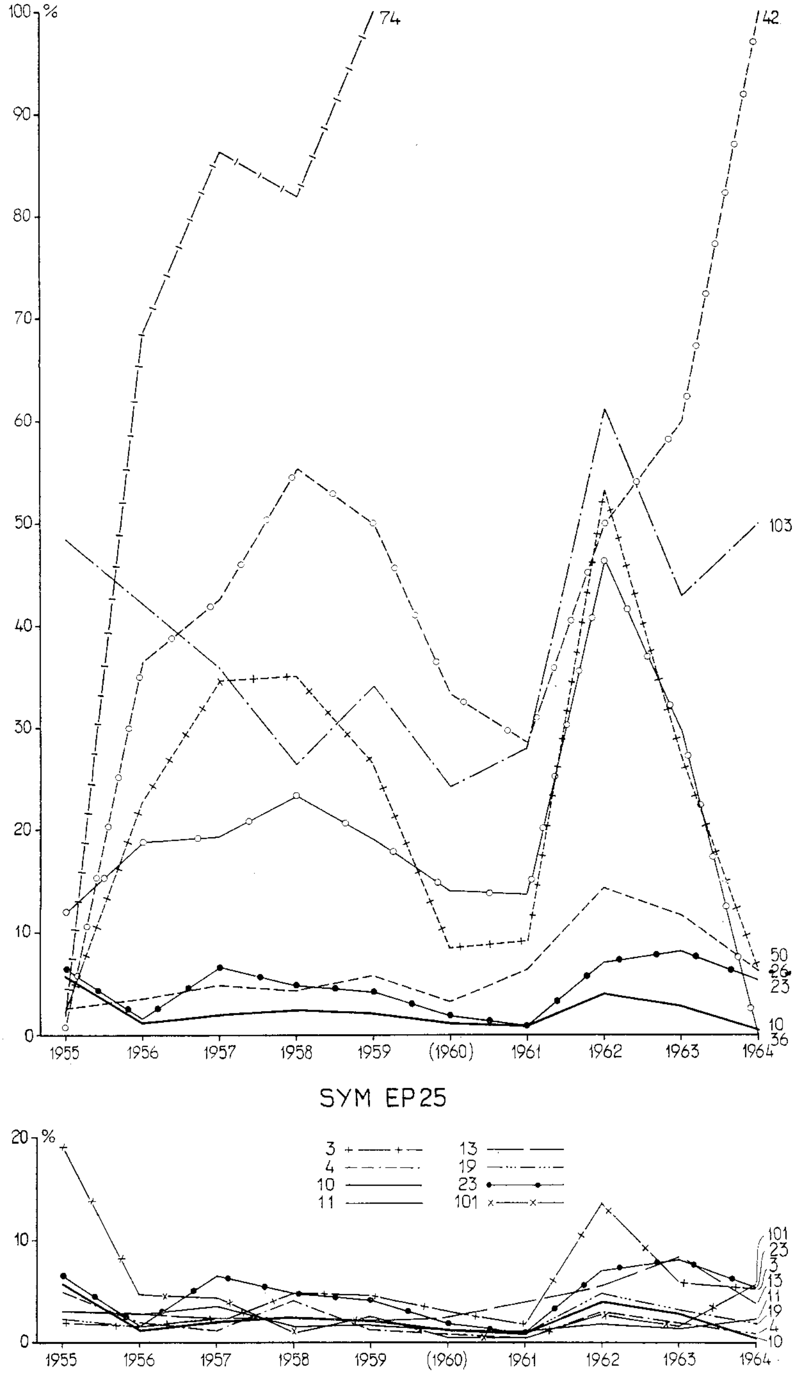


Fig. 51 B I and B II. SYM of 14 PRs in EP 25 (see Table 15).

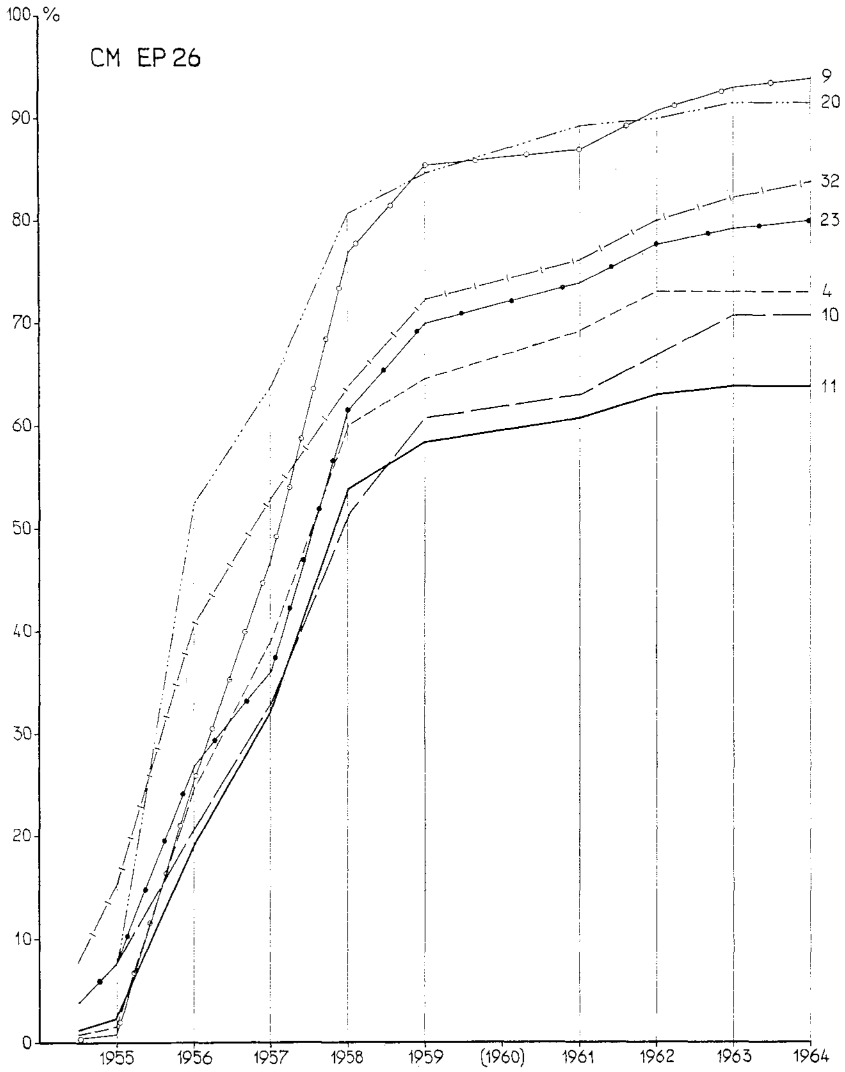


Fig. 52 A. CM of 7 PRs in EP 26 (see Table 16).

to cold, might be compared with PR 101. The transplants of PR 74, 50 and 42 were supplied from the nursery in the province of Stockholm. They were strong, and therefore the mortality curves of these PRs up to 1956 and 1958 differed from the two other non-hardy PRs 103 and 36.

EP 25 had suffered from cold and frost only to a moderate degree. In 1964 CM rates were 19 %—21 % for the hardy PRs 4 and 11, as well as for the local PR 10 and PR 19. For PRs 3, 13, 23 and 101, as well as for PR 26,

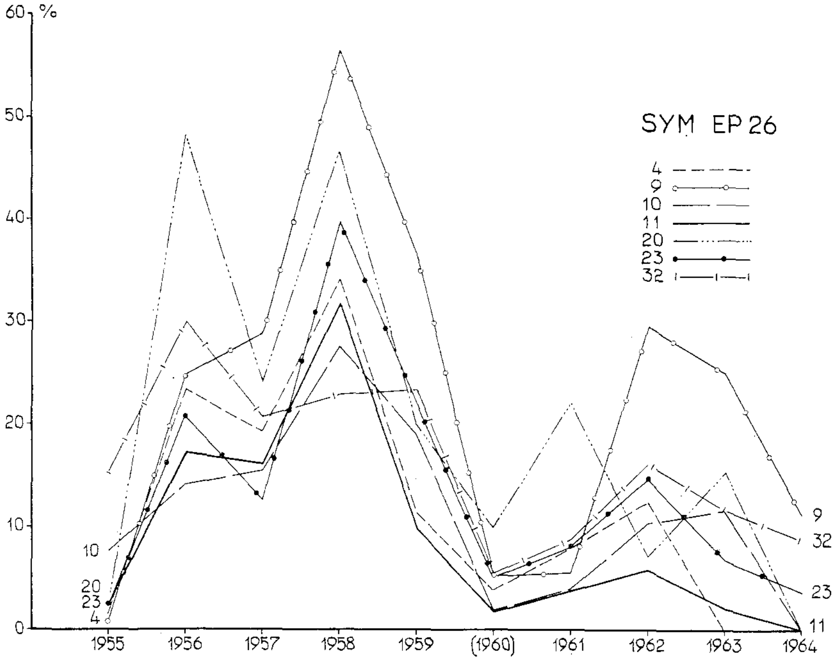


Fig. 52 B. SYM of 7 PRs in EP 26 (see Table 16).

which had suffered only moderately, CM rates were 32 %—48 %. CM rates in long-distance transfer PRs 36, 50, 103, 42 and 74 were 90 %—100 %.

In 1955 frequencies of losses in plants (Fig. 51 B I and B II) were insignificant, with the exception of PRs 103 and 36. In 1956 death-rates in PRs susceptible to cold were the result of the winter cold of 1955. From 1957 to 1960 cold and frosts repeatedly damaged non-hardy PRs. In 1960/61 cold damage occurred in all PRs, particularly in those susceptible to cold. In non-hardy PRs death-rates culminated in 1962, but in hardy ones in 1962 or in 1963. This phenomenon was also recorded on other EPs, and might be explained by heavier damage in PRs susceptible to cold, and by lighter damage in hardy PRs (Chap. 3.1.1.2). However, the severe spring frosts of 1963, in their turn, contributed to the dieback of the trees cankered in 1961. SYM rates of 1964 show that the dieback of the trees had ceased. Nevertheless, the recovery of trees damaged in 1961 had not been completed in 1964. PR 101 was an exception; in the July frosts of 1964 the dwarfs, whose development had been retarded and which had remained in the ground zone, perished. The segregation of dwarfs in the progeny of some individual trees of this PR might have a genetic background.

Table 16. Experimental plantation 26. Norrbotten, Gällivare, Linalombolo. φ: 67° 14′, λ: 20° 29′, H_s: 470, Y: 98.

No.	PR φ	PR λ	PR H_s	PR Y	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1964 N* %
	Locality											
4	69° 07′	18° 35′	100	105	—210	+370	— 7	73.07	114.5	48.45	6.92	35
	Norway, Målselv, Moen											*26.93*
9	67° 18′	14° 25′	30	119	— 7	+440	—21	93.84	147.0	68.46	7.69	8
	Norway, Bodö, Mulstrand											*6.16*
10	66° 53′	23° 03′	175	114	+ 39	+295	—16	70.77	110.8	50.00	9.23	38
	Norrbotten, Korpilombolo, Smedberg											*29.23*
11	67° 14′	20° 29′	470	98	—	—	—	63.85	100.0	44.62	4.62	47
	Norrbotten, Gällivare, Linalombolo											*36.15*
20	65° 38′	21° 07′	75	127	+178	+395	—29	91.54	143.4	39.23	5.39	11
	Norrbotten, Älvsbyn, Asplövberg											*9.46*
23	65° 08′	18° 53′	305	118	+234	+165	—20	80.00	125.3	53.08	8.46	26
	Västerbotten, Malå, Strömfors											*20.00*
32	64° 34′	18° 15′	555	109	+297	— 85	—11	83.85	131.3	43.08	10.00	21
	Västerbotten, Tallträsk, Storberget											*16.15*

* The number of plants at the time of layout of the experiments = 130

Experimental plantation 26. Fig. 52 A and B. Table 16

and

Experimental plantation 29. Fig. 53 A and B. Table 17

Both EPs are situated near each other on a large logged-off area on an upland plateau, near the timberline. Bare hill tops encompass the plateau. This deforested area is bordered on the east by a virgin pine forest. In the beginning of the 1950's a birch undergrowth was exterminated on this logged-off area which was thus made completely bare. Trees, representing local PR 11, were chosen from a stand growing in the vicinity of the EP on the edge of a forest. On both EPs the same PRs were tested.

EP 29 lies on the edge of a forest, close to the stand representing PR 11. EP 26 is situated on a logged-off area 1 km to the west of EP 29 and its site is a characteristic frost hollow. The edaphic conditions on the logged-off area are variable. Although much care was devoted to the choice of the EP sites, two PR plots in one of the replications on EP 29 and two whole replications on EP 26 had to be excluded from estimations of experimental data in connection with the losses in plants caused by the summer drought of 1955.

The position of CM curves representing different PRs is similar on both EPs. However, death-rates on EP 26, for all PRs, are considerably higher than those for EP 29. PR 9 differs slightly from the others by its response to the extreme weather conditions prevailing in 1956, 1958 and particularly in 1961. Local PR 11 had the least CM rate, which in 1964 was 64 % on EP 26 and 40 % on EP 29. Local PR 11 proved to be most resistant to cold and suffered least from the BSG of 1961. Even PR 4, originating from 69° latitude in the north of Norway, had a higher CM rate in 1964, namely, 73 % on EP 26 and 54 % on EP 29. The higher degree or hardiness in the local PR is not surprising and theoretically it is well founded. Data found in Tables 16 and 17 on the transfer of PRs elucidate this most clearly.

High SYM rates emerge in a wave-like manner. SYM curves form three culmination cycles, one in 1956, the other in 1958 and the third from 1961 to 1963. The cause of the high SYM rates of 1956 was chiefly the summer drought of 1955. The second culmination in 1958 was due to winter cold and early spring frosts. It is of interest to note that in 1958 SYM rates on EP 26, which lies in a frost hollow, were much higher than those on EP 29, which is situated on a flat area on the edge of a forest. SYM rates in 1958 were higher than during the period 1961—1964. Nevertheless, on both EPs total losses of trees caused by the BSG of 1961 were higher from 1961 to 1963 than losses in the single year 1958. The third culmination cycle had the highest values as regards the SYM rates on EP 29 in 1963, but on EP 26 they were highest in

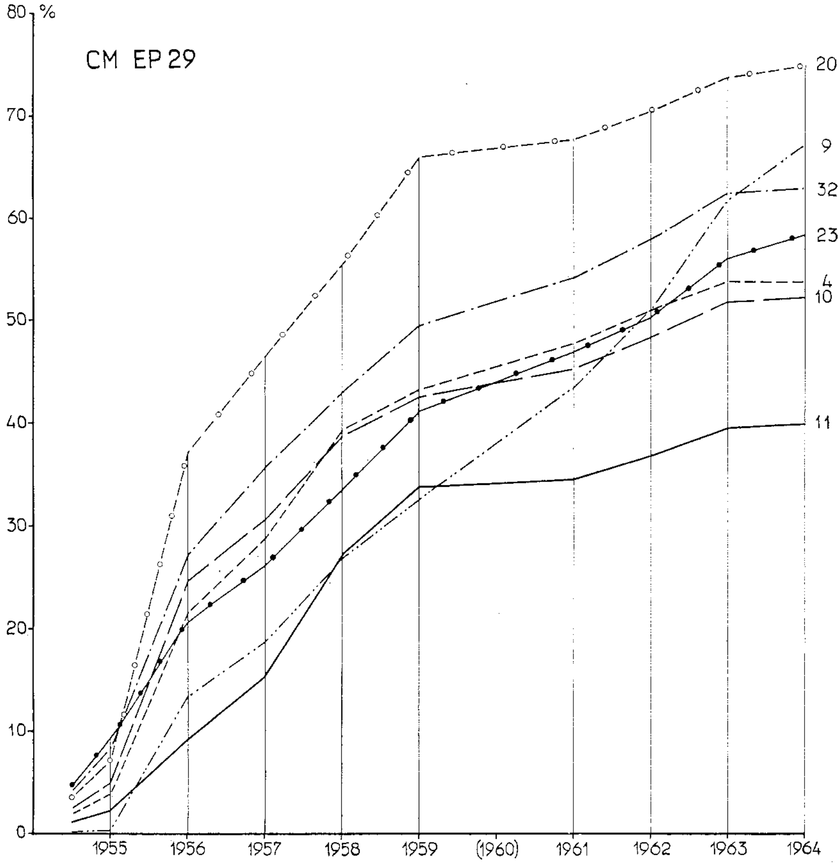


Fig. 53 A. CM of 7 PRs in EP 29 (see Table 17).

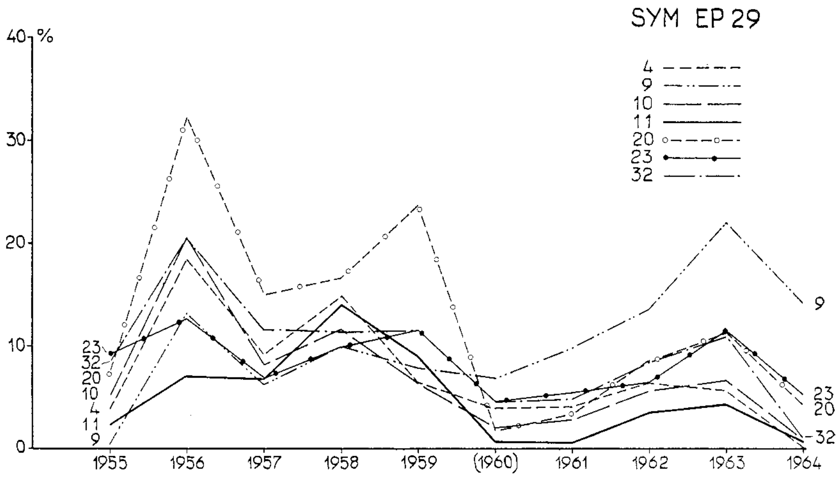


Fig. 53 B. SYM of 7 PRs in EP 29 (see Table 17).

Table 17. Experimental plantation 29. Norrbotten, Gällivare, Linalombolo. φ: 67° 14′, λ: 20° 29′, H_s: 475, Y: 98.

	PR				Transfer of PR			CM 1964		Diff. CM		Living trees 1964
No.	φ Locality	λ	H_s	Y	φ km	H_s m	Y	%	R	1964—1956 %	1964—1960 %	N %
4	69° 07′	18° 35′	100	105	—210	+375	— 7	64.24	160.6	38.09	8.09	93
	Norway, Målselv, Moen, Olberg											*35.76*
9	67° 18′	14° 25′	30	119	— 7	+445	—21	67.31	168.3	53.85	30.00	85
	Norway, Bodö, Mulstrand											*32.69*
10	66° 50′	23° 09′	185	114	+ 45	+290	—16	52.31	130.8	27.69	8.46	124
	Norrbotten, Korpilombolo											*47.69*
11	67° 14′	20° 29′	470	98	—	+ 5	—	40.00	100.0	30.77	5.77	156
	Norrbotten, Gällivare, Linalombolo											*60.00*
20	65° 38′	21° 07′	75	127	+178	+400	—29	81.54	203.8	39.62	5.39	48
	Norrbotten, Älvsbyn, Asplövberg											*18.46*
23	65° 08′	18° 53′	305	118	+234	+170	—20	58.46	146.2	37.69	14.61	108
	Västerbotten, Malå, Strömfors											*41.54*
32	64° 34′	18° 15′	510	111	+297	— 35	—13	63.08	157.7	35.77	11.16	96
	Västerbotten, Lycksele, Storberget											*36.92*

1961, 1962 and 1963 respectively, owing to the susceptibility of PRs to cold, and also to the degree of severity of the BSG.

In 1961 snow damage manifested itself in the upper part of the crowns on both EPs, and in 1963 leaders were killed by frost during the spring frosts. Recovery of trees girdled in 1961 has not yet proceeded satisfactorily.

The results obtained from the experiments on both EPs clearly show the difficulties which arise when afforestation is carried out in site conditions on large logged-off areas. The average afforestation results on areas in the neighbourhood of the EPs show even worse results.

Experimental plantation 27. Fig. 54 A and B and Fig. 55. Table 18

The EP is situated at a distance of 8 km from the centre of the actual town of Kiruna, on an upland plateau. The site of the EP is surrounded by a pine forest and mountain birch undergrowth. The site is flat and is a characteristic frost locality.

Mortality curves expressing SYM rates show definite peaks in 1956 and 1963. The cause of particularly high frequencies of losses in 1956 was the exceptional drought of 1955, as well as the spring frosts of 1956. The combined effect of both factors was such that it was impossible to distinguish how important each of them had been separately. In the ensuing years, after 1956, frequencies of losses diminished gradually until 1961. This is a characteristic phenomenon in those cases when trees are severely damaged by cold. One is inclined to assume that cold had been a more formidable cause of damage than the excessive drought of 1955.

In the spring frosts of 1963 the above EP suffered more than all others (Chap. 2.1). The influence of frost on trees was of a twofold character. Damage was caused both to healthy trees, which had not been injured by cold during the preceding years, and also to those which were partially girdled and cankered in 1961. In trees which had not been injured previously, cold damage manifested itself in the form of dead leading shoots and lateral branches, but at the same time vigorous, well-developed trees, which had reached a height of 1 metre to 1.5 metres, were killed by cold. Losses in plants were considerable in PR 8, which originated from a locality in the vicinity of the timberline near Kiruna, and also in PR 10 (Fig. 54 B). In the frequencies of dead trees were also included those girdled in 1961 and some individuals injured by rodents. However, the primary cause of losses in plants in 1963 was the effect of the spring frost of the same year, which also influenced frequencies of losses in 1964. In 1964 SYM rates on EP 27 were relatively high in comparison with those on the other EPs, on which SYM rates had already diminished to a considerable extent and trees cankered in 1961 had recovered.

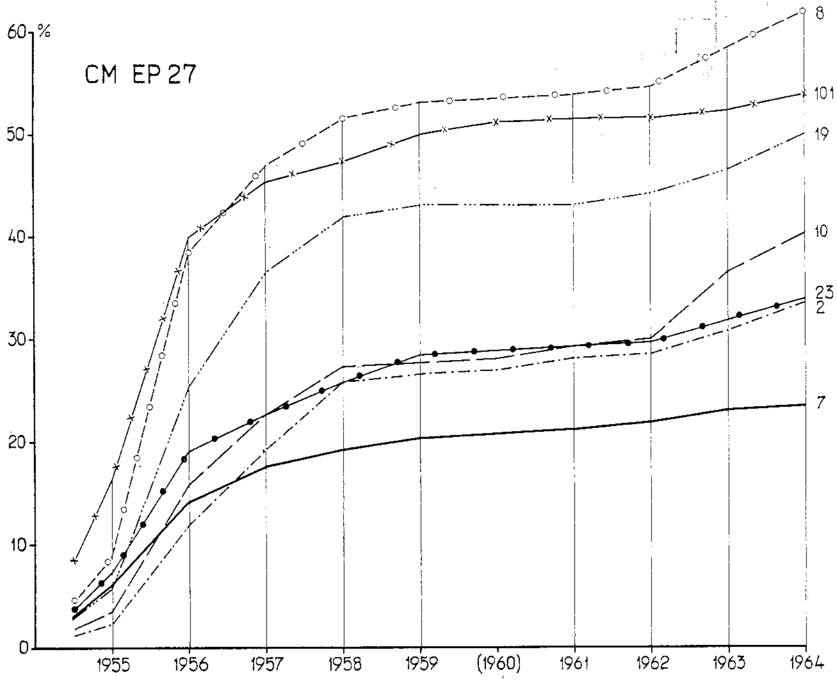


Fig. 54 A. CM of 7 PRs in EP 27 (see Table 18).

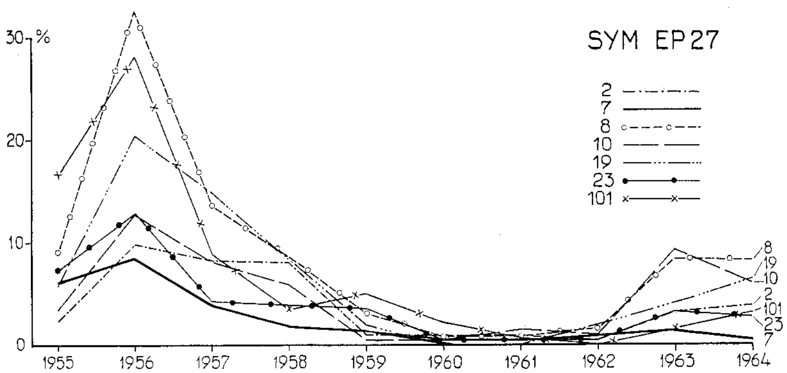


Fig. 54 B. SYM of 7 PRs in EP 27 (see Table 18).

Table 18. Experimental plantation 27. Norrbotten, Kiruna, Kauppinen. φ: 67° 50′, λ: 20° 27′, H_s: 360, Y: 100.

PR					Transfer of PR			CM 1964		Diff. CM		Living trees 1963									a_2 (%)	
No.	φ (Locality)	λ	H_s	Y	φ km	H_s m	Y	%	R	1964—1956 %	1964—1960 %		A %	a (%)	a_1 (%) (x)	a_1 x	a_1 $\underline{x}$	a_1 $\underline{\underline{x}}$	a_1 Σx		BSG	Rod.
2	69° 55′	23° 15′	20	104	—232	+340	— 4	33.46	142.6	21.54	6.54	0	180	54	26	85	9	5	125		1	—
	Norway, Alta, Aronäs												*69.23*	*30.00*	*14.44*	*47.22*	*5.00*	*2.78*	*69.44*		*0.56*	
												t	228	66	31	106	15	8	160		2	—
													68.67	*28.95*	*13.60*	*46.49*	*6.58*	*3.51*	*70.17*		*0.88*	
7	67° 50′	20° 27′	355	100	—	+ 5	—	23.46	100.0	9.23	2.69	0	200	95	9	82	7	2	100		1	4
	Norrbotten, Kiruna, Kauppinen												*76.92*	*47.50*	*4.50*	*41.00*	*3.50*	*1.00*	*50.00*		*0.50*	*2.00*
												t	242	118	11	96	8	4	119		1	4
													77.32	*48.76*	*4.54*	*39.67*	*3.31*	*1.65*	*49.17*		*0.41*	*1.65*
8	67° 50′	20° 16′	480	94	—	—120	+ 6	61.69	263.9	23.46	8.46	0	108	36	8	36	8	7	59		—	13
	Norrbotten, Kiruna, Nokutosvara												*41.54*	*33.33*	*7.41*	*33.33*	*7.41*	*6.48*	*54.63*			*12.04*
												t	146	44	9	51	10	14	84		—	18
													43.20	*30.14*	*6.16*	*34.93*	*6.85*	*9.59*	*57.53*			*12.33*
10	66° 50′	23° 09′	185	114	+111	+175	—14	40.38	172.1	24.61	12.30	0	165	27	16	95	16	9	136		—	2
	Norrbotten, Korpilombolo												*63.46*	*16.36*	*9.70*	*57.58*	*9.70*	*5.45*	*82.43*			*1.21*
												t	219	34	20	131	19	12	182		1	2
													64.04	*15.52*	*9.13*	*59.82*	*8.68*	*5.48*	*83.11*		*0.46*	*0.91*
19	65° 50′	23° 18′	30	128	+223	+330	—28	50.00	213.1	24.62	6.92	0	139	35	3	70	8	5	86		1	17
	Norrbotten, Kalix, Mörtträsk												*53.46*	*25.18*	*2.16*	*50.36*	*5.75*	*3.60*	*61.87*		*0.72*	*12.23*
												t	207	53	10	90	13	17	130		1	23
													54.91	*25.61*	*4.83*	*43.48*	*6.28*	*8.21*	*62.80*		*0.48*	*11.11*
23	65° 08′	18° 53′	305	118	+300	+ 55	—18	33.85	144.3	14.62	5.00	0	177	64	10	73	8	5	96		3	14
	Västerbotten, Malå, Strömfors												*68.08*	*36.16*	*5.65*	*41.24*	*4.52*	*2.83*	*54.24*		*1.69*	*7.91*
												t	232	91	13	90	9	8	120		5	16
													72.05	*39.23*	*5.60*	*38.79*	*3.88*	*3.45*	*51.72*		*2.15*	*6.90*
101	66° 03′	17° 57′	460	105	+198	—100	— 5	53.85	229.5	13.85	2.70	0	124	41	2	72	3	3	80		2	1
	Norrbotten, Arjeplog												*47.69*	*33.07*	*1.61*	*58.06*	*2.42*	*2.42*	*64.51*		*1.61*	*0.81*
												t	218	77	8	119	8	3	138		2	1
													54.50	*35.32*	*3.67*	*54.59*	*3.67*	*1.37*	*63.30*		*0.92*	*0.46*

0: original trees
t: total = original + replaced trees
A: total number
a: unimpaired
a_1: damaged by spring frost in 1963
a_2: damaged by BSG in 1961 and by rodents in 1963
(x): frozen needles
x : frozen tips
$\underline{x}$: frozen leaders and lateral branches
$\underline{\underline{x}}$: frozen down to base

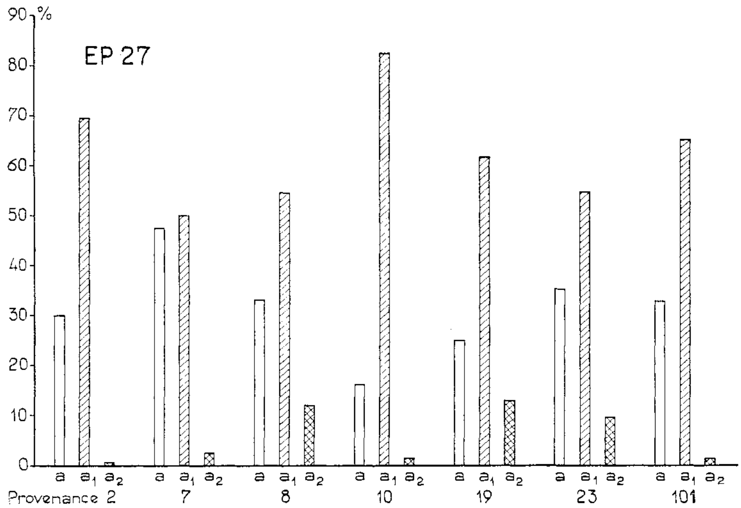


Fig. 55. Effect of severe spring frosts in 1963 on 7 PRs in EP 27 (see Table 18); unimpaired trees (a), damaged by frost (a_1) and damaged by other agents (a_2).

Frequencies of the spring frost injuries of 1963 in different PRs are shown in Fig. 55 and Table 18. Assessment was carried out in September 1963, approximately four months after the occurrence of spring frosts. At the same time these data indicate the cause of losses in trees of different PRs in 1964 (Fig. 54 B). Owing to the spring frosts PR 8, which may be reckoned as one of the most hardy PRs, had suffered most of all. Some of the trees in this PR had already flushed and had formed shoots a few centimetres in length. However, most of the trees had not yet flushed. The frozen leading shoots showed at what stage of flushing the trees had been when spring frosts occurred. PR 10 was the next in order as regards injuries caused by spring frosts, but PR 7, whose mother trees grow close to the EP, suffered least in the spring frosts of 1963. The variable response of PRs to spring frosts may be explained by the different timing of flushing. It is also of importance to note that there had been two spring frost periods, one in the end of May and the other in the middle of June. Cases, where trees from northern sources were poorly adapted to southern latitudes and had severely suffered from spring frosts, were reported by HEIKINHEIMO (1949) in *Picea excelsa*, by OZOL (1953; *cf.* PARKER, 1963, p. 158) in *Juglans mandshurica* and *J. cinerea*, as well as by KRIEBEL (1957) in *Acer saccharum*.

Beginning with 1957 the CM rates of local PR 7 were constantly the lowest, whereas the highest CM rates were recorded in PR 8. It is true that the development of plants in PRs 8 and 101 during the initial years was weak, and this explains the high frequencies of losses in both PRs in 1955 and 1956. Beginning with 1958 the CM curves of PRs 8 and 7 ran parallel up to 1963, when PR 8 suffered considerably in the spring frosts. The CM curves of other PRs occupy the position in the diagram which corresponds to their hardiness to cold. An exceptional place is occupied by PR 10, which suffered heavily in the spring frosts.

Experimental plantations in mountain districts, where moderate cold damage occurred in 1960/61 (Subregion II:3)

Three EPs located in the mountain districts have several common characteristics as regards the occurrence of BSG, although their localities are wide apart and their site conditions are not similar. In these EPs the death-rate in plants caused by BSG in 1960/61 was not high. The position of the girdle on the stems was near the ground surface (mostly at the butt of the trees) or even sometimes under the ground surface, in the upper layer of the soil (Chap. 3.1.1.1).

The high frequencies of losses in plants were caused by the summer drought of 1954, by the exceptionally intense drought of 1955, and in 1958 and in 1959 by the winter cold and spring frost.

In this paper it is impossible to penetrate deep enough into the problem of the occurrence of BSG in the mountain districts, where the above-mentioned three EPs are situated. The number of the EPs is not sufficient and the sites of all three EPs are sheltered against the wind, which is not the case with the EPs in all other groups. However, even in the mountain districts, where these EPs are situated, BSG manifested itself on several occasions in afforested areas with devastating force, causing considerable losses. It should be stressed that EP 13, belonging to group II: 2, might serve as an example of an EP located in a deforested area in a mountain district, on which losses caused by BSG were most considerable.

In mountain districts the position of BSG was conspicuously near the ground surface, whereas on EPs belonging to other distribution groups trees were girdled at different heights on the stem. One is inclined to assume that in the mountain districts girdles were not found on a higher level because no thawing periods occurred here in winter, and therefore no hard ice crust was formed in the upper layer of the snow. On the other hand, the delayed thawing of the snow in the spring of 1961, with sudden fluctuations in temperature, induced the formation of ice crust on the ground surface and the occurrence of BSG.

This interpretation of the occurrence of BSG is supported by the fact that damage by snow in the upper part of the crowns (Chap. 3.1.3) was rare on these three EPs. This shows once again that either no ice crust in the upper

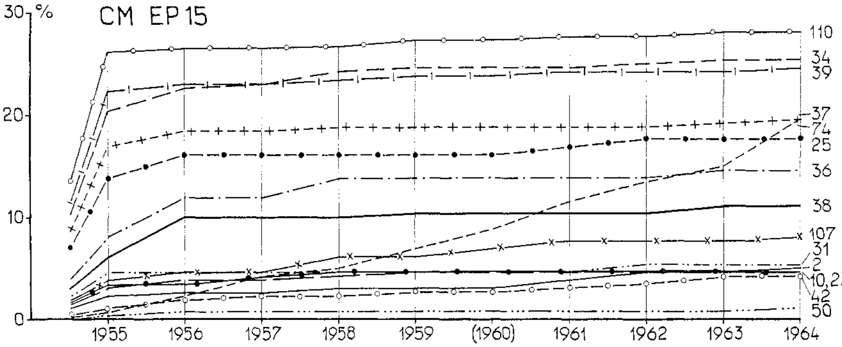


Fig. 56 A. CM of 14 PRs in EP 15 (see Table 19).

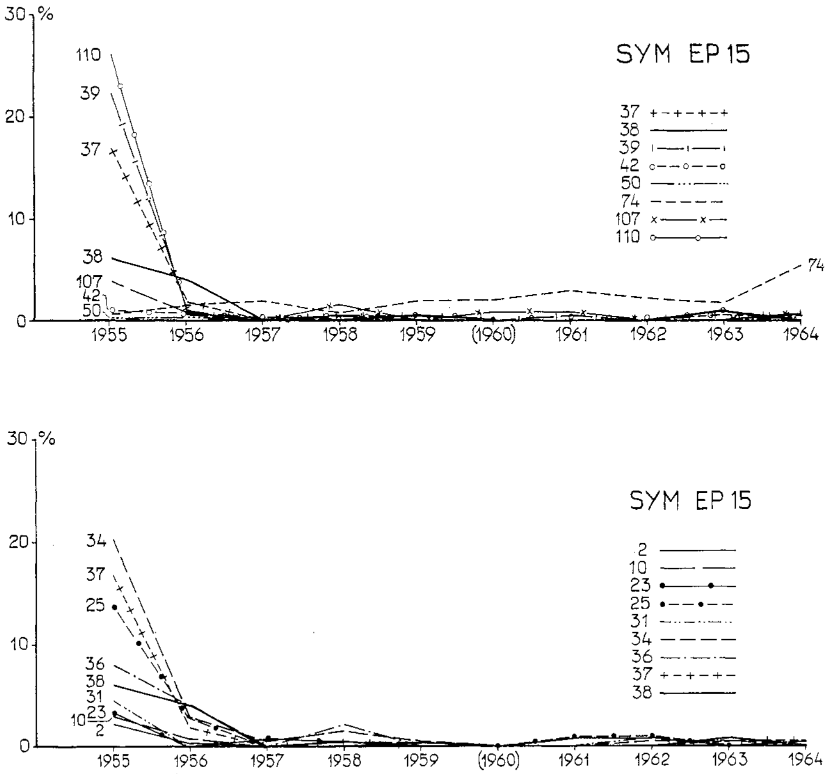


Fig. 56 B I and B II. SYM of 14 PRs in EP 15 (see Table 19).

Table 19. Experimental plantation 15. Jämtland, Vallbogården. φ: 63° 10′, λ: 13° 04′, H_s: 540, Y: 117.

No.	PR φ	PR λ	PR H_s	PR Y	Locality	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1964—1956 %	Diff. CM 1964—1960 %	Living trees 1964 N	Living trees 1964 %
2	69° 55′	23° 15′	20	104	Norway, Alta, Aronäs	—751	+520	+13	5.00	44.8	2.31	1.92	248	*95.00*
10	66° 50′	23° 09′	185	114	Norrbotten, Korpilombolo	—408	+355	+ 3	4.62	41.4	0.77	0	248	*95.38*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	—219	+235	— 1	4.62	41.4	1.16	0	248	*95.38*
25	64° 58′	15° 28′	560	106	Västerbotten, Marsfjäll	—200	— 20	+11	17.69	158.7	1.54	1.54	104*	*82.31*
31	65° 10′	17° 27′	570	105	Västerbotten, Storuman, Gubberget	—223	— 30	+12	5.38	48.3	0.76	0.76	123*	*94.62*
34	63° 15′	18° 47′	8	144	Västernorrland, Örnsköldsvik, Alfredshem	— 9	+532	—27	25.38	227.6	2.69	0.76	194	*74.62*
36	63° 02′	16° 39′	200	134	Jämtland, Bispfors	+ 15	+340	—17	14.62	131.1	2.70	0.77	222	*85.38*
37	63° 13′	14° 03′	315	128	Jämtland, Hallen	— 6	+225	—11	19.62	176.0	1.16	0.77	210	*80.38*
38	63° 10′	13° 04′	540	117	Jämtland, Vallbogården	—	—	—	11.15	100.0	1.15	0.77	231	*88.85*
39	63° 07′	12° 55′	700	110	Jämtland, Vallbo, lappläger	+ 6	—160	+ 7	24.62	220.8	1.54	0.77	197	*75.38*
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+124	+155	—15	4.23	37.9	2.31	0.54	249	*95.77*
50	61° 27′	13° 28′	550	127	Kopparberg, Bunkris	+191	— 10	—10	1.15	10.3	0.38	0.38	258	*98.85*
74	57° 36′	14° 13′	225	165	Jönköping, Eckersholm	+620	+315	—48	19.62	175.0	17.31	10.77	221	*80.38*
107	63° 08′	16° 39′	455	122	Jämtland, Sveg, Malmbäcken	+ 4	+ 85	— 5	8.08	72.5	3.46	1.16	240	*91.92*
110	63° 17′	18° 42′	145	137	Västernorrland, Örnsköldsvik, Varvsberget	— 13	+395	—20	28.08	251.8	1.54	0.77	187	*71.92*

* The number of plants at the time of lay-out of the experiments = 130

part of the snow cover was formed at all, or, if formed, then not in such a degree as to cause girdles or damage by snow. But if, in spite of all, BSG was manifested in high frequencies in certain limited areas, this should be explained by local climatic and site conditions, which must have favoured the production of damage.

Experimental plantation 15. Figs. 56 A, B I and B II. Table 19

The EP is situated on a highland plateau, enclosed by bare mountain tops. Dense natural reproduction areas of pine and a pine forest surround the EP.

The CM rates on the EP were strikingly low, considering the altitude of the EP locality. This phenomenon can be explained solely by the favourable location of the site, by the propitious local climate, and by the favourable edaphic conditions.

The position of the CM curves of the different PRs in the diagrams was chiefly determined by losses in plants, which occurred in the summers of 1954 and 1955. The southern PR 74 is, however, an exception, since its CM curve transverses the other PR curves in the diagram. Transplants of PRs 42, 50 and 74, just as was the case on EPs discussed previously, had been grown in the nursery of the Stockholm province and were more vigorous than those of other PRs.

In southern PRs, after the winter of 1958, when snow abounded, the fungus canker manifested itself in insignificant frequencies (Chap. 3.1.1.3). After 1961 frequencies of losses caused by BSG were insignificant, although trees with different degrees of damage were found on the EP. The highest SYM rate in PR 74 was recorded in 1964, which can be explained by the dieback of trees, caused by the severe spring frosts of 1963. These trees had been heavily girdled and cankered in 1961. However, in hardy PRs only the leading shoots were damaged by the spring frost of 1963.

Experimental plantation 19. Fig. 57 A and B. Table 20

The EP is situated on a high plateau. The site of the EP is encompassed by a mixed pine and spruce forest. The composition of the soil is loam, with variable characteristics. The development of the EP was unfavourably influenced by edaphic conditions, which are far from being uniform.

In 1955 and 1956 there were significant frequencies of losses, due to the summer drought of 1954 and the exceptionally dry summer of 1955. In the ensuing years frequencies of losses in all PRs were insignificant, with a slight acceleration after 1961, caused by BSG. Among the girdled trees there were several in which the damage had occurred immediately under the ground surface (Chap. 3.1.1.3, Fig. 27). The increase in the frequencies of losses in

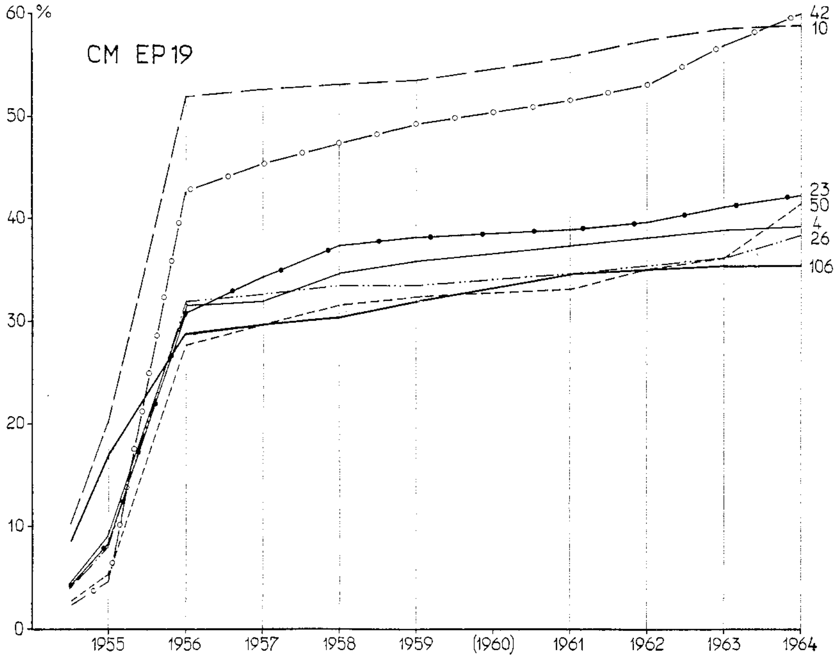


Fig. 57 A. CM of 7 PRs in EP 19 (see Table 20).

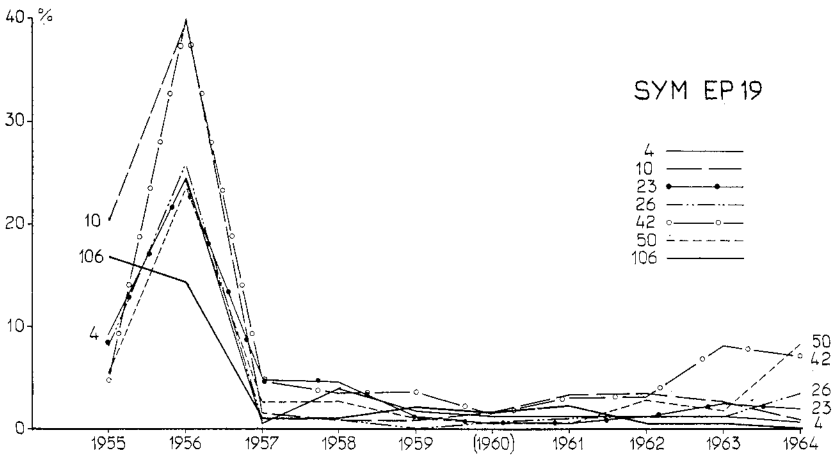


Fig. 57 B. SYM of 7 PRs in EP 19 (see Table 20).

Table 20. Experimental plantation 19. Jämtland, Harrsjön. φ: 64° 18′, λ: 15° 23′, H_s: 360, Y: 120.

PR						Transfer of PR			CM 1964		Diff. CM		Living trees 1964	
No.	φ	λ	H_s	Y	Locality	φ km	H_s m	Y	%	R	1964—1956 %	1964—1960 %	N	%
4	69° 07′	18° 35′	100	105	Norway, Målselv, Moen	—536	+260	+15	39.23	110.9	7.69	2.69	158	*60.77*
10	66° 50′	23° 09′	185	114	Norrbotten, Korpilombolo	—282	+175	+ 6	58.85	166.3	6.93	4.62	107	*41.15*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	— 93	+ 55	+ 2	42.31	119.6	11.54	3.85	150	*57.69*
26	64° 12′	20° 48′	50	136	Västerbotten, Robertsfors	+ 11	+310	—16	38.46	108.7	6.54	4.61	160	*61.54*
42	62° 03′	14° 19′	385	132	Jämtland, Sveg, Malmbäcken	+250	— 25	—12	60.00	169.6	17.31	10.00	104	*40.00*
50	61° 27′	13° 28′	550	127	Kopparberg, Bunkris	+317	—190	— 7	41.54	117.4	13.85	8.85	152	*58.46*
106	64° 18′	15° 23′	360	120	Jämtland, Harrsjön	—	—	—	35.38	100.0	6.54	2.30	168	*64.62*

1963 in PRs 42 and 10, and in 1964 in PR 26, might be explained by the effect of the severe spring frost of 1963 upon the heavily cankered trees. The significant frequencies of losses in PR 50 were caused by attacks of rodents in 1964.

In 1964 the local PR 106 had the least CM rate of all PRs. However, PRs 26, 4 and 23 differed only slightly from the local PR. The hardy northern PR 10 differs significantly from the others. However, its high CM rate was due to the losses during the first two years after the layout of the EP. A pleasant surprise was offered by the coastal PR 26, which in spite of the long distance transfer proved to possess a higher degree of capacity to adaptation than PR 42.

The manifestation of BSG in insignificant frequencies and the surprisingly good adaptation results of most of the PRs can be explained by the favourable local climate.

Experimental plantation 23. Fig. 58 A and B. Table 21

Among all other EPs the above EP is the only one which is located above the timberline in the mountain birch region, characteristic for northern Scandinavia. The EP is situated on the top of a hill, with an undulating earth surface. Elevations of the earth surface encompassing it, together with the stands of mountain birch provide a sufficient shelter for the EP. The plants grew up under the overhead shelter of birch, and were thus protected against the extremes of air temperature. Water formed by the melting snow could flow down unimpeded from the EP area in north and south directions. Both local climate and edaphic conditions are favourable for the development of the plants.

In order to protect the plants against rodents, hares and black grouse, *Lyrurus tetrix*, preventive chemical treatment was applied every autumn. The treatment was effective during all the years, except in 1964, when injuries caused by rodents occurred mostly in the upper part of the stems. Considerable losses were recorded particularly in PRs 10 and 23.

Great losses in plants occurred in 1955 and, even greater, in 1956, due to the summer drought of 1954 and that of 1955. In 1958 a slight increase in frequencies of losses was registered, caused by the winter cold of the same year. If compared with the frequency values of other EPs, *e.g.*, with those of EP 26 and 29, losses in EP 23 were negligible. From 1961—1964 losses in plants were caused by the BSG of 1961, which culminated in 1962. However, damage caused by BSG was insignificant. The sudden increase in the frequencies of losses in 1964 was due to damage by rodents. The spring frost of 1963 did not cause any injuries on the EP.

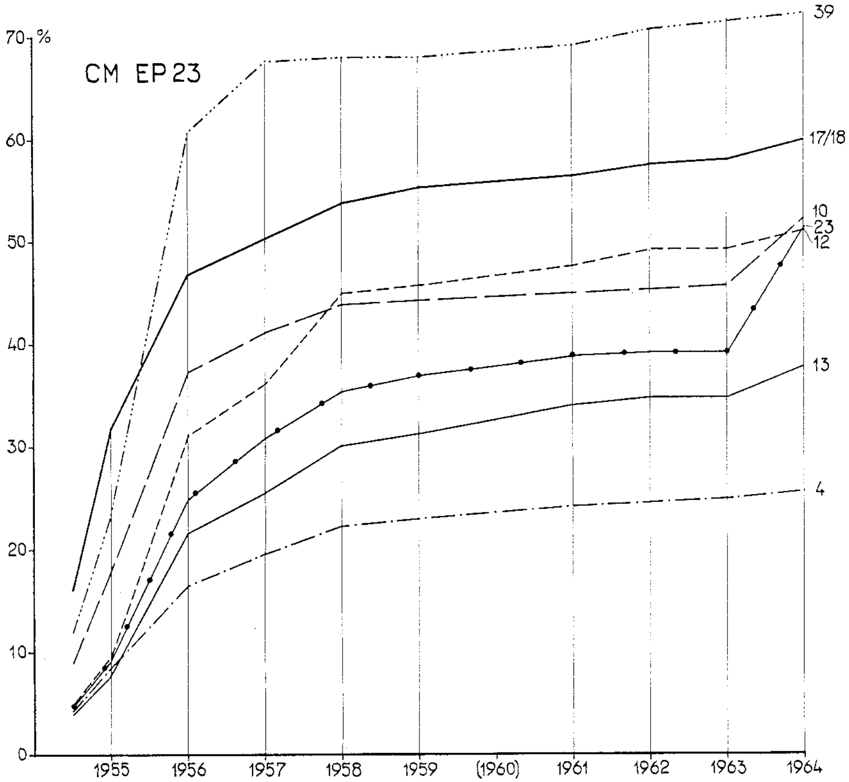


Fig. 58 A. CM of 7 PRs in EP 23 (see Table 21).

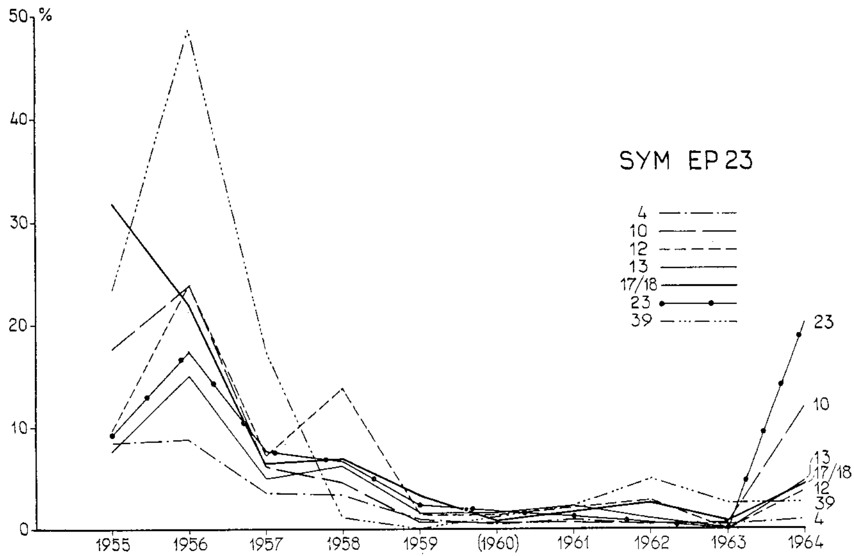


Fig. 58 B. SYM of 7 PRs in EP 23 (see Table 21).

Table 21. Experimental plantation 23. Västerbotten, Tärnaby, Snebacken. φ: 65° 43′, λ: 15° 06′, H_s: 630, Y: 98.

No.	PR φ	PR λ	PR H_s	PR Y	PR Locality	Transfer of PR φ km	Transfer of PR H_s m	Transfer of PR Y	CM 1964 %	CM 1964 R	Diff. CM 1963—1956 %	Diff. CM 1964—1960 %	Diff. CM 1963—1960 %	Living trees 1964 N %
4	69° 07′	18° 35′	100	105	Norway, Målselv, Moen	—378	+530	— 7	25.77	42.95	8.96	2.31	1.54	193 *74.23*
10	66° 50′	23° 09′	185	114	Norrbotten, Korpilombolo	—124	+445	—16	52.31	87.18	8.44	7.69	1.15	124 *47.69*
12	66° 56′	18° 35′	480	99	Norrbotten, Tjåmotis, Seitvare	—135	+150	— 1	51.15	85.25	18.08	4.61	2.69	127 *48.85*
13	66° 18′	14° 10′	75	123	Norway, Mo i Rana, Båsmo	— 65	+555	—25	37.84	63.07	13.13	5.41	2.32	161 *62.16*
17/18	66° 02′	16° 11′	540/650	101/96	Västerbotten, Ammarnäs	— 35	+90/—20	—3/+2	60.00	(100.0)	11.16	4.23	2.31	104 *40.00*
23	65° 08′	18° 53′	305	118	Västerbotten, Malå, Strömfors	+ 65	+325	—20	51.54	85.90	14.23	13.46	1.15	126 *48.46*
39	63° 07′	12° 55′	640/700	113/110	Jämtland, Vålådalen	+289	—10/—70	—15/—12	72.31	120.52	10.77	3.85	3.08	72 *27.69*

The CM curves show conspicuously the differences between the PRs. During the first year after the layout of the EP the death-rate in PRs 17 and 18, which most resemble the local PR, was disproportionately large on account of the weak transplants. PRs 4 and 13, which originate from the Atlantic coastal district in Norway, showed very good adaptation results, better than PRs 10, 12 and 23, which originate from northern Sweden.

4.3. Cumulative mortality and mortality in single years

The analysis made in Chap. 4.2 of the factors causing mortality among trees includes 20 EPs located N of latitude 60°. On this wide area the southernmost EP 9 lies on latitude 60° 4′, and EP 27 on latitude 67° 50′ is situated farthest north. EP 14, whose altitude is 5 metres, comes nearest to the level of the Gulf of Bothnia, and EP 13 has the highest altitude, 765 metres (Fig. 7). The range of the latitude in the meridional direction is thus 864 km and the range of altitude in vertical direction 760 metres.

The latitudinal and altitudinal range of the natural habitats of PRs tested on the EPs is even wider than that of the localities of the EPs under discussion. The range of latitude for PRs originating in Scandinavia is from 55° 51′ (PR 82) to 69° 55′ (PR 2), which makes 1,566 km in meridional direction. The altitudes of the growth places of the PRs vary from 5 metres (PRs 40 and 60) to 850 metres (PR 45).

The wide variation of the external factors and also that of the hereditary qualities of different PRs reveal the complex nature of all EPs. The interrelation of these two variable components in the experiment obtains a most variable expression in connection with the different response of PRs to site conditions on the individual EPs. It is not only the general climate of the localities which is of great importance, but also the micro-climate of individual EPs. On account of this each EP thus becomes an independent experiment object. A short review on EPs is to be found in Chap. 4.2.

The problem of mortality in trees, which characterizes the adaptation of PRs for survival, becomes more complex, due to the different agents causing the death of trees in single years. The factors which call forth the death of trees on different EPs in one and the same year can be most dissimilar. In field experiments the control of all the different factors causing the death of trees is incomplete in such cases where damage is the result of the combined effect of several external factors, *e.g.*, of the summer drought or of winter, spring, and autumn colds, all of which occur in the same year.

The treatment and reducing to a system of all the data obtained on all EPs during 1954—1964 was carried out according to three guiding principles: (1) Only original plants were included in the estimation of the data obtained;

(2) Mortality rates were expressed graphically in diagrams; (3) EPs were divided into groups, thus introducing a geographical interpretation into the analysis of factors causing mortality in trees.

Only original plants which had been growing on the EPs since the layout of the experiments were included in the estimation. Thus it was possible to reduce greatly the uncontrolled variation of mortality connected with dissimilar replacements in different PRs.

Data on the mortality in plants for each PR on individual EPs, that is, for each PR block, were transformed into two types of relative mortality values. These values are plotted against the time scale on the horizontal axis in the diagrams. Two types of PR time-mortality curves, the CM curves and SYM curves, make up the two diagrams (A and B) for each EP. Such graphical representation of mortality data supplies the possibility of describing the mortality curves qualitatively and, at the same time, of stating the magnitude of values in the mortality variation. There are several reasons why the data of both diagrams should be compared simultaneously in order to draw conclusions regarding the cold hardiness of PRs (Chap. 4.1).

Cumulative mortality

When analysing the character of the CM curves, it was found advantageous to divide each of them into three sections. Each section of the curve thus corresponds to a certain period of years: (1) The initial section of the curve shows the initial CM rates and covers the period from the year of the layout of the EP up to 1956; (2) The middle section of the curve corresponds to the period from 1956 up to 1960; (3) The third section of the curve covers the period 1961—1964 after the occurrence of BSG. Data on CM rates are to be found in the table for each individual EP.

When comparing EPs with different geographical locations, as well as different PRs on individual EPs, considerable differences can be established between the CM curves. In this connection it is relevant to mention the distribution of EPs into groups (Chap. 4.2): I, II:1, II:2 and II:3. Although this grouping chiefly renders it possible to show the variable intensity of BSG from a geographical point of view, it can be advantageously applied to describe CM curves.

The shape of the CM curves of the EPs located outside the region of the severe BSG of 1960/61 (group I) is of a simple character. The most conspicuous example in this respect is EP 14 (Fig. 38 A). The initial mortality rates which in the diagram correspond to the years 1954, 1955 and 1956 are rather high, but they are different for individual PRs. During these years the rise of the curves is moderately steep. The remaining part of the curves runs almost parallel to the horizontal axis and the mortality rates in 1964 differ only insignificantly from those of 1956. In 1964, when trees were 14 years old, the EP was at that stage of development when natural mortality among trees, due to their mutual struggle for space and nutrition, had not yet begun. Between 1956 and 1964 no injuries occurred which might have been caused by extreme weather conditions or other external factors. In 1960/61 the occurrence of BSG was insignificant and of a sporadic nature.

EPs in the transition zone, where moderate damage occurred in 1961 (group II:1), display a more intricate shape in the CM curves. The values of the initial CM rates vary consistently as regards different PRs. With the exception of some special cases, hardy and non-hardy PRs display their characteristics already during the first two years after the layout of the experiments. From 1956 to 1964 the difference between CM curves of PRs in EP group II:1 and those in EP group I sharply increased. The difference between the CM rates in 1964 and those in 1956 varies in different PRs. The CM rates in the section of the curves which correspond to the period 1960—1964 are rather low. The cause of the mortality in plants here is chiefly, and on some EPs exclusively, BSG.

EP 18 (Fig. 41 A) gives an example of EP group II:1. PRs 10 and 23 show negligible CM rates. The shape of the curves representing these EPs does not deviate from the shape of the curves representing EP group 1. PR 102, in spite of its high initial CM rates, is similar to PRs 10 and 23 as regards cold hardiness. The shape of the curves representing PRs 42, 103 and 74 differs considerably from that of PRs belonging to EP group I. Owing to the fact that the survival of plants was influenced by heavy heaving in spring, EP 17 (Fig. 40 A) differs from EPs 11 and 18 in EP group II:1.

The shape of the CM curves in the EP group II:2 differs notably from that of the other EP groups. The initial CM rates in several EPs and particularly among cold hardy PRs is low. In the second and especially in the third section of the CM curves the CM rates rise swiftly. The rise of the CM curves is particularly remarkable after the BSG of 1961. Differences between the CM rates in 1964 and those in 1956 are very great for non-hardy PRs and considerable for the other PRs. Some of the northern and upland PRs with a high cold resistance make an exception, since their CM differences for this period of years are moderate. CM curves of EPs 12 (Fig. 43 A), 16 (Fig. 45 A), 20 (Fig. 47 A), 24 (Fig. 50 A) and 25 (Fig. 51 A) are the most representative for group II:2.

The shape of the CM curves for the EP group II:3 is characterized by high initial CM rates and moderate CM rates in the second and third section of the CM curves. However, the available data from these three EPs [EP 15 (Fig. 56 A); EP 19 (Fig. 57 A) and EP 23 (Fig. 58 A)] do not adequately elucidate the mortality problem in mountain districts. It cannot be denied, however, that several traits exist which cause EP group II:3 to differ from EP group II:2 (Chaps. 2.3 and 6.3).

CM curves of PRs 42 and 74 in the EP 18 (Fig. 41 A) differ from the other PR curves. The same may be said of PRs 42, 50 and 74 in the EP 17 (Fig. 40 A). The initial CM rates of these PRs are negligible. There is a steep rise in the middle section of the curves in 1958 and 1959, which becomes still more conspicuous in the third section. This characteristic of the shape of the CM curves is also displayed in EP groups II:2 and II:3 of those PRs whose transplants were grown in the nursery in the province of Stockholm and were bigger in size than the transplants of other PRs. These cases show how sensitively the response of the PRs to the external factors, depending on the size of the transplants at the start of the experiment, is reflected in the CM curves. More vigorous transplants on such occasions warrant a reduced provenance CM in the initial section of the curves. However, in the last two sections of the curves the initial advantages of these PRs disappear, due to the cold damage of 1958 and 1961.

CM curves for PRs with long-distance transfer from the south rose steeply after the BSG of 1961, and then approached their asymptote, *i.e.*, 100% of CM rates. However, in 1962 in several cases the asymptotical CM rates assumed constant values and CM curves ran parallel to the horizontal axis. CM curves show that of these PRs only a few trees survived, and most of them were heavily cankered. On a few occasions some individual trees survived unimpaired. The character of the micro-site of these trees gives no support to the assumption that some particularly favourable external factors had been decisive. The survival of a few individuals with a high resistance to cold must be looked upon as the result of natural selection. The genetical constitution of the whole population as well as the variation of the inherent traits in the progeny of individual trees have been decisive in this case. The CM curves of EP 12 (Fig. 43 A) PRs 59 and 74, EP 16 (Fig. 45 A) PRs 42 and 36, EP 20 (Fig. 47 A) PR 55 and EP 25 (Fig. 51 A) PRs 50 and 36 illustrate what has been said above.

Mortality in single years

SYM curves as a means of expressing mortality in plants provide the possibility of showing more precisely the importance of single years and also that of a cycle of years for each individual EP. On the other hand, when comparing SYM of several EPs, the geographical location of the latter and the role played by the general climatic conditions stand out in sharp relief. But SYM expresses also the individual site conditions of an EP. This circumstance is of importance when an analysis of mortality of plants is being made.

After the BSG of 1961 SYM values on EPs located on logged-off areas were very great (Chap. 4.2). Unfortunately, it is difficult to elucidate the relationship between SYM and the EP site conditions on account of lack of material as regards the micro-climate of each single EP.

The SYM curves consistently show increased mortality values during certain years, although there are differences among EPs. However, SYM values vary considerably also as regards different PRs in each EP. As a rule the shape of a SYM curve has four distinct peaks which appear in connection with the increased SYM rates in certain years. The positive excess of SYM rates does not always express itself in one year; it often covers two or three years in succession. These four peaks, or rather four cycles of years, give a characteristic expression to SYM curves.

EP 13 (Fig. 44 B) may serve as an illustration of the above statement. The position of the individual SYM curves in the PR arrangement, with the exception of PR 10 in 1954, does not vary from 1954 to 1964. The three SYM peaks correspond to the years 1954, 1956 and 1958, but the fourth peak corresponds to the three-year cycle from 1961 to 1963.

SYM and CM curves have the same time scale on the horizontal axis. The first two peaks of the SYM curves in 1954 and 1956 correspond to the initial section of the CM curves. The peak of SYM curves in 1958 corresponds to the second section of the CM curves, and the SYM peak during 1961—1963 corresponds to the third CM section.

The first peak of the SYM curves shows the losses in plants during the first year after the layout of the EP. For EPs 9, 10, 11, 12, 13 and 14 the first check-up of the mortality in plants was made in 1954 and for the other EPs in 1955.

The SYM during the first year should be considered as being composed of mortality components caused by several factors. The most important of these factors are those which have to do with differences among PRs, such as variable quality of seeds, divergencies in the size and in the degree of vitality of the transplants in the nurseries and, lastly, the variable response of PRs to the site conditions in the EPs during the first year. The differences among PRs are of both a modificative and a hereditary character and it is difficult to draw a line of demarcation between them.

The quality of the seeds of PRs originating from the subalpine zone, and particularly of those whose natural habitat lies just on the timberline, was low. However, the low germination capacity of the seeds of these PRs should be explained by the insufficient maturity of the seeds in bad climatic conditions, and is therefore a PR trait of modificative character (SIMAK and GUS-

TAFSSON, 1954). On the other hand, mortality in plants in some of the subalpine PRs in the EPs was very high during the first year and also in the succeeding years, although the quality of the transplants used in the experiments was comparatively satisfactory. The following PRs may serve as an illustration of this: PR 8 (Fig. 54 A and B); PRs 12, 17 and 18 (Fig. 58 A and B) and PR 39 (Fig. 56 A and B).

The causes of an increased mortality in plants of subalpine PRs during the first year may be of a different character, such as the small size of the transplants, their low vitality, an earlier start of the growth process and an increased sensibility during spring frosts, owing to early cambial activity. Inbreeding depression also may be one of the explanations of the debility of plants and of their increased mortality. In any case, these considerations may be applied to the progeny of some individual trees.

An assumption could be made that in some isolated trees within some populations an imposed self-fertilization had occurred. In this connection PR 102, which was represented by pines growing dispersedly and closely encompassed by a virgin Norway spruce forest, might be mentioned (*cf.* EPs 18 and 21, Figs. 41 and 48). Inbreeding depression might also have been one of the causes of increased mortality among the progeny of some individual trees in PR 101 (Fig. 51 A and B) and in PR 103 (Fig. 41 A and B).

When agents causing variable mortality among PRs during the first year are enumerated, an important factor should be mentioned, namely, the two kinds of PR transfer. The first is the transfer of the seeds from the natural PR habitat and the growing up of the transplants in the nursery, and the second is the transfer of the transplants from the nursery to the EPs. If both are long-distance transfers an increased mortality in plants during the first year is by no means surprising, even as regards hardy provenances. PR 10 in the EP 13 (Fig. 44 A and B) may serve as an illustration.

In EPs whose first peak of the SYM curves appears in 1954 and corresponds to the first check-up in 1954, mortality in plants caused by external factors is of a relatively simple character. The principal cause of mortality in this case was the early summer drought of 1953, and on EP 9 and EP 10 the cause was vigorous ground vegetation, as well as a powerful attack of *Hylobies* beetle on plants in EP 14, in spite of preventive treatment applied on the EP.

On the EPs whose first check-up was made in 1955, which also coincides with the first peak of the SYM curves, the external factors were of another character. In this case the decisive role was played by cold damage which occurred in plants in the autumn of 1954 and by the winter cold of 1954/55. However, the manifestation of BSG during the check-up in June 1955 was not yet complete. Therefore the BSG of 1955 and the dieback of the plant tops which caused losses in plants manifested themselves on EPs only in

1956. The characteristics of the BSG, the swelling of the stem above the girdle and the rupturing and piling off of the bark, appeared only on some occasions. In the succeeding years the dead plants, which hardly showed any external signs of damage, were so frail that they broke at the BSG at the slightest touch. The section of the BSG with a variable height from 5 to 30 cm above the ground surface was infiltrated by resin. On such occasions no primary breaks or fractures of the stem were recorded.

Only on some EPs does the first peak of the SYM curves, corresponding to the year 1955, manifest itself conspicuously. EP 24 (Fig. 50 B) where the cause of mortality was the autumn frost of 1954 and the winter cold of 1954/55 as well as EP 23 (Fig. 58 B), where mortality was caused by the summer drought of 1954, exemplify this statement. On the remaining EPs no peak of the SYM curves appears, or, if it does, then only in a small degree, since the second peak of the SYM curves assumes a most striking expression in 1956.

The second peak of the SYM curves appeared in 1956, and was the result of the exceptionally severe summer drought of 1955 which embraced the whole of southern and central Sweden, but was not experienced in several districts in northern Sweden. On EPs 11 (Fig. 39 B), 13 (Fig. 44 B), 19 (Fig. 57 B) and 23 (Fig. 58 B) the mortality in plants was caused exclusively by drought. On the other hand, on EP 27 (Fig. 54 B), as well as on EPs 26 (Fig. 52 B) and 29 (Fig. 53 B), mortality in plants was the result of the combined effect of drought and the early spring frost of 1956. In 1956 on some EPs, for instance, on EPs 12, 16, 20 and 24, some plants had perished owing to the BSG which had occurred in 1955. EPs 24 (Fig. 50 B) and 25 (Fig. 51 B) are examples of those EPs which were not influenced by the drought of 1955, and where the second peak of SYM curves is lacking.

The third peak in the SYM curves appears most conspicuously in 1958. EPs 13 (Fig. 44 B), 16 (Fig. 45 B), 23 (Fig. 58 B) and particularly EPs 26 (Fig. 52 B) and 29 (Fig. 53 B) are examples of this. Mortality in plants on these EPs should be explained by cold damage which occurred in the winter and early spring of 1958. On several EPs the third SYM peak was reached during 1958 and 1959, for instance, on EPs 18 (Fig. 41 B), 20 (Fig. 47 BI and BII) and 22 (Fig. 42 B). EP 24 (Fig. 50 B) is an exception, since an increased SYM rate began to make itself noticeable already in 1957. Mortality in plants in 1959 was the delayed effect of cold damage of 1958. However, there is evidence that in 1959 cold damage occurred on several occasions and that mortality in plants in 1959 was independent of the cold of 1958. Unfortunately, it was not possible, for technical reasons, to clarify these phenomena connected with cold damage. The dissection of the stem of some plants made in 1962 and 1963 revealed frost rings in PRs susceptible to cold in the annual ring of 1958 and sometimes also in that of 1959. The position of the frost ring was at the very beginning of the annual ring, but frequently the injured part of the wood took up the whole spring wood in the annual ring. This indicates that the occurrence of cold damage took place in winter or in early spring (DAY, 1934; RHOADS, 1923; MIX, 1913).

The fourth peak of the SYM curves comprises the cycle of years from 1961 to 1964 and is the graphical expression of the mortality process in trees girdled and heavily cankered in 1961. This cycle of years corresponds to the age period of trees from 10 to 14 years. It is the age when trees have already grown out of the dangerous ground air zone. In this paper attention is principally drawn to the unexpected extermination of PR stands of high quality.

In 1961 on some EPs mortality values were still rather low, for instance, on EP 20 (Fig. 47 B I and B II), and only in 1962 did they increase very rapidly. This should be connected with the peculiar character of the manifestation of BSG, although the degree of cold injury decided whether death would occur immediately after the cold damage had taken place, or in the years to come. In PRs susceptible to cold, mortality rates were high as early as 1961, but in hardy PRs the rise in the values was noticeable only from the beginning of 1962.

During the cycle of years from 1961 to 1964 the SYM rates culminated in 1962 and in 1963. For EPs 21 (Fig. 48 B), 24 (Fig. 50 B), 29 (Fig. 53 B) and 27 (Fig. 54 B) the culminations of mortality rates were clearly expressed in 1963, but for EP 13 (Fig. 44 B) the culminations of these rates were reached during 1961 and 1963, with a negative excess of mortality rates in 1962. The weather conditions prevailing after 1961 must have played a considerable role in the mortality process of the injured trees. The winter cold of 1962, and particularly the spring frosts of 1963, injured the sensitive tissues in the callus overgrowth, hindered the healing of wounds in the partially girdled trees, and killed severely cankered trees (Chap. 2.1 and 5.1). The culmination of SYM rates in 1963 should be explained as the result of the severe spring frosts of 1963, which caused an increased mortality in trees cankered as early as in 1961.

EP 27 (Fig. 55) offers examples of new injuries in healthy trees and mortality in trees caused by the late spring frosts of 1963. In 1963 frost injury of a similar kind, only in a slighter degree, was recorded also on other EPs in the frost region (Chap. 2.1). During these spring frosts even hardy PRs originating from northern habitats were also injured.

In 1964 mortality in trees expressed by the fourth cycle of SYM curves may be considered as being completed. On most EPs the mortality rate of different PRs assumed those values which they had in 1960, *i.e.*, before the occurrence of the BSG of 1961. On some EPs, however, mortality rates were still rather high; for instance, on EPs 27 (Fig. 54 B), 13 (Fig. 44 B) and 24 (Fig. 50 B). During 1961—1964 most of the cankered trees perished. The recovery of trees with a slighter degree of BSG still proceeded. It is well known that the callus overgrowth of the edge of the wound is a very delicate process. "Once frost has started a canker, several seasons more or less free from frost are required before it can heal again" (DAY, 1945, p. 30).

4.4. Cumulative mortality rates in relation to the transfer of the provenances

The PR time-mortality curves, both the CM curves and the SYM curves, show a distinctly balanced arrangement, *i.e.*, a definite PR scale in the EP diagrams. Deviations in some of the sections of the PR curves have already been mentioned, but they should be regarded as exceptions. In PRs originating from the northern habitats mortality rates are low, but in PRs whose natural growth places are located to the south of the EP site mortality rates, in most cases, reach very high values.

The CM rates should be regarded as the result of two factors. These values are dependent on the inherent resistance of the PRs to cold and on EP site conditions. In this connection the transfer of the PRs is of paramount interest, and the relationship between the CM rates and the transfer of the PRs has both a theoretical and a practical importance for silviculture. The gradient of CM rates in relation to the transfer of PRs is the clue as to how the transfer of the PRs should be applied in afforestation.

When the analysis of the relationship between CM rates and the transfer of PRs was being made, it was possible to state that the gradient of the CM rates was not the same for all the twenty EPs, and that the differences were connected with the geographical location of the EPs. In order to show the importance of the geographical aspect EPs were arranged in groups. It proved to be advantageous to retain the principle of grouping the EPs applied in Chap. 4.2, which shows the differences in the manifestation of the severe BSG of 1961 from a geographical point of view. Thus it is obvious that the more severe the climatic conditions on the sites of the EPs, the more strikingly do the differences among the PRs express themselves (Chap. 4.2) and the greater the gradient of CM rates in relation to the transfer of PRs.

The relation of CM rates to the transfer of PRs is shown on the diagrams for four EP groups; group I, comprising three EPs (Fig. 59); group II:1, comprising three EPs (Fig. 60); group II:2, comprising eleven EPs (Fig. 61); and group II:3, comprising three EPs (Fig. 62). In the last group (II:3) the data on the CM rates are most heterogeneous.

EP group II:2 is the principal group and it has been made use of in this paper in order to elucidate the relationship between the CM rates and the

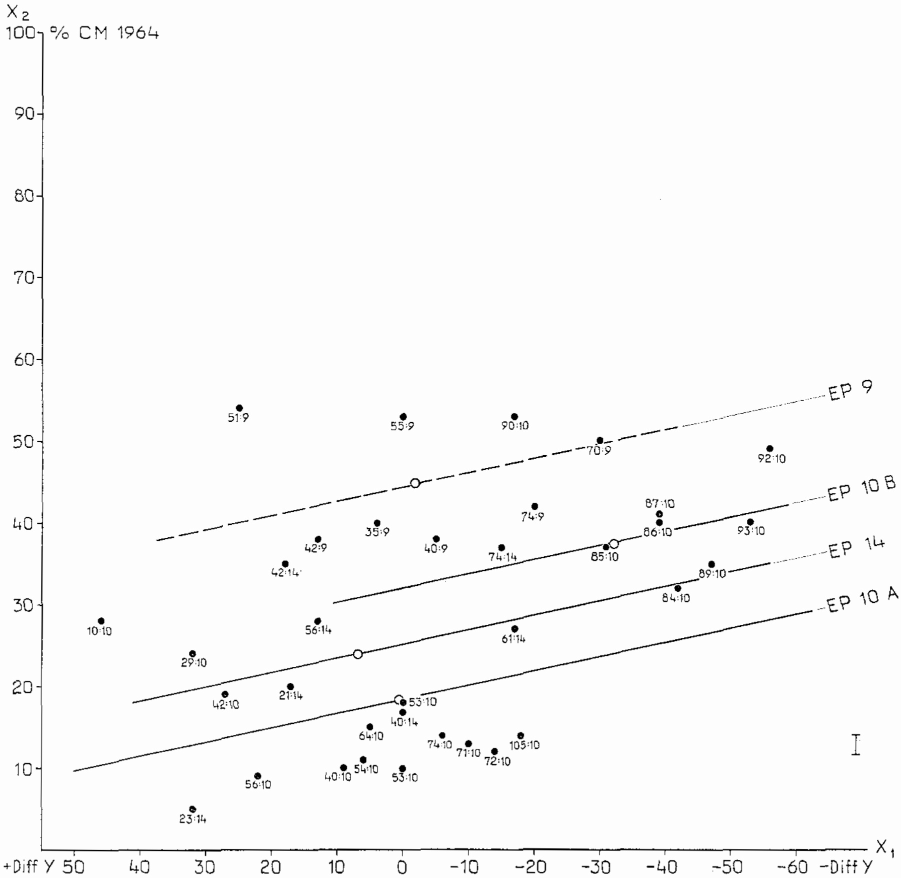


Fig. 59. Parallel regressions of X_2 on X_1 in EPs 9, 10A, 10B and 14 within region I (Tables 22 and 23).
X_2 = CM rates 1964 in single PRs.
X_1 = differences in the length of growing season (+Diff. Y and —Diff. Y) in connection with the transfer of PRs from their natural habitats to EP sites.
Black dots = single PRs in single EPs, *e. g.*, 23—14 = PR 23 in EP (14 CM = 4.62 and +Diff. Y = 32).
Circles on regression lines = mean values (X_2X_1) in single EPs.
Regression line in EP 9 (----) makes an exception owing to the fact that mortality in plants was chiefly depending on vigorous ground vegetation on EP site.

transfer of the PRs. The eleven EPs are located in the interior of northern Sweden and represent districts where afforestation difficulties are not unusual. In any case, the eleven EPs cover a large subregion which is of considerable importance to silviculture. Professor L. Tirén (1945, 1948, 1949) paid particular attention to the problems of afforestation connected with this region, and made valuable suggestions as regards the choice of the location of the

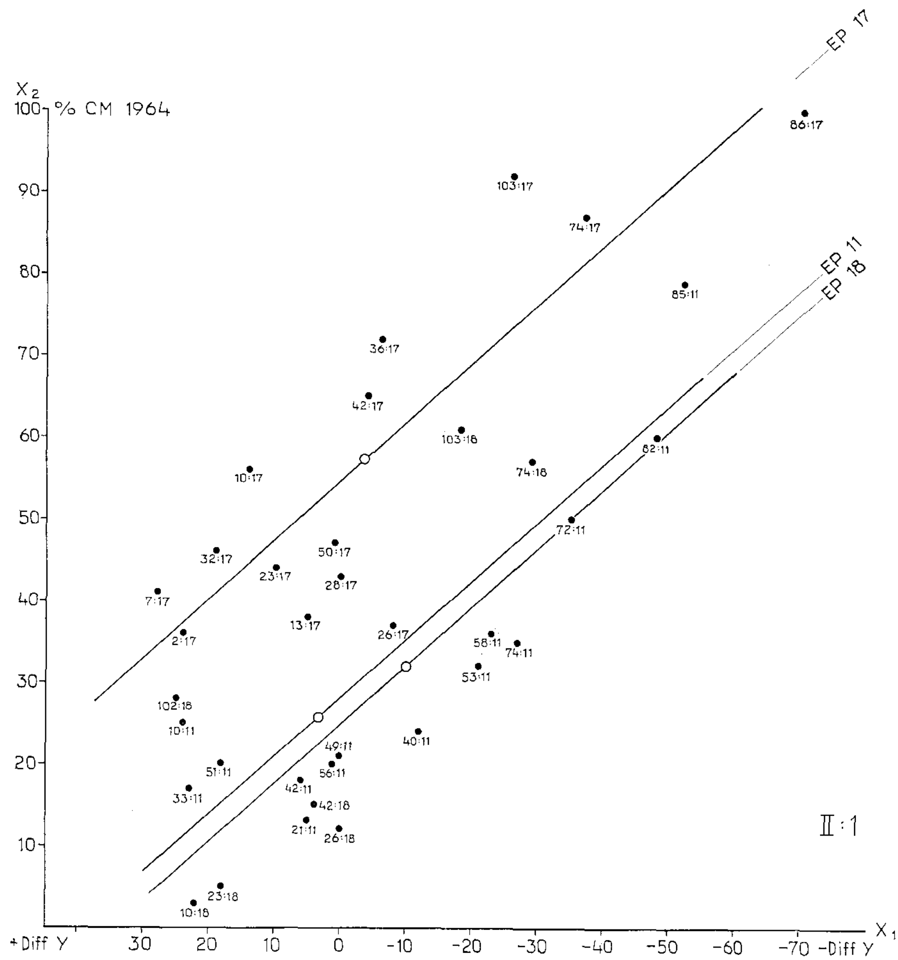


Fig. 60. Parallel regressions of X_2 on X_1 in EPs 11, 17 and 18 within subregion II:1 (Tables 22 and 23). Variables X_2 and X_1 as well as designations used in the diagram, see Fig. 59.

EPs when guiding principles for the experimental series were being laid down in 1948.

The differences in the duration of the growing season (+Y and —Y) have been used as a means of expressing the transfer of PRs from their natural habitat to the EP site. The +Y and —Y values make the scale of the horizontal axis of the diagrams. The length of the growing season (Y) is expressed by the number of days with normal mean temperature $\geq 6\,^{\circ}$C per year. Y values have been computed according to LANGLET's formula (LANGLET,

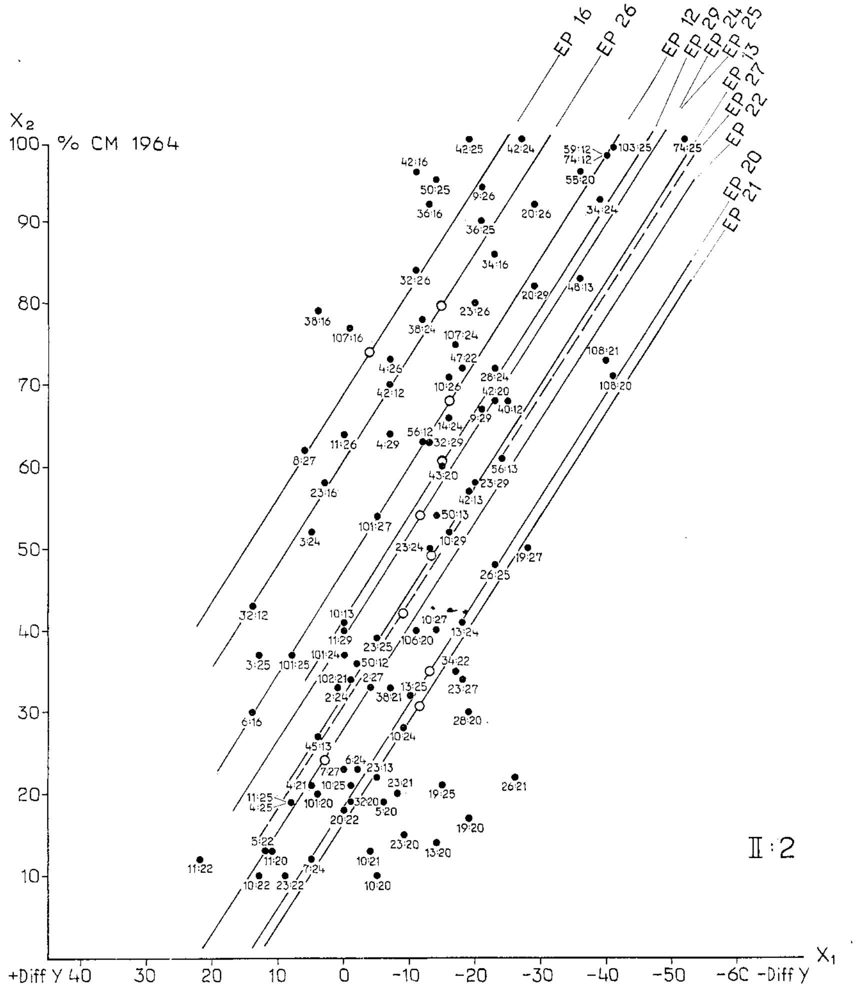


Fig. 61 A. Parallel regressions of X_2 on X_1 in EPs 12, 13, 16, 20, 21, 22, 24, 25, 26, 27 and 29 within subregion II:2 (Tables 22 and 23).
Variables X_2 and X_1 as well as designations used in the diagram, see Fig. 59. Regression line in EP 27 (----) makes an exception owing to the severe spring frost of 1963 when northern and cold-hardy PRs suffered.

1936, p. 344). The Y, +Y and —Y values, as well as the corresponding CM rates of 1964, are to be found in the tables for each single EP (Chap. 4.2).

Figs. 59, 60, 61 and 62 show that CM rates vary considerably. Similar PR transfer values often correspond to most variable CM rates. Variations in the general climate and in the local climatic conditions on EP sites are the cause of a broad variation range of the PR response to external factors. Even the

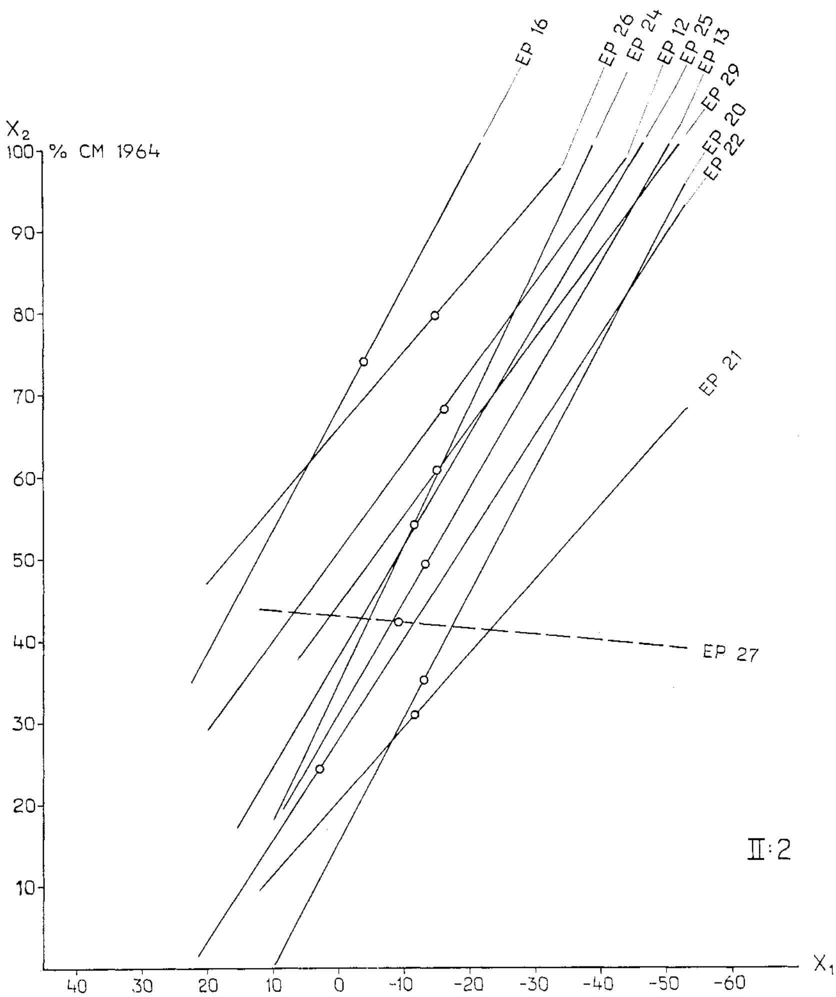


Fig. 61 B. Individual regressions of X_2 on X_1 in EPs 12, 13, 16, 20, 21, 22, 24, 25, 26, 27 and 29 within subregion II:2 (Tables 22 and 23).
Variables X_2 and X_1 as well as circles on regression lines, see Fig. 59. *Cf.* Fig. 60 A.
Regression line in EP 27 (----) makes and exception owing to the severe spring frost of 1963 when northern and cold-hardy PRs suffered.

variation of the CM rates in the local PRs is most striking, and can be most frequently explained by different site conditions on individual EPs. A great variation exists among the CM rates of local PRs in EP group II:2, as seen from Fig. 61:19 % (EP 20), 21 % (EP 25), 24 % (EP 27), 34 % (EP 21), 36 % (EP 12), 37 % (EP 24), 40 % (EP 29), 64 % (EP 26) and 77 % (EP 16). These CM rates show that the local PR does not always possess the necessary

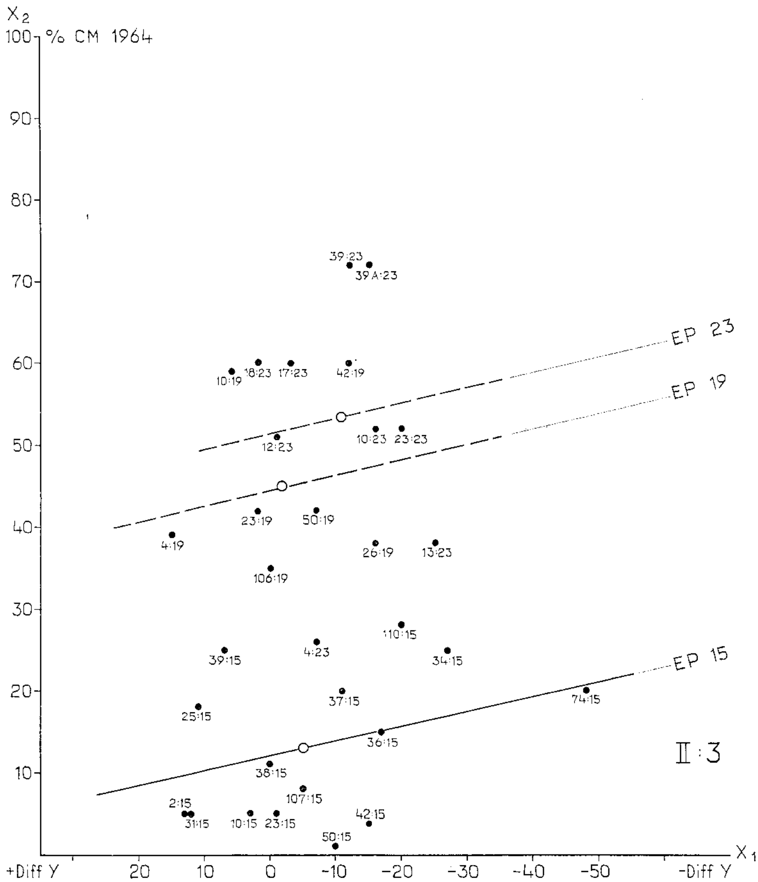


Fig. 62. Parallel regressions of X_2 on X_1 in EPs 15, 19 and 23 within subregion II:3 (Tables 22 and 23).
Variables X_2 and X_1 as well as designations used in the diagram, see Fig. 59. Regression lines of EP 19 and EP 23 (----) make exceptions, owing to mortality in plants caused by rodents in 1964.

degree of adaptation. This circumstance has been referred to earlier (Wibeck, 1933; Gustafsson, 1962; Eiche, 1962). On EP 16 the value of the local PR for afforestation aims is insignificant, whereas PRs 23 and 6 (Fig. 45 A and B; Table 11) originating from the north, show the best adaptation to EP site conditions.

In EP group II:2 the CM rates of the PRs transferred from the south to the north are so high that the transfer of these PRs with the view of afforestation is hardly worth consideration. However, on the EP sites with unfavourable climatic conditions the transfer of PRs from northern

Table 22. Regressions of X_2 on X_1.
(Calculated on the basis of data in Tables 2—21, Chap. 4.2)

EP group	EP	Regression equation	Coefficient in regressions	a_i in parallel regressions
I	9	$X_2 = 45.05+0.0280X_1$	$+0.0280 \pm 0.1687$	44.68
	10A	$X_2 = 18.58—0.1734X_1$	$—0.1734 \pm 0.1057$	18.58
	10B	$X_2 = 30.52—0.2228X_1$	$—0.2228 \pm 0.2341$	32.10
	14	$X_2 = 26.48—0.3410X_1$	$—0.3410 \pm 0.2262$	25.34
Total regression		$X_2 = 27.54—0.2313X_1$	$—0.2313 \pm 0.0903$	
Parallel regressions		$X_2 = a_i \quad —0.1739X_1$	$—0.1739 \pm 0.0767$	
II: 1	11	$X_2 = 25.47—0.6622X_1$	$—0.6622 \pm 0.1048$	24.86
	17	$X_2 = 54.88—0.7149X_1$	$—0.7149 \pm 0.1276$	54.85
	18	$X_2 = 28.83—0.9446X_1$	$—0.9446 \pm 0.3079$	28.13
Total regression		$X_2 = 37.68—0.6881X_1$	$—0.6881 \pm 0.1289$	
Parallel regressions		$X_2 = a_i \quad —0.7228X_1$	$—0.7228 \pm 0.0829$	
II: 2	22	$X_2 = 27.99—1.2332X_1$	$—1.2332 \pm 0.3640$	28.07
	12	$X_2 = 50.59—1.0882X_1$	$—1.0882 \pm 0.2234$	47.79
	13	$X_2 = 30.83—1.3746X_1$	$—1.3746 \pm 0.2520$	32.33
	16	$X_2 = 68.24—1.4933X_1$	$—1.4933 \pm 0.4821$	69.13
	20	$X_2 = 15.22—1.5156X_1$	$—1.5156 \pm 0.3444$	18.54
	21	$X_2 = 20.29—0.9135X_1$	$—0.9135 \pm 0.3925$	16.24
	24	$X_2 = 34.43—1.6846X_1$	$—1.6846 \pm 0.3592$	39.40
	25	$X_2 = 38.17—1.3577X_1$	$—1.3577 \pm 0.3398$	39.28
	26	$X_2 = 65.92—0.9287X_1$	$—0.9287 \pm 0.3016$	60.95
	27	$X_2 = 42.97+0.0762X_1$	$+0.0762 \pm 0.5229$	30.92
	29	$X_2 = 44.55—1.0768X_1$	$—1.0768 \pm 0.3725$	41.73
Total regression		$X_2 = 37.34—1.2558X_1$	$—1.2558 \pm 0.1456$	
Parallel regressions		$X_2 = a_i \quad —1.2629X_1$	$—1.2629 \pm 0.1163$	
II: 3	15	$X_2 = 11.62—0.2659X_1$	$—0.2659 \pm 0.1234$	12.03
	19	$X_2 = 44.85—0.0851X_1$	$—0.0851 \pm 0.4225$	44.68
	23	$X_2 = 53.90+0.2197X_1$	$+0.2197 \pm 0.6109$	51.66
Total regression		$X_2 = 30.20—0.3041X_1$	$—0.3041 \pm 0.2822$	
Parallel regressions		$X_2 = a_i \quad —0.1862X_1$	$—0.1862 \pm 0.1484$	

Variables: X_2 = CM rates 1964 in single PRs
X_1 = differences in the length of growing season (+ Diff. Y and — Diff. Y)

districts has proved to be efficient not only as regards plant mortality, but also as regards the tree height of these PRs, which is seen from the corresponding EP tables. This phenomenon has been the subject of earlier comment (Wibeck, 1933; Gustafsson, 1962; Eiche, 1962; Stefansson, 1965). However, at present it is not possible on the basis of the available data to regard the faster growth of the PRs transferred from the north as being a general rule.

The gradient of the CM rates in relation to the transfer of PRs clearly differentiates the four EP groups. This is seen mos tdistinctly when EP group I

Table 23. Analysis of variance in regressions. Regressions of X_2 on X_1.
(Calculated on the basis of data in Tables 2—21, Chap. 4.2)

EP group	Source of Variation	Sum of Squares	D.F.	Mean Square	F
I	A. Individual regressions (single EPs)	2 708.53	27	100.32	1
(Fig. 59)	B. Parallel regressions	2 854.93	30	95.16	—
	C. Total regression	6 134.66	33	185.90	—
	D. B—A	146.40	3	48.80	0.49
	E. C—B	3 279.73	3	1 093.24	10.90***
	F. C—A	3 426.13	6	571.02	5.69***
II: 1	A. Individual regressions (single EPs)	4 023.58	29	138.74	1
(Fig. 60)	B. Parallel regressions	4 179.24	31	134.81	—
	C. Total regression	11 217.90	33	339.94	—
	D. B—A	155.66	2	77.83	0.56
	E. C—B	7 038.66	2	3 519.33	25.37***
	F. C—A	7 194.32	4	1 798.58	12.96***
II: 2	A. Individual regressions (single EPs)	19 524.68	76	256.90	1
(Fig. 61)	B. Parallel regressions	21 981.76	86	255.60	—
	C. Total regression	43 094.76	96	448.90	—
	D. B—A	2 457.08	10	245.71	0.96
	E. C—B	21 113.00	10	2 111.30	8.22***
	F. C—A	23 570.08	20	1 178.50	4.59***
II: 3	A. Individual regressions (single EPs)	3 210.20	25	128.41	1
(Fig. 62)	B. Parallel regressions	3 354.44	27	124.24	—
	C. Total regression	13 819.53	29	476.54	—
	D. B—A	144.24	2	72.12	0.56
	E. C—B	10 465.09	2	5 232.54	40.75***
	F. C—A	10 609.33	4	2 652.33	20.66***

*** Statistically significant at the 0.1 per cent level
Variables: X_2 = CM rates 1964 in single PRs
X_1 = differences in the length of growing season (+ Diff. Y and — Diff. Y)

is compared with group II:2. The differences between the diagrams (Figs. 59, 60, 61 and 62) are expressed by means of regression curves. A statistical analysis of the relation of the CM rates to the transfer of PRs supplements the graphical representation of the data (Tables 22—25). Most attention has been devoted to group II:2 (Fig. 61), since it is the most important of the four groups.

The gradient of CM rates in EP group I (Fig. 59) is quite insignificant and the transfer of PRs from the south can be applied successfully. EP 10 (Fig. 37, Table 3) is an example of how successful the long-distance transfer of PRs can be. In EP group II:1 (Fig. 60) the gradient of the CM rates is expressed more clearly; however, a moderate transfer of PRs in this EP group is still possible. On the other hand, in EP group II:2 (Fig. 61) all southern PRs suffered great losses in plants, and even local PRs did not always prove to be

Table 24. Regressions of X_2 on X_1 and X_3.

(Calculated on the basis of data in Tables 9—18, Chap. 4.2)

EP group	EP	Regression equation	Coefficient in regressions	
II: 2	12	$X_2 = 49.33—0.7136X_1+0.0120X_3$	$—0.7136 \pm 0.4812$	$+0.0120 \pm 0.0136$
	13	$X_2 = 31.58—0.9804X_1+0.0129X_3$	$—0.9804 \pm 0.7354$	$+0.0129 \pm 0.0223$
	16	$X_2 = 77.19—2.2460X_1—0.0797X_3$	$—2.2460 \pm 0.3690$	$—0.0797 \pm 0.0248$
	20	$X_2 = 16.48—0.7267X_1+0.0253X_3$	$—0.7267 \pm 0.6930$	$+0.0253 \pm 0.0194$
	21	$X_2 = 24.02+0.9448X_1+0.0512X_3$	$+0.9448 \pm 1.0242$	$+0.0512 \pm 0.0268$
	24	$X_2 = 34.53—1.6266X_1+0.0020X_3$	$—1.6266 \pm 0.8427$	$+0.0020 \pm 0.0261$
	25	$X_2 = 38.29—1.4237X_1—0.0019X_3$	$—1.4237 \pm 0.6899$	$—0.0019 \pm 0.0170$
	26	$X_2 = 79.00—1.0734X_1—0.0051X_3$	$—1.0734 \pm 1.0854$	$—0.0051 \pm 0.0361$
	27	$X_2 = 66.58+1.3962X_1—0.0595X_3$	$+1.3962 \pm 1.1817$	$—0.0595 \pm 0.0483$
	29	$X_2 = 55.67—0.6490X_1—0.0151X_3$	$—0.6490 \pm 1.2862$	$—0.0151 \pm 0.0429$
Total regression		$X_2 = 38.81—0.9965X_1+0.0069X_3$	$—0.9965 \pm 0.3115$	$+0.0069 \pm 0.0088$
Parallel regressions		$X_2 = a_i \quad —1.0537X_1+0.0069X_3$	$—1.0537 \pm 0.2480$	$+0.0069 \pm 0.0071$

Variables: X_2 = CM rates 1964 in single PRs
X_1 = differences in the length of growing season (+ Diff. Y and — Diff. Y)
$X_3 = (X_1)^2$

Table 25. Analysis of variance in regressions. Regressions of X_2 on X_1 and X_3.

(Calculated on the basis of data in Tables 9—18, Chap. 4.2)

EP group	Source of Variation	Sum of Squares	D.F.	Mean Square	F
II: 2	A. Individual regressions (single EPs)	16 287.63	61	267.01	1
	B. Parallel regressions	20 780.72	79	263.05	—
	C. Total regression	41 167.58	88	467.81	—
	D. B—A	4 493.09	18	249.62	0.93
	E. C—B	20 386.86	9	2 265.21	8.48***
	F. C—A	24 879.95	27	921.48	3.45***
	Individual regressions of X_2 on X_1 — Individual regressions of X_2 on X_1 and X_3				
	Linear Regression (X_2 on X_1)	18 578.90	71	261.67	
	Curved Regression (X_2 on X_1 and X_3)	16 287.63	61	267.01	1
	Difference	2 291.27	10	229.13	0.86

*** Statistically significant at the 0.1 per cent level
Variables: X_2 = CM rates 1964 in single PRs
X_1 = differences in the length of growing season (+ Diff. Y and — Diff. Y)
$X_3 = (X_1)^2$

sufficiently hardy. Thus, the transfer of northern PRs becomes an urgent, pressing problem. In localities with severe climatic and unfavourable edaphic conditions the transfer of northern PRs seems to be the only satisfactory solution with the view of meeting the requirements of afforestation. The gradient of the CM rates in EP group II:3 (Fig. 62) is moderate. Some of the PRs transferred from the south (Fig. 56, EP 15, PR 50) show very good adaptation to the site conditions on the EP. Unfortunately, the data on the CM rates in this EP group are not sufficient.

As seen from the analysis on the mortality of plants, the north of Sweden cannot be regarded as that region to which equal requirements as regards the transfer of PR are necessary. Besides, when choosing PRs with the view of afforestation particular attention should be paid to both the extreme local climatic conditions and also to the unfavourable edaphic conditions (*cf.* LANGLET, 1957).

5. Cause of damage to plants

Among the various agents causing damage to plants, cold is the primary factor. Damage by cold, in its turn, actuates damaging agents of a secondary character. The severe cold damage of 1960/61 is an example of the complex effects caused by cold. Of all the different types of cold damage in trees, the most severe proved to be BSG. High mortality rates in trees during the period 1961—1964 furnish us with evidence regarding the scope of the damage. The occurrence of BSG is connected with extreme climatic conditions prevailing in the late winter and early spring of 1961 (Chap. 2). The mutual relationship between BSG and other types of cold damage and their modifications has already been dealt with in Chap. 3. In the present chapter attention is principally devoted to BSG, and an analysis of the agents causing damage is made. As regards the other types of cold damage it is not too difficult to find an explanation of their origin if cold is accepted in principle as the primary damaging agent.

In order to avoid misunderstanding, it should be stressed that cold is not the only primary cause of damage and mortality in plants in northern Sweden. That which is very dangerous to plants is a fungus disease, snow blight, *Phacidium infestans*. The disastrous effects of this disease on afforestation areas are well known (Björkman, 1948) and its negative role has been proved by previous PR experiments (Schotte, 1923; Langlet, 1936). *Phacidium infestans* is often considered to be the chief cause of mortality in plants, and views have been expressed that if it were possible to avert the infection of plants by *Phacidium infestans*, the transfer of PRs in northern direction with the view of afforestation could be carried out efficiently, thus obtaining a higher growth rate in trees (Langlet, 1957). Southern PRs are most susceptible to damage by *Phacidium infestans*, whereas northern PRs show a remarkable degree of resistance to this disease.

The varying susceptibility of different PRs to infection by *Phacidium infestans* was re-examined in field experiments by the common efforts of the Department of Forest Genetics and by the Department of Forest Botany. An experimental series was laid out in 1954. Plants were infected according to a definite plan, beginning with 1956. The same PRs and transplants from the same nurseries and of the same age were used in the experiment as those in the PR experimental series (Chap. 1). These experiments, where plants were infected with *Phacidium infestans*, confirmed the previous findings, namely, that southern PRs and PRs originating from low altitudes are more susceptible to this disease than northern and upland PRs (Björkman, 1963).

On EPs the infection of plants by *Phacidium infestans* was eliminated by consistent annual spraying of plants in late autumn shortly before the fall of snow, until trees reached a height where the disease no longer could jeopardise them. From 1962 spraying was interrupted on some EPs, and in the following years on others. Protection of plants against *Phacidium infestans* was carried out on 18 EPs, located in the region north of the river Dalälven, where plants are exposed to danger as regards this disease. It often proved to be necessary to spray the plants two or three times during the same autumn, in those cases where snow had melted, or where continuous rain had washed off fungicides applied by spraying. This consistent protection of plants gave satisfactory results, and it was possible to ascertain that on EPs treated in this way mortality in plants was not caused by *Phacidium infestans*, since this fungus had been completely eliminated by spraying.

Protection of plants against attacks by *Hylobies* beetles was also consistently carried out during the first few years after the layout of the experiments by spraying those parts of plants which were exposed to danger. In order to protect EPs against the damage by elk (*Alces alces alces*) and reindeer (*Rangifer tarandus*) special fences were erected. Among twenty EPs only six did not require any protection by fencing. Much work has been devoted to provide necessary protection of EPs against all the damaging agents mentioned above, and it is gratifiyng to state that these protective measures proved to be satisfactory. Even if on individual EPs some plants were damaged (Chap. 4.2), such damage was not frequent and cannot exercise any influence on the conclusions regarding the role of climatic factors and their being the primary cause of mortality in plants.

The PR time-mortality curves on the diagrams of the EPs are a convincing proof of the fact that the principal cause of mortality in plants is cold (Chap. 4.2 and 4.3). The CM and SYM rates in these PR curves have been obtained by transforming the data on the death of individual plants, recorded on the EPs. However, taking into consideration different views regarding the origin of BSG and also regarding the other types of cold damage, it is necessary to give a description of the external conditions under which damage by cold occurs.

The further analysis of the problem is made by considering two aspects of the diseases in plants, caused by cold effect. This approach to the problem has a historical background, but by no means lacks current interest. What is of importance in this connection is the relative roles played by the climatic conditions on the one hand, and the infection by fungi on the other. *Physical factors* and *pathogens* can be described as the concrete definition of the pro-

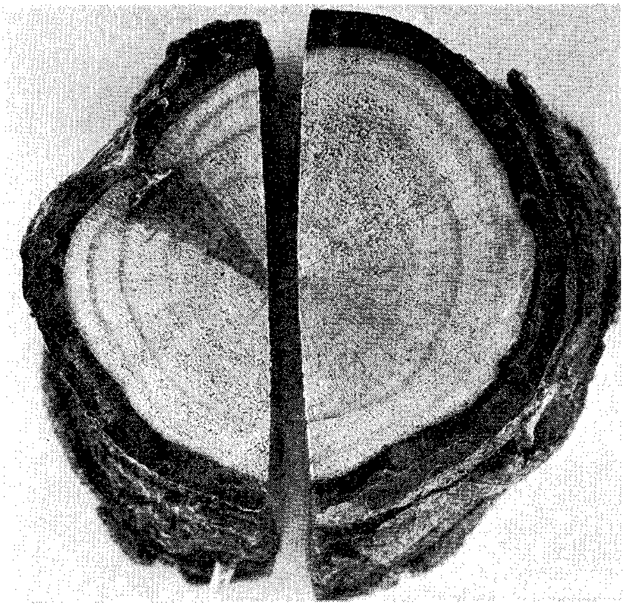


Fig. 63. Cambium killed in 1961, on a restricted area at the base of the stem with adjacent sector of injured xylem infiltrated by resin, in EP 12, PR 56. Owing to the callus overgrowth the wound was healed within two years. Photographed in the spring of 1963.

blem. These two terms have been used by Stevens and Young (1927), Day (1928, 1945) and Boyce (1961) and they correspond to concrete conceptions.

5.1. Physical factors

5.1.1. Destruction and dieback of cambium, phloem and cortex

The size of the BSG portion on the stems of the damaged trees varies considerably. Its diameter varies from approximately 0.6 cm to 6 cm. The height of the BSG portion sometimes hardly reaches 1 cm, but the portion may be 50 cm high or even higher. The location of BSG above soil level also varies considerably. In most cases BSG is situated on the stem in the 30 cm zone above the ground surface. However, on several occasions BSG occurred immediately below the surface of the ground and sometimes exactly at the ground surface level. Only in a few cases had girdles occurred higher than 50 cm above the ground surface. However, in these cases more or less clearly expressed signs of BSG were also recorded at a lower level on the same stem. In any case, these phenomena definitely differ from another type of cold damage, namely, the girdling of the main stem in its upper part (Chap. 3.1.1.7). The injury in the BSG portion normally centres in the cambial region. The death of cambium represents the severest degree of this type of damage. The girdling is complete when killed cambium encircles the stem. In most cases the stem is only partly girdled. The dead portion of the cambium sometimes appears only on a restricted area in the shape of small patches (Fig. 63) and, thanks to the callus overgrowth, the wound is healed within a few ensuing years. However, as a rule the affected area usually encircles a smaller or larger part around the stem. If no other types of cold injuries occur in such partly girdled trees, if the crown of the tree is unimpaired and the vigour of the tree in the following summer is sufficient to produce new photosynthetic products, callus overgrowth is formed on the edge of the injured area and frost canker begins to develop. In those cases where a vigorous callus overgrowth is formed, a swelling appears on the stem above the girdle (Figs. 1, 2, 26).

Three samples of partly girdled trees with varying characteristics will be discussed here. Figs. 64—66 represent the longitudinal and transverse sections of the BSG portions in trees. From the transverse sections which were taken from the injured parts of the tree at a distance of 2.5 cm apart, only the most representative were chosen, whereas efforts were made to include the whole portion of the BSG.

In Fig. 64 the histological analysis shows an example of BSG where the injury affected more than a half of the area around the stem. The BSG was 25 cm high and was situated on the tree immediately above the soil level. The crown of the tree was unimpaired and the injury had influenced the growth rate of the tree only inconsiderably. The structure of the stem in the BSG portion is seen in the transverse sections. Only a half of the xylem which had been formed before the occurrence of the damage of 1961 was left unimpaired. The further formation of the wood in the damaged portion was excentric and actually took place outside the circumference of the stem of 1960. In the interior of the stem a sharp dividing line was formed by resin between the injured and unimpaired wood (Fig. 64 c). Owing to the resin infiltration the wood was well protected against dehydration and also partly against infections by fungus diseases. There is every reason to assume that such a healing of the wound favours the recovery of the tree. The vigour of the tree did not deteriorate during the first three years after the occurrence of the damage. However, the callus overgrowth was injured by the winter cold of 1962, the edge of the canker was cut back at some points and resin infiltration occurred in the newly-injured area. This illustrates the well-known fact that the edges of the canker are particularly susceptible to cold and that they are liable to be killed (Day, 1928, 1931; Day and Peace, 1946).

Fig. 65 shows a partly girdled tree where cambium was killed in the BSG portion on two large areas, on the opposite sides of the stem. In connection with the intense dieback of the canker for three years in succession, the shape

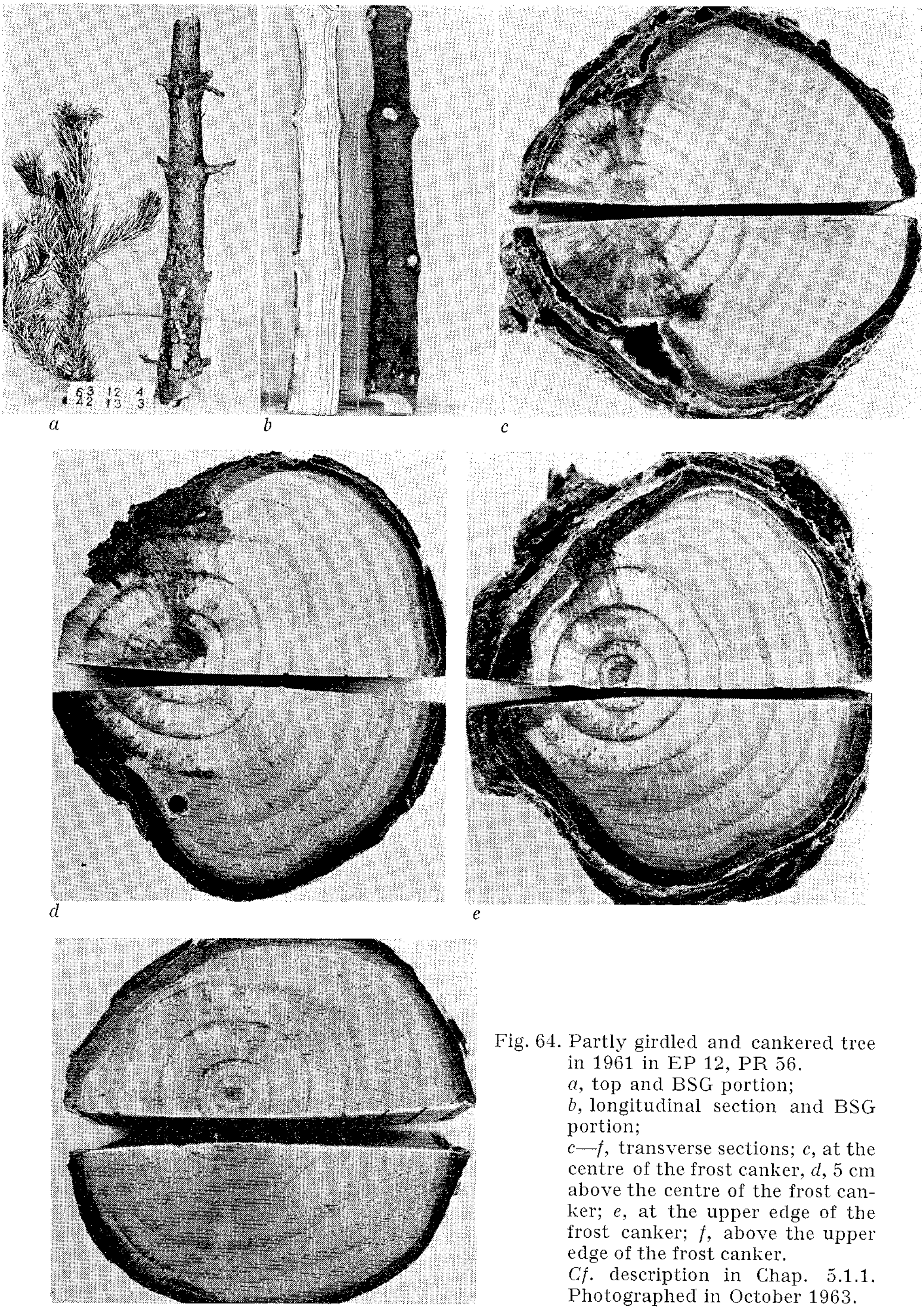
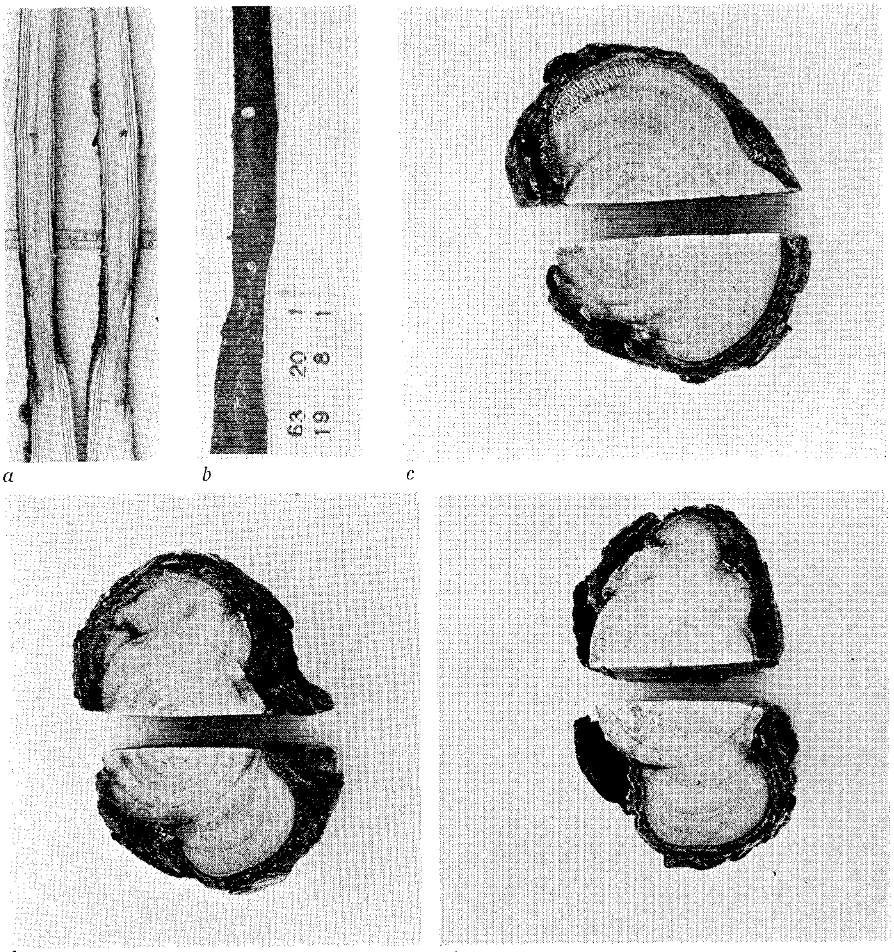


Fig. 64. Partly girdled and cankered tree in 1961 in EP 12, PR 56.
a, top and BSG portion;
b, longitudinal section and BSG portion;
c—f, transverse sections; *c*, at the centre of the frost canker, *d*, 5 cm above the centre of the frost canker; *e*, at the upper edge of the frost canker; *f*, above the upper edge of the frost canker.
Cf. description in Chap. 5.1.1. Photographed in October 1963.



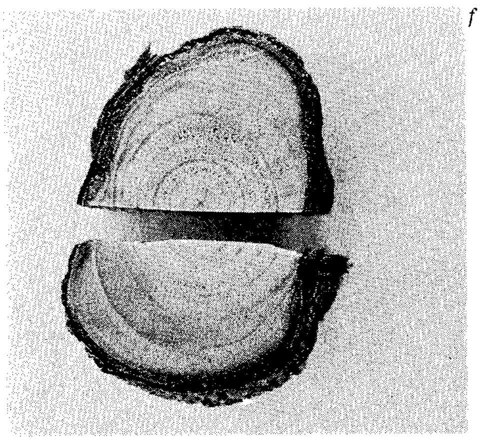
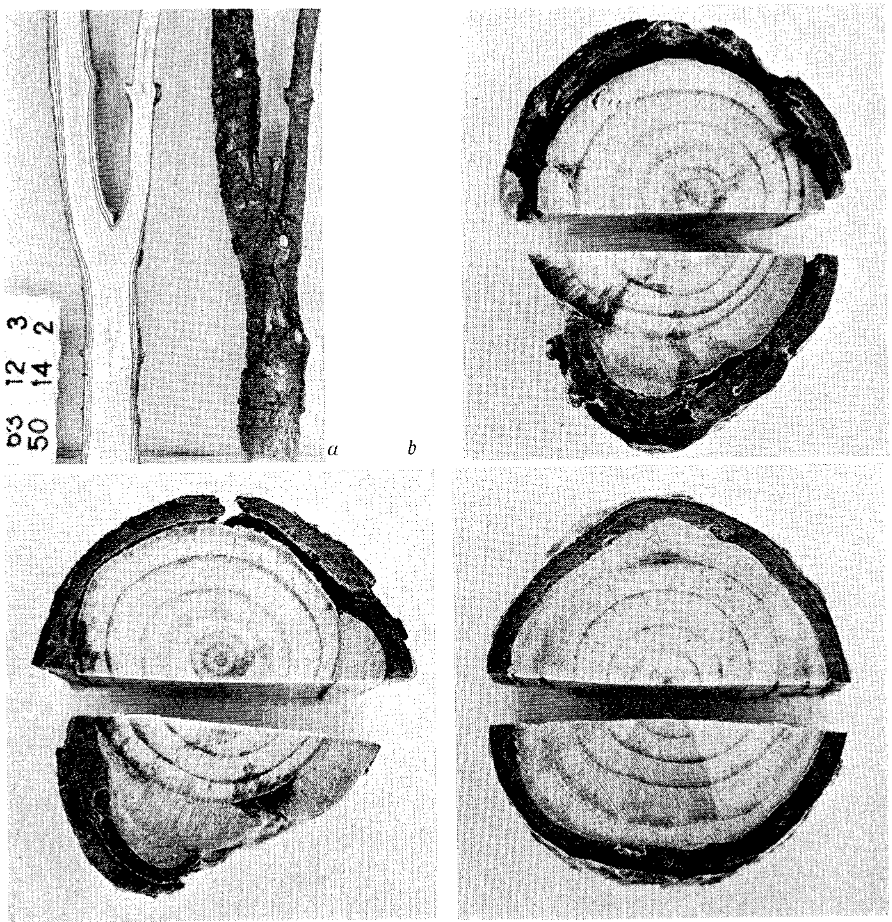


Fig. 65. Partly girdled and cankered tree in 1961 with flattened stem in the damaged portion in EP 20, PR 19.
a, longitudinal section of BSG portion;
b, BSG portion;
c—*f*, transverse sections; *c*, near the lower edge of the frost canker; *d* and *e*, at the centre of the frost canker; *f*, at the upper edge of the frost canker.
Cf. description in Chap. 5.1.1. Photographed in October 1963.



a b

c d

e

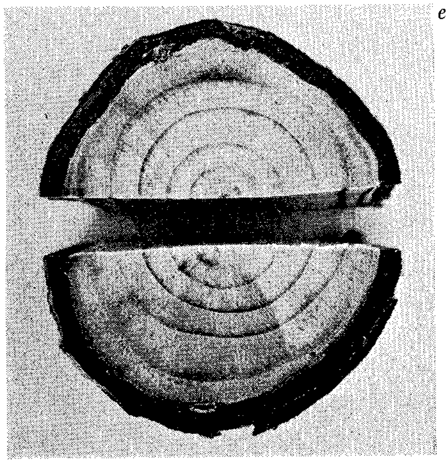


Fig. 66. Tree partly girdled and heavily cankered in 1961 (EP 12, PR 50); died in the autumn of 1962.
a, longitudinal section and BSG portion;
b—e, transverse sections; *b* and *c*, at the centre of the frost canker; *d* and *e*, at the upper edge of the frost canker, showing sectors of xylem with resin infiltration which occurred after the cold damage of 1962.
Photographed in October 1963.

of the stem became flattened in the damaged portion. This particular case of BSG was most conspicuous, and it was easy to discern it both among damaged and also unimpaired trees. It is hardly to be expected that trees suffering from such kind of BSG could survive. However, on EPs laid out by Schotte and Wibeck during 1909—1911 a few trees damaged in this way had survived as late as 1946.

A still more severe case of BSG is shown in Fig. 66. Killed cambium took up approximately two-thirds of the circumference of the stem. However, boundaries between sectors with injured and unimpaired xylem in the BSG portion were not clearly defined. The edge of the canker had been cut back after the winter cold of 1962 and the tree lingered on up to the autumn of 1962. This BSG case is representative for a great many trees girdled in 1961. However, in most cases the damage was of a more complicated nature.

Fig. 26 shows a case of BSG where only a narrow string of cambium was unimpaired and the annual ring of 1961 was very thin at this particular place. The tree died in the early spring of 1962. The examples shown in Fig. 1 are analogous to this case. The cases of BSG shown in Fig. 2 are characteristic for the girdle located on the stem approximately 40—45 cm above soil level, with a few small branches covered with living foliage below the girdle. At the base of the tree very thin annual rings had been formed in 1961 and 1962, but annual rings formed above the girdle in 1961 and 1962 were broad, whereas the annual ring of 1963 was narrow. These trees survived for a further three years after the occurrence of BSG.

There are several reasons why BSG is often inconspicuous and difficult to discover, and why no swelling appears above the girdle in the damaged trees. The principal reason is defoliation of the crown. Defoliation, in its turn, can be induced by other types of cold damage. Fig. 4 is an example of how even severe cases of BSG often pass unnoticed. The portion of the BSG on the stem is often not clearly seen in partly girdled trees, even when girdling occurs at several levels above the ground surface, and damage is situated on different sides of the tree. In such cases the damaged area is not clearly defined and does not differ from the unimpaired part of the stem. The healing of the wounds proceeds slowly or does not take place at all, the pan formation of the canker is inconspicuous. Naturally, the varying characteristics of BSG are greatly dependent on the degree and extent of the injury.

The damage in partly girdled trees is most conspicuously expressed in the centre of the frost canker. At this level of the BSG portions in transverse sections (Figs. 26, 64 c, 65 c and 66 c) the dead area is larger than in the transverse section up and down from the centre of the canker. Between the xylem and the outer bark all living tissues, cambium, phloem and inner bark are killed. Sometimes even the outer bark is sloughed off on the BSG portion

(Chap. 3.1.1.4) and xylem is exposed. In the corresponding xylem sector, inwards from the dead area around the stem, all live elements in cambial rays and resin ducts are killed. Thus the damage embraces not only the periphery, but also reaches the centre of the stem in radial direction. The resin infiltration in the damaged parts of the stem can be most complicated. In most cases it colours the xylem sector brown in radial direction as far as the centre of the stem (Fig. 63). Resin infiltration in xylem takes place most vigorously in the vicinity of the edge of the wound (Fig. 64 c). The colouring of resin infiltration in the periphery of the dead xylem may sometimes vary quite considerably (Fig. 66 c). There is every reason to believe that the death of the cambium around the stem at different points did not always occur simultaneously, but that it proceeded successively.

The demarcation line between the dead and the live areas of the BSG in the vertical direction up and down from the centre of the canker is expressed just in the same way as was the case in the transverse sections. It is clearly seen in the longitudinal and transverse sections in Figs. 64—66. The only difference here is the vigorous callus overgrowth and often a swelling in the upper part of BSG above the girdle, which never occurs in the lower part of BSG.

The nature and the extent of BSG are sufficiently revealed in the examples discussed above as regards partly girdled trees. No essential differences exist as regards the nature of the damage between completely girdled and partly girdled trees. Only a narrow cambium strip left unimpaired in the case of BSG shown in Fig. 26 marks it off from complete girdling. However, in the cases of BSG discussed above there is not sufficient evidence to show in what succession the death of cambium, phloem and even of periderm had occurred.

Indirect evidence of phloem injuries caused by the cold of 1962 is seen in transverse sections in Fig. 66. Resin infiltration had occurred in a limited xylem sector in radial direction of the cambial rays, and had reached the centre of the stem. Thus the annual ring of 1961 formed the outer limit of the xylem sector. The formation of the annual ring of 1962 had proceeded without impediment, and no resin infiltration had occurred. It might be assumed that the phloem had been injured by the cold of 1962, and that in the adjacent BSG area the supply of nutrition to the cambial rays in the xylem sector had been interrupted (Braun, 1963, p. 100), causing the death of the living elements in this xylem sector, while leaving the cambium unimpaired (Chandler, 1913).

A mosaic consisting of thin rents, slightly marked by resin flow in the dead outer bark (Chap. 3.1.1.2, Fig. 29 a), also indicates that the phloem had been injured in the corresponding area of the stem. Resin flow originates in the schizogenous resin ducts, which are located in the phloem. Such rents in the bark are considered to be typical symptoms of phloem killed by cold (Day, 1931, p. 52). The anatomical examination of the injured parts was not made immediately after the occurrence of the damage in 1961. Later, in 1962 and 1963, the rupture of the phloem could be discerned, but among other uninjured tissues injury did not appear in well-defined outlines, as the rhytidom strings had penetrated into some portions of the injured phloem.

On the strength of field observations on the EPs, and on the basis of laboratory analyses, it can be concluded that in the affected areas of the BSG portions injured by the cold of 1961 all living tissues had, in the majority of cases, been killed. However, on some occasions on the restricted areas of the BSG portions only phloem (and also the periderm) had been injured.

The annual ring of 1960 in the BSG portions appeared to be normal and uninjured. This annual ring differed from the others only by slight lignification in the summer wood, which was less apparent. In northern PRs the differences between the annual rings are not very conspicuous, whereas in PRs having natural habitats located to the south of the EP these differences are striking. The slight lignification of the summer wood in the annual ring of 1960 was caused by unfavourable weather conditions prevailing during the growing season of that year (Dietrichson, 1961, 1964).

The annual ring of 1961 was formed after the occurrence of the severe cold damage, which took place in winter and early spring. This annual ring did not appear in trees where cambium had been killed. The formation of callus overgrowth at the edge of the wounds, and the development of frost canker, are typical for areas affected by cold. In the earliest stages of the 1961 annual ring parenchymatous tissues were sometimes found at the edge of, and near, the canker. "Frost tissues" of this kind, which touched the annual ring of 1960, indicate that cambium had been injured before new wood was formed (Mix, 1916; Rhoads, 1923; Harris, 1934; Day, 1928, 1931; Day and Peace, 1934). On the other hand, there are no indications of the formation of abnormal tissue in the zone of the spring wood of 1961 in either the unimpaired parts of the stem or in the BSG portions.

No ruptures were found in the tracheid walls in the xylem sectors of the BSG portions infiltrated with resin. On the other hand, such ruptures were revealed in the tangential walls of tracheary elements in cambial rays and in leaf and branch traces. Ruptures manifested themselves in radial sections. Anatomical examination was made of some BSG portions selected for that purpose. There is every reason to assume that injury of this nature is rather frequent.

In severe cases of BSG, rents filled with resin are seen in xylem in radial sections. They stretch themselves in the longitudinal direction of the stem

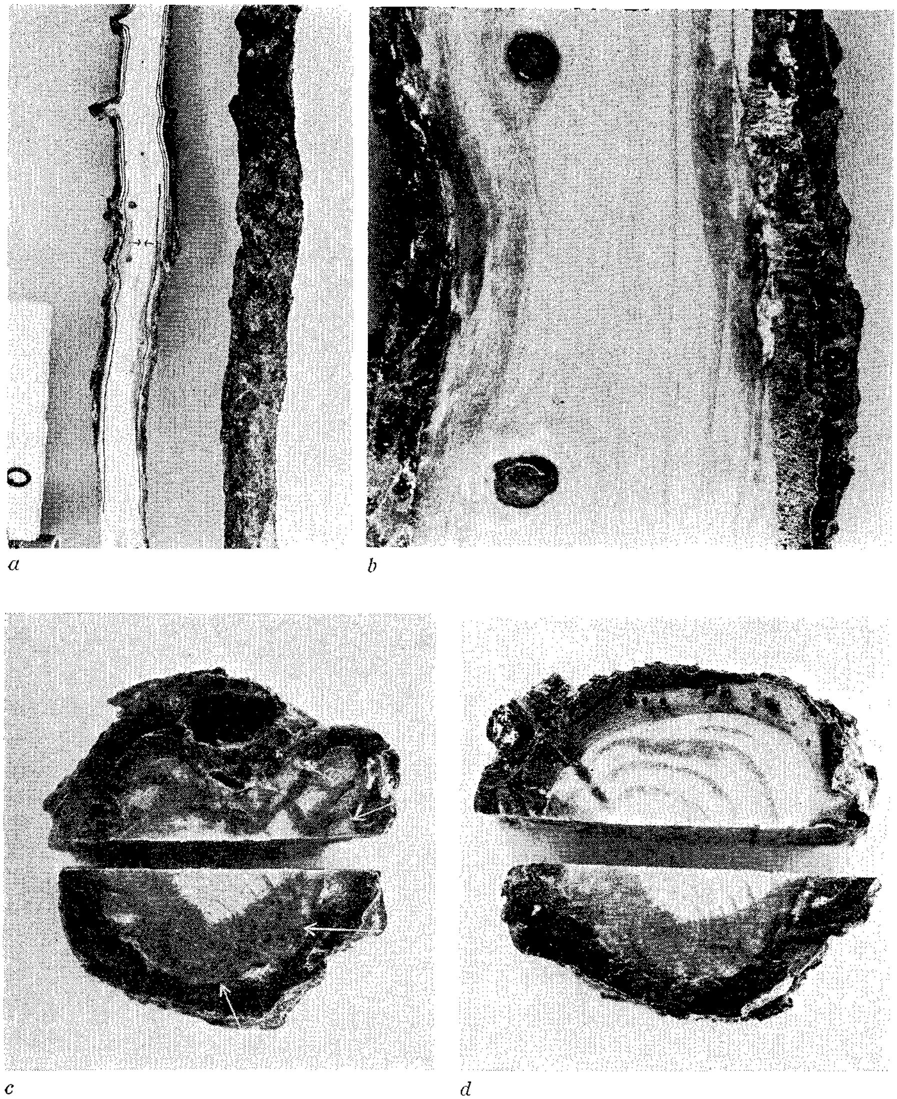


Fig. 67. Naturally regenerated tree in the surround of EP 26; partly girdled in 1955. The edge of the frost canker died back slowly during 1955—1960, but was cut back after the winter cold of 1961 and severe spring frost of 1963. The tree died in the autumn of 1963. Photographed in October 1963.
a, longitudinal section and BSG portion;
b, longitudinal section at the centre of the frost canker;
c and *d*, transverse sections; *c*, at the centre of the frost canker; white arrows point to the edge of the frost canker in the springs of 1955, 1961 and 1963; *d*, above the centre of the frost canker.

and coincide with the vertical resin ducts (Fig. 67). The BSG in Fig. 67 is at the same time an example of heavy frost canker. BSG occurred in 1954/55 and the canker died back eight years in succession. In 1961 BSG re-occurred at the same place as in 1954/55, and during three years in succession the edge of the canker was cut back at an accelerated speed. The tree died in the autumn of 1963.

When summarizing the data obtained in the analysis of BSG as regards its character, extent and various characteristics of damage, it can be concluded that injury chiefly centres in the living tissues around the stem. Those cases where the dead cambium encircles the stem represent the severest degree of the damage. The death of the parenchymatous cells in cambial rays, and the death of the epithelial cells in resin ducts in the wood of the stem, should be regarded as the direct effect of cold, or as the result of the death of cambium or phloem in the area adjacent to the BSG portion.

5.1.2. Factors causing the damage

The environmental conditions causing BSG are characterized by alternate periods of cold and thaw, and by the fluctuations of diurnal temperature during late winter and early spring (Chap. 2.3). The origin of other types of cold damage has been investigated experimentally by artificially inducing injury into plants (Chaps. 3.1.1.7 and 3.1.2). As regards the origin of BSG, such experimental data are lacking. The data on weather conditions prevailing in winter and spring, which influence the magnitude of the rise and fall of temperature on the surface of the snow cover and in the adjacent air layer, and which play an important role in the occurrence of BSG, are also incomplete.

When considering the role played by those physical factors which have a share in the origin of BSG, attention should principally be directed to: (1) The heat balance on the micro-site surrounding that part of the stem where BSG occurs; (2) The thermal conductivity in the upper layer of snow cover and in the ice crust; (3) The changes in pressure exercised upon the stem of the tree by the ice crust in connection with the melting of the snow and ice, as well as by the swift freezing of the thaw water, both of which are caused by extreme fluctuations in temperature (Chap. 2.1).

In addition to these three physical factors, some other physical processes which take place in the stem in connection with its freezing should be mentioned. These processes are responsible for the origin of some other types of cold damage, and in most cases they are present when BSG occurs. Owing to the unequal contraction of the bark and wood during the freeze, and also to the unequal expansion in the subsequent thawing, the pressure in the stem changes and plays an important role in the origin of cold injury (Day, 1931; Wagener, 1949). The pressure which develops in connection with the formation of ice layer in the region of inner bark is considered to be one of the causes of injury to cambium and the formation of abnormal wood (Hartig, 1895). Several biophysical and biochemical processes in the living tissues and cells, which are associated with cold injury or cold resistance, should also be mentioned in this connection.

The diurnal fluctuation of temperature in late winter and early spring is the result of insolational heating by day and radiational cooling by night. The fresh snow reflects most of the solar radiation. Its reflexive capacity (the albedo) is 81 %, according to Ångström (1925). The temperature of the air above the snow cover varies very little by day, but at night the fall of the surface temperature of the snow and of the air above it attains very large values (Brunt, 1945). The values of the thermal conductivity and heat capacity of the snow, of which about nine-tenths is air, are very low (Ibid.). The snow cover protects the parts of the tree covered by it against the fluctuations in temperature and against cold.

In connection with thaws in late winter, and owing to the melting of the snow in spring, the albedo values undergo certain changes. Each thaw is connected with distinct fall of albedo. According to Kalitin's data (1929, cit. Galachov, 1959, p. 91), during the first phase of the spring the albedo values diminish from 82 % to 60 %, and when the snow has melted they sink to 20 %. The absorption of insolational energy calls forth increased melting of the snow and of the ice crust. Simultaneously the stem of the tree is warmed up, and the frozen tissues thaw and are saturated with water. During the night the water, formed by the melting of the snow, and the thawed tissues in the stem, swiftly freeze again. Such changes in temperature occur repeatedly during winters with extreme climatic conditions (Chap. 2.2). The micro-site around the stem of the tree is formed by the ice crust, which melts during the day and freezes during the night. The fall in temperature is exceedingly sharp even in the tissues of the stem as, according to Maximov (1913, 1952, p. 97), the thermal conductivity of ice is from one-third to four times greater than that of water. The portion of the stem where BSG occurs is exposed to frequent changes of temperature and alternate thawing and freezing of the water surrounding the stem. During the freeze the stem of the tree is also subject to pressure from outside, which occurs when water freezes and thus expands. The present author has no available data as to the strength of the pressure exercised by the ice crust upon the stem under the weather conditions described in Chap. 2.1. That such pressure exists and is very powerful was proved by an experiment performed outside the laboratory by freezing slightly melted snow.

The significance of the pressure of ice and ice crust has been elucidated by TUMANOV (1940, 1951, p. 46) in experiments with winter cereals. Ice crust formed on ground surface exercises a violent pressure upon plants. In experiments, made by injecting water centrifugally into plants, it was proved that such plants developed increased susceptibility to ice pressure only during severe cold, but could withstand such pressure during slight cold without being injured. Plants saturated with water froze and died at considerably higher temperatures than plants used in control experiments.

According to TUMANOV and KRASAVCEV (1959) cold resistant woody plants (birch and spruce) can withstand sudden fluctuations of temperature in winter owing to their capacity to dehydrate, which takes place because of water flow from the hardened protoplasts and formation of ice in the intercellular spaces. TUMANOV and KRASAVCEV (1962) also made a study of the influence of the thawing rate on the survival of hardened woody plants. The cause of death after rapid thawing is the almost instantaneous absorption of large amounts of thawed ice water from intercellular spaces by the dehydrated protoplasts.

In Germany, as early as 1883, HARTIG described cases of BSG (Einschnürung) found in nurseries, in seedlings and transplants of Norway spruce and European silver fir two to four years old. Damage took up a portion of the stem between 2 and 4 mm wide, and was situated at the ground surface level. HARTIG explains that the damage was due to the late frosts in May, when the division of cambium cells in the plant was in progress. Frost occurred after rain, when the soil was saturated with water. The death of cambium is explained by HARTIG as the result of the pressure exercised by the upper layer of the frozen soil and ice crust upon cambial tissues. In those places in the nurseries where the earth surface was covered by a thin layer of moss, plants were protected against the pressure of ice crust. When HARTIG presents his hypothesis he points, however, to the lack of experimental evidence, and to the fact that such kinds of damage had not been met with in afforestations. Later HARTIG's collaborators diverted the explanation of the causes of this damage by centralizing attention upon fungus diseases.

BSG (Trockengürtel) in maple and ash seedlings growing in nurseries was observed by AUMANN (1883) in 1879 and 1883 in Germany. AUMANN considers severe March and April frosts, which occurred immediately after a spell of warm weather in late winter, to be responsible for the occurrence of the damage. AUMANN also mentions the weather conditions which prevailed during the previous autumn, which were most unfavourable for the hardening of plants. The injury was located 2—4 cm above soil level, and comprised a portion of the stem between 1 and 2 cm wide. The damaged area on the stem coincided with the surface of the frozen snow cover. AUMANN assumed that the sudden fluctuations of the diurnal temperature, which affected the contact area of the plant adjacent to the snow cover, had been the cause of the damage.

The fundamental investigations of BSG carried out by Day (1928, 1931) and by Day and Peace (1934, 1937, 1945) deal with several species of conifers. Douglas fir, Sitka spruce and other conifers suffered severely in England at the end of April and the beginning of May, 1927, owing to frost killing the cambium and thus causing cankers. The most serious loss was caused by canker girdling the lower part of the stem, thus entirely ruining the tree (Day, 1928, p. 29). The cause of BSG was the low temperature of the air lying immediately above the ground flora, in which grass dominates (Ibid., p. 30). On those occasions the cold affected the actively-dividing cambium, which is sensitive to low temperatures. When analysing frost canker in European larch, Day (1931) proved that injury to cambium can occur during all seasons of the year when cambium changes from a cold-hardy to a cold-sensitive condition.

During the particularly severe May frosts of 1935 in England excessively low temperatures occurred among the tips of the herbage, and in small trees the cambium was killed at that level and not above it (Day and Peace, 1945, p. 30). Damage of this kind was specially noticed in Scots pine (Ibid., p. 30). Summarizing the effect on Scots pine of the May frost in 1935, Day and Peace (1945, p. 51, Table XVII), however, consider injuries as being insignificant (see Introduction). On the basis of data collected by Day and Peace regarding BSG in Scots pine, it might be inferred that, although Scots pine is liable to be girdled, the damage did not manifest itself on a large scale in spite of the severe May frosts of 1935 and in spite of cambial susceptibility to cold during this season of the year.

The origin of BSG in northern Sweden differs from the origin of BSG in Germany and Britain, described above. In Sweden BSG occurs in late winter and early spring when cambial activity has not yet begun. However, at this time of the year the cambial tissues are no longer under winter resting conditions and are no longer cold-resistant. BSG does not occur every year and no cases of BSG have been observed even during severe May and June frosts. BSG occurs in years with extreme climatic conditions (Chap 2.3) such as those which prevailed in northern Sweden in 1960/61.

From the varying characteristics of BSG, the inference can be drawn that damage had occurred repeatedly during a period of three to four months, from January to early May. The level of the damage above the ground surface is connected with the changes in the depth of the snow cover. On most occasions damage occurred in April, when the ground surface was covered by solid ice crust. The extreme diurnal fluctuations of temperature when snow melts and freezes quickly should be considered as the factor which constitutes the environment in which BSG occurs. The relative roles of different factors in the production of damage could hardly have been equally significant at different levels of the snow cover above the ground surface, and also during the lengthy period comprising late winter and early spring. Many more analyses and experiments dealing with the induction of the damage must be made before a complete solution of the problem can be reached.

5.2. Pathogens

Extensive systematic work has been carried out in connection with the elimination of the infection by fungi on trees in experimental PR series, and much attention has been devoted to this subject. This refers chiefly to *Phacidium infestans* which has already been mentioned. *Lophodermium pinastri* is another fungus disease which should be mentioned, although it is by no means so dangerous to plants as *Phacidium infestans*. In earlier experiments (Langlet, 1936; Heikinheimo, 1949) different PRs showed most various degrees of resistance to *Lophodermium pinastri* disease. In nurseries it was possible to eliminate this disease completely by spraying the plants, and on EPs the fungus disease appeared only sporadically and no harm was done. Infection by *Melampsora pinitorqua* was also averted in nurseries by spraying the plants, and on EPs 9 and 10 all aspens (*Populus tremula*) growing in the neighbourhood were exterminated, thus avoiding attacks by *Melampsora pinitorqua* on trees in EPs. A few individual trees on EPs 10 and 11 became victims of *Fomes annosus* diseases and died. Other fungus diseases registered on EPs were of a sporadic nature.

When summarizing the effect of fungus diseases on trees in EPs, it should be definitely stressed that they played a minor role among those factors which decided the survival or mortality of plants in the whole PR experimental series. These fungus diseases as the cause of mortality in plants were of a very slight importance and did not influence the mortality rates at all.

Differences of opinion as regards fungus diseases arose in connection with damage in plants caused by cold. It is well known that parts of trees injured by cold are, as a rule, infected by fungi. These fungi are capable of living as saprophytes and are usually facultative parasites, but become dangerous only when their host has been injured or reduced in vigour (Day, 1928, p. 28; 1945, p. 5). Although, in most cases, cold is the primary cause of the injury, misinterpretations often arise, and attacks by fungi are considered to be of primary importance. This particularly refers to girdled and cankered trees, where the injured part often remains unnoticed, and those fungi which colonize dead bark may not infrequently be blamed for the trouble (Day, 1928, p. 28).

Attempts to attribute origin of BSG to pathological causes are not at all new. Hartig (1883), examining the BSG portion in the injured plants, found there only saprophytic fungi. Tubeuf (1888, cit. 1914, p. 26) discovered a new fungus species, *Pestalozzia Hartigii*, and determined that it was responsible for the damage caused. In spite of repeated inoculation of living tissues with this fungus, experiments did not give conclusive evidence. Attention was also directed to other analogous phenomena and to other causes of injury (Münch, 1913, 1914). The inoculation of the living tissues of the plant with fungus diseases was repeated by other scientists in the years to follow, and this problem is of interest even today.

The question as to what role some parasitic and facultative parasitic fungi play in causing death to pine plants and young trees in Scandinavia has become a pressing problem during the last 10—15 years. Already more than 50 years ago Lagerberg (1912) described damage in dying pines in northern Sweden and assumed that the cause of death was a fungus disease, *Crumenula abietina, i.e., Scleroderris lagerbergii.* Another fungus disease which was then found on injured pines was *Dasyscypha fuscosanguinea.* In this connection it is not out of place to mention that the manifestation of fungus diseases was preceded by severe climatic conditions prevailing in the winter of 1910/11 (Chap. 2.1; H. E. Hamberg, 1912).

1959 Björkman described losses caused by *Crumenula abietina, i.e., Scleroderris lagerbergii* in nurseries. Kohh (1964) wrote on the extent of the damage caused by this fungus in the nurseries, and on the measures applied in the struggle against it, as well as on how frequently it is encountered in afforested areas in northern Sweden. Kohh points to the distribution of this disease and its connection with damage caused by cold in 1957/58 and in 1962/63, and also with damage caused by snow pressure in 1960.

Roll-Hansen (1964, p. 169) considered *Scleroderris lagerbergii* to be the cause of the girdling of the stem, basing his conclusions upon his findings of pycnidia or apothecia of the fungus on the dead bark, or upon the results obtained by him when isolating the fungus from the dead bark, as well as on his inoculation experiments. Evidently Roll-Hansen considers *Scleroderris lagerbergii* fungus to be the primary cause of the damage. However, on pages 161, 169, 170 of Roll-Hansen's paper one can read that "it is reasonable to assume that the girdling had been caused by the fungus entering through frost necroses or small wounds". In this respect one can only agree with the views expressed above, namely, that the girdling was primarily caused by cold and that only then had fungus attacked the cold injured areas.

When the importance of facultative parasitic fungi is being discussed, it is hardly possible to avoid mentioning the fundamental works of DAY (1928, 1931, 1945, 1958 and 1961) and of DAY and PEACE (1934, 1937), and the conclusions they had arrived at when investigating several conifer species. When analysing the dying back of Corsican pine, DAY (1945, 1961) also describes the role played by *Brunchorstia destruens, i.e., Crumenula abietina* or *S. lagerbergii* among other fungi. In the text and reference book "Forest Pathology" written by BOYCE (1937, 1961) an analysis of this problem is made, and the conclusions arrived at refer to conditions in the U.S.A. In the works of the authors mentioned above the origin of the BSG and the formation of the canker are examined at a greater length than ever before.

The question as to whether *Scleroderris lagerbergii* acts as a virulent parasite, or only affects parts of the tree injured by cold, can be solved only in an experimental way. However, the injuries which were obtained by ROLL-HANSEN (1964) by infecting plants with this fungus, differ from cold injuries both as regards their external and internal signs (Chaps. 3 and 5.1). The fact that fungus mycelium was found in the wounds and cankered trees does not supply sufficient evidence for the assumption that fungus has been the primary cause of the damage.

If it were possible to prove by inoculation experiments that this fungus can manifest itself as an injury of varying characteristics, whose symptoms and signs are identical with those in cold injuries, and if it were possible to establish as true that this fungus can cause damage during single years, and varying mortality in plants of different PRs, as shown on EP diagrams (Chap. 4.2), then there would be no reason to doubt the virulence of *Scleroderris lagerbergii*. No such evidence is available at present.

Cold damage and mortality in plants in northern Sweden form an urgent and pressing problem, and it is important that, when trying to find ways of solving this complex problem, attention should not be diverted from cold as the primary cause of damage, to secondary and accessory factors. Injuries caused by *Scleroderris lagerbergii* and by attacks of *Pissodes* beetles may be fatal to many trees injured by cold, but it is essential to decide which of the factors causing mortality in plants is of a primary character.

6. Cold damage, healing of wounds and mortality— connected phenomena in a chain of biological processes in plants

The occurrence of cold damage and the anatomical and physiological changes which take place in plants owing to the effect of cold are by no means independent phenomena isolated from the complex of metabolic processes in the organism of a plant. Both the life cycle and the annual cycle in the ontogeny make an organic sequence of physiological processes. The changes within these physiological processes are related to seasonal changes of environmental conditions, and are thus dependent upon the geographical location and local site conditions. Normally a plant or a tree is adapted to the variations of environmental conditions. The response of a tree to the manifold and varying environmental conditions is genetically controlled. Cold resistance and resistance to unfavourable winter conditions depend on the genetic constitution of a plant, *i.e.*, of a young tree. Inherited traits and external factors interact in several ways and the relative roles of the genotype and environment as regards cold resistance in trees belonging to different PRs are of a most complicated nature.

In the present chapter attempts are made to explain the extent of cold damage and mortality in plants based on the data obtained from EPs, and to show the connection between these phenomena and the factors which contributed to their origin. The cold damage of 1960/61, owing to its specific importance in the whole PR experimental series, inevitably assumes a central position among other injuries caused by cold which occurred during 1953—1964. The specific laboratory problems connected with cold and winter hardiness in woody plants were not the object of study in PR experimental series. The expanding literature of recent years, and the conclusions arrived at when solving these problems, provided the necessary background for the interpretation of the data obtained in PR experimental series. As regards the role of the genetic factors in the varying cold resistance among different PRs, it has been possible to penetrate this question only within the frame of the PR experimental data.

6.1. Cold and winter hardiness

According to modern biology, cold and winter hardiness are complex properties which woody plants develop in autumn and in early winter, after having completed their growth period. Hardening in plants comprises several intricate physiological and biochemical processes, which follow each other in a definite succession. According to TUMANOV (1940, 1951) and TUMANOV and KRASAVCEV (1962) complete winter hardiness can be reached only when the plants have definitely accomplished their apical and lateral growth and have then gone through two definite hardening phases. Thus hardening takes place successively, depending on the gradual increase in the degree of severity of the temperature fluctuations in autumn. The degree of winter hardiness which the plant develops can vary from year to year, depending on the climatic conditions, but it can also vary considerably in different parts of the plant, due to prevailing nutritive conditions, water supply and metabolism. Hardening processes proceed also during winter, but longer thaw periods cause dehardening.

The gradual passing of the plants from a state susceptible to cold to a cold-hardy state is connected with changes in the biochemical and biophysical properties of the living cells, and also with the accumulation of reserve food, which exercises protective effect on the living cells. The affinity between cold resistance and the content of proteins, amino acids, lipids and sugars, and their related compounds, has been confirmed by the results of the investigations of many scientists. Several theories have been launched which try to solve the problem of the causes of cold resistance (References: LEVITT, 1956, 1958; PARKER, 1963; GENKEL, 1965). A new interpretation of this question was put forward by LEVITT (1962) and his collaborators (LEVITT, SULLIVAN, JOHANSSON, PETTIT, 1961; LEVITT, SULLIVAN, JOHANSSON, 1962; KOHN, WAISE, LEVITT, 1963) by advancing a "sulfhydryl—disulfide hypothesis of frost injury and resistance in plants", which attributes a decisive role to the content of sulphydryl in the proteins of protoplasm.

LANGLET (1936, 1959, 1962), in his "Studies on the physiological variability of Scots pine in relation to climate", supplies significant evidence on this problem, and shows that in autumn the dry matter content in the needles of pine seedlings serves as a criterion for this variability. Dry matter content values of different PRs characterize both climatic conditions of their natural growth places and also the degree of cold resistance of these PRs. Dry matter content values are correlated with sugar contents, osmotic pressure in the cells, and with certain other properties in PRs connected with geographical variability of Scots pine. According to LANGLET (1936, p. 238) the hardening processes are of a complex nature, and all regularly expressed changes in the organic compounds, as well as in the reserve food, at the end of the growing season and at the onset of dormancy should be regarded as being more or less connected with these hardening processes.

The climatic factors which induce cold hardiness are primarily low temperatures and short photoperiods. SAKAI (1958, 1960) obtained artificially induced hardiness by gradually hardening woody plants down to −30°. These plants then survived in temperatures as low as −196°. TUMANOV and KRASAVCEV (1959, 1962) induced almost unlimited cold resistance in woody buds (−253° C) by hardening them at low temperatures. PARKER (1960, 1962) found in freezing experiments with plants and foliage that the winter resistance of several conifers can range all the way from a few degrees below freezing point to below −189° C. Hardwood twigs withstood even −196° C. However, PARKER stresses that the rates of cooling and warming are most important in such work and should not be changed.

MOŠKOV (1930, 1932, 1935), in his experiments with woody plants in Leningrad, obtained not only earlier cessation of growth and an earlier onset of dormancy, but also greater cold resistance, by shortening by a few hours daily the photoperiod during the summer. When the daily photoperiod was prolonged, contrary results were obtained. BOGDANOV (1931) experimented in Leningrad with various woody plants (including Scots pine seedlings originating from Boržom in the Caucasus and from Poznan in Poland) and succeeded in eliminating autumn frost injuries and winter cold damage by shortening the photoperiod, beginning with the month of July. TUMANOV (1951, p. 28) found that by shortening the photoperiod of the long summer day conditions in northern regions, it was possible to harden experimentally not only woody plants, but also herbaceous plants. TUMANOV stresses that shortening the day-length is effective only when it is carried out already during the summer, when the temperature of the air is sufficiently high. ROBACK (1957) experimented with several conifer species in Norway (latitude 60° 15′N) by shortening the natural photoperiod beginning with the 1st of July. The shortened fourteen-hour photoperiod caused a pronounced acceleration of terminal bud formation, which began several weeks earlier than usual. However, the effect of short-day treatment as regards winter hardiness and survival of plants in different species did not always give satisfactory results.

The connection between the photoperiod and dormant condition in plants has attracted the attention of many scientists (KLEBS, 1914, 1917), GARNER and ALLARD (1920, 1923), and is still the object of study in recent works (References: VEGIS, 1965 a, b).

An analysis of the role of the photoperiod in the geographical variability of Scots pine in Sweden was made by LANGLET (1943). His conclusions were chiefly based upon data obtained from 600 Swedish PRs concerning dry matter content in the needles of seedlings in the autumn. The correlation between the dry matter content values on the one hand, and the latitude and the length of growing season for the native habitats of these PRs on the other, had a high statistical significance (LANGLET, 1936, p. 357). The presence and participation of some third factor in this correlation was therefore hardly conceivable. While trying to establish the relative roles of the two factors (the latitude and the length of growth period) on the physiological state of the pine seedlings, LANGLET came to the conclusion that three-fifths of the total variation of the dry matter content values were connected with the latitude, and two-fifths with the length of the growing season. According to LANGLET, the length of the growing season (the number of days per annum with a mean temperature $\geq 6°$ C) depends upon the latitude and the altitude of the native habitats of PRs, and it is thus possible to estimate the value of the length of the growing season (LANGLET, 1936, p. 344). The role of latitude is much more intricate. The duration of the daily light and dark periods is a function of latitude. However, the effect of the photoperiod on the physiological processes is connected with the temperature, and the relationship between the dry matter content and the length of daylight and temperature also point to this (LANGLET, 1959, 1962).

In the PR experimental series, in connection with the transfer of the PRs from their native habitats to the EP sites, in both meridional and vertical directions, the climatic conditions were different from those to which these PRs had been adapted. The range of the new climatic conditions affects different PRs in different ways. These changes influence not only the growth activity but also the cessation of growth, the hardening processes and the onset of dormancy, as well as the rest period. When the respective roles of temperature and photoperiod are estimated, one is inclined to think that the combined effect of these two factors is decisive in this case. After subjecting plants to different daily light periods, many research workers have proved that temperature plays a very important role. Temperature during the diurnal dark period is considered to be of the utmost importance, and often to be a decisive factor in the growth response of plants to the photoperiod (References: VEGIS, 1964, p. 205). In most experiments the role of the photoperiod is defined more exactly. Long-day conditions favour the continuation of growth, and prevent, or at least delay, the cessation of growth and the onset of dormancy. Short-day conditions cause the cessation of growth and formation of terminal buds, but not the onset of dormancy (VEGIS, 1964, pp. 199, 208). In its turn, the cessation of growth is an indispensable physiological state in plants in whose absence no hardening processes can begin. Woody plants which have not completed growth cannot develop cold resistance (TUMANOV, 1940; TUMANOV and KRASAVCEV, 1962).

When discussing the origin of cold damage in Scots pine in the late winter and early spring of 1961, and the varying degree of cold and winter resistance among PRs, the question arises as to what state of dormancy the plants were in at that time. It is well known that during the "middle phase" of the rest period in the winter woody plants are in a state of "true dormancy" (VEGIS, 1964) or "deep dormancy" (SERGEJEV, 1961, cit. 1964). During this physiological state the response of the plants to external influences is insignificant, and normal growth cannot be induced. After the cessation of growth in the autumn, transition to true dormancy occurs gradually, and is connected with hardening processes in plants, which comprise the so-called "predormancy state" (VEGIS), or "concealed growth state" (SERGEJEV). The investigations of SERGEJEV and his collaborators (1964, 1965) showed that in the central regions of the Soviet Union most forest trees have completed their deep dormancy state in November and December, and a few species only as late as January. When trees enter the next state, "imposed dormancy" or "postdormancy state" (VEGIS, 1964), the response of plants to unfavourable weather conditions changes. Non-resistant plants and trees become susceptible to cold and unfavourable weather conditions. Owing to considerable fluctuations of diurnal temperature, and also to the periods of thaw and insolation of the stem and different parts of the crown, trees are affected by cold. Winter hardy species, as well as hardy strains, are resistant to weather factors, because the hardening processes had already been completed before the onset of dormancy.

It is of interest to mention that in the experiments of DAY and PEACE (1934, 1937) on the artificial production of cold injury, Scots pine proved to be surprisingly susceptible to winter cold, and quick freezing combined with quick thawing was always the most damaging. WINKLER (1913) found that trees and shrubs which had rapidly frozen in winter were severely damaged, and that alternate thaw and freeze periods were most unfavourable. These injuries occur when plants are in the state of "imposed dormancy", during which they are most susceptible to external factors.

The varying cold and winter hardiness of different PRs on the EP sites should be regarded as dependent chiefly on the cessation of growth in these PRs, and also upon the hardening processes which follow when growth in plants is completed. No hardening processes can take place before the completion of growth and, since trees have not yet become resistant to cold, they can be damaged by cold in autumn, late winter or early spring. Those PRs whose natural growth places are situated south of the EP site, or at a lower altitude, are most subject to the influence of the extreme unfavourable weather conditions which occur during certain years. During years with normal climatic conditions these PRs complete their growth and develop a higher or lower degree of cold resistance. In the years with extreme, unfavourable weather conditions, a sudden cold wave can affect the plants earlier, when the growth processes have not yet been completed, thus interfering with, and eliminating, the hardening processes. On the other hand, in northern PRs the cessation of growth occurs much earlier, and trees become cold-hardy even in the years with extremely unfavourable weather conditions. In this connection it might be mentioned that the EP site not only tests the degree of cold resistance in different PRs, but also induces some changes in the response of plants to temperature and photoperiod, owing to the transfer of PRs from their natural habitats. It might also be mentioned that under the same EP site conditions, the rate of decrease in cold resistance in southern PRs is greater than the rate of the increase of cold resistance in northern PRs.

6.2. Injury, recovery and mortality

Of all the data on cold damage in the experimental PR series given in the preceding chapters, the clearest picture was supplied by that part which deals with the period 1960—1964. The severe cold damage of 1961 started a whole series of phenomena which occurred during the following years. Cold injury occurred in late winter and early spring, and was caused by extreme weather conditions (Chaps. 2.3 and 5.1). The amount and extent of damage as well as mortality rates in plants varied among PRs (Chaps. 4.2). This variation should be connected with the different degrees of hardening in plants. The unfavourable weather conditions which prevailed in the summer and autumn of 1960 had considerably influenced resistance to cold and mortality among PRs (Chap. 6.1). Thus the occurrence of damage in 1961 links the development of EPs during the five year period into an organic sequence. It should be stressed that in 1964 the recovery of plants damaged in 1961 had not yet been completed. Cold damage covered a large region in the north of Sweden, and the occurrence of cold damage in connection with the general weather conditions of 1960/61 is conspicuous (Chap. 2.2). The variation within the local climatic conditions, in its turn, caused great differences among EPs as regards the degree of severity of cold damage and mortality rates (Figs. 59—62, Chap. 4.4). In the analysis of the problem of cold damage it is of great importance to note that cold injury affected a large region, and that it was not merely of local character. This makes possible the use of the data obtained from 17 EPs located in the cold damage region (Region II, Fig. 8). For the sake of comparison, data from three EPs (Region I), located outside the cold damage region, were used. Thus it was possible to obtain a sufficient amount of experimental data for statistical calculations.

In 1961 all above-ground parts of the trees suffered from injuries caused by cold. However, most of the injuries with varying patterns had occurred to old wood (Chap. 3), and among all types of injury to old wood, the most serious proved to be the girdling of the main stem. BSG (which damages the tree at its base) is the most dangerous type of injury, and usually results in the death of the whole tree (Chaps. 3.1.1 and 5.1). Girdling of the main stem in the upper part of the tree (Chap. 3.1.1.7), which is connected with the dieback of the top of the tree, can also have a most serious effect, and the more severe the damage, the nearer to the base of the tree does the damage extend. In 1958, and probably also in 1959, only severe dieback of the plant top was registered, while in 1961 BSG predominated. These two types of damage have several common characteristics, but they also differ in many other respects.

As regards the origin of BSG, three principal considerations should be borne in mind: the type of damage, external conditions under which damage occurs and the mechanism of the damage. BSG has been known as one of the types of cold damage for quite a long time (Hartig, 1883; Aumann, 1883; Day, 1928). However, external conditions in the north of Sweden differ from those under which BSG occurred in Germany and Britain. In Britain, BSG occurred in spring when cambium cells were dividing, or when cambial activity was awakened, but the growth processes had not yet begun (Day, 1928, 1931; Day and Peace, 1946). In the north of Sweden, BSG occurs in late winter and early spring, when plants are in the phase of "imposed dormancy", and are liable to be influenced by external factors. In Britain, BSG is connected with spring frosts. As a characteristic example may be mentioned the severe May frosts of 1935. The location of the BSG on the stem coincided with the lowest minimum temperature during the frost periods and particularly with the level of the tips of the herbage, the so-called "grass-minimum". The cambium may be killed at that level but not above it. Consequently, BSG is the result of the direct effect of low temperatures, and the occurrence of BSG coincides with temperature minima during a frost period or on a certain day. On the other hand, the occurrence of BSG in the north of Sweden should be attributed to combined effect of cold and other weather factors during winter. The fluctuations of temperature, together with low temperatures, are associated with alternate melting of the snow cover and its compression, as well as with the freezing of melted snow water and the formation of an ice crust. Such extreme weather conditions can, with some intervals, continue from three to four months, from January to the middle of May. The damage originates in the portion of the tree at or below the snow surface, in the snow crust, or in the ice crust layer. Often the upper edge of the BSG is clear-cut (Fig. 4) and constitutes the most severe part of the damage round the stem. However, there is great diversity in the breadth of the girdle and the dimensions of the damaged area of the BSG portion. Although on many occasions purely mechanical action of the ice can be observed on the BSG portion in the shape of ruptures and compressions, the most essential part of the damage is the killing of cambium, phloem, cortex or the destruction of live cells in the xylem elements (Chap. 5.1.1). Consequently, BSG does not differ basically from other types of damage by cold, when living tissues are injured. However, the mechanism of the origin of BSG differs from that of other types of cold damage, since not only the effect of cold, but also other external factors, co-operate in causing it (Chaps. 3.2 and 5.1.2). Still, even in the case of BSG, low temperatures and temperature fluctuations play a decisive role. A striking evidence of this is furnished by partly girdled trees, with BSG near the ground surface. In most cases damage occurs on the SW side, but it can also spread over a wider circumference from the E to W sides. Sometimes BSG merges with narrow, vertical lesions in the bark, occurring in connection with strong solar radiation in spring, when the ground is covered by ice crust. The basal part of the tree is most exposed to the effect of external factors and is more severely damaged than the other, above-ground parts of the tree. It is difficult to decide whether the basal part is also the most susceptible to cold. However, it has been proved by freezing experiments (Kraevoi, Oknina, Ipekdžijan, 1954) that the butt-swelling is that part in oak seedlings which is most susceptible to cold. In other experiments on damage by cold, indirect evidence has been obtained which shows that the basal part of the tree is the part most susceptible to cold. BSG is not only the severest type of cold damage, but also the most intricate. It often happens that external signs are so slight that BSG remains unnoticed, not only during the first summer after the occurrence of the damage, but also during the following summer. The damaged portion of the tree then becomes colonized by *Pissodes* weevils and by fungi. The foliage of the dying tree is a suitable ground for fungus diseases, and when interpreting the primary cause of the damage in trees suffering from BSG it is possible to arrive at hasty conclusions and misconceptions. If the tree does not suffer from injuries other than BSG, its crown and lateral shoots develop a certain amount of growth in the same summer. Completely girdled trees died outright in the spring or autumn of the year following the damage, namely, 1962. In 1962, when the dying trees suffering from BSG were analysed, conspicuous black spots could be observed in different parts of their root system, which spots were found neither in healthy trees, nor in the damaged trees during the first summer after the occurrence of damage. This damage in the root system was considered to be the result of deficiency in nutritive substances owing to the strangulation of the stem, rather than the direct consequence of cold effect. This phenomenon was tested experimentally in March 1963 in the neighbourhood of Stockholm by mechanical ringbarking and by filing off the outer annual rings in the basal part of the tree. The exposed portion was carefully protected against dehydration. The test was carried out on trees of the same age as those in PR experimental series and comprised 36 plants, which were subjected to mechanical injury of nine different degrees. In the summer of 1963 the development of terminal and lateral shoots and their length were analogous to that which was observed in the summer of 1961 in trees suffering from BSG on EPs in PR experimental series. In the summer of 1964 the development of black spots in the root system of the trees mechanically injured was also analogous to that observed in the summer of 1962 in trees suffering from BSG. On the basis of the data obtained it can be concluded that the transport of water and minerals from the root system upwards to the crown is more or less obstructed in trees suffering from BSG. However, even more important is the circumstance that the translocation of photosynthetic products in the phloem from the crown of the tree downwards does not reach the root system, which results in the dying off of the root system owing to the lack of nutrition. Recovering of partly girdled and cankered trees thus becomes an intricate problem. "The canker is particularly liable to damage, and if fairly severe frosts occur for several years running, it may spread rather than heal and eventually girdle the branch or the stem on which it is situated" (Day and Peace, 1946, p. 30). Figs. 63—66 and particularly Fig. 67, clearly illustrate what has been said above. However, the survival of the BSG trees is not decided only by the BSG portion of the tree. It should be taken into consideration that the girdling of the tree considerably influences its metabolism. Most probably the supply of water and mineral elements in partly girdled trees is only partially delayed and influences the metabolical processes only slightly, since the movement of water in a tree can proceed in different directions (Kozlowski, 1961, 1963) and simply pass the damaged patches in the xylem. On the other hand, impediments in growth processes decrease the resistance of the tree to cold and pathogens. Partly girdled trees thus become more susceptible to cold, and their recovery is dependent on weather conditions during several years after the occurrence of the damage. In the PR experimental series, in connection with winter cold of 1962 and the May and June frosts of 1963, the recovery of trees damaged in 1961 had proceeded only in a few EPs, namely, on those where weather and edaphic conditions were favourable and contributed to the rapid healing of wounds. The great majority of partly girdled trees died from 1961 to 1964, and the rate of mortality among PRs was very variable (Chaps. 4.2 and 4.3). Only those trees on which the damaged area on the BSG portion was small had any chance of survival.

Snow cover does not directly influence the occurrence of girdling of the main stem in the upper part of the tree, as is the case with BSG. This type of damage most often occurs in early spring when the ground is bare, immediately after the snow has melted, or during May and June frosts, as happened in 1963. Damage of this type can also occur in winter and early spring when the ground is covered by snow, as in 1961. Early autumn frosts, contrary to expectations, caused only slight damage on EPs. The only losses worth mentioning occurred during the August frosts of 1954 in PRs whose native habitats are situated south of EP sites. Girdling of the main stem occurs because of diurnal fluctuations of temperature in the ground air zone. These radiation frosts are particularly dangerous during the periods of cold waves when serious damage occurs on frost localities, as illustrated by mortality curves on EP 27 in 1963 and on EPs 26 and 29 in 1958 and 1959. When damage is slight, compensatory adventitious shoots are developed to replace the killed leaders. But when damage is serious the recovery of damaged trees proceeds slowly, growth development is considerably delayed, the stem is deformed (Wibeck, 1928; Langlet, 1937) and the shape of the tree is permanently changed.

6.3. Environment and genetic background

Great diversity as regards cold damage and mortality in plants is exhibited among PRs in the PR experimental series in the EPs. The variation of mortality rates and the diverse adaptation of PRs have already been discussed from different aspects in this paper. Mortality among PRs on individual EPs was dealt with in Chap. 4.2. When summarizing the data obtained from individual EPs, the occurrence of cold damage and the manifestation of mortality covering a period from 1954 to 1964 were discussed in Chap. 4.3. The geographical aspect of cold damage was presented in Chap. 4.4, where all 20 EPs were divided into four groups, and mortality rates in relation to the transfer of PRs from their native habitats to the EP sites were shown in diagrams (Figs. 59—62).

The problem of mortality and survival of plants is thus composed of two fundamental parts. The diversity of inherent physiological characteristics among PRs makes one part of this problem and forms its genetic background. The various climatic conditions in different parts of the north of Sweden, the changeable weather conditions during 1954—1964, and extreme weather conditions in single years make the second part of the mortality problem. It should be stressed that diverse mortality among PRs is an essential characteristic of their adaptability to different EP sites. Adaptive physiological properties of PRs are tested here by such decisive components of external environment as varying temperature and extreme fluctuations of temperature connected with other weather elements during winter and early spring. The testing of the PRs is carried out here in a wide range of environmental conditions.

Conspicuous differences between PRs in regard to their hereditary characteristics and geographical variability in Scots pine are revealed and proved by experimental evidence in the works of a great many scientists and in silvicultural practice, beginning with the nineteenth century. LANGLET, in a review *"Two Hundred Years of Genecology"* (1964, in Swedish), as well as in a yet unpublished, extended review on the same subject, presents a detailed representation of the pioneer and basic views and progress made as regards investigations into the hereditary variation in plants in relation to their environment.

When interpreting the data obtained from the experimental PR series, it is necessary to point to contemporary, basic premises in regard to the differentiation of adaptive physiological properties among PRs and to the geographical variability in Scots pine.

The most general characters of organisms are adaptations. Many of the physiological and biochemical processes carried out by animals, plants and micro-organisms are clearly adaptive, and adaptation is thus a general feature of the relationships between organisms and their environment (GRANT, 1963, pp. 116f.). Adaptation to different ecological conditions is of particular importance in plants. The life activity of plants during their development depends on varying ecological factors. The adaptation of plants to heterogeneous ecological conditions is connected with the evolutionary origin of adaptive characters, and is the result of natural selection, acting upon hereditary variation, which exists both within an individual population occupying a small area, and in large regions occupied by different populations.

In the present investigation two different aspects of the adaptation of Scots pine are met with. Adaptation of different PRs to the climatic conditions of their natural habitats within a wide distribution range and differentiation of inherent properties among PRs is one aspect, and adaptation and experimental control of adaptive properties in the progeny of these PRs in particular climatic conditions on EP sites during 1954—1964, is the other.

Of all the facts on hereditary variation in Scots pine proved by experimental evidence, two fundamental conclusions should be considered as being of utmost importance: (1) individual PRs, represented by adaptively important characters, are physiological correlates of the decisive external factors affecting these PRs in their native habitats, and (2) the geographical variation of the inherent characters of PRs is revealed in a pattern of continuous variability. These conclusions were arrived at in Sweden mainly owing to investigations carried out by WIBECK (1912—1933); SCHOTTE (1923); ENEROTH (1926—1927, 1928) and LANGLET (1929, 1934, 1936). The continuous variability in Scots pine (corresponding to clinal pattern of variation, HUXLEY, 1939) versus discontinuous variability was worked out by LANGLET. In his later works LANGLET has further elaborated and elucidated the concept of the continuous nature of ecological variability (LANGLET, 1959, 1962, 1963).

It is well known that climate plays a decisive role in the adaptation and survival of the plants, although the edaphic conditions, in their turn, may exert a local influence. For characterization of the climatic conditions on the EP sites, as well as on the PR natural habitats, the length of the growing season (Y), expressed by the number of days with average temperature $\geq + 6$ C, has been used. These figures are computed values (LANGLET, 1936, p. 344), and their consistent application in all cases in the whole PR experimental series unites all the data obtained in the experiment into a uniform system.

In Tables 2—21 the values expressing the length of the growing season characterize each of those PRs which constitute a single EP. Experimental data on diverse CM of 1964 among PRs, and the corresponding values which characterize the climatic conditions of the natural habitats for these PRs, show the interrelation of these two series of values in the tables. The shortening (−Y) or the lengthening (+Y) of the growing season in connection with the transfer of the PRs from their native habitats to the EP site makes the mutual relationship between the two series of values still more conspicuous. Besides, the diverse adaptability of the PRs on the EP sites is compared with that of the local PR, expressing the CM of 1964 in relative values (R of local PR = 100). The graphical representation of the data on CM and SYM obtained from single EPs (Figs. 36—58) covers the period from (1953) 1954 to 1964, when plants reached the age of 14 years. The first 14 years of the ontogeny under varying weather conditions are decisive for the adaptation of PRs on a particular site of a single EP. A single EP is thus a basic experimental unit. Each of these EPs consistently and conspicuously shows that PRs transferred from the north reveal a higher degree of resistance to unfavourable climatic conditions and a better adaptation for survival. On the other hand, PRs transferred from the south often show a bad adaptation, and their silvicultural value is low.

When summarizing the data on CM obtained from single EPs, the shortening (−Y) and lengthening (+Y) of the growing season in connection with the transfer of PRs to the EP sites has been used as the *common denominator*. These +Y and −Y values constitute the independent variable in the diagrams (Figs. 59—62) and CM rates make the dependent variable. The arrangement of EPs into four groups is based chiefly upon the ascension of CM curves of different PRs in single EP diagrams (Figs. 36—58). Each of the four EP groups (Fig. 8 and Chap. 4.4) represents a particular spatial variation (MATÉRN, 1960, Chap. 4). The relation of CM rates of 1964 to the transfer of PRs is revealed by linear regression, and expressed both graphically and by regression equations (Figs. 59—62 and Table 22). The gradients of the CM rates of the four EP groups differ from each other, which is clearly expressed by the slope of the regression lines and by the coefficients in regressions. Within each of the four EP groups the relation of CM rates to the transfer of PRs is expressed by regressions which are statistically highly significant (Table 23).

The linear regression expressing the relation of CM rates to the transfer of PRs requires a further analysis. In Chaps. 4.2 and 4.3 it was pointed out that when the CM curves of some southern PRs transferred to the north approached their asymptote (100 % CM rate), the CM rates assumed constant values and CM curves ran parallel to the horizontal axis. Theoretically, in extreme cases, one might have expected higher CM rates also in long-distance PRs transferred from the north to the south, but in the experimental PR series such cases were not observed. EP group II: 2, containing 11 single EPs, was used for curve fitting (Tables 24 and 25). However, the analysis of variance in regressions shows that in this sampling of the data the linear regression better expresses the relation between both variables than any curved regression.

The arrangement of statistical data into four groups, each of which represents a particular spatial variation is inevitably connected with the concept of "boundaries" of these sampling units. The idea of "boundaries" may, however, lead to the misconception that there exist regions having distinct outlines. Such a conception, in its turn, contradicts the facts, since spatial variation in climatic conditions takes place gradually, and the adaptive differences among PRs are expressed in the pattern of continuous variability.

Regions I and II (Fig. 8) represent the largest units in the grouping. The boundary between these regions was drawn according to the shape of the CM curves of the PRs in the EP diagrams. The occurrence of the severe cold damage of 1960/61 in northern Sweden is marked by this boundary, although cold damage also occurred sporadically farther south. This boundary coincides to some extent with that used in forestry practice, which distinguishes northern and southern Sweden as regards the functions and tables for computing the cubic volume of standing trees (Näslund, 1940—41, 1947, Fig. 3). The boundary between region I and region II also corresponds approximately with the southern border of the "taxonomic unit" of *Pinus silvestris lapponica* (Neger, 1913; and Sylvén, 1916). Langlet (1959, Figs. 1—3; 1962, Figs. 23—24), when examining the morphology of Scots pine in northern and central Sweden, came to the conclusion that no sharp contrasts exist between Scots pine in these two parts of the country, and that the characteristics analysed are expressed in gradual changes. Of the nine characteristics subjected to analysis, five were found to be modifiable, expressing variation caused by environment, but four of them were considered to be mainly hereditary. According to LANGLET (1959, p. 433) more rapid changes in these characteristics take place in the transition zone, which might be represented by a boundary drawn approximately from Sundsvall in the province of Västernorrland in a SW direction towards the northern part of the province of Värmland. When comparing the above boundary, described by LANGLET, with that dividing regions I and II in the present paper, one can state that almost no differences exist between them, although the conclusions arrived at are based upon different data.

The data from only three of the twelve EPs located in region I have been used in the present paper. Mortality in plants in the remaining EPs corresponds to the pattern expressed in the diagrams by the data obtained from EPs 9, 10, 14. A slow decrease in mortality towards the south is noticeable in connection with changes in the climate, which is shown in Figs. 7 and 8. However, the exceptionally dry summer of 1955, various edaphic conditions, as well as ground vegetation, were often the principal cause of mortality in plants.

In region II, on the other hand, the effect of cold was the decisive factor as regards the adaptation of PRs to particular sites of EPs. The 17 EPs located in this region have been divided into three groups, each group having a particular spatial variation. For technical reasons these territorial units have been named "subregions", with the reservation that the boundaries between the subregions are even more vague than between the two regions. The gradient of the CM rates in subregion II: 1 (Fig. 60) differs conspicuously from that in region I (Fig. 59) and subregion II: 2 (Fig. 61 A and B). Subregion II: 1 is a transition zone from region I to subregion II: 2. The gradient of CM rates in subregion II: 3 (Fig. 62) differs considerably from that of subregion II: 2. Subregion II: 3 occupies the western and northern parts of the province of Jämtland, where, owing to the influence of the Atlantic Ocean, the climate is milder than in subregion II: 2, which lies to the east. The boundary between the subregions has been drawn only approximately, according to the data obtained from EPs. Reference should be made once again to the maps of environmentally caused variation of five modifiable characteristics (LANGLET, 1959, Fig. 2). The boundary of subregions mainly coincides with the transition zones where rapid changes in the five modifiable characteristics are shown in LANGLET's maps.

Subregion II: 2 is that part of northern Sweden to which is directed principal attention regarding the PR experimental series. It is the largest spatial unit discussed in this paper, and is represented by eleven EPs. In this subregion, in the large, logged-off areas, difficulties in afforestation arise most frequently as a result of cold damage which causes mortality in plants. CM rates of 1964 of local PRs in the eleven EPs have a wide range of variation, and a local PR is rather often very badly adapted to the particular site of the EP (Chap. 4.4, Fig. 61 A and B). The relation of PRs to the EP site conditions is expressed by parallel regressions which have a definite arrangement in the diagram (Fig. 61 A). The position of the regression line of a single EP in this arrangement depends on the micro-climate and other specific site conditions. For instance, EP 16, whose site conditions are extremely unfavourable, occupies the highest position in the arrangement of parallel regressions, but EP 21, with a more favourable site condition, occupies the lowest.

The influence of extreme climatic conditions causing cold damage is felt more acutely on large, logged-off areas and on sites with peculiar topography (Chap. 2.3), and near the timberline the impact of this influence increases. The two cardinal patterns of the cold damage, the BSG and the dieback of the top of the plants, are injuries characteristic of deforested areas, and of areas with peculiar site conditions. The two types of cold damage mentioned above rarely or never occur in naturally regenerated plants which are protected by the canopy of forest stands. The fitness of the adaptive characteristics of the local PR in the endogenous environmental conditions, under the protection of forest stands, is quite satisfactory, but local PRs adapt themselves badly to the exogenous environmental conditions prevailing on bare, deforested areas.

The CM rates of PRs transferred from the north are, as a rule, lower than those of local PRs. Northern PRs are also better adapted to the EP sites. PRs transferred from their natural habitats located on higher elevations than those of the EP sites exhibit the same tendency as northern PRs, with the exception of some PRs whose native habitats are situated at the timberline (Chap. 4.3). The gradient of CM rates in relation to the transfer of PRs for single EPs is expressed by coefficients in regressions (Table 22) and by graphs (Fig. 61 B). The choice of a PR with maximum fitness is best determined by reference to the character of the site. Thus the long-distance transfer PR 6 showed the best adaptation on the most unfavourable site of EP 16 (Table 11). However, there are cases when the local PR shows the best fitness, for instance, EP 12 (Table 9).

The data obtained from the EP series show convincingly that by transferring PRs from the north it is possible in the great majority of cases to avoid mortality in plants in afforestation areas, which is one of the most serious problems in silvicultural practice in the north of Sweden. Certain exceptions, however, have to be taken into consideration. Frost pockets and frost hollows, as well as flat heath areas near the timberline, are sites where afforestation results are not solely dependent on the choice of cold-hardy PRs (EP 27; Table 18, Fig. 61 B). It seems that reproduction on such exceptional, unfavourable sites can be ensured chiefly by the protection afforded by a forest stand.

The fitness of PRs to particular sites is primarily characterized by the mortality and survival of plants. The survival is the first step in adaptation. In the climatic conditions prevailing in the north of Sweden, survival becomes the principal problem. The next phase in the adaptation of PRs, which is no less important than survival, is growth and development. The tree growth is partly dependent upon the impact of climatic conditions causing cold damage and, to some extent, it is also connected with the cold damage itself. However, many other factors influence the tree growth, and it is not suggested that the data for the mean height of trees which were obtained from eight EPs give an exhaustive solution to the problem of differences in tree growth among PRs.

Injuries in trees caused by cold always interfere with growth processes. Unlike external damage patterns (Chap. 3), the concealed patterns inhibiting the tree growth in most cases remain unnoticed. The recovery of the trees damaged by cold, as well as their physiology and growth, is of a most intricate nature (TUMANOV, 1940). In this connection it is worth mentioning that the discolouration of needles observed in the summer of 1961 in PRs transferred from the south was most conspicuous. This phenomenon should be connected with the distortion of the protoplast in needles, which occurred during the winter and spring of 1961. Subtle differences in the colour of the needles, in comparison with the normal green colour, were often observed. This was connected neither with the cold injuries mentioned in Chap. 3, nor with the seasonal changes in the pigmentation of needles in northern PRs. In connection with the intensive solar radiation and the fluctuations of temperature in the late winter of 1962, these subtle nuances were intensified. The cold injuries mentioned above, as well as others, inhibited in various degrees the growth processes and influenced the variation in tree growth among PRs.

Irrespective of cold damage, the variation in tree growth among PRs in unimpaired trees comprises several problems of which only a few can be touched upon here. The response of the genotype of the PRs to the various site conditions of EPs, which is connected with the transfer of PRs, is revealed in different phenotypical expressions. The ontogenic adaptation is expressed by a wide range of variation in regard to tree growth. Some characteristic examples of this are to be found in Tables 2, 3, 5, 9, 11, 12, 13 and 15. The lengthening (+Y) or shortening (–Y) of the growing season in connection with the transfer of PRs is a criterion by which the variation of the tree growth among PRs should be judged. One can assume that dry matter content in needles (Langlet, 1936, 1959) can form the basis of this judgment just as well, or even better.

PRs transferred from natural habitats where the length of the growing season is greater than that on the EP sites (–Y) generally attain a greater tree height than local PRs. PRs 26 and 23 on EP 21 (Table 13) are characteristic examples of this. Long-distance transfer PRs 74 and 50 on EP 15 (Table 19), as well as PRs 50 and 26 on EP 19 (Table 20), might supply even more outstanding examples, if the necessary data on tree height were at hand. On EP 11 (Table 5) the long-distance transfer PR 53, in this respect, shows a tendency to be the best among the other PRs. On the other hand, in PR 42 on EPs 16 and 20 (Tables 11 and 12), there is a better tree height, but at the same time an increased CM rate. On many other EPs (subregion II: 2) PRs transferred from S to N, or from lower to higher altitudes, as well as local PRs, show a low tree height and high CM rates. The correlation between tree growth and cold damage in these cases is evident. One might assume that micro-climatic conditions on EPs influence the variation of the tree growth among PRs. The sites of EPs 11, 15, 19 and 21 are small clear-felled areas, whereas the sites of several other EPs are located on large logged-off areas.

On EPs 20 (Table 12) and 25 (Table 15) PR 19 has the greatest tree height and a comparatively insignificant CM rate. PR 19 was transferred to EP 20 from N to S, and to EP 25 from S to N. In most cases, however, those PRs which were transferred from N to S show a better adaptation to EP sites in regard to tree growth, whereas the length of the growing season in these PRs, as a rule, becomes somewhat shorter (–Y). On the other hand, in PRs transferred from N to S, in cases where growing season on EP sites is longer (+Y), their tree growth is lower than that of the corresponding local PR, for instance, PR 32 on EP 12 (Table 9).

It is hardly possible to solve the problem of the variation of the tree growth among PRs, in connection with the transfer of the latter, by basing conclusions on available data for the mean height of the trees. Neither has this been the intention of the author. The principal attention in the present work has been directed to the analysis of cold damage and mortality in plants. These phenomena have been approached from different angles and dealt with as thoroughly as circumstances have permitted, presenting new evidence and suggesting new views of the problem.

Summary

Cold damage, mortality and survival of plants in Scots pine in experimental provenance series laid out during 1952—1955 have been dealt with in this paper. The experimental series comprises thirty plantations distributed over different parts of Sweden and covers an area of 36 ha. The data of only 20 experimental plantations located north of latitude 60° N, representing Norrland, *i.e.*, the northern part of Sweden, have been used. During the period 1953—1964 severe cold damage manifested itself in this part of Sweden not only on experimental plantations, but also on afforestation areas of high quality with trees up to twenty years old. In some districts afforested areas were strongly reduced and sometimes laid bare. The factors causing this high mortality rate among trees were difficult to determine. With the view of arriving at the cause of death among Scots pine, the principal attention has therefore been devoted to the analysis of cold damage referred to in this paper as *basal stem girdle* of 1960/61 and its connection with extreme climate. However, other and more common types of damage by cold and injuries caused by climatic factors have also been taken into account.

Planting stock of the experimental provenance series was raised in two nurseries (in the province of Stockholm, φ: 59° 25′, H_S: 20 and in the province of Västernorrland, φ: 63° 30′, H_S: 200) from the seeds of 100 provenances originating from natural habitats (Fig. 7). From this provenance material 90 populations are represented by the progeny of individual trees. The total number of individual trees tested in the experiment is 2,200. Seed was sown in 1951 and in the whole experimental series trees were of the same age. The areas of experimental plantations were prepared and carefully scarified. Planting was carried out in open pits by using seedlings (2 + 0) and transplants (2 + 1 and 2 + 2).

Provenance experiments were conducted in four randomised blocks with restrictions similar to YUODEN square design. The number of provenances tested in each experimental plantation was 7 and 7 + 7 respectively. The seven provenances were made up as follows: one local and two standard provenances together with two plus two provenances whose natural habitats lie to the north or to the south of the experimental site respectively. One of the provenances in each of the latter cases originates from a higher and the other from a lower altitude than the altitude of the experimental site.

The transfer of the provenances was, as a rule, restricted to 150 km in meridional direction and to 100 m in vertical scale. On experimental plantations with 7 + 7 provenances the first seven were made up as above mentioned and the remaining seven provenances were taken from habitats more remote in relation to the experimental site than those of the first seven.

Uniform tending of plants on experimental plantations was carried out. Fencing of the plantations with the view of protecting them against the attacks of reindeer, elk and roe appeared to be necessary on many experimental sites. Extensive work was carried out in connection with the elimination of the infection by fungus *Phacidium infestans* (during 1954—1955) and also in connection with averting attacks by *Hylobies* beetles (during 1953—1955), by rodents and other biotic factors. These measures proved to be satisfactory in providing necessary protection against different damaging agents and chance occurrence of injuries. Thus the climatic factors remained the primary and almost the sole cause of damage and mortality in plants, and the analysis of the import of these factors on provenance experimental series refers to the period 1954—1964. Reservation should, however, be made here as regards the secondary phenomena, *e.g.*, the activity of facultative parasitic fungi and the attacks of insects which, as a rule, affect plants and trees damaged by cold.

Check-up and assessment of experimental plantations were carried out every year. Mortality and changes in plants were examined as minutely and carefully as the scope of the experiment permitted. Thus each plant functioned as a permanent experiment object. The treatment and reducing into a system of all the data obtained from all experimental plantations during 1954—1964 was carried out according to three guiding principles: (1) Only original plants were included in the estimation of the data obtained; (2) Mortality rates were expressed graphically in diagrams; (3) Experimental plantations were divided into groups (regions and subregions) introducing thus a geographical interpretation into the analysis of factors causing mortality in trees. The circumstance that only original plants were used in the estimation greatly reduced the uncontrolled variation of plant mortality.

Data on the mortality in plants for each provenance on an individual experimental plantation were transformed into relative mortality values of two types—cumulative mortality rates (CM) and mortality rates in single years (SYM). These two types of mortality rates constitute provenance time-age-mortality curves in diagrams A and B (Figs. 36—58) for each experimental plantation. These curves show the adaptation of different provenances to the individual site conditions of experimental plantations during 1954—1964, and each experimental plantation makes an independent unit in the experimental series. The provenance mortality curves show a distinctly balanced arrangement, *i.e.*, a definite provenance scale in the experimental plantation diagrams. In provenances originating from northern habitats mortality rates are low, but in provenances whose growth places are located to the south of the experimental site mortality rates in most cases reach very high values. (Each experimental plantation is supplemented with a table containing necessary explanations.)

According to their shape the cumulative mortality curves may be divided into three sections, covering a certain period of years: (1) from the year of the layout up to 1956; (2) from 1956 up to 1960; (3) from 1960 up to 1964. The curves expressing mortality rates in single years show increased mortality values during certain years. As a rule, the shape of these curves has four distinct peaks (*e.g.* Fig. 44 B). Each of them corresponds either to a certain year, or, in some cases, to two or three years in succession. In the latter case plant mortality during the second or the third year expressed by the same peak was the delayed effect of that cold which caused the death of plants in the first year. The first two peaks of the curves refer to 1954 and 1956 and correspond to the first section of the cumulative mortality curves; the third refers to 1958 and corresponds to the second section; while the fourth peak covers the period from 1961 to 1963 and corresponds to the third section of the cumulative mortality curves.

In the first section the cumulative mortality curves of the provenances whose transplants were grown in the nursery in the province of Stockholm differ from those of the provenances grown in the nursery of Västernorrland (*e.g.* provenance 42 and 74 in Fig. 41 A). The response of the former provenances to climatic extremes is shown in the curves by the reduced mortality rates, for which stronger and bigger transplants were responsible. However, the deviation exists only in the first section of the curves. In the two last sections, after the cold of 1958 and 1961, the initial advantages of the provenances disappear.

Rates in the cumulative mortality curves for some long-distance provenances transferred from the south assume constant values in the third section, when the curves approach their assymptote (100 % rates) and run parallel to the horizontal axis. The survival of a few individuals with a high resistance to cold should be looked upon as a result of natural selection (*e.g.* provenances 59 and 74 in Fig. 43 A). In this section provenances with moderate-distance transfer reveal an analogous tendency in the direction of the curves, but their rate of survival is higher than in long-distance provenances.

Adaptation of different provenances to the experimental site conditions as shown by provenance mortality curves in diagrams is largely determined by the general climate and also by local climatic conditions prevailing on these sites. The climatic factors can often be dissimilar on different experimental plantations during the same year. The death of the tree is often the result of the combined effect of several factors. Of various climatic factors which caused increased mortality in certain years the following should be mentioned: May frost and summer drought of 1953; early summer drought and August frost of 1954; severe winter and early spring cold of 1955; exceptionally severe summer drought of 1955; winter and early spring cold of 1956, 1958 and 1959; severe winter and early spring cold of 1961; May and June frosts of 1963 and slight July frosts of 1964. The most serious and decisive of these were late winter and early spring damage together with May and June frost injuries. Only slight damage was caused by autumn frost in August 1954.

The most extensive part of the analysis on damage patterns in plants covers the period 1961—1964, when severe winter and early spring injuries of 1961, and later the process of the recovery of affected trees, were examined. This analysis refers to the third section of cumulative mortality curves and to the fourth peak in the single year mortality curves. The most conspicuous types of cold damage are the basal stem girdle and the dieback of the top, which affect the two cardinal above-ground parts of the tree most susceptible to cold.

In the majority of cases basal stem girdle was situated on the stem in the 30 cm zone above the ground surface. On some occasions it had occurred below and sometimes exactly at the ground surface, and only in a few cases higher than 50 cm above the ground. The injury in the basal stem girdle portion normally centres in the cambial region. The girdling is complete when killed cambium encircles the stem. In most cases the stem is only partly girdled and, owing to the callus overgrowth at the edge of the injured area, frost canker begins to develop. Most of the cankered trees perished during 1961—1964, but the recovery of the trees with a slighter degree of basal stem girdle proceeded. Various kinds of basal stem girdle are shown in Figs. 1—4, 25—31 and 63—67.

Basal stem girdle occurs only when extreme weather conditions prevail. The cause of this type of damage is the effect of low temperatures on living cells. When basal stem girdle occurs, the environmental conditions are characterized by alternate periods of cold and thaw and by fluctuations of diurnal temperatures during late winter and early spring. The level of the damage above the ground surface is connected with the changes in the snow cover. Frequently damage occurred in April when the ground surface was covered by solid ice crust. Sometimes basal stem girdle merges with narrow, vertical lesions in the bark (winter sunscald) occurring in connection with strong insolation in spring when the ground is covered by ice crust.

After the winter of 1954/55 basal stem girdle was registered on experimental plantations, but in 1960/61 this type of damage to ten-year-old trees appeared again on a large scale with a devastating force.

The distribution of the basal stem girdle of 1960/61 covers region II (Fig. 8) and is connected with general weather conditions during the winter and early spring of 1961. On the other hand, there is not sufficient evidence that changing weather conditions during the summer and autumn of 1960 in different parts of the region had influenced the hardening of plants and the occurrence of damage in various ways. However, climatic conditions during late winter of 1962, and May and June frosts of 1963, were responsible for the way in which the recovery of trees cankered in 1961 proceeded in different parts of the region.

Dieback of the top of the plant is a common type of cold damage which occurs in different seasons of the year (Figs. 5, 6 and 34). Frequently the damage is limited to the top of the tree, but during severe cold waves the plants themselves are killed.

Diverse cumulative mortality rates of 1964 express the hereditary adaptation of provenances to experimental sites during the first 14 years of ontogeny under varying weather conditions. When summarizing the data on cumulative mortality obtained from single experimental plantations, the shortening (—Y) and the lengthening (+ Y) of the growing season in connection with the transfer of provenances to the experimental sites has been used as the common denominator. In this work experimental plantations are divided into four groups, each of which represents a particular spatial variation (region I and subregions II: 1, II: 2 and II: 3, Fig. 8).

The relation of cumulative mortality rates to the transfer of provenances is revealed by linear regressions, which are statistically highly significant within each of the four experimental plantation groups (Table 23). Subregion II: 2 is that part of northern Sweden to which principal attention is directed. Difficulties in afforestation in the large, logged-off areas arise here most frequently as a result of cold damage, which causes mortality in plants. Survival of plants thus becomes the fundamental problem in this subregion. By transferring provenances from the north it is possible, in the great majority of cases, to avoid mortality in plants in afforestation areas.

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REFERENCES

AALTONEN, V. T., 1948: Boden und Wald. — Berlin, Hamburg.

ABBE, L. B. and CRAFTS, A. S., 1939: Phloem of white pine and other coniferous species. — Bot. Gaz., 100: 695—722.

AGER, B. H., 1964: Studier över klimatet i Norrland, Dalarna och Värmland. (Studies of the climate in north and central Sweden.) — Stud. For. Suec., 19: 1—105.

AULITZKY, H., 1958: Waldbaulich-ökologische Fragen an der Waldgrenze. — Cbl. Ges. Forstw., 75: 18—33.

— 1961: Lufttemperatur und Luftfeuchtigkeit. — Mitt. Forstl. VersAnst. Mariabrunn, 59: 105—125.

ANDERSSON, G., 1905: Om talltorkan i öfre Sverige våren 1903. — Medd. Statens SkogsförsAnst. 2: 49—80.

ANDERSSON, G., 1944: Gas change and frost hardening studies in winter cereals. — Lund.

AUMANN, 1883: Frost-Beschädigung. — Forstl. Beil. Z. Ver. nassauischer Land-Forstwirthe, 29: 75—76.

BAKER, W. C., 1954: A contribution to the concept of wound repair in woody stems. — Can. J. Bot., 32: 486—490.

BATES, C. G., 1930: The frost hardiness of geographic strains of Norway pine. — J. For., 28: 327—333.

BELYEA, H. C. and MACALONEY, H. J., 1926: Weather injury to terminal buds of Scotch pine and other conifers. — J. For., 24: 685—690.

BJÖRKMAN, E., 1948: Studier över snöskyttesvampens (*Phacidium infestans* Karst.) biologi samt metoder för snöskyttes bekämpande. (Studies on the biology of the *Phacidium*-blight (*Phacidium infestans* Karst.) and its prevention.) — Medd. Statens SkogsforsknInst., 37: 1—136.

— 1957: Norrländsk tallkräfta (*Dasyscypha fuscosanguinea*) i sådder och planteringar i höjdlägen. — Skogen, 44: 522.

— 1959: Ny svampsjukdom i skogsträdsplantskolor. — Skogen, 46: 292—293.

— 1963: Resistance to snow blight (*Phacidium infestans* Karst.) in different provenances of *Pinus silvestris* L. — Stud. For. Suec., 5: 1—16.

BLOCH, R., 1941: Wound healing in higher plants. — Bot. Rev., 7: 110—146.

— 1952: Wound healing in higher plants. II. — Bot. Rev., 18: 655—679.

BOERKER, R. H., 1914: Damage to reproduction by snow. — Soc. Am. Foresters Proc., 9: 267—268.

BOGDANOFF (BOGDANOV), P. L., 1931: Ueber Photoperiodismus bei den Holzarten. Vorläufige Mitteilung (In Russian; German summary). — Trudy i issled. po lesn. hoz. i lesn. promyšl., 10: 21—55.

BOYCE, J. S., 1961: Forest pathology. — New York, Toronto, London.

BRAUN, H. J., 1963: Die Organisation des Stammes von Bäumen und Sträuchern. — Stuttgart.

BRUNT, D., 1945: Some factors in micro-climatology. — Q. J. R. met. Soc., 71: 307/308: 1—10.

BUCKLAND, D. C., REDMOND, D. R. and POMERLEAU, R., 1957: Definitions of terms in forest and shade tree diseases. — Can. J. Bot., 35: 675—679.

BURSTRÖM, H. G. and ODHNOFF, C., 1964: Vegetative anatomy of plants. — Stockholm.

CALLAHAM, R. Z., 1962: Geographic variability in growth of forest trees. — Tree growth, pp. 311—325.

CHANDLER, W. H., 1913: Freezing of plant tissues by low temperature. — Missouri Agric. Exp. Sta. Res. Bull., 8: 143—309.

— 1915: Some peculiar forms of winter injury in New York state during the winter of 1914—1915. — Proc. Am. Soc. Hort. Sci., 12: 118—120.

CHILDS, T. W., 1961: Delayed killing of young-growth Douglas-fir by sudden cold. — J. For., 59: 452—453.

DAUBENMIRE, R., 1957: Injury to plants from rapidly dropping temperature in Washington and northern Idaho. — J. For., 55: 581—585.
DAY, W. R., 1928: Damage by late frost on Douglas fir, Sitka spruce and other conifers. — Forestry, 2: 19—30. (With a note on the occurrence of *Pityogenes bidentatus*, Herbst., on frosted Douglas fir, by R. N. CHRYSTAL).
— 1928: Frost as a cause of disease in trees. — Q. J. For., 22: 179—191.
— 1931: The relationship between frost damage and larch canker. — Forestry, 5: 41—56.
— 1934: The relation between disease and the constitution and environment of the tree. — J. R. Agric. Soc. England, 95: 54—72.
— 1939: Local climate and the growth of trees with special reference to frost. — Q. J. R. met. Soc., 65: 195—209.
— 1945: A discussion of causes of dying-back of Corsican pine, with special reference to frost injury. — Forestry, 9: 4—26.
— 1958: Variation in susceptibility of European larch of differing seed origin in Scotland to injury by experimental freezing. — Scot. For. 12: 143—146.
— 1961: Crown die-back and debility in Corsican pine (*P. nigra var. calabrica*) in Britain. — Forestry, 34: 145—173.
DAY, W. R. and PEACE, T. R., 1934: The experimental production and the diagnosis of frost injury on forest trees. — Oxf. For. Mem., 16: 4—60.
— 1937: The influence of certain accessory factors on frost injury to forest trees. — Forestry, 11: 13—29.
— 1946: Spring frosts. With special reference to the frosts of May 1935. — For. Comm., Bull., 18: 1—111.
DAY, W. R. and BARRET, D. K., 1962: Injury by experimental freezing to various provenances of black pine (*Pinus nigra* Arnold). — Scot. For., 17: 37—43.
DENGLER, A., 1910: Junifrostschäden an der Kiefer. — Z. Forst- u. Jagdw., 42: 670—764.
— 1932: Junifrostschäden an der Kiefer. — Z. Forst- u. Jagdw., 64: 97—99.
DEXTER, S. T., 1933: Effect of several environmental factors on the hardening of plants. — Plant Physiol., 8: 123—140.
DIETRICHSON, J., 1961: Breeding for frost resistance. — Silvae Genet., 10: 172—179.
— 1964:. Proveniensproblemet belyst ved studier av vekstrytme og klima. (The provenance problem illustrated by studies of growth-rythm and climate.) — Medd. norske Skogsförsöksv., 19: 71: 501—656.
DORMLING, I., 1963: Anatomical and histological examinations of the union of scion and stock in grafts of Scots pine (*Pinus silvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.). — Stud. For. Suec., 13: 1—136.
DUFFIELD, J. W., 1956: Damage to western Washington forests from November 1955 cold wave. — U.S. Dep. Agr., For. Serv., Pac. Northwest For. Range Exp. Sta., Circ. 129.
EBELING, F., 1957: Den nuvarande norrlandslinjen inom svenskt skogsbruk — tillfällig moderiktning eller välgrundad nydaning? (The new Norrland line of policy in Swedish forestry: A passing fashion or a well-founded reorganization?) — K. Skogs- o. LantbrAkad. Tidskr., 4: 264—288.
— 1959: Skogarna och deras vård i övre Norrland från och med 1930-talet. — Sveriges skogar under 100 år. K. Domänstyrelsen, pp. 413—443. Stockholm.
— 1961: Vindens betydelse för skogens avverkning och föryngring särskilt i de norrländska höjdlägena. — Norrlands SkogsvFörb. Tidskr., pp. 169—180.
EHRENBERG, C. EKLUNDH, 1963: Genetic variation in progeny tests of Scots pine (*Pinus silvestris* L.). — Stud. For. Suec., 10: 1—135.
EICHE, V., 1955: Spontaneous chlorophyll mutations in Scots pine (*Pinus silvestris* L.). — Medd. Statens SkogsforsknInst., 45: 13: 1—69.
— 1962: Nya aspekter på plantavgång och bristande vinterhärdighet i norrländska tallkulturer. — Skogen, 49: 423—426, 432.
ENEROTH, O., 1926—1927: Studier över risken vid användning av tallfrö av främmande proveniens. (A study on the risks of using in a particular district pine-seed from other sources.) — Medd. Statens SkogsförsAnst., 23: 1—62.
— 1928: Ytterligare bidrag till frågan om tallfröets proveniens. (Weitere Beiträge zur Frage der Provenienz des Kiefernsamens.) — Svenska SkogsvFören. Tidskr., 26: 39—62.
— 1930: Till frågan om sambandet mellan en orts värmeklimat och härdigheten hos dess tallvegetation. — Norrlands SkogsvFörb. Tidskr., pp. 1—49 and 153—172.

FILEWICZ, W. and MODLIBOVSKA, I., 1955: The hardiness of the south-western part of the tree as the major factor in the survival during test winters. — XIV Int. Hort. Congr., Rep. I: 879—886.

FRIES, R. E., 1918: Strödda iakttagelser över Bergianska trädgårdens gymnospermer. — Acta Horti Bergiani, 6: 4.

— 1941: Iakttagelser angående inverkan av vintern 1939—1940 på lignoserna i Bergianska trädgården. — Acta Horti Bergiani, 13: 1—101.

FRIEDEL, H., 1961: Schneedeckenandauer und Vegetationsverteilung im Gelände. — Mitt. Forstl. VersAnst. Mariabrunn, 59: 317—370.

GALAKHOV (GALACHOV), N. N., 1959: Studies on the structure of the climatic seasons of the year (In Russian). — Akad. Nauk S.S.S.R., Moscow, pp. 1—183.

GENKEL (HENKEL), P. A. and OKNINA, E. Z., 1964: Dormancy and cold resistance in fruit trees (In Russian). — Akad. Nauk S.S.S.R., Moscow, pp. 1—243.

GRANT, V., 1963: Te origin of adaptation. — New York.

GUSTAFSSON, Å., 1962: Genetik och växtförädling i skogsbrukets tjänst. (Genetics and plant breeding as applied to Swedish forestry.) — Svenska SkogsvFören. Tidskr., 60: 111—150.

HAMBERG, A., 1907: Die Eigenschaften der Schneedecke in den lappländischen Gebirgen. — Naturwissenschaftliche Untersuchungen des Sarekgebirges in Schwedish-Lappland, 1: 3: 1: 1—68.

HAMBERG, H. E., 1912: Om skare och flen i Lappland. — K. Svenska Vetenskapsakad. årsbok 1912, Uppsala, pp. 225—303.

HARRIES, H. A., 1934: Frost ring formation in some winter-injured deciduous trees and shrubs. — Am. J. Bot., 21: 485—498.

HARTIG, R., 1883: Eine neue Art der Frostbeschädigung in Fichten- und Tannensaat und Pflanzbeeten. — Allgem. Forst-Jagd-Zeitung, 59: 406—409.

— 1891: Lehrbuch der Anatomie und Physiologie der Pflanzen. — Berlin.

— 1895: Doppelringe als Folge von Spätfrost. — Forstl. Naturwiss. Z., 4: 1—8.

— 1900: Lehrbuch der Pflanzenkrankheiten. — Berlin.

HARVEY, R. B., 1918: Hardening process in plants and developments from frost injury. — J. Agric. Res., 15: 83—112.

— 1930: Length of exposure to low temperature as a factor in the hardening process in tree seedlings. — J. For., 28: 50—53.

HEDLUND, T., 1912: Om frosthärdigheten hos våra kalljordsväxter. — Svensk bot. Tidskr., 56: 1—57.

— 1913: Till frågan om växternas frosthärdighet. — Bot. Notiser, 65: 153—173.

HEIKINHEIMO, O., 1949: Results of experiments on the geographical races of spruce and pine. — Comm. Inst. for. Fenn., 37: 2: 37—44.

HEMENWAY, A. F., 1926: Late frost injury to some trees in Central Kentucky. — Am. J. Bot., 13: 364—366.

HEPTING, G. H., 1960: Climate change and forest diseases. — Proc. Fifth World For. Congr., 2: 842—847.

HOFFMANN, D., 1895: Frostschäden bei Kiefern. — Z. Forst- u. Jagdw., 2: 87—89.

HOFKER, H., 1919: Über den Einfluss der Winterwitterung auf die Gehölze mit besonderer Berücksichtigung des strengen Frostes im Winter 1916/17. — Mitt. dtsch. dendrol. Ges., 25: 196—207.

HOLMERZ, C. G. and ÖRTENBLAD, TH., 1886: Om Norrbottens skogar (Sur les forêts de la Norrbothnie). — Bihang till Domänstyrelsens underdåniga berättelse rörande skogsväsendet år 1885, Stockholm, pp. 1—120.

HOLMGREN, A., 1963: Ytterligare bidrag till belysande av expositionens betydelse för tallkulturernas utveckling på stora hyggen å hög nivå i Norrland. — Norrlands Skogsv-Förb. Tidskr., pp. 1—56.

JACOBS, M. R., 1945: The growth stresses of woody stems. — Commonw. For. Bur., Canberra, Bull., 28: 1—67.

KALELA, A., 1937: Zur Synthese der experimentellen Untersuchungen über Klimarassen der Holzarten. — Comm. Inst. for. Fenn., 26: 1—434.

KIHLMAN, A. O., 1890: Pflanzenbiologische Studien aus Russisch Lappland. Ein Beitrag zur Kenntnis der regionalen Gliederung an der polaren Waldgrenze. — Acta Soc. pro Fauna et Flora Fennica, Helsingfors, 6: 3.

Kohh, E., 1964: Om tallens gren- och granens topptorka och dess bekämpning. — Skogen, 51: 200—203.

Kozlowski, T. T., 1961: The movement of water in trees. — For. Sci., 7: 177—192.

— 1964: Water metabolism in plants. — New York.

Kraevoj (Krayevoi), S. J., Oknina, E. Z. and Ipekdžijan, V. M., 1954: Effect of low critical temperatures on oak seedlings (In Russian). — Dokl. Akad. Nauk S.S.S.R., 95: 841—844.

Krasavcev (Krasavzev), O. A., 1961: Hardening of arboreal plants to extremely low temperatures (In Russian; English summary). — Izvest. Akad. Nauk, Ser. Biol., 26: 228—232.

Kriebel, H. B., 1956: Some Analytical Techniques for Tree Race Studies. — Proc. Soc. Am. Foresters, Memphis, pp. 79—82.

— 1957: Patterns of genetic variation in sugar maple. — Ohio Agric. Exp. Sta., Res. Bull., 791: 1—56.

Lagerberg, T., 1912: Studier öfver den norrländska tallens sjukdomar, särskilt med hänsyn till dess föryngring. (Studien über die Krankheiten der norrländischen Kiefer mit besonderer Rücksicht auf ihre Verjüngung.) — Medd. Statens Skogsförsöksanst., 9:135—170 (xxi—xxiv).

— 1913: En abnorm barrfällning hos tallen. (Eine Schütte-epidemie der schwedischen Kiefer.) — Medd. Statens SkogsförsöksAnst., 10: 139—180 (xvii—xxii).

— 1913: Granens topptorka. — Medd. Statens SkogsförsAnst., 9—44.

Langlet, O., 1929: Die Entwicklung der Provenienzfrage in Schweden. — Verh. int. Kongr. forstl. VersAnst., Stockholm 1929, pp. 333—342.

— 1934: Om variationen hos tallen (*Pinus silvestris* L.) och dess samband med klimater. (Über die Variation der Kiefer (*Pinus silvestris* L.) und deren Zusammenhang mit dem Klima.) — Svenska SkogsvFören. Tidskr., 32: 87—110.

— 1935: Till frågan om sambandet mellan temperatur och växtgränser. (Über den Zusammenhang zwischen Temperatur und Verbreitungsgrenzen von Pflanzen.) — Medd. Statens SkogsförsAnst. 28: 3: 299—412.

— 1936: Studier över tallens fysiologiska variabilitet och dess samband med klimatet. Ett bidrag till kännedomen om tallens ekotyper. (Studien über die physiologische Variabilität der Kiefer und deren Zusammenhang mit dem Klima. Beiträge zur Kenntnis der Ökotypen von *Pinus silvestris* L.) — Medd. Statens SkogsförsAnst., 29: 219—470.

— 1936: Study of the physiological variability of pine and its relation to the climate. — U.S. For. Serv., Trans. 293: 1—89.

— 1937: Ett exempel på samband mellan härdighet och stamform. — Norrlands Skogsv-Förb. Tidskr., 2: 275—288.

— 1938: Proveniensförsök med olika trädslag. Översikt och diskussion av hittills erhållna resultat. (Provenienzversuche mit verschiedenen Holzarten.) — Svenska Skogsv-Fören. Tidskr., I—II: 55—278.

— 1940: Om utvecklingen av granar ur frö efter självbefruktning och efter fri vindpollinering. (Über die Entwicklung von teils nach künstlicher Selbstbestäubung, teils nach freier Windbestäubung entstandenen Fichten) — Medd. Statens Skogs-försAnst., 32: 1: 1—22.

— 1943: Photoperiodismus und Provenienz bei der gemeinen Kiefer (*Pinus silvestris* L.). — Medd. Statens SkogsförsAnst., 33: 295—330.

— 1945: Om möjligheten att skogsodla med gran- och tallfrö av ortsfrämmande proveniens. Svenska SkogsvFören. Tidskr., 1: 68—78.

— 1952: Proveniensfrågan. Statens skogsforskningsinstitut 1902—1952. — Medd. Statens SkogsförsAnst., 42: 271—286.

— 1957: Vidgade gränser för förflyttning av tallprovenienser till skogsodlingsplatser i norra Sverige. — Skogen, 44: 319.

— 1959: A cline or not a cline — a question of Scots pine. — Silvae Genet., 8: 1: 1—36.

— 1959: Norrlandstallens praktiska och systematiska avgränsning. — Svenska Skogsv-Fören. Tidskr., 3: 425—436.

— 1962: Ecological variability and taxonomy of forest trees. — Tree Growth, pp. 357—369.

— 1963: Patterns and terms of intra-specific ecological variability. — Nature, 200: 347—348.

— 1964: Tvåhundra år genekologi. — Svensk bot. Tidskr., 58: 273—308.

LARCHER, W., 1963: Zur Frage des Zusammenhanges zwischen Austrocknungsresistenz und Frosthärte bei Immergrünen. — Protoplasma, 57B: 569—587.
LEVITT, J., 1956: The hardiness of plants. — New York.
— 1957: The moment of frost injury. — Protoplasma, 48: 289—302.
— 1958: Frost, drought and heat resistance. — Protoplasmatologia VIII. Physiologie des Protoplasmas, 6: 1—87.
— 1962: A sulfhydryl—disulfide hypothesis of frost injury and resistance in plants. — J. Theor. Biol., 3: 355—391.
LEVITT, J., SULLIVAN, CH. Y. and JOHANSSON, N. O., 1962: Sulfhydryls — a new factor in frost resistance. III. Relation of SH to protein, glutathione oxidizing activity. — Plant. Physiol., 37: 266—271.
LEVITT, I., SULLIVAN, CH. Y., JOHANSSON, N. O. and PETTIT, R. P., 1961: Sulfhydryls — a new factor in frost resistance. I. Changes in SH content during frost hardening. — Plant Physiol., 36: 611—616.
LIDFORSS, B., 1907: Die wintergrüne Flora. Eine biologische Untersuchung. — Lunds Univ. Årsskr. N. S., 2: 2: 13: 1—78.
LINES, R. and MITCHELL, A. F., 1964: Results of some older Scots pine provenance experiments. — Rep. For. Research, pp. 172—194.
LUTZ, H. J., 1936: Scars resulting from glaze on woody stems. — J. For., 34: 1039—1041.
MATHESON, T., 1961: Frost damage — late spring 1961, and forest tree clearing office. — Q. J. For., 55: 345—346.
MATÉRN, B., 1960: Spatial Variation. Stochastic models and their application to some problems in forest surveys and other sampling investigations. — Medd. Statens SkogsforsknInst., 49: 1—144.
MATTSSON-MÅRN, L., 1922: Snötryckskador å ungtall (Dégâts de neige chez des jeunes pins sylvestres). — Medd. Statens SkogsförsAnst., 19: 515—528.
MEYER, B. S., 1928: Seasonal variations in the physical and chemical properties of the leaves of the pitch pine, with especial reference to cold resistance. — Am. J. Bot., 15: 449—470.
METZGER, K., 1908: Über das Konstruktionsprinzip des sekundären Holzkörpers. — Naturwiss. Z. Forst-Landw., 6: 249—273.
MIX, A. J., 1916: The formation of parenchyma wood following winter injury to the cambium. — Phytopathology, 6: 279—283.
MORK, E., 1946: Vedanatomi. — Oslo.
— 1960: Om sambandet mellom temperatur, toppskuddtilvekst og årringens vekst og forvedning hos gran (*Picea abies* (L.) Karst.). (On the relationship between temperature, leading shoot increment and the growth and lignification of the annual ring in Norway spruce (*Picea abies* (L.) Karst.) — Medd. norske Skogsforsøksv., 16: 225—261.
MOSHKOV (MOŠKOV), B. S., 1935: Photoperiodism and frost resistance of perennial plants (In Russian; English summary). — Trudy po prikl. botan., genet. i. selek., 3: 5: 235—261, 17—19.
MÜNCH, D., 1913: Hitzeschäden an Waldpflanzen. — Naturwiss. Z. Forst-Landw., 11: 557—562.
— 1914: Nochmals Hitzeschäden an Waldpflanzen. — Naturwiss. Z. Forst-Landw., 12: 169—188.
— 1928: Frostgefährdung wintergrüner Gehölze. — Mitt. dtsch. dendrol. Ges., 11: 175—186.
NEGER, F. W., 1913: Die nordische oder Lapplandkiefer (*Pinus silvestris* L. *var. lapponica* Fr.). — Tharandter forstl. Jb., 64: 101—125.
— 1915: Rauchwirkung, Spätfrost und Frosttrocknis und ihre Diagnostik. — Tharandter forstl. Jb., 66: 195—212.
Norrlands skogsvårdsförbunds exkursion till Lappland (Norrbotten) den 27—28 juni 1961. — Norrlands SkogsvFörb. Tidskr., 1961, pp. 390—437.
NÄSLUND, M., 1940—41: Funktioner och tabeller för kubering av stående träd. Tall, gran och björk i norra Sverige (Funktionen und Tabellen zur Kubierung stehender Bäume. Kiefer, Fichte und Birke in Nordschweden). — Medd. Statens SkogsförsAnst., 32: 87—142.
— 1947: Funktioner och tabeller för kubering av stående träd. Tall, gran och björk i södra Sverige samt i hela landet. (Functions and tables for computing the cubic volume of standing trees. Pine, spruce and birch in Southern Sweden, and in the whole of Sweden.) — Medd. Statens SkogsförsAnst. 36: 3: 1—81.

ODIN, H., 1964: Skogsmeteorologiska undersökningar i höjdlägen. (Investigations of forest meteorology in upland terrain.) — K. Skogs- LantbrAkad. Tidskr., 103: 198—226.

PARKER, J., 1957: Seasonal changes in some chemical and physical properties of living cells of *Pinus ponderosa* and their relation to freezing resistance. — Protoplasma, 48: 147—163.

— 1959: Seasonal changes in white pine leaves: A comparison of cold resistance and free-sugar fluctuation. — Bot. Gaz., 121: 46—50.

— 1960: Survival of woody plants at extremely low temperatures. — Nature, 187: 1133.

— 1963: Cold resistance in woody plants. — Bot. Rev., 29: 123—200.

PISEK, A., 1950: Frosthärte und Zusammensetzung des Zellsaftes bei *Rhododendron ferrugineum*, *Pinus cembra* und *Picea excelsa*. — Protoplasma, 39: 129—146.

— 1963: An den Grenzen des Pflanzenlebens in Hochgebirge. — Jb. 1963 des Vereins zum Schutze der Alpenpflanzen und -Tiere, V, 28: 112—129.

POMERLEAU, R., 1944: Observations sur quelques maladies non parasitaires des arbres dans le Quebec. — Can. J. Res., 22—C: 171—189.

RADNOVA (RYADNOVA), I. M. and EREMIN (YEREMIN), G. V., 1964: Winter hardiness of fruit trees in southern U.S.S.R. (In Russian). — Moscow, pp. 1—207.

Reports of the First Conference on Winter Hardiness in Plants, December 23, 1960, in Latvian S.S.R., 1962: Winter and cold hardiness (In Latvian, Russian summary). — Latvijas P.S.R. Zin. Akad., Riga, pp. 1—187.

Reports of the Second Ural Conference on Ecology and Physiology of Woody Plants (In Russian), 1965 — Ural Filial Akad. Nauk S.S.S.R., Ufa, pp. 1—258.

Resolution of Conference on Physiology of Plant Hardiness, Adopted March 7, 1959 (In Russian), 1959 — Fiziol. Rast., 6: 643—648.

RHOADS, A., 1923: The formation and pathological anatomy of frost rings in conifers injured by late frosts. — U.S. Dep. Agric., Dep. Bull., 1131: 1—15.

ROBAK, H., 1951: Noen iakttakelser til belysning av forholdet mellom klimatiske skader og soppangrep på nåletrær. (Some observations contributing to the study of the connections between climatal damages and fungus attacks on conifers.) — Medd. Vestland. Forstl. Forsøksta., 8: 2: 1—43.

— 1957: Sambandet mellom daglengden og avslutningen av den årlige vekstperioden hos en del nåletreslag av interesse for vårt skogsbruk. (On the connection between day length and termination of the annual growth period in seedlings of some conifers of interest to Norwegian forestry.) — Medd. Vestland. Forstl. Forsøkssta., 10: 1—55.

ROLL-HANSEN, F., 1964: *Scleroderris lagerbergii* Gremmen (*Crumenula abietina* Lagerb.) and girdling of *Pinus silvestris* (L.). (*Scleroderris lagerbergii* Gremmen (*Crumenula abietina* Lagerb.) og barkringning av furu.) — Medd. norske Skogsforsøksv., 19: 157—175.

RUDEN, T., 1957: Arvelige dvergformer av furu (*Pinus silvestris* L.) fra Skjåk, Gudbrandsdal. (Abnormal types of Scots pine (*Pinus silvestris* L.) from Skjåk, Gudbrandsdal.) — Medd. norske Skogsforsøksv., 14: 412—443.

SAKAI, A., 1956: The effect of temperature on the maintenance of the frosthardiness. — Low Temp. Sci., Ser. B., 14: 1—5.

— 1956: The effect of temperature on the hardening of plants. — Low Temp. Sci, 14: 7—15

— 1956: Survival of plant tissue at superlow temperatures. — Low Temp. Sci., 14: 17—24.

— 1958: Survival of plant tissue at superlow temperature. — Low Temp. Sci., 16: 41—53.

— 1959: The frost hardening process of woody plant. III. Relation of low temperature to frost-hardening. — Low Temp. Sci., 17: 29—34.

— 1959: The frost hardening process in woody plants. V. The relationship between developmental stage and frost hardening. — Low Temp. Sci., 17: 43—49.

— 1960: Survival of the twigs of woody plants at —196° C. — Nature, 185: 393—394.

— 1960: Survival of woody plants at extremely low temperatures. — Nature, 187: 1134.

— 1962: Studies on the frost-hardiness of woody plants. I. The causal relation between sugar content and frost-hardiness. — Low Temp. Sci., Ser. B., 11: 1—40.

SALISBURY, E. J., 1939: Ecological aspects of meteorology. — Q. J. R. met. Soc., 65: 337—358.

SARVAS, R., 1950: Investigations into the natural regeneration of selectively cut private forests in northern Finland. — Comm. Inst. for. Fenn., 38: 5—95.

SAX, K., 1954: The control of tree growth by phloem blocks. — J. Arnold Arboretum, 35: 251—258.

SENEFIELD, G. and WARDROP, A. B., 1962: The nature of reaction wood. — Aust. J. Bot., 10: 2: 93—105.

SCHMID-VOGT, H. *et al.*, (1965): Forstsamengewinnung und Pflanzenanzucht für das Hochgebirge. — München, Basel, Wien.

SCHMUTZ, W., SULLIVAN, CH. Y. and LEVITT, J., 1961: Sulfhydryls — a new factor in frost resistance. II. Relation between sulfhydryls & relative resistance of fifteen wheat varieties. — Plant. Physiol., 36: 617—620.

SCHNELLE, F. *et al.*, 1963: Frostschutz im Pflanzenbau. B. 1. Die meteorologischen und biologischen Grundlagen der Frostschadensverhütung: B. 2. Die Praxis der Frostschadensverhütung. — München, Basel, Wien.

SCHOTTE, G., 1923: Tallfröets proveniens — Norrlands viktigaste skogsodlingsfråga. (La provenance des semences du pin sylvestre — une question très importante pour la régénération des forêts en Norrland.) — Medd. Statens SkogsförsAnst., 20: 305—400.

SCHWERDTFEGER, F., 1957: Die Waldkrankheiten. — Hamburg, Berlin.

SERGEEV, L. I., 1964: Morphological and physiological investigations into winter hardiness in woody plants (In Russian). — Physiology of winter hardiness in woody plants. Akad. Nauk S.S.S.R., Moscow, pp. 5—20.

SIMAK, M. and GUSTAFSSON, Å., 1954: Fröbeskaffenheten hos moderträd och ympar av tall. (Seed properties in mother trees and grafts of Scots pine.) — Medd. Statens SkogsforsknInst., 44:2: 1—73.

SINNOTT, E. W., 1952: Reaction wood and the regulation of tree form. — Am. J. Bot., 39: 1: 69—78.

SOMMERVILLE, W., 1916: Abnormal wood in conifers. — Q. J. For., 10: 132—136.

SMHI: Årsbok II: 2, Meteorologiska iakttagelser i Sverige.

SMHI: Årsbok I, Månadsöversikt över väderlek och vattentillgång.

SORAUER, P., 1921: Handbuch der Pflanzenkrankheiten. I. Nicht-parasitäre Krankheiten. — Berlin.

SPAULDING, P. and BRATTON, A. W., 1946: Decay following glaze storm damage in woodlands of central New York. — J. For., 44: 515—519.

STAUDACHER, 1924: Die Frostschaden in Forstbetrieb, deren Ursachen und Bekämpfung. — Forstwiss., Cbl. 1—13.

STEBBINS, G. L., 1950: Variation and evolution in plants. — London.

STEFANSSON, E., 1964: Försök med tallprovenienser i nordsvenska höjdlägen. — Fören. Skogsträdsförädl., Årsbok 1964, pp. 61—84.

STEVENS, F. L. and YOUNG, P. A., 1927: On the use of the terms saprophyte and parasite. — Phytopathology, 17: 409—411.

STONE, E. L. J., 1952: An unusual type of frost injury in pine. — J. For., 50: 560.

SYLVÉN, N., 1917: Den nordsvenska tallen (Die nordschwedischer Kiefer). — Medd. Statens SkogsförsAnst., 13—14: 9—110 (I—XII).

— 1924: Om våra främmande barrträds vinterhärdighet. (Über die Winterfestigkeit fremder Nadelbäume in Schweden.) — Medd. Statens SkogsförsAnst., 21: 101—148.

— 1940: Lång- och kortdagstyper av de svenska skogsträden. — Svensk PappTidn., 43: 317—324; 332—342; 350—354.

TIKHOMIROV (TICHOMIROV), B. A., 1963: Contributions to the biology of arctic plants (In Russian). — Akad. Nauk. S.S.S.R., Moscow, pp. 1—153.

TIRÉN, L., 1945: Erfarenheter av naturlig föryngring i Norrland. — Svenska Skogsv-Fören. Tidskr., 2: 117—135.

— 1948: Några synpunkter på Norrlands skogsodlingsproblem. — Svenska SkogsvFören. Tidskr., 3: 161—179.

— 1949: Om den naturliga föryngringen på obrända hyggen i norrländsk granskog. (On natural regeneration in unburnt cutting areas in Norrland spruce forests.) — Medd. Statens SkogsforsknInst., 38: 9: 1—210.

TRANQUILLINI, W. and TURNER, H., 1961: Untersuchungen über die Pflanzentemperaturen in der subalpinen Stufe mit besonderer Berücksichtung der Nadeltemperaturen der Zirbe. — Mitt. Forst. VersAnst. Mariabrunn, 59: 127—151.

TUBEUF, C., VON, 1914: Hitzetot und Einschnürungskrankheiten der Pflanzen. — Naturwiss. Z. Forst-Landw., 12: 19—36.

TUMANOV, I. I., 1940: The physiological basis of winter hardiness in cultivated plants (In Russian). — Leningrad, pp. 1—366.

— 1951: Basic achievements of Soviet science in the studies of cold hardiness in plants (In Russian). — Akad. Nauk S.S.S.R., Moscow, pp. 1—54.

TUMANOV, I. I., 1955: Vegetating and winter resistant stages in plants (In Russian). — Fiziol. Rast., 2: 283—291.
— 1963: Frost resistivity of fruit trees (In Russian; English summary). — Izvest. Akad. Nauk S.S.S.R., Ser. Biol., 28: 459—464.
TUMANOV, I. I. and KRASAVCEV (KRASAVZEV), O. A., 1955: Cold resistance of woody plants (In Russian). Fiziol. Rast., 2: 320—333.
— — 1959: Hardening of northern woody plants by negative temperature treatment (In Russian; English summary). — Fiziol. Rast., 6: 654—667.
— — 1962: Effect of thawing rate on survival of vitrified cells and hardened plants (In Russian; English summary). — Fiziol. Rast., 9: 595—606.
— — 1962: A study of the mechanism of dying of rapidly thawing plants (In Russian; English summary). — Fiziol. Rast., 9: 718—729.
— — and HVALIN (KHVALIN), N. N., 1959: Promotion of resistance of birch and black currant to — 253° C by cold hardening (In Russian). — Dokl. Akad. Nauk S.S.S.R., 127: 1301—1303.
WAGENER, W. W., 1949: Top dying of conifers from sudden cold. — J. For. 47: 49—53.
WAISEL, Y., KOHN, H. and LEVITT, J., 1962: Sulfhydryls — a new factor in frost resistance. IV. Relation of GSH — oxidizing activity to flower induction & hardiness. — Plant. Physiol., 37: 272—276.
VASILJEV, I. M., 1956: Wintering of plants (In Russian). — Akad. Nauk S.S.S.R., Moscow, pp. 1—308.
VEGIS, A., 1964: Dormancy in higher plants. — Ann. Rev. Plant. Physiol., 15: 185—224.
— 1965: Ruhezustände bei höheren Pflanzen, Induktion, Verlauf und Beendigung: Übersicht, Terminologie, allgemeine Probleme. — Encycl. Plant Physiol., 15: 2: 499—533.
— Die Bedeutung von physikalischen und chemischen Aussenfaktoren bei der Induktion und Beendigung von Ruhezuständen bei Organen und Geweben höherer Pflanzen. — Encycl. Plant Physiol., 15: 2: 529—668.
WHETZEL, H. H., 1926: The terminology of phytophatology. — Proc. Int. Congr. Plant. Sci., 1926, II: 1204—1215.
WIBECK, E., 1912: Tall och gran av sydlig härkomst i Sverige. (Über das Verhalten der Kiefer und Fichten von ausländischem, besonders deutschem Saatgut in Schweden.) — Medd. Statens SkogsförsAnst., 9: 75—134 (XIII—XX).
— 1913: Om självsådd och skogsodling i övre Norrland. (Über natürliche und künstliche Verjüngung in den Wäldern Nordschwedens.) — Medd. Statens SkogsförsöksAnst., 10: 91—138 (XI—XVI).
— 1919: Om tall- och granfrö från Norrland. — Skogen, 6: 97—107.
— 1928: Om tallens klimatformer och trädslagets förhållande till vertikalförflyttning. — Skogen, 15: 53—58.
— 1933: Till skogens rasfråga på lokala kallorter. — Norrlands SkogsvFören. Tidskr., pp. 225—250.
WINKLER, A., 1913: Über den Einfluss der Aussenbedingungen auf die Kälteresistenz ausdauernder Gewächse. — Jb. wiss. Bot., 52: 467—506.
ZON, R. G., 1903: Effects of frost upon forest vegetation. — For. Q., 11: 14—21.
ÅKERMAN, Å., 1927: Studien über den Kältetod und Kälteresistenz der Pflanzen nebst Untersuchungen über die Winterfestigkeit des Weizens. — Lund, pp. 1—232.
ÅNGSTRÖM, A., 1925: The albedo of various surfaces of ground. — Geogr. Annlr., 7: 323—342.
ÖRTENBLAD, TH., 1903: Talltorka. — Skogsvännen, pp. 110—111.
— 1903: Frostskador å tallen. — Skogsvännen, pp. 111—113.
— 1904: Af köld dödade tallskott. — Skogsvännen, pp. 119—121.

Sammanfattning

Föreliggande arbete behandlar köldskador och plantdöd resp. överlevnadsförmåga hos tallplantor i en proveniensförsöksserie utlagd 1952—1955. Denna serie omfattar 30 planteringsytor fördelade över större delen av Sverige med en sammanlagd areal av 36 ha. Här har endast material från 20 försöksytor kommit till användning, nämligen från de ytor, som är belägna norr om 60° N. I denna del av Sverige har under perioden 1953—1964 inträffat betydande köldskador, vilka observerats icke blott på försöksytorna utan även i andra planteringar och på träd intill en ålder av 20 år. Inom vissa områden var planteringarna mycket skadade och i några fall har de t. o. m. helt gått ut.

Orsaken till köldskadorna och till den stora avgången har tillskrivits olika faktorer. Detta arbete har i främsta rummet avsett undersökning av den typ av köldskador, som här betecknats såsom »basal stem girdle» eller »strangulering» (»strangulation sickness», »Trocken Gürtel», »Einschnürung») och dess samband med extrema klimatförhållanden under vissa år. Även förekomsten av andra slag av köldskador och skador förorsakade av andra klimatfaktorer har emellertid beaktats.

Det i proveniensförsöksserien använda plantmaterialet har erhållits ur frö från 100 naturliga bestånd av olika proveniens. Av dessa provenienser representeras 90 av avkomma från individuella träd. Det totala antalet skördade och undersökta moderträd är 2 200. Fröet utsåddes 1951 i två plantskolor: vid Röskär (Stockholms län) och i Sundmo (Västernorrlands län).

Försöksytorna markbereddes omsorgsfullt och iordningställdes för plantering året innan denna ägde rum. Planteringen skedde i öppen grop. Plantmaterialet var vid planteringen 2/0, 2/1 eller 2/2.

Varje försöksyta omfattar en eller två avdelningar med vardera fyra slumpmässigt fördelade block enligt Youden's modifierade kvadratmetod. Varje avdelning omfattar 7 provenienser: lokalproveniens (motsvarande) och 2 standardprovenienser jämte 2 provenienser av nordligare och 2 av sydligare härkomst än försöksytan. Samtidigt skulle inom de sistnämnda proveniensparen den ena proveniensen representera ett högre, den andra ett lägre område än planteringsorten. Förflyttningen var principiellt begränsad till 150 km i nordlig riktning, 200 km i sydlig riktning samt 100 m uppåt eller nedåt. I de fall försöksytorna omfattar 2 avdelningar, har inom den ena avdelningen använts proveniens som förflyttats över längre avstånd resp. höjdskillnader.

En enhetlig behandling av samtliga plantor på försöksytorna har eftersträvats. I flertalet fall visade det sig nödvändigt att hägna ytorna mot ren, rådjur och älg. Då försöket avsåg undersökning av klimatfaktorer, var det nödvändigt att eliminera infektion av snöskytte, vilket skedde genom besprutning åren 1954—1962. Vidare har åtgärder vidtagits för att skydda plantorna mot angrepp av snytbaggar (1953—1955) och gnagare samt att motverka andra biotiska faktorer. Vidtagna åtgärder visade sig effektiva mot förekommande skadegörare samt reducerade uppkomsten av slumpskador. Såsom primära och praktiskt

taget enda återstående orsaker till skador och avgång i försöket kvarstod således såsom avsett endast de klimatiska faktorerna. Dessa faktorers inverkan har sålunda kunnat studeras under perioden 1954—1964, liksom deras följdverkningar. En reservation görs för sekundära faktorer såsom angrepp av fakultativa parasitsvampar och insektsangrepp på redan köldskadade träd.

Revision av försöksytor och granskning av plantor har utförts varje år. Varje planta har behandlats såsom ett permanent försöksobjekt. Data från åren 1954—1964 har bearbetats enligt följande:

1. Endast ursprungligen utsatta plantor har beaktats;
2. Plantavgången har återgivits i diagram;
3. Försöksytorna har sammanförts inom regioner och subregioner med hänsyn till den geografiska förekomsten av de faktorer, som orsakat köldskador och plantdöd.

Det förhållandet att data endast från ursprungligen utsatta plantor medtagits vid bearbetningen har i hög grad minskat den variation i plantavgång, som kan hänföras till okända orsaker.

Data över plantavgången inom de enskilda provenienserna på varje försöksyta sammanställas här i två typer av diagram, återgivande

A. den samlade plantavgången CM (»cumulative mortality»);
B. den årliga plantavgången SYM (»single year mortality»).

Dessa två typer av diagram återfinns för de olika ytorna i figs. 36—58. Kurvorna illustrerar de olika proveniensernas anpassning till försöksytornas lokala förhållanden under tiden 1954—1964. De olika provenienserna intar i diagrammen en viss ordningsföljd, i det att provenienser från trakter norr om ytorna visar relativt låg avgång, medan sådana från trakter söder om ytorna visar en ofta mycket hög dödlighet. Förflyttningen i höjdled kan även påverka plantavgången.

Kurvorna av typ A kan indelas i tre sektioner, omfattande följande tider: 1. från plantering till 1956; 2. 1956—1969; 3. 1960—1964. Kurvorna av typ B visar en med olika år varierande plantavgång. I regel kan man urskilja fyra olika maxima, vilka motsvaras av endera ett bestämt år eller av två eller tre på varandra följande år. I det senare fallet föreligger en fördröjd verkan av faktorer, som orsakade skadan under det första året. De båda första maxima å B-kurvorna motsvara den första sektionen av A-kurvorna. B-kurvornas 3:e maximum hänför sig till 1958 och dess 4:e maximum till 1961—1963, eller till A-kurvornas 2:a resp. 3:e sektioner (jfr fig. 44 B).

Inom första sektionen av A-kurvorna märks det förhållandet, att plantor uppdragna i trakten av Stockholm reagerat på ett annat sätt än plantor uppdragna vid Sundmo. De förstnämnda (jfr fig. 41 A provenienserna 42 och 74) visar till en början relativt ringa plantavgång sammanhängande med plantornas goda utveckling och större storlek. I kurvornas senare sektioner är denna skillnad eliminerad.

Inom den 3:e sektionen närmar sig kurvorna för en del av de sydligare provenienserna sina asymptotiska värden, dvs. en total avgång. Det faktum, att några få individer har kunnat överleva bör tillskrivas den naturliga spridningen av köldresistensen olika individer emellan (t. ex. provenienserna 59 och 74 i fig. 43 A). En del provenienser, som endast förflyttats norrut över måttliga distanser visar samma kurvtyp, ehuru antalet överlevande i dessa fall är större.

Olika proveniensers anpassning till klimatförhållandena på ytorna är i hög grad bestämd av dels klimatet på deras ursprungsorter, dels de lokalt rådande klimatförhållandena på planteringsytorna. Bland de senare faktorerna, vilka orsakat ökad plantavgång under vissa år bör följande nämnas:

majfrost och sommartorka 1953;
tidig sommartorka och augustifrost 1954;
sträng vinter och kall förvår samt extrem sommartorka 1955;
kall vinter och förvår 1956, 1958, 1959 och 1961;
maj- och junifrost 1963;
lätta julifroster 1964.

De allvarligaste köldskadorna var de som uppkom under senvintern och på förvåren samt till följd av maj- och junifroster. Endast under augusti 1954 uppstod lättare höstfrostskador.

De mest ingående undersökningarna utfördes 1961—1964, nämligen av de svåra köldskador, som orsakats av köldperioder under vintern och förvåren 1961. Samtidigt studerades även trädens återhämtning efter köldskadorna. Nämnda skador inträffade således under en period motsvarande sista sektionen av A-kurvorna resp. B-kurvornas 4:e maximum. De viktigaste skadetyperna var i föreliggande fall strangulering och topptorka, som visar sig å de för köldskador mest ömtåliga partierna av plantornas ovanjordiska delar.

Strangulering uppträdde i flertalet fall inom en zon omfattande stammens understa del upp till 30 cm över marken. I vissa fall har strangulering uppträtt i markytan och, ehuru sällan, även högre än 50 cm över marken.

De primära skadorna vid stranguleringen är normalt koncentrerade till kambiet. I de flesta fall sträcker sig dessa skador endast runt en del av stammen — fullständig strangulering är mindre vanlig. En efterföljande övervallning vid sårytornas kanter kan ge upphov till frostsvulster. De svårast angripna träden dog under något av åren 1961—1964, medan lindrigare stangulerade träd återhämtade sig. Olika grader av strangulering visas i figs. 1—4, 25—31, 63—67.

Strangulering uppkommer endast vid extrema väderleksförhållanden och orsakas direkt av den effekt, som låga temperaturer kan ha på levande celler. Förutsättningen är perioder av omväxlande kyla och tö och med stora temperaturskillnader mellan dag och natt under senvinter och förvår. Skadegörelsens höjd över marken betingas av snötäckets djup. Nämnda typ av skador uppkommer vanligen i april, när markytan är täckt av en hård isskorpa, s. k. flen.

Smala, vertikala sprickor i barken kan uppkomma vid stark solstrålning på våren, om markytan är täckt av isskorpa. Sådana skador uppträder ibland samtidigt med strangulering.

Stranguleringsskador registrerades efter vintern 1954/55 och i stor skala efter vintern 1960/61 — i det senare fallet på tioåriga träd med ofta ödeläggande effekt. Förekomsten av stranguleringsskador har varit begränsad till subregion II: 2 (jfr fig. 8). De har säkerligen förorsakats av väderleksförhållandena under vintern 1961. De skadade tallplantornas återhämtning blev starkt påverkad av en köldperiod under senvintern 1962 och vårfroster under maj och juni 1963.

Topptorka är en vanlig typ av köldskada på tallplantor, som kan uppkomma under olika årstider (figs. 5, 6, 34). Skadan är vanligen begränsad till toppregionen, men extrema skador kan orsaka plantans död.

Den sammanlagda avgången uttrycker proveniensens anpassning till försöksytornas miljö under plantornas första 14 år. Vid sammanställning av materialet har vegetationsperiodens förkortning (—Y) resp. förlängning (+Y) i samband med proveniensens förflyttning till försöksytorna använts som oberoende variabel. Sambandet mellan denna variabel och den samlade plantavgången (A-kurvorna) framträder i lineära regressioner, vilka inom samtliga fyra försöksytegrupper har ett högt signifikansvärde (tab. 23).

Subregion II: 2, dvs. i stort sett Norrlands inland, är det område, som i detta arbete huvudsakligen kommit att behandlas. Föryngringssvårigheterna inom detta område på kalhuggna arealer förorsakas vanligen av köldskador, som resulterar i plantornas död. Det fundamentala problemet är här sålunda att få plantorna att överleva. Genom att använda nordligare plantmaterial, som har större köldresistens än ortens proveniens, är det i de flesta fall möjligt att undvika plantdöd i tallkulturer.

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