KUNGL. SKOGSHÖGSKOLANS SKRIFTER
BULLETIN OF THE ROYAL SCHOOL OF FORESTRY
STOCKHOLM, SWEDEN
Nr 34 Redaktör: Professor LENNART NORDSTRÖM 1961

Development and yield of Douglas fir (*Pseudotsuga taxifolia* (Poir.) Britt.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in southern Scandinavia and on the Pacific Coast

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AKADEMISK AVHANDLING

som med vederbörligt tillstånd av Kungl. skogshögskolans
lärarråd för vinnande av skogsvetenskaplig
doktorsgrad offentligen försvaras
på Skogshögskolan, lärosal III
lördagen den 11 mars 1961 kl. 10

AV

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STOCKHOLM 1961

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Introduction

In 1950 and 1951 the growth conditions of Douglas fir (Pseudotsuga taxifolia) and Sitka spruce (Picea sitchensis) in their ranges along the Pacific coast of North America were the subject of the author's study. Extensive travelling in the large area provided inclusive information on largely different habitats with respect to climate and soil. This strenghtened the opinion that, under certain conditions, these two species should succeed in the southern and south-western counties of Sweden, too.

Douglas fir, which in north-west America exhibits an impressive growth on many locations within its large range (McArdle 1930, Munger and Morris 1936, Isaac 1949), has also shown promise in Danish experiments (Opperman 1915, 1922, Fabricius 1926, Holm 1940 etc.). Similar experience has been reported in Germany by e. g. Kanzow (1937) and Schenck (1939). Later studies published by Hummel and Christie (1953) give accounts of considerable increment in sample plots of Douglas fir and Sitka spruce in Great Britain.

Early Danish investigations (Opperman 1923 and Fabricius 1926) also suggested that in certain cases the yield of Sitka spruce is appreciably greater than that of Norway spruce (Picea Abies) of German origin.

The results of several preliminary studies of the development in southern Scandinavia of both these tree species (Karlberg 1952), and the results from sample plot studies in Scotland (Karlberg 1955) and northern Germany, compare well with the results reported in the literature cited.

For this reason the author considered it important to attempt an analysis of the value of Douglas fir and Sitka spruce to forestry in the south of Sweden. The analysis may be of particular interest against the background of the research currently being aimed at raising the yield by the introduction of Norway spruce from more southerly parts of its range (Germany and Poland) or by the breeding of high-yielding Norway spruce of Swedish origin.

In conjunction with the examination of the growth of the two American species in relation to that of Norway spruce, the latter was also subjected to investigation, when stands of these species have been growing side by side in similar conditions.

Since the stands of Sitka spruce and Douglas fir in southern Sweden are few and small with incomplete management records, they would be unsuitable for a comprehensive study of the yield. For this reason the field work was chiefly undertaken in Denmark, where the climate is generally similar to that prevailing in southern Sweden. Furthermore, many of the Danish stands are well known with respect to their early development.

Collecting the material, the predominant part of which was obtained between 1951 and 1953 and later supplemented, the author has received invaluable assistance from Danish forest owners and foresters. To all I would like to extend my warmest thanks. The assistance given by the Danish Forest Experiment Station, the Danish National Forest Survey and The Royal College of Agriculture in Denmark in the form of information and advice is also acknowledged and sincerely appreciated. The author is also indebted to the many specialists of the Forest Research Institute and the Royal School of Forestry in Sweden, with whom I had the privilege of discussing the work plans. Special gratitude is due Dr John D. Duffield, Nisqually, Wash., and Mr Leo Isaac, Portland, Oreg. for their valuable assistance during the stay in the U.S.

The investigation was financed by grants from the Foundation for Forest Research. A grant awarded by the Swedish-American Foundation made possible the studies in U.S.A. (1950—1951), which provided a broad basis for evaluating the prospects of growing these two species in Sweden. Grants have also been received from the H. Ax:son Johnson Foundation for visits to Great Britain and Holland to study the development of various strains of Sitka spruce and Douglas fir in these countries. Germany and Norway have also been visited on the same purpose.

I. The compilation of yield tables for Douglas fir and Sitka spruce

Since the method of compilation has generally been consistent, the following account of the collection and processing of the data is common to both species to keep the presentation concise and avoid repetition.

The collection of data

a. Occasionally established plots

Only stands which have developed practically free from attacks by fungae and insects are included in the study. The sample plots have been established in pure stands with a maximum admixture of Norway spruce of 10 per cent. The size of the sample plots has only exceptionally been less than 0,25 hectare.

The shape of the sample plots has been adapted to the locality. Regarding the rectangular plots, laid out by means of a right angle prism, a difference in lenght between the parallel sides of up to 1 metre has been accepted. In the case of irregular quadrangles the diagonals have been measured and the area calculated according to the Heron formula. Distances were measured with a steel tape and readings were rounded off to nearest decimeter.

All the trees were cross calipered at breast height and the readings rounded off to nearest centimeter. Calipered trees have been clearly marked. All measurements were made in the autumn after the termination of growth, or in the early spring (cf. Tirén 1929).

Heights were measured with a controlled Blume-Leiss hypsometer on the basis of two readings per sample tree. A steel tape was used to measure the distance from the observer to the tree. The height measurements were plotted on a graph paper over the diameter and fitted graphically. The method used by Näslund (1929) to ascertain the number of sample trees required to establish an accurate height curve was combined with the standard deviation calculations initially made in various stands. Thus, it was possible on the basis of experience to determine from case to case the number of measurements required to keep the standard deviation of the mean height within $\pm 2\%$. (Cf. the procedure of estimating the requisite number of increment cores on p. 34).

Vital statistics concerning the age of the stands have been obtained from forest administration records, where information on the year of establishment as well as the age of the seedlings used is kept.

The breast height form-factor was determined whenever possible (felled trees). Simultaneously, the lenghts of the last five leaders were measured. In stands where boring was permitted cores were collected for a calculation of the basal area increment. Measurements of bark thickness were also carried out.

b. Sample plots established by forest districts

The method of examining this sample plot material has generally been similar to that applied on the occasionally established plots. Of course, the mensuration systems used on these plots have varied quite considerably, and in certain cases, e.g. regarding form-factors, minor adaptations were necessary. Concerning the character and utilization of this material, reference is made to page 33.

c. Sample plots established by the Danish Forest Experiment Station

By courtesy of the Danish Forest Experiment Station the author was allowed to study their sample plots in stands of Sitka spruce and Douglas fir. Additional information on these plots has been extracted from Opperman (1912, 1914, 1922), Fabricius (1926), Holm (1940) and Henriksen (1951). Reference is made to C. H. Bornebusch's (1946) »Oversigt over Det forstlige Forsøgsvæsens Prøveflader og Kulturforsøg» regarding the mensuration system used for these plots.

d. The Danish National Forest Survey material

Allowed access to the estimates made by the Danish National Forest Survey, the author was able to supplement his material. The methods employed when surveying the Danish state forests vary according to the character of the stand. Whereas the young stands are described only and estimated ocularly, the more advanced stands (12—20 cm mean diameter) are estimated by means of circular sample plots. Generally, it is only the stands with a diameter exceeding 30 cm (in exceptional cases 20 cm) that are completely measured by a tree tally. Naturally, the latter type of estimate provides material of great interest in this investigation. The method of gathering data from these plots is generally similar to that described in the case of occasionally established sample plots.

The total number of sample plots supporting this investigation is 187 for

Douglas fir and 119 for Sitka spruce. The sample plot material is described in the appendices 1 and 2.

The classification of Sitka spruce sites

For the purpose of site classification the height of the mean basal area tree after thinning $\left(\frac{\Sigma\, gh}{\Sigma\, g}\right)$ was shown graphically with the age as abscissa.[1] The Sitka spruce material consists of 42 plots, which have been estimated for a number of years. Single observations are of no interest in this context, and they are therefore not shown in the graph. Neither are the sample plots included, where the lengths of the last five leaders were measured, since the data were considered comprehensive enough without adding this extra information.

If the site class curves for Norway spruce in Denmark (Möller 1933) are superimposed on this material, it is obvious that the curves do not coincide with the material contained in the present work, in that Norway spruce does not reach the height of Sitka spruce. In addition, the height of Norway spruce describes a rather more level course. For this reason the possibility of using Norway spruce height curves as an aid in establishing site class curves for Sitka spruce is precluded.

Although the sample plot material was rich, a numerical computation of the heights according to the method of least squares was considered unsuitable because of uneven representation in the various age classes (fig. 3). It was therefore judged more advantageous to define the curves by means of a suitable and manageable function. Apart from describing the material faithfully, the function should be adjustable to all the curves without a change of a number of constants.

Generally, the height curves and the majority of growth curves reach a turning point which corresponds to a culmination of the growth, subsequently to approach a finite maximum value (fig. 2). The normal frequency funktion, $\Phi\,(x)$, where

$$\Phi\,(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{t^2}{2}}\, dt,$$

[1] The upper height (Petterson 1927) is undoubtely a more situable index for site classification than the height of the mean basal area tree, since it is less affected by variations in the stand treatment than the mean height (Wiedemann 1939). As far as occasionally established plots are concerned, there would be no difficulty in calculating the upper height. On the other hand, this is not always the case with the old data obtained from other sources. Moreover, since the object of this study is the comparison of the growth of Sitka spruce with that of Norway spruce (Möller 1933) the site classification must be made the common system on the height of the mean basal area tree in this investigation.

Fig. 1. Sitka spruce stand at Gisselfeld, (plot. No. 2 in the list).
Site class II. After thinning at 54 years, height 29.1 m, diameter 41.1 cm, number of trees per hectare 383 and basal area 52.5 m². The lesser vegetation consisted of raspberry (Rubus ideaus), dog's mercury (Mercurialis perennis) and nettles (Urtica dioica). The soil is a loamy-sandy morain. The stand has been described by S. Kindt (1935 and 1956).

graphically describes such a course and it is also easy to handle. The following equation has been designed on the basis of this function:

$$h = A\ \Phi \left(\frac{{}^{10}\log\ t - m}{\sigma} \right)$$

where h = the height in metres.
A = maximum height at finite age.
t = age in years.
m = ${}^{10}\log$ for the age at half the height.
σ = standard deviation.

The factors m and σ were here determined graphically. For this purpose four curves, covering the material, were drawn freehand. An examination showed that the best agreement between these curves and that of the function, was obtained when it was assumed that half the height (A/2) was reached at 50 years. On this assumption m becomes a constant equal to ${}^{10}\log$ 50, i.e. 1,6990. All that remained was to determine the value of σ, after which

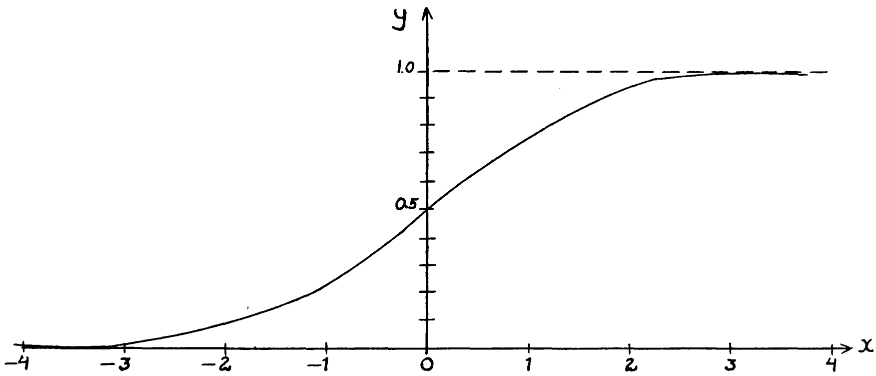

Fig. 2. The normal frequency function Φ (x) in graphical presentation.

the other values could easily be obtained from the normal frequency tables (Pearson 1948, Cramér 1949, Matérn 1955).

For this reason t^1 was taken from the hand-drawn curves as representing the age when the height h_{t^1} is 31,27 % of the height at 50 years $\left(\frac{\Phi(-1)}{\Phi(0)} = 0.3173\right)$. According to the definition σ can be obtained from the equation: $\sigma = {}^{10}\log 50 - {}^{10}\log t^1$.

When σ was calculated for the hand-drawn curves, it was found (Table 1) that there was a linear relationship between σ and A, and that in this case $\sigma = 0.21 + 0.0033$ A.

Accordingly, if h_{50} is the height at 50 years and h_t the height at t years, the following equation is obtained for the Sitka spruce material:

$$h_t = 2\,h_{50}\;\Phi\left(\frac{{}^{10}\log t - 1.6990}{0.21 + 0.0066\,h_{50}}\right)$$

Table 1. Example of the calculation of σ.

A metres	$\frac{A}{2}$ metres	m	h_{t^1} metres	t^1 years	log t^1	σ
63	31.5	1.70	10.0	19.0	1.28	0.42
54	27	1.70	8.56	20.4	1.31	0.39
45	22.5	1.70	7.14	22.0	1.34	0.36
39	19.5	1.70	6.16	23.3	1.37	0.33

The method of calculating the curves, i.e. the relationship between age and height for different A and σ by means of the normal frequency tables already referred to (the first two columns of Table 2) is shown in the following example, where A = 54 and σ consequently = 0.39.

Table 2. Example of the method of calculating the relationship between age in years (t) and height in metres (h) when A = 54 and σ = 0.39. In the case of negative x-values, Φ (—x) = 1 — Φ (x) applies.

$x = \frac{^{10}\log t - m}{\sigma}$	Φ (x)	$^{10}\log t = (m + \sigma x)$	t (years)	h (metres) A Φ (x)
—0.4	0.3446	1.543	34.9	18.6
0	0.5000	1.699	50.0	27.0
0.3	0.6179	1.816	65.5	33.4

Thus, having established the relationship between age and height for different curves, we have arrived at the site classification. An examination shows that the material can suitably be differentiated into four site classes. This classification has been made for a stand age of 50 years, and the site classes for Sitka spruce have been defined in Table 3.

The height at a stand age of 50 years has been chosen as site index partly because the stands have then stabilized themselves, and partly because Möller (1933) used the same index for Norway spruce with which these species are intended to be compared.

Table 3. Definition of the four site classes for Sitka spruce.

Site Class I	The stands have reached or are assumed to reach a mean height of 30 metres (28½—31½) at 50 years.
Site Class II	The stands have reached or are assumed to reach a mean height of 27 metres (25½—28½) at 50 years.
Site Class III	The stands have reached or are assumed to reach a mean height of 24 metres (22½—25½) at 50 years.
Site Class IV	The stands have reached or are assumed to reach a mean height of 21 metres (19½—22½) at 50 years.

The site class curves and the mean height development of the material are shown in Fig. 3. Single observations are of minor interest in this context and they are therefore not shown in the diagram. The figure illustrates the very good agreement between the curves and the original field material. This agreement is so good that practically none of the individual stand curves deviates from its mean site class.[1]

The way in which the material is segregated into quality classes can be seen from table 4. Sitka spruce, Site Class IV has a height at 50 years equelling that of Norway spruce, Site Class II in Möller's tables (1933), and Sitka spruce in Site Class III, has a height equalling that of Norway spruce

[1] Sample plot GU at the Danish Forest Experiment Station, has been excluded because of an abnormally long period of stagnation. Furthermore, 7 of the original 126 sample plots were omitted because of severe root-rot (Fomes annosus).

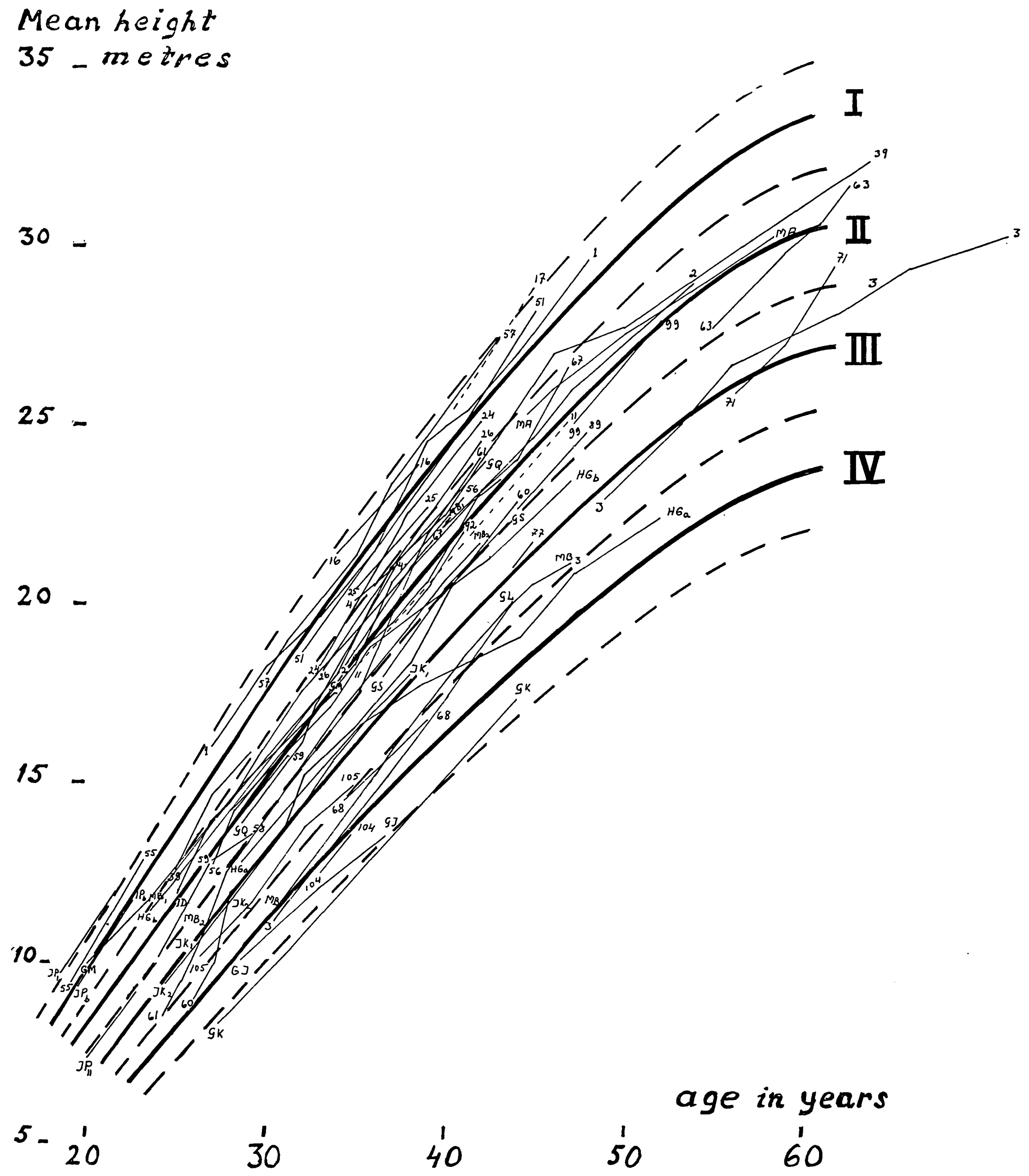

Fig. 3. Relationship between age and the mean height of the stand for the Sitka spruce material and according to the four site class tables. The dashed lines indicate the limits between adjacent site classes.

Table 4. The distribution of the Sitka spruce sample plots by site classes.

Site Class I Sample plot Nos.	Site Class II Sample plot Nos.	Site Class III Sample plot Nos.	Site Class IV Sample plot Nos.
1, 6, 7, 10, 12, 13, 14, 16, 17, 19, 21, 22, 23, 24, 25, 26, 27, 30, 32, 34, 35, 36, 38, 39, 40, 44, 46, 48, 49, 51, 53, 55, 57, 62, 73, 82, 83, 84, 90, 94, 95, 96, 97, 101, 102, IP_6, IP_7, IP_{10}	2, 4, 8, 9, 11, 15, 28, 29, 37, 41, 42, 45, 50, 52, 54, 56, 58, 59, 61, 63, 65, 66, 67, 74, 79, 81, 89, 92, 98, 99, 100, GM, MA, GQ, GS, HG_6, ID, MB_1, MB_2	3, 31, 33, 60, 64, 71, 77, 80, 87, 91, 93, 105, IP, HG_A, IK, IK_2	68, 69, 70, 72, 75, 76, 78, 85, 86, 88, 104, 106, 107, GJ, GK, GL, MB_3
48 plots	38 plots	16 plots	17 plots

in Site Class I. Since it was desirable to retain this division for the comparison between Sitka spruce and Norway spruce, an asymmetrical division of the material has been obtained. This is of no significance, howewer, because the material is not intended for and should not be used for calculating the mean height development, mean yield etc. of Sitka spruce.

The classification of Douglas fir sites

The method of classifying Douglas fir sites was the same as that used for Sitka spruce. The material consists of forty-five plots which have been estimated for several years. Even though it was clear from the outset that the height curves showed rather good agreement with those obtained from previous growth investigations (Mc Ardle 1930, Wiedemann 1949, Hummel and Christie 1953), there was no reason to depart from the method of constructing curves used here by means of the normal frequency distribution tables already described.

It was seen here, as was also the case with Sitka spruce, that the best agreement between the curves and the material was obtained when it was assumed that half the height (A/2) is reached at 50 years. Even σ was calculated in the same way as that used for Sitka spruce. For Douglas fir there was a linear relationship $\sigma = 0.24 + 0.0044$ A, which produced the following equation:

$$h_t = 2h_{50}\,\Phi\left(\frac{{}^{10}\log t - 1.6990}{0.24 + 0.0088\ h_{50}}\right)$$

In the same way as before, the values for age (t) and corresponding height (h) for the desired curves could subsequently be obtained from the normal frequency tables.

Fig. 4. Douglas fir stand at Petersvaerft (plot No. 25 in the list). Site Class II. After thinning at 37 years, height 23.9 metres, diameter 32.0 centimetres, number of trees per hectare 370, and basal area 29.9 square metres.

An examination of the Douglas fir material showed that even in this case a differentiation into four site classes would be most suitable. In this case, too, the height at 50 years was used as the basis of classification, and the site classes have been defined in Table 5. For the same reasons as those presented in the case of Sitka spruce (page 9), the mean height of the stand after thinning, was shown graphically with the age (Fig. 5).

As can be seen from Fig. 5, the agreement between the height curves of

Table 5. Definition of the four site classes for Douglas fir.

Site Class I	The stands have reached or are assumed to reach a mean height of 32 metres (30½—33½) at 50 years.
Site Class II	The stands have reached or are assumed to reach a mean height of 29 metres (27½—30½) at 50 years.
Site Class III	The stands have reached or are assumed to reach a mean height of 26 metres (24½—27½) at 50 years.
Site Class IV	The stands have reached or are assumed to reach a mean height of 23 metres (21½—24½) at 50 years.

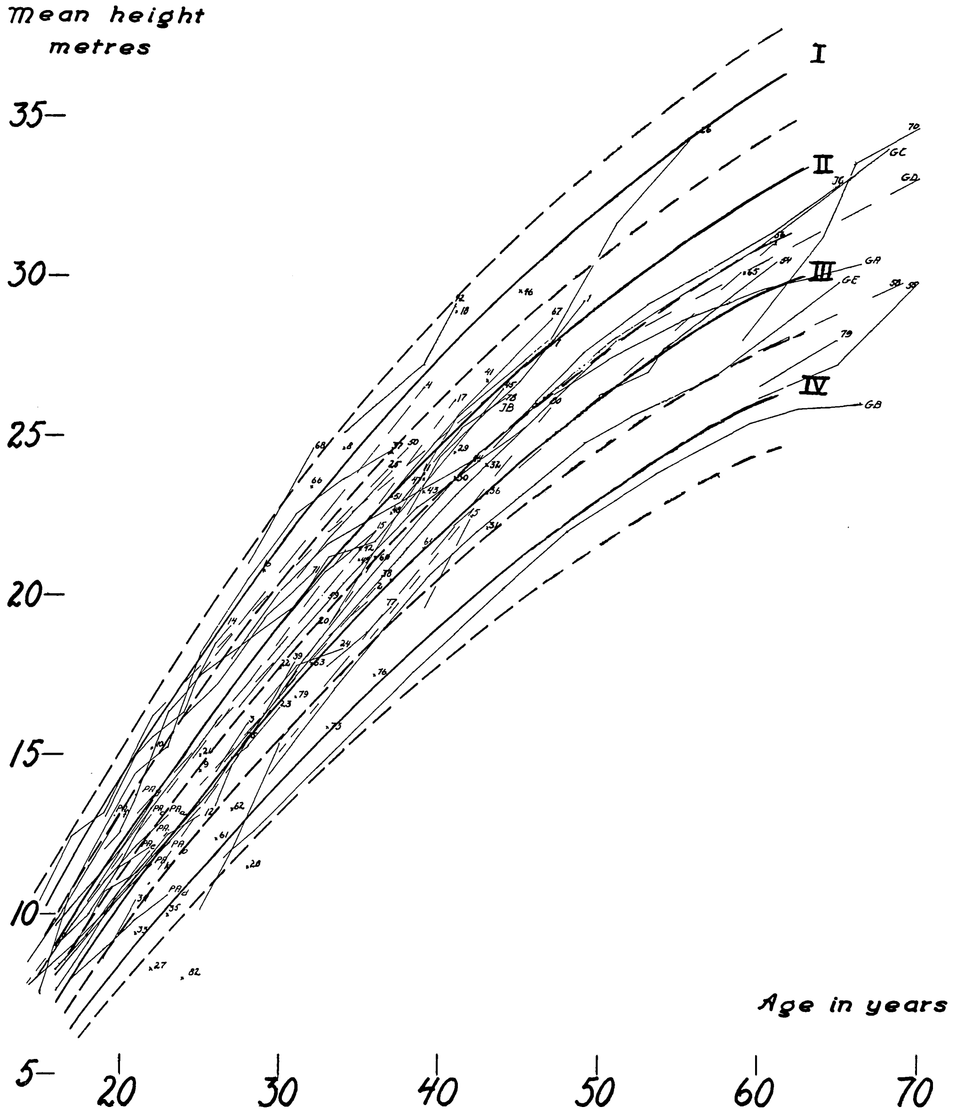

Fig. 5. Relationship between age and the mean height of the stand for the Douglas fir material and according to the four site tables. The dashed lines indicate the limits between adjacent site classes.

the material and the constructed site class curves is extremely good as in the case of the Sitka spruce material. Only a few cases deviate from their mean site class. The distribution of the material by site classes is shown in Table 6.

Table 6. The distribution of the Douglas fir sample plots by site classes.

Site Class I Sample plot Nos.	Site Class II Sample plot Nos.	Site Class III Sample plot Nos.	Site Class IV Sample plot Nos.
4, 8, 14, 16, 18, 26, 37, 46, 66, 68, 72, 92, 114, 144, 146, 149, 151, 156, 162	1,7, 11,15,17, 21, 25, 29, 30, 41, 42, 43, 44, 45, 47, 48, 49, 50, 51, 59, 60, 67, 69, 71, 78, 83, 85, 88, 93, 94, 97, 99, 100, 104, 106, 107, 136, 142, 148, 154, 158, 159, 164, IB, IC, P-Aa, PA-c, PA-f, PL-g, PA-i, PA-o	2, 3, 5, 6, 9, 10, 12, 13, 19, 20, 22, 23, 24, 31, 32, 34, 36, 38, 39, 40, 54, 56, 63, 64, 65, 70, 74, 75, 77, 80, 81, 84, 86, 87, 89, 90, 95, 96, 98, 102, 103, 116, 123, 133, 137, 138, 141, 143, 145, 146, 147, 153, 156, 161, 163, 165, GA, GC, GE, PA-6, PA-e, PA-h, PA-k, PA-m, GD	27, 28, 33, 35, 52, 53, 55, 58, 61, 62, 73, 76, 79, 82, 91, 101, 105, 108, 110, 111, 112, 115, 118, 120, 121, 122, 124, 125, 126, 127, 128, 129, 131, 132, 134, 139, 140, 150, 152, 155, 157, 160, 109, 113, 117, 119, 130, 135, 166, 167
19 plots	51 plots	65 plots	52 plots

It is of course possible that individual stands, which have been estimated once only, may have failed to follow the normal height development. Growing out of one site class into another, they consequently show untrue qualities. However, this possibility is negligible since the agreement between long observed development courses and the site class curves is very good. On the other hand, the possibility cannot be altogether ruled out that the old stands, which have been estimated once only, may differ from the young stands with respect to treatment and development (Petrini 1948). The use of a sufficient number of sample plots with long-term observations will reduce the possibility of such discrepancies. In cases with great deviations from the outlined mean development, it has usually been possible to explain these deviations (See page 38).

Yield tables

The material was further treated by graphic fitting of a number of observations, as this method was considered more suitable for heterogeneous material than numerical calculation.[1] One of the obvious advantages of graphic treatment in this case was the opportunity of following each individual observation all the time. Naturally, the absence of mathematical formulae and tables, which the graphic method entails, need not mean that

[1] To obtain as comprehensive data as possible it has been necessary, inter alia, to utilize all the old material, which can be regarded as reliable (page 33). In this way the material has become slightly heterogeneous. It therefore consists both of plots which have been the subject of long-term estimations (e.g. the sample plots established by the Danish Forest Experiment Station), and plots, which have been estimated once only. Further, the material includes data from occasional plots which have been the subject of increment and form-factor investigations.

it is less accurate. Various kinds of graphic treatments have previously been used by i.a. Wiedemann (1931 and 1936), Möller (1933), and Schober (1949). Further, Hummel and Christie (1953) in their yield tables for Great Britain utilized this method common to all quality classes after plotting the total yield over height. This procedure, however, presupposes that a sufficient number of sample plots are observed from an early age.

The observations, which have been the subject of graphic treatment in this investigation and which will later be discussed, are:

A. Relationship between the number of trees per hectare and age for various site classes[1] (page 20)
B. Relationship between the mean basal area diameter and age for various site classes (page 23)
C. Relationship between basal area per hectare and age for various site classes (page 24)
D. Relationship between form-height and height, common to all site classes (page 26)
E. Relationship between volume per hectare and age for various site classes (page 28)
F. Relationship between the mean diameter of the trees removed in thinning and the mean diameter of the remaining stand for all site classes (page 31)
G. Relationship between the mean height of the trees removed in thinning and the mean height of the remaining stand for all site classes (page 31)
H. Current annual basal area increment for various site classes obtained partly from increment cores and partly from the sample plots with continuous measurements (page 32)
I. Current annual volume increment for various site classes (page 39)
J. Total yield (page 40)

It has been mentioned that different types of data have been used in the compilations. The calculations, however, have been concentrated on the basal area, since this is a directly measurable and essential quantity. To avoid to the greatest possible extent all subjective factors in the establishment of the basal area curves, the latter also have been constructed by fitting graphically the product of the curve values representing the number

[1] The factors presented below may be employed when converting these figures and tables from the diameter system, true measure with metric units to the quarter-girth system with British units of measurements.
Number of trees per hectare × 0.4047 = number of trees per acre.
Diameter in centimetres × 0.3092 = diameter in inches quarter-girth.
Square metres per hectare × 3.421 = square feet quarter-girth per acre.
Cubic metres per hectare × 11.22 = cubic feet quarter-girth per acre.
Metres × 3.2808 = feet.

Table 7. Part of the complete yield table (Sitka spruce Site class II) presented to show the procedure of calculation. When the curves are correctly drawn, the table must tally in all columns.

Stand remaining after thinning							Trees removed in thinning						Increment				
Age, years	Height, metres	Diameter, cm.	Number of trees per hectare	Basal area, m²/hectare	Form-height, metres	Volume, m³/hectare	Number of trees per hectare	Diameter, cm	Basal area m²/hectare	Form-height, metres	Height, metres	Volume m³/hectare	Annual basal area increment, m²/hectare	Basal area increment, per cent	Annual volume increment, m³ hectare	Volume increment, per cent	Total yield m³/hectare
34	18.0	22.4	857	33.7	9.4	316	144	18.4	3.9	8.7	16.4	34	2.11	6.1	29.2	8.8	587
36	19.3	24.3	736	34.1	9.9	339	121	20.1	3.8	9,3	17.8	35	2.00	5.7	28.7	8.1	595
38	20.5	26.2	639	34.4	10.5	360	97	21.9	3.7	9.8	18.9	36	1.90	5.4	28.4	7.6	652
40	21.6	28.1	558	34.6	11.0	380	81	23.8	3.6	10.2	19.9	37	1.78	4.7	27.4	6.9	709

of trees and their mean basal area. Further processing is obtained by fitting graphically the quotient of the curve values representing mean volume and form-height.

For the construction of that part of the site class table, which shows »the stand remaining after thinning» (see Table 7), there remains in addition to the data accounted for on page 18, only data pertaining to the thinning interval for various ages and site classes. This data could be extracted from the sample plot material. Regarding the lowest site classes, it has been necessary, however, to deviate slightly from the material, which has resulted in a shorter thinning interval than that actually applied. This was intended to improve the possibilities of making comparisons between the quality classes.

In the section of the tables showing »trees removed in thinning» (see Table 7), the number of trees removed has been obtained as a difference from the curve for the number of trees (Figs. 6 and 7). The basal area of the trees removed in thinning has been obtained as a product of this number of trees and their mean basal area. This in turn was obtained from the relationship between the mean diameter of the remaining stand and the mean diameter of the trees removed, shown graphically in Figs. 16 and 17. As previously explained, the volume of the trees removed in thinning is the volume of the whole trunks from ground to tip of tree, and it is finally a product of this basal area and the form-height corresponding to the height of the trees removed in thinning (Figs. 18 and 19). On account of the table control (agreement in all columns), this method is principally not different from calculating the volume of trees removed in thinning by means of the basal area data and the common series for basal area increment (page 32). Thus the table stand is allowed to grow until the next thinning and the basal area of removed trees is then formed as a difference between the basal area value just obtained and the value after thinning derived from the basal area curve.

The basal area of the »stand remaining after thinning» and the basal area of the »trees removed in thinning» at the same age, together constitute the basal area before thinning. The same naturally applies to the volume. »Current annual increment» in Table 7 has therefore been obtained as the difference between the stand before thinning (K_2) and the stand after thinning at the previous thinning (K_1) divided by the thinning interval

$$\frac{(K_2—K_1).}{n}$$

These increment figures have, however, as explained on page 18, been the subject of control in that current basal area increment was calculated by means of a graphic fitting of increment data derived directly from the material (page 32).

The method used in the construction of the yield tables enables a many-sided and continuous control of the columns by means of the various procedures used in calculating the values. Some minor adjustments have naturally been necessary so that the calculations would agree in every respect. These adjustments, however, have not been large enough to necessitate any alterations in the curves originally constructed. As an example of the accuracy of the agreement it may be mentioned that one removed tree more or less, higher up in the ages, not only results in a considerable deviation from the increment curve, but also discrepancies in the basal area and volume.

A. The number of trees per hectare

The number of trees for the entire material has been plotted over age grouped into site classes and fitted graphically. Age refers to that reached at the time of thinning. The curves of the number of trees for the two species are shown in Figs. 6 and 7. Since the ordinate axis has been divided logarithmically for practical reasons, the curves representing the number of trees do not follow the typical hyperbolic course.

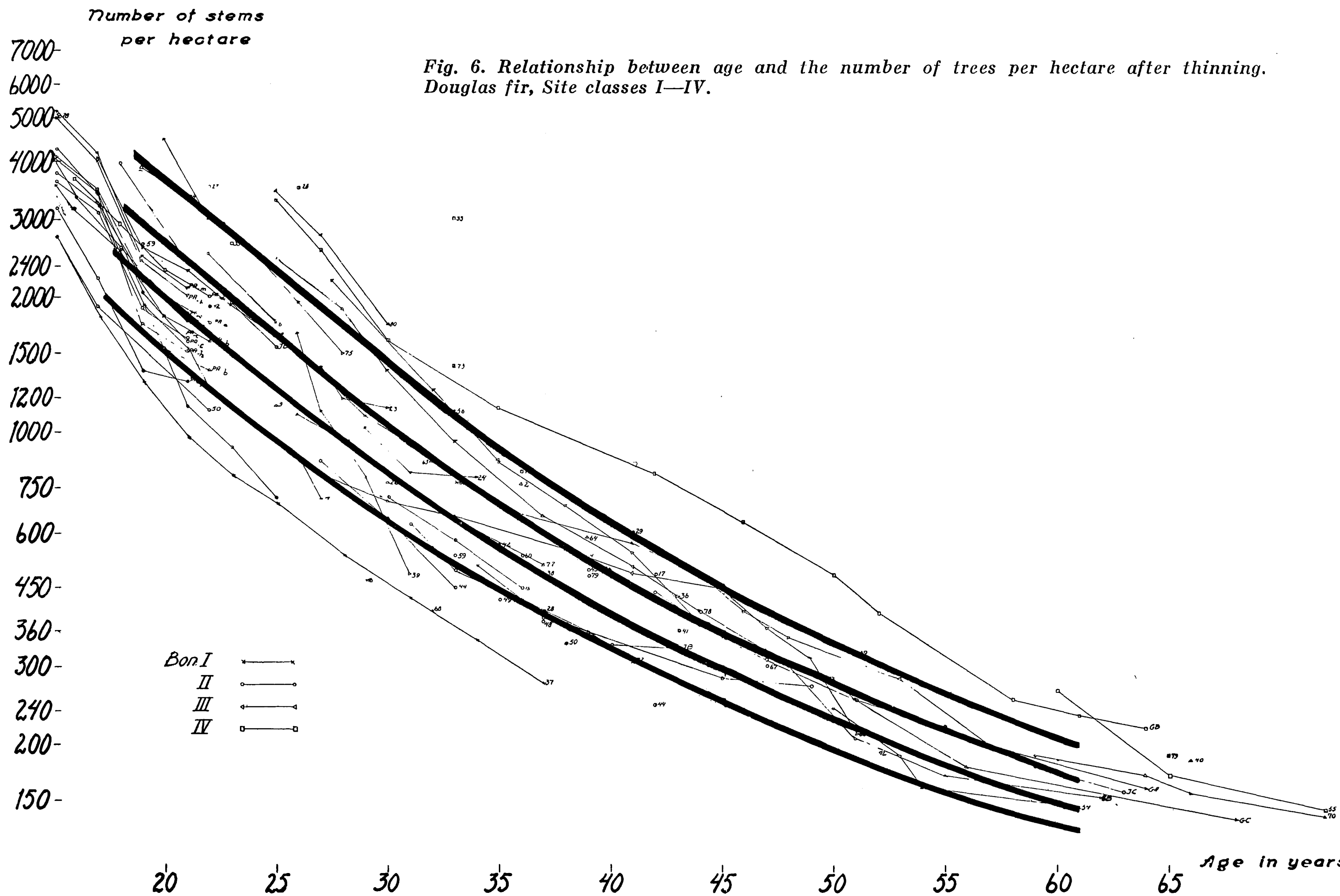

Fig. 6. Relationship between age and the number of trees per hectare after thinning. Douglas fir, Site classes I—IV.

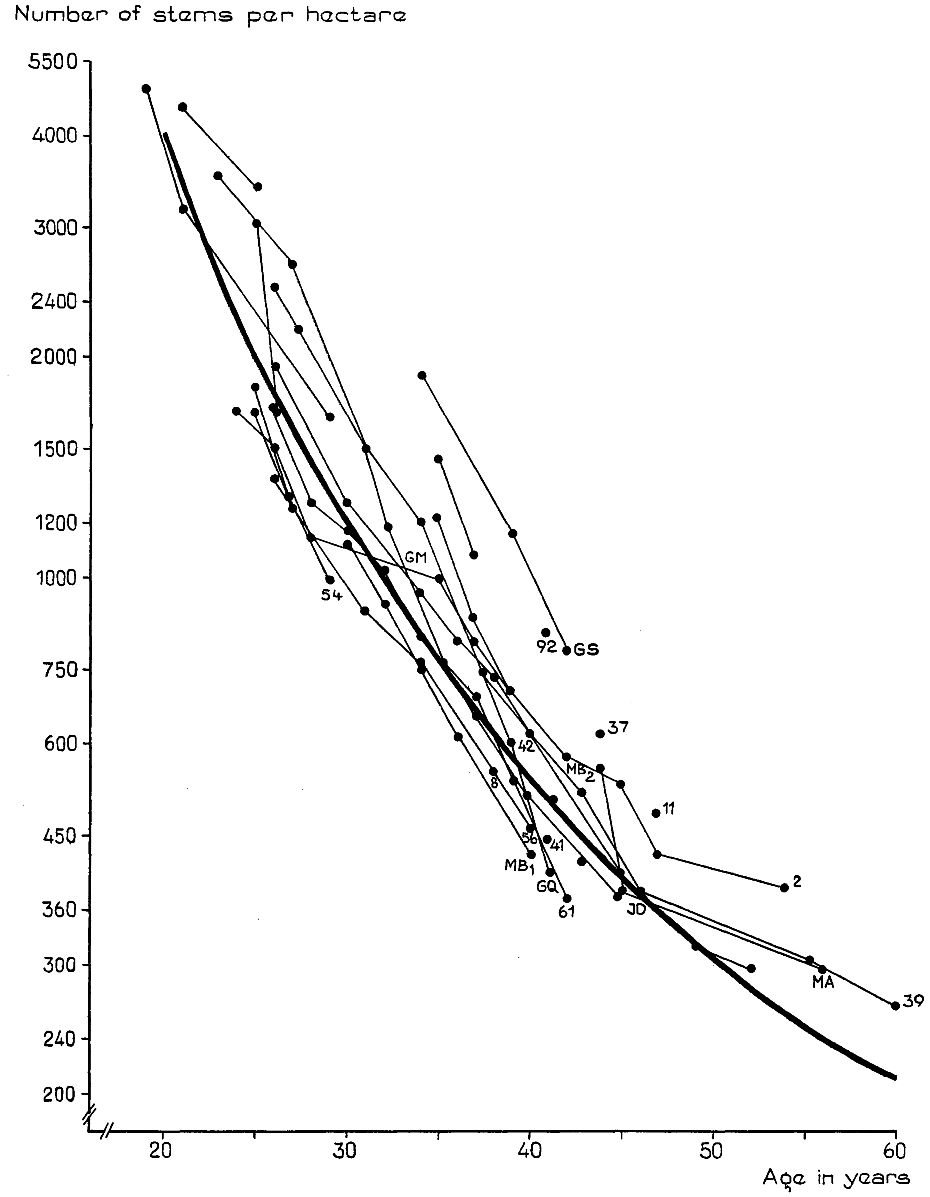

Fig. 7. Relationship between age and the number of trees per hectare after thinning. Sitka spruce. Site class II.

B. The mean basal area diameter

Plotted over age for each site class, the diameter shown in Figs. 8 and 9 is the diameter corresponding to the mean basal area of the trees remaining after thinning. As in the drawing of other curves, the different site class curves have guided each other. The entire material has been utilized in the construction of these curves.

The figures show, that the curves almost follow the straight line. This is usually the case of young cultivated stands, which have been treated with continuous thinning. This implies that the current false diameter increment should be almost constant. As shown later on, this is actually the case.

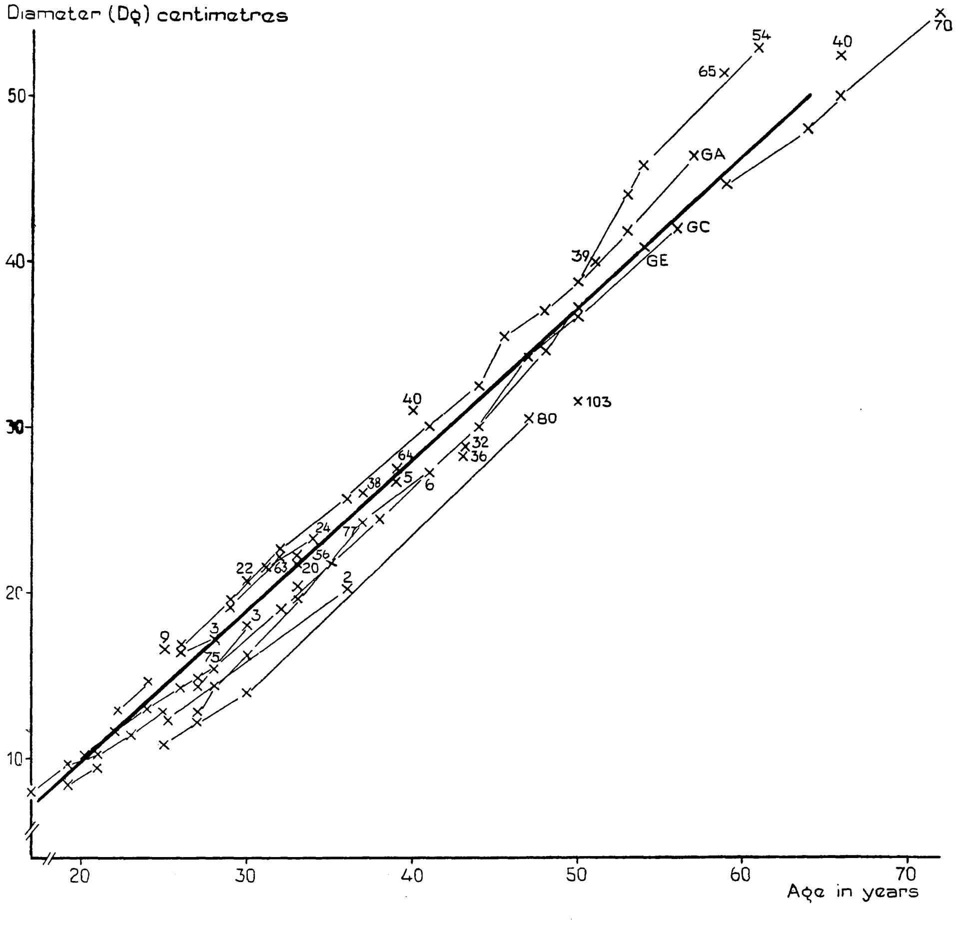

Fig. 8. Relationship between the mean basal area diameter after thinning and age. Douglas fir. Site class III.

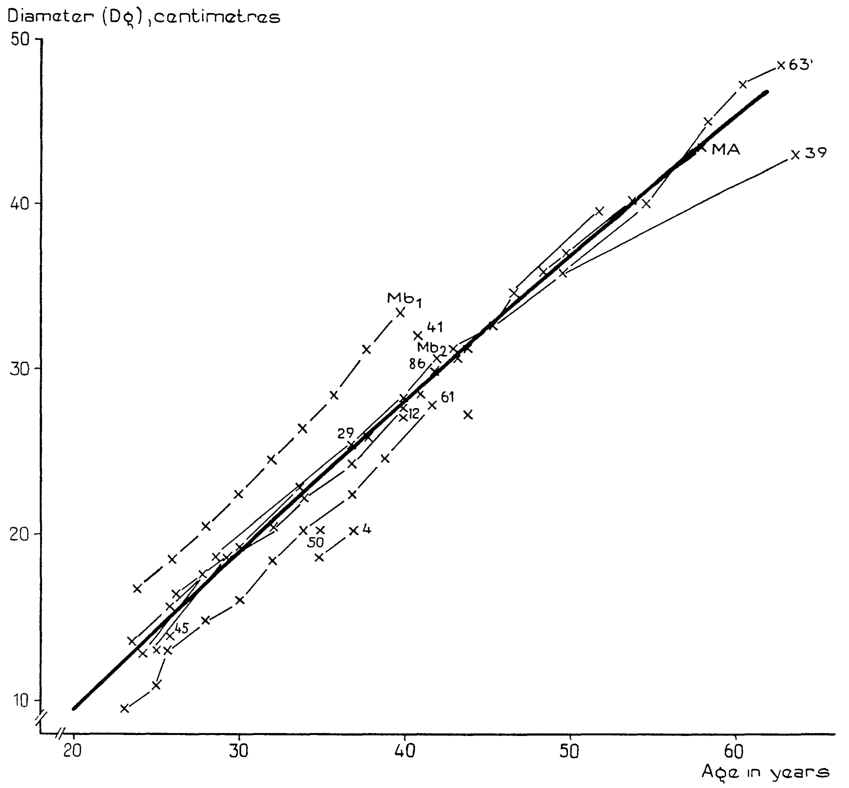

Fig. 9. Relationship between the mean basal area diameter after thinning and age. Sitka spruce. Site class II.

C. Basal area per hectare

In the construction of the basal area curves it has been possible to utilize the entire material. Figs. 10 and 11 show that the dispersion within the various site classes is considerable. This should be rather normal when the basal area is placed in relation to age.

A fitting on the basis of these basal area data could therefore easily be subjective, even though the site class curves are capable of supporting each other in the customary way.

Since, however, curves for the mean basal area diameter and the number of trees per hectare have already been constructed, and the dispersion around them is less than that affecting the basal area per hectare, the product of the values of the mean basal area and the number of trees has been used to support the construction of the basal area curves of the stand.

The curves obtained agree very well with the material, even though the dispersion of individual site classes may be rather pronounced. Showing

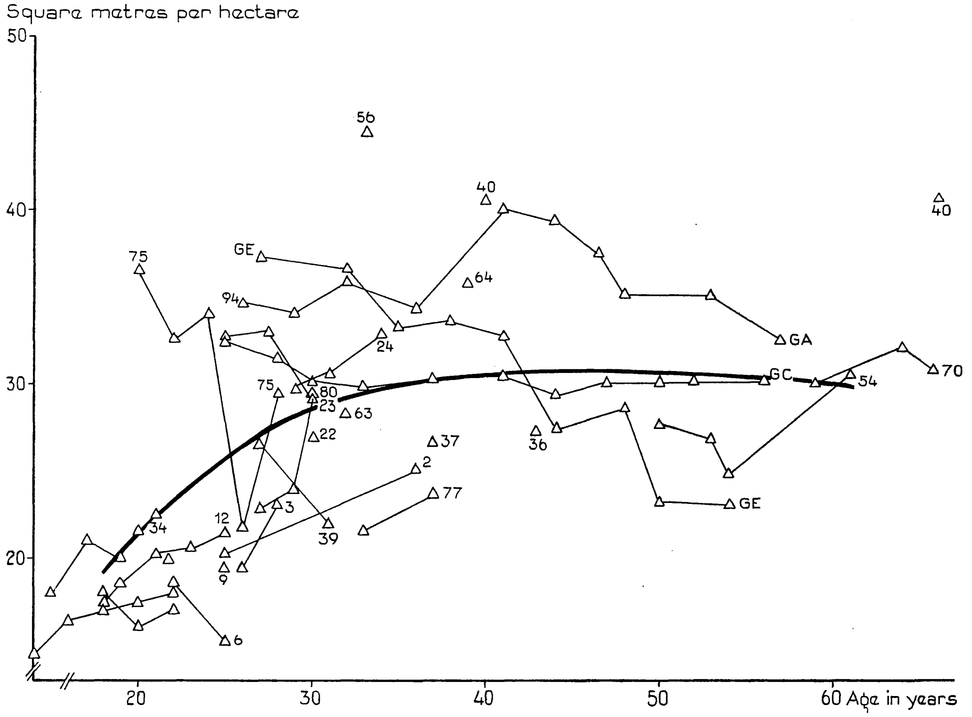

Fig. 10. Relationship between the basal area per hectare after thinning and age. Douglas fir. Site class III.

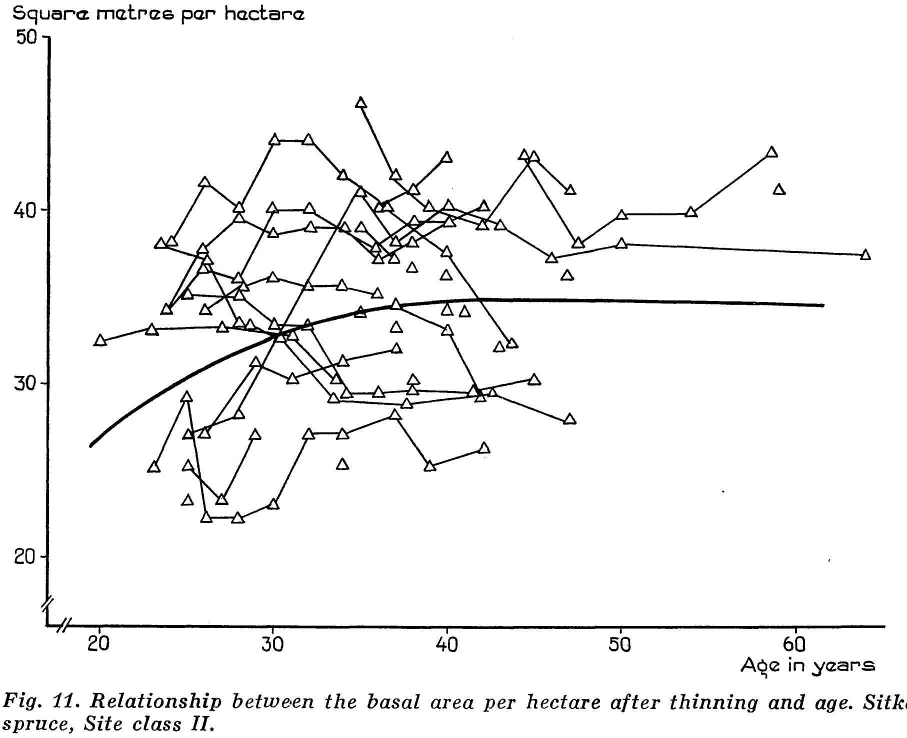

Fig. 11. Relationship between the basal area per hectare after thinning and age. Sitka spruce, Site class II.

lower values throughout for the inferior site classes, the basal area curves for both Sitka spruce and Douglas fir, however, displayed good agreement mutually. After the sharp rise of the basal area curves in the young ages, Douglas fir, especially for this grade of thinning, shows a tendency towards a constant or even diminishing basal area at increasing age. This is illustrated in fig. 10.

D. Form—height

A determination of volume requires an expression for the form. This was obtained by plotting form-height over mean height common to all site classes. Figures 12 and 13 for Douglas fir and Sitka spruce show that the dispersion round the mean curve is slight.

This was also experienced by Petrini (1938 and 1942), who in the compilation of tables for beech and oak used a rectilinear function as an expression of the relationship between form-height and height.

Form-height is here calculated as a product of the breast height form-factor and height. The form-factor material gathered in conjunction with the sample plot investigations, include 286 trees on 18 plots in Douglas fir, and, 162 trees on 17 plots in Sitka spruce. Since this form factor material could not be considered sufficient, supplementation was necessary. This was made possible by courtesy of the Danish Forest Experiment Station, which allowed access to their extensive material.

In the selection of sample trees carried out in conjunction with the form-

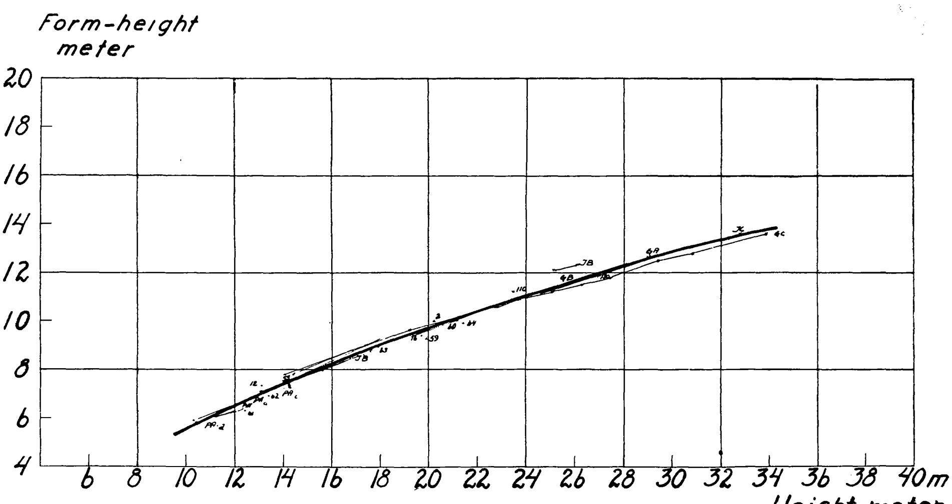

Fig. 12. Relationship between form-height and height. Douglas fir all site classes.

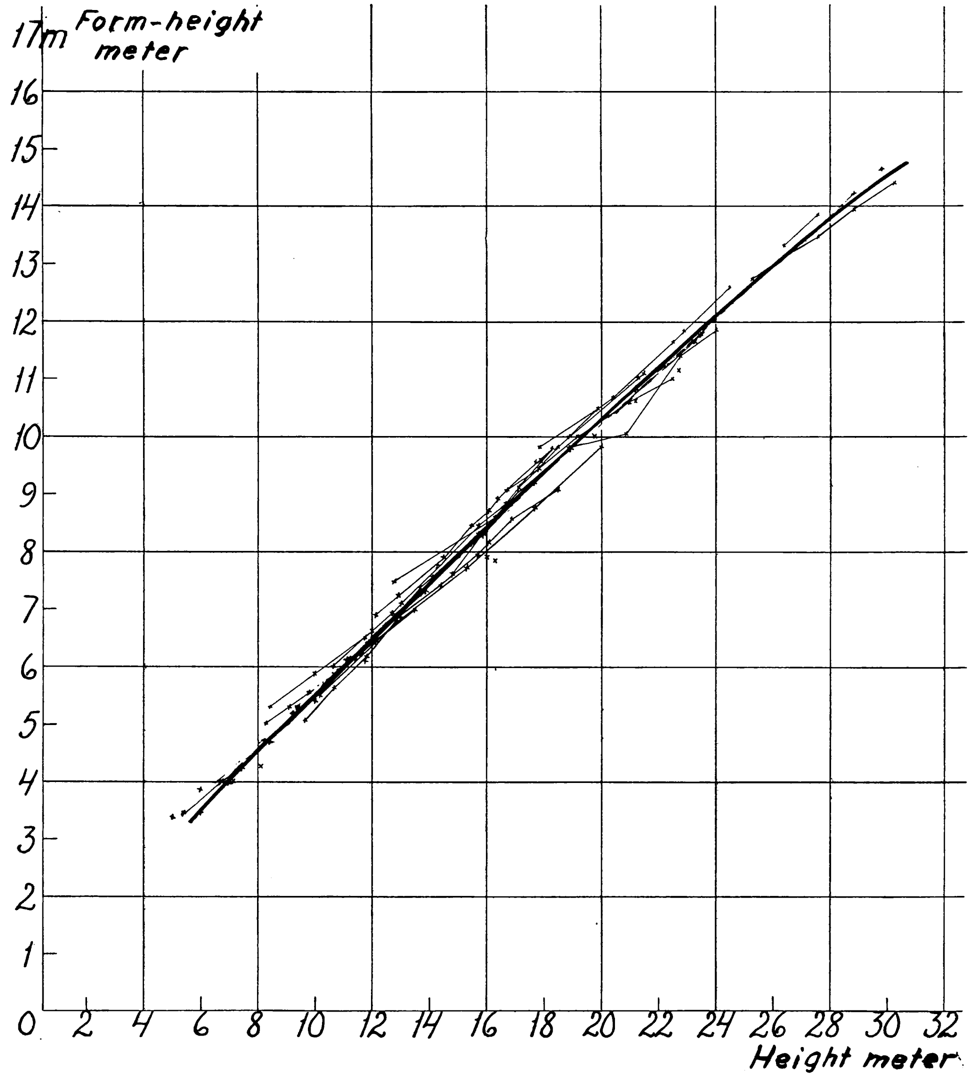

Fig. 13. Relationship between form-height and height. Sitka spruce all site classes.

factor investigation, only such trees the height of which was within 10 % of the mean height of the diameter class (Näslund 1936) were accepted. The trees were cross calipered and the measurements were recorded in millimetres. Bark thickness and the length of the last five leaders were also measured. Sectional volume determination of sufficient accuracy (Petrini 1928), was obtained by keeping the number of sections to 12 throughout, 10 of which above breast height.

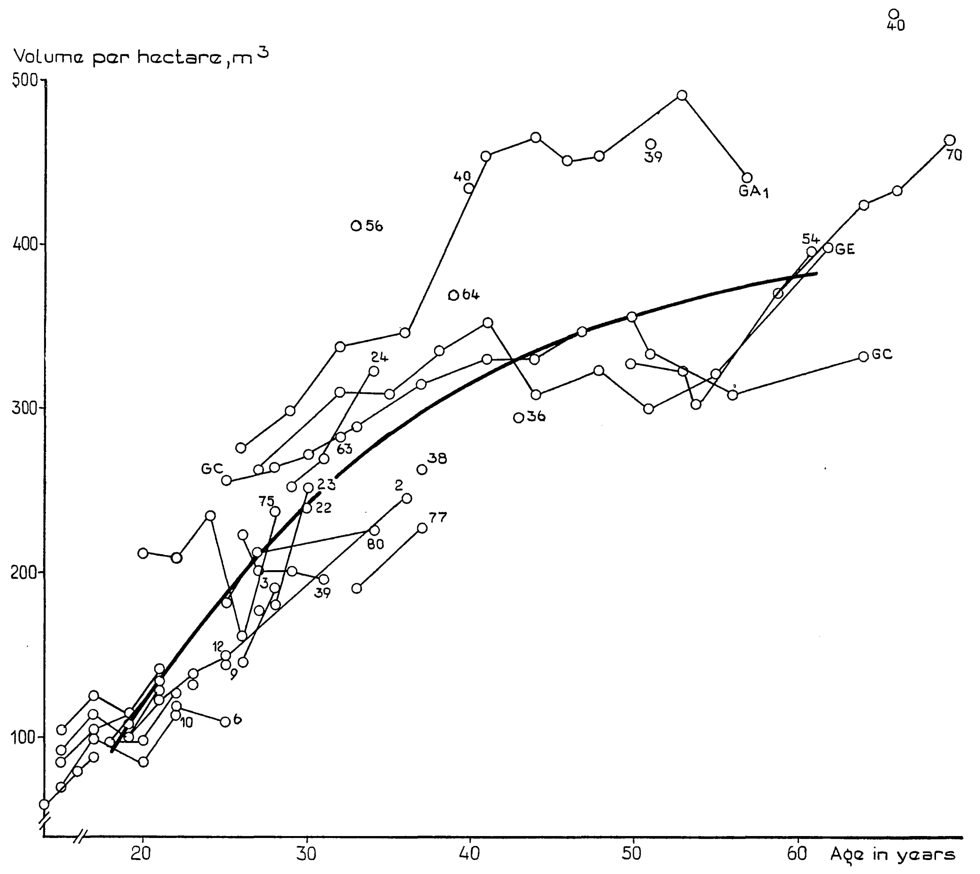

Fig. 14. Relationship between volume per hectare after thinning and age. Douglas fir. Site class III.

E. Volume per hectare

Values obtained from the material regarding the volume of the stand at various ages after thinning have been plotted over age for each site class and fitted graphically by the same method as that used for the basal area. Thus, the volume has been calculated according to the formula $M = G \times H \times F$, where $H \times F = C$ (the form-height of the mean basal area tree). The form-height values have mostly been obtained from the form-factor calculations for the plot, but in other cases from the form-height curve. (Figs. 12 and 13). Instead of calculating the volume in each diameter class, which is most common in Sweden, the calculation was based on the mean basal area tree. This method has previously always been utilized for the old sample plot material. Although volume determination by diameter classes provides more accurate results, there is no reason to suppose that the method

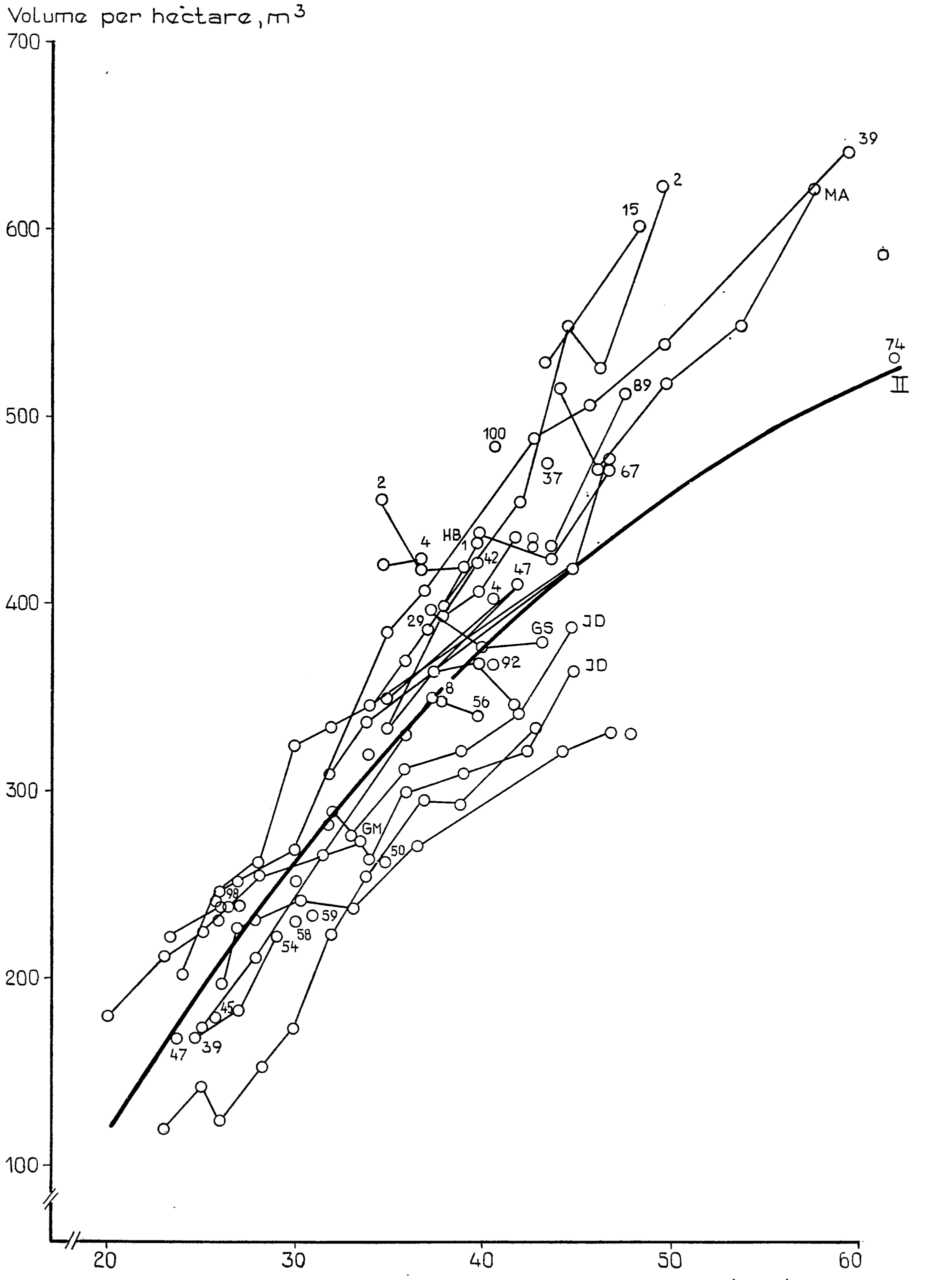

Fig. 15. Relationship between volume per hectare after thinning and age. Sitka spruce. Site class II.

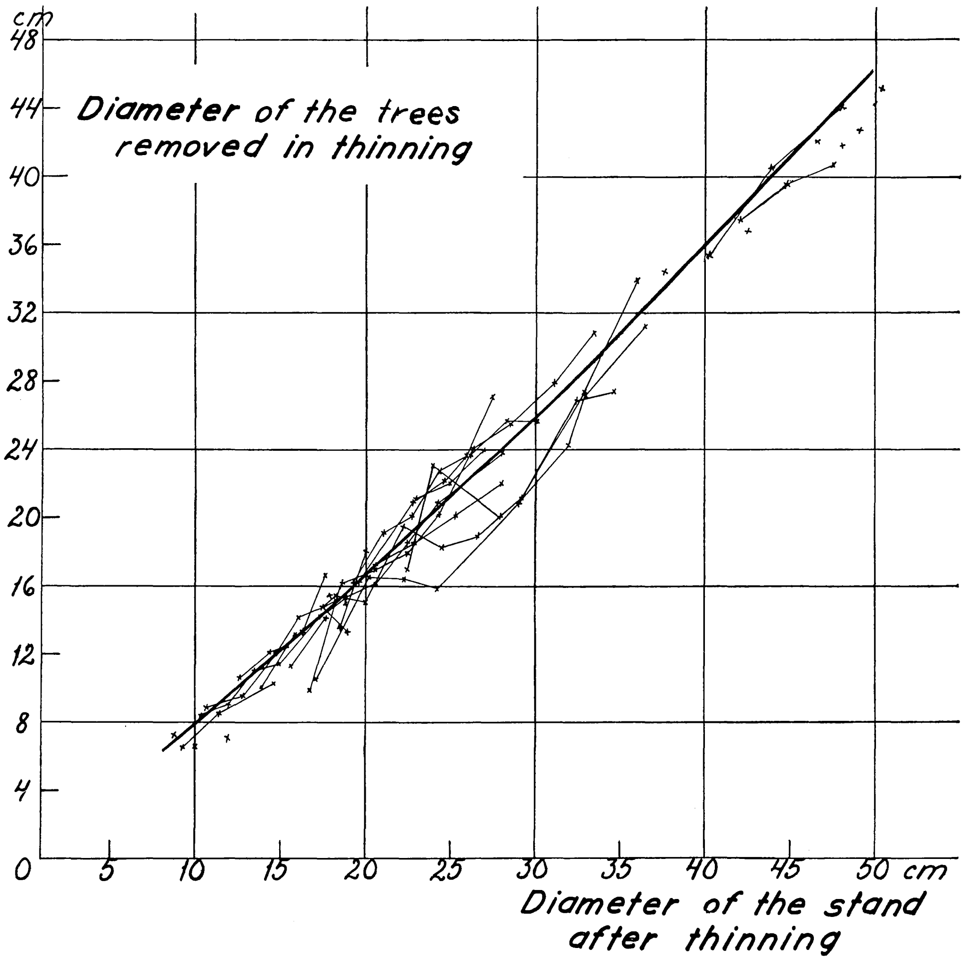

Fig. 16. Relationship between the mean diameter of the trees removed in thinning and the mean diameter of the stand after thinning. Douglas fir, all site classes.

employed here will give rise to any considerable error (Henriksen 1951). Möller (1951) too, stated that there is no reason to assume a greater standard deviation than about 1 % in even-aged coniferous stands treated with normal thinning.

The accuracy of these curves has then been checked by calculating the volume by means of fitted values for basal area per hectare and form-height. Examples of the drawing of volume curves and the dispersion around them are presented in Figs. 14 and 15.

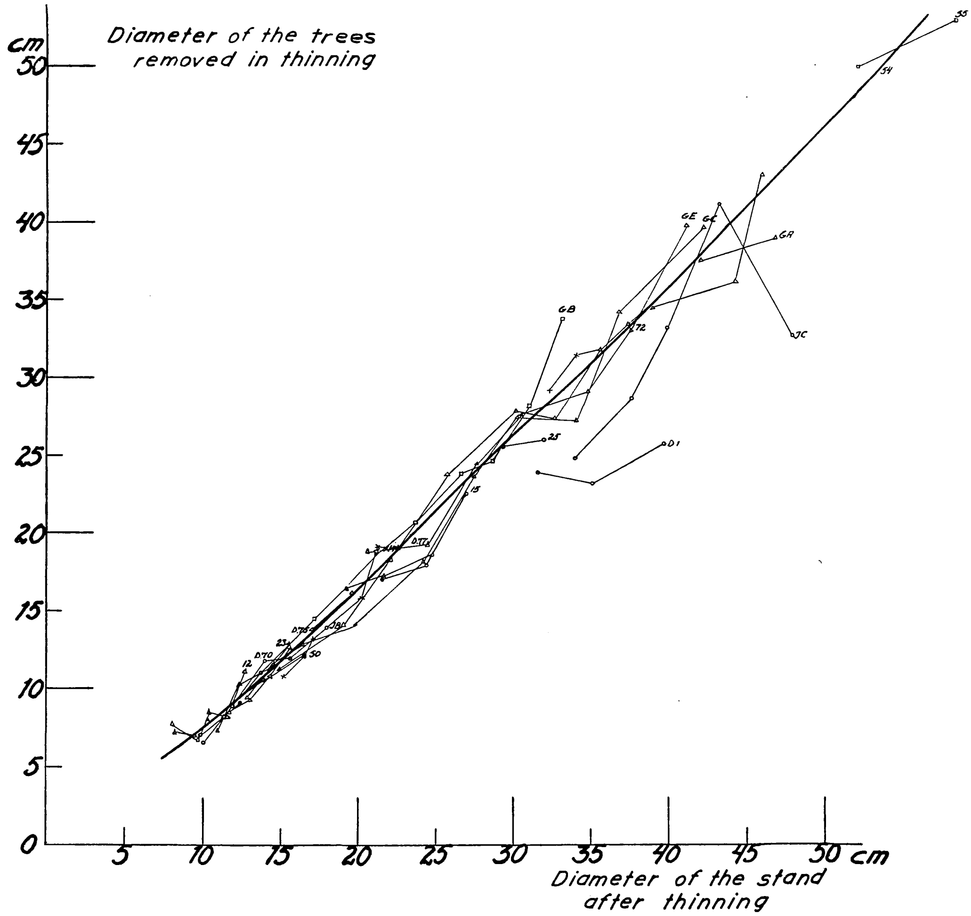

Fig. 17. Relationship between the mean diameter of the trees removed in thinning and that of the stand after thinning. Sitka spruce, all site classes.

F. The mean diameter of the trees removed in thinning

To obtain information on the trees removed in thinning, the relationship between its mean basal area diameter and the corresponding diameter of the stand after thinning has first been determined. This relationship is shown for Douglas fir and Sitka spruce in Figs. 16 and 17, respectively.

G. The mean height of the trees removed in thinning

The relationship between the mean basal area height of the trees removed in thinning and that of the remaining stand, has also been obtained graphically and it is shown in Figs. 18 and 19.

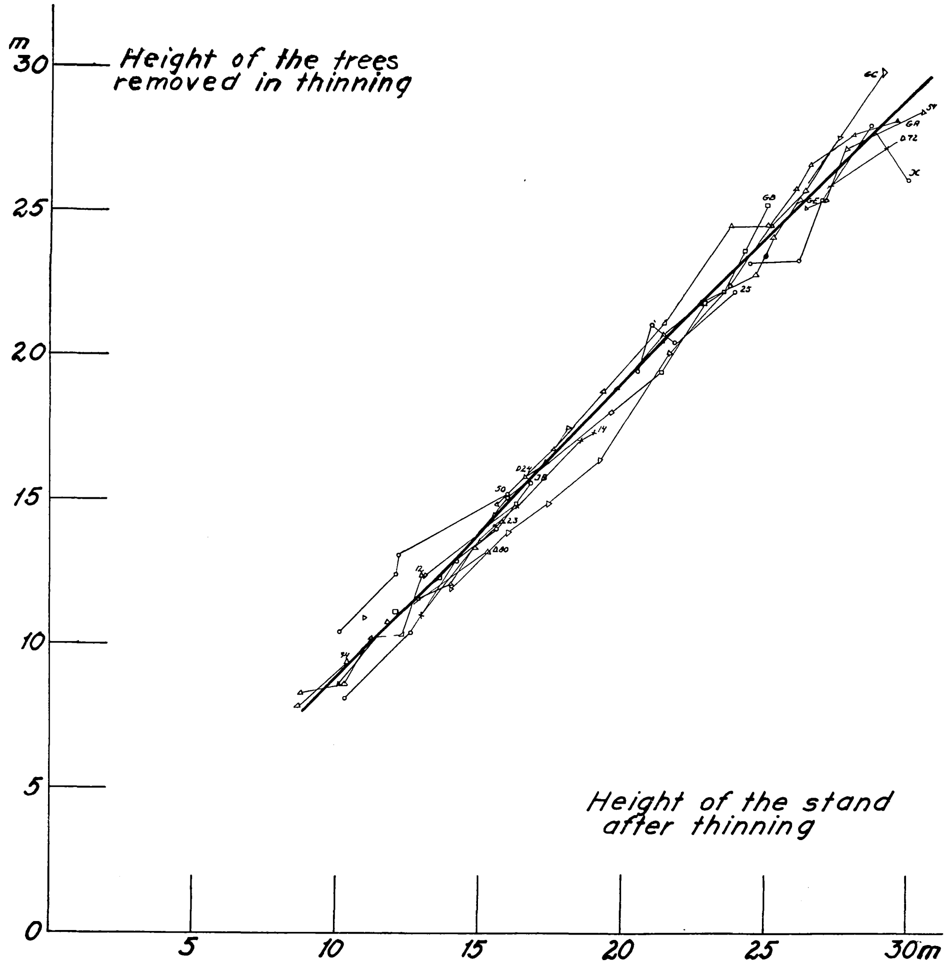

Fig. 18. Relationship between the mean basal area height of the trees removed in thinning and that of the thinned stand. Douglas fir, all site classes.

H. The basal area increment

To form a more reliable basis for increment calculations than that provided by a calculation by means of tables alone (see page 20), the current basal area increments has, as previously pointed out, been calculated by special methods. The increment figures obtained from the long observed sample plots and from the increment core material have been plotted graphically over age. (Figs. 20 and 21).

When the increment is obtained as a difference between two consecutive estimates (the so-called checking method) the possibility of error increases,

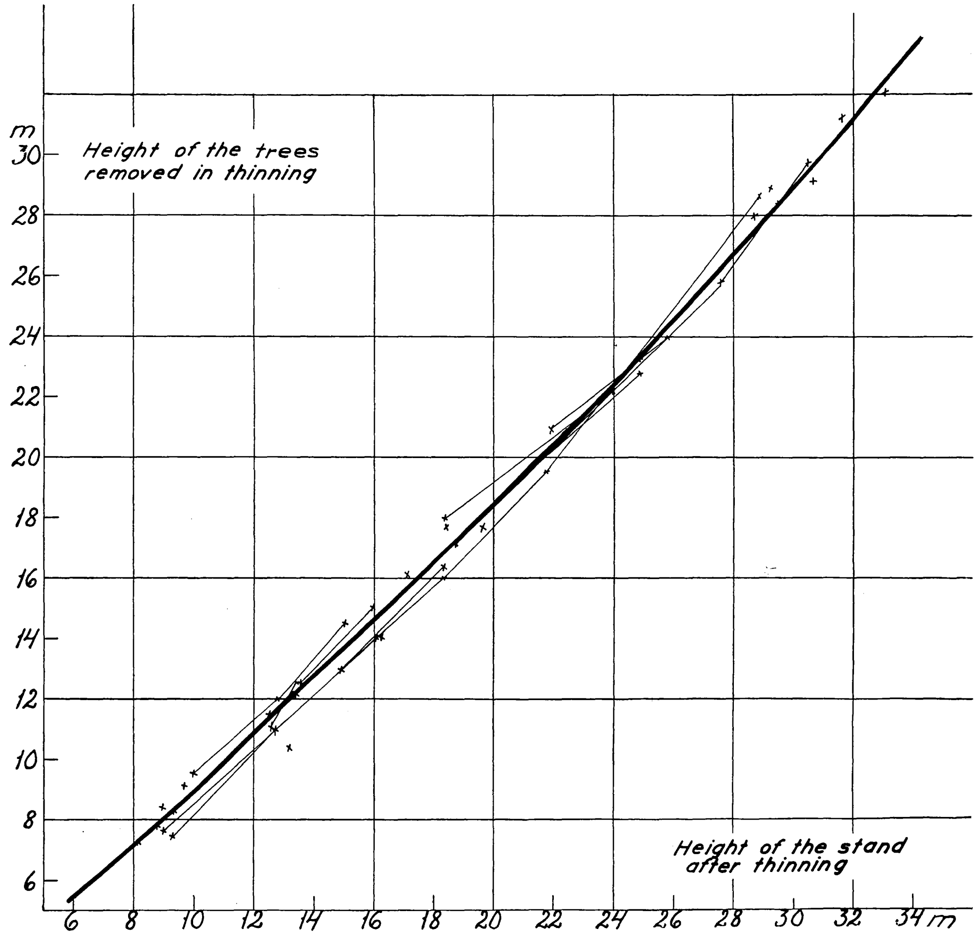

Fig. 19. Relationship between the mean basal area height of the trees removed in thinning and that of the thinned stand. Sitka spruce, all site classes.

since the standard deviation of the basal area increment becomes appreciably greater than the standard deviation of the basal area

$$\varepsilon_{\Delta G} = \pm \sqrt{\varepsilon^2_{G_1} + \varepsilon^2_{G_2}}$$

even if the sample plots have been closely observed for a long period of time (Näslund 1936 and Petrini 1948).

Regarding increment investigations in sample plots with continuous registration, it was also found that almost only the material emanating from the Danish Forest Experiment Station was measured with such a care that the increment could be calculated with satisfactory accuracy. The results also infer that in general only sample plots with numbered trees and marked points of caliper measurements would supply increment figures that are acceptable. Although a considerable number of forest administration sample plots with continuous records have not been included in the increment calculations because of irregularities, this material could still be used in other calculations.

The formula $p = 100 \left(\sqrt[n]{\frac{K}{k}} - 1 \right)$ has been used for calculating the increment percentages. Providing acceptable results in this case (Petrini 1925) the same method has also been employed for calculating the tabled increment percentage. Since the figures can be found in existing tables, this method has also proved to be the most simple one.

In stands where boring was permitted (33 Douglas fir and 24 Sitka spruce stands), the basal area increment percentage has been determined by means of increment cores.

On account of the rapid growth of the species studied and the short thinning interval, the period of investigation has been limited to cover the previous five years.

For reasons already mentioned, the volume computation has been based on the mean basal area tree instead of on the trees in the respective diameter classes. It was therefore considered advantageous to use a similar method of increment calculation, i.e. by establishing a relationship between the increment and the mean basal area tree.

According to Meyer (1932), Prodan (1951) and others, the relationship between diameter increment and diameter at breast-height can be described with a straight line ($Z_d = kD + l$). The increment of the average tree consequently corresponds to the mean value of all diameter increments in the stand. Thus it is possible, as proved by Prodan (1951), to determine the diameter increment and the increment of the basal area, by making an investigation of the increment of the mean basal area tree. Moreover, Möller (1951) points out that the relationship between the diameter increment percentage and the diameter remains almost unchanged right down to the suppressed trees. This is also confirmed by the material in this investigation. Therefore, as pointed out by Möller (l.c.), any marked error would hardly result from determining the basal area increment percentage of the stand by means of the methods previously described, i.e. by a graphical fitting of the relationship between the diameter increment and the diameter.

To determine the approximate number of increment cores required for each plot, a number of standard error calculations were made in the beginning of the investigation. Expressed in percent the deviations from the fitted curve were considered to be errors. The dispersion of increment core measurements being rather wide, it was found that, depending on the diameter distribution of the stand, between 40—50 increment cores were necessary to produce a standard error below 5 %.

Simultaneously with the boring, double bark thickness was measured and put in relation to diameter. The mean values in the respective diameter classes were subsequently fitted graphically. The bark increment obtained in this manner was then added to the other increment to avoid systematic errors.

Presenting annual ring indexes for various species, Holmsgaard (1955) made increment corrections possible. The investigation chiefly comprised beech (Fagus silvatica) and Norway spruce (Picea Abies), but a few Douglas fir and Sitka spruce plots were also included. For the period investigated the Sitka spruce increment is normal, while that of Douglas fir is below normal. This could probably justify a correction of the Douglas fir increment figures, even if the slight increase in increment percentage caused by continually recurring thinning is considered. Since, however, the section of the Douglas fir material in which increment was examined by means of cores is but a small portion of the complete material, the increment figures obtained have not been corrected. The entire material incidentally covers a long period when rainfall and temperature conditions were normal.

If, on the other hand the increment figures in the yield tables are compared with figures for a shorter period obtained from a single stand, there is every reason to consider the great variations in increment which can be caused by climate and serious calamaties.

The increment cores were measured at the Forest Research Institute in Stockholm, according to a method described by Eklund (1949 and 1951). The basal area increment was subsequently calculated according to the formula $p_g = 2p_d + \frac{p_d^2}{100}$; where p_d was calculated on the basis of compound rate of interest.

Two methods were available for the increment investigation, i.e. by means of the basal area increment percentage or by direct increment values. The calculation for Douglas fir, carried out first, was based on the increment percentage as it was assumed that this would vary only slightly from one site class to another.

This proved to be the case to some extent in fig. 20. The curves for the various site classes are here showing a normal course with somewhat lower values for the higher site classes, especially at lower ages.

When these increment figures for Douglas fir were related to the basal areas shown in the tables, it was found that, apart from certain discrepancies in the low ages, there were no appreciable differences in basal area increment between the four site classes.

For this reason it was decided to base the calculations for Sitka spruce

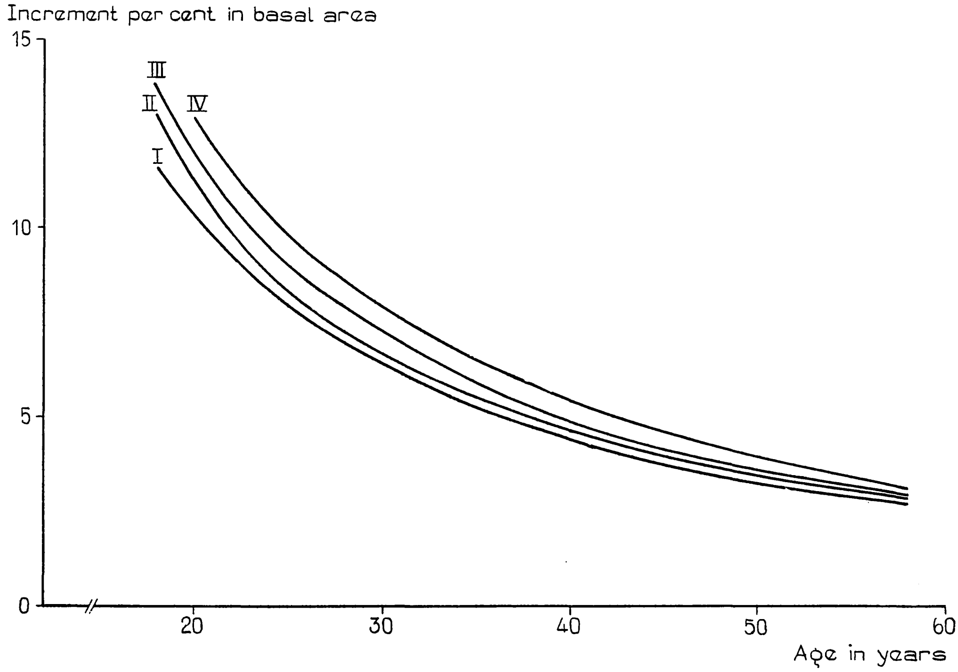

Fig. 20. Relationship between the basal area increment percentage and age. Douglas fir, site classes I—IV.

directly on the basal area increment. When the current increment in square metres per hectare for Sitka spruce was related to age, it was found — as shown in Fig. 21 — that the observations from the various site classes were intermixed.

Related to age, however, the basal area increment is dependent on the site quality in low ages. This is manifested as greater increment in the higher site classes. Although no other differences between the site classes were ascertained on the basis of this relatively limited material, this naturally does not mean that the basal area increment is equal in all site classes. Any potential differences except those in low ages can, however, be regarded as being so small that they may be disconsidered in this context.

Wiedemann (1931) and Möller (1933) have shown for beech (Fagus silvatica) that when thinning is uniform the basal area increment is about equal in the various site classes. The situation is not quite the same in the Möller tables (1933) for Norway spruce, where the better sites give a somewhat higher basal area increment throughout. Likewise Wiedemann (1934) reported some minor differences (approx. 10 %) in the basal area increment between the various site classes for Norway spruce.

According to Fig. 21 the basal area increment has already culminated

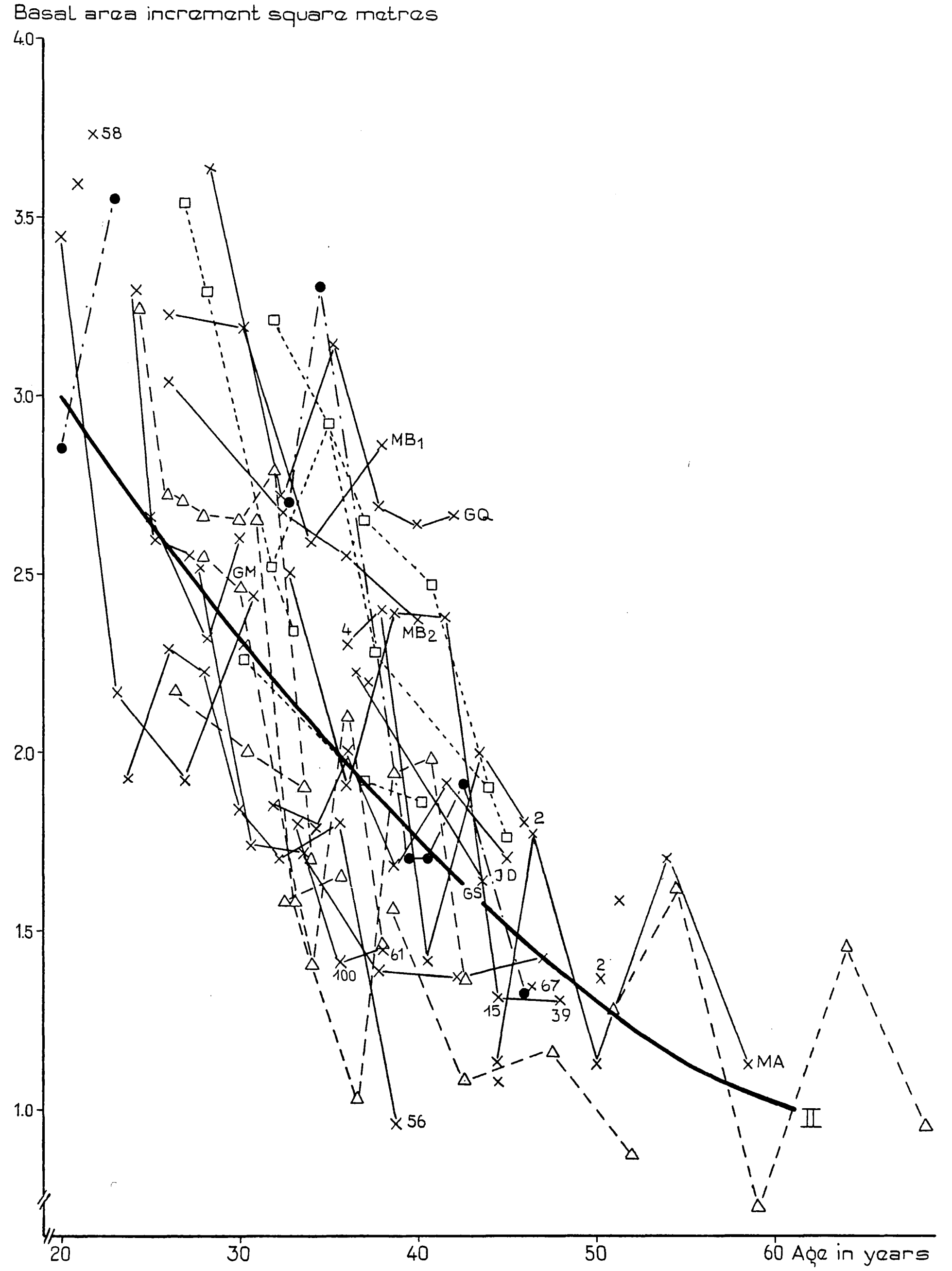

Fig. 21. Relationship between the basal area increment and age for Sitka spruce, all site classes. The curve for site class II has been superimposed.

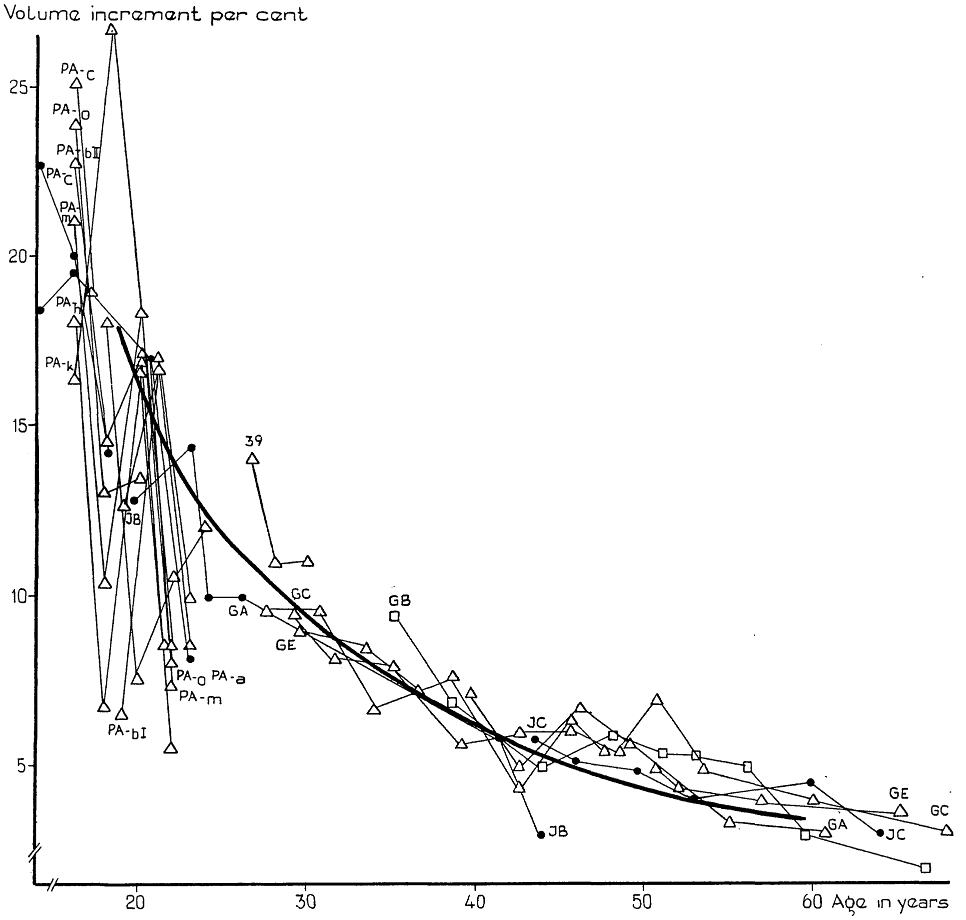

Fig. 22. Relationship between the volume increment percentage and age according to the table, Douglas fir, site class II, (heavy line ———) and that shown by the material.[1]

and similar to the increment percentage it declines markedly as age increases.

Since the basal area increment is relatively independent of the site, it can be assumed that the variation in increment is connected with the basal area itself. It is therefore probable that a curve showing the mean basal area increment in relation to basal area without regard to site class, would show less dispersion.

1 The figure shows that the young PA stands have a low increment differing from the material in general. This must be considered caused by the severe attacks of Swiss needle cast (Phaeocryptopus Gäumannï), described in detail by Thulin (1949) and Lundberg (1952).

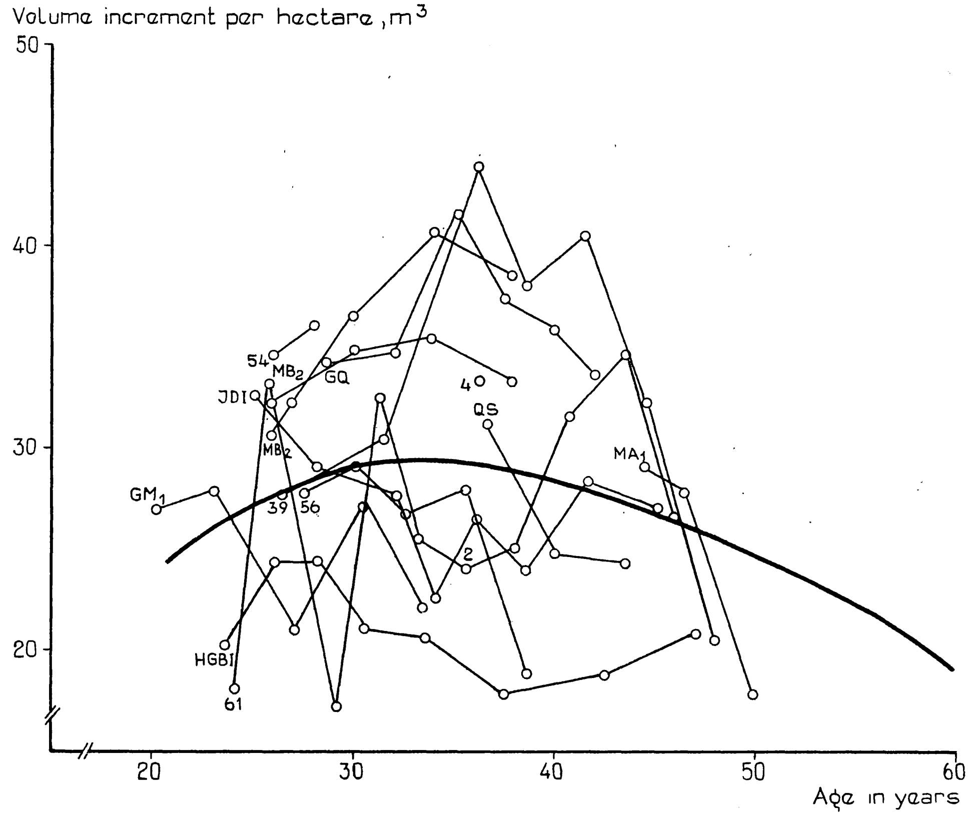

Fig. 23. Relationship between the volume increment and age according to the table, Sitka spruce site class II (heavy line ———) and that shown by the material for the same site class.

I. The volume increment

Once the other data were determined, the increment percentage and the current annual volume increment were calculated by means of the tables. The values thus obtained were again checked by a graphic fitting of the volume increment data plotted over age. Data used in this increment check were obtained from sample plots with continuous registration and partly from stands where felled trees could be measured. The volume increment was obtained by combining the partial increment values of basal area, height and form-factor $(1.0p_v = 1.0p_g \cdot 1.0p_h \cdot 1.0p_f)$.

Figure 22 shows good agreement between the increment percentage obtained from the tables and that contained in the material.

The increment percentage is high in the low ages — as it should be on account of the low volume — and then declines rapidly. In the young ages the high site classes show a somewhat lower volume increment percentage than the low site classes (see the yield tables, on page 41). On the other hand, the differences between the various site classes are less in the high ages.

The Sitka spruce volume increment was checked in a similar way. In this way the increment calculated by means of the table, was placed together with the increment curves obtained directly from the material. Such a comparison is shown in Figure 23 for Sitka spruce, site class II.

J. Total yield

The remaining column in the table — total yield — was obtained by adding the initial volume to the annual increments. The calculation started with the first thinning and includes the status prior to this thinning. The mean diameter of the trees removed in the first thinning was approximately 8 cm.

Table 8. Yield tables for Douglas fir.

Douglas fir
Site Class I
$H_{50} = 32{,}0$

Age years	Stand remaining after thinning					Trees removed in thinning			Current annual increment				Total yield m³ per hectare
	Mean height metres	Mean diameter cm	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	m² per hectare	Increment %	m³ per hectare	Increment %	
18	12.5	12.4	1 983	24.1	160				3.20	11.7	32.0	16.7	183
20	14.2	14.6	1 548	26.2	196	435	4.3	28	3.00	10.3	32.0	14.0	246
22	15.8	16.8	1 262	28.0	229	286	4.2	31	2.85	9.3	32.3	12.8	311
24	17.3	19.0	1 041	28.6	260	221	4.1	34	2.65	8.3	32.0	11.6	276
26	18.8	21.2	878	30.9	288	163	4.0	36	2.45	7.5	31.5	10.5	440
28	20.2	23.4	747	32.0	314	131	3.9	37	2.25	6.9	30.8	9.5	503
30	21.6	25.5	637	32.7	338	110	3.8	38	2.15	6.4	29.9	8.7	565
32	22.9	27.7	553	33.3	359	84	3.7	39	2.00	6.0	28.9	7.9	625
34	24.1	29.8	484	33.7	378	69	3.6	39	1.90	5.6	27.7	7.3	691
36	25.2	31.9	426	34.0	394	58	3.5	39	1.80	5.2	26.6	6.7	738
38	26.3	34.0	377	34.0	407	49	3.4	40	1.70	4.8	25.6	6.1	791
40	27.4	36.1	335	34.1	418	42	3.3	40	1.57	4.3	24.3	5.5	842
43	28.8	39.2	285	34.3	435	50	4.5	56	1.47	3.9	23.0	5.1	915
46	30.3	42.2	245	34.4	449	40	4.3	55	1.30	3.6	21.5	4.7	984
49	31.6	45.2	212	34.2	460	33	4.1	54	1.23	3.4	20.6	4.3	1 049
52	32.9	48.3	185	34.0	469	27	3.9	53	1.10	3.2	19.3	4.0	1 111
55	34.1	51.4	163	33.7	476	22	3.6	51	1.00	2.9	18.0	3.6	1 169
58	35.2	54.2	145	33.4	481	18	3.3	49	0.90	2.7	17.0	3.4	1 223
61	36.2	57.0	129	33.0	485	16	3.1	47					1 274

Douglas fir
Site Class II
$H_{50} = 29,0$

Age years	Stand remaining after thinning: Mean height metres	Mean diameter cm	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Trees removed in thinning: Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Current annual increment: m² per hectare	Increment %	m³ per hectare	Increment %	Total yield m³ per hectare
18	10.7	10.2	2 560	21.5	126				3.15	13.0	27.5	17.9	147
20	12.2	12.1	2 038	23.8	156	522	4.0	25	2.95	11.2	28.0	15.2	202
22	13.6	14.0	1 649	25.8	185	389	3.9	27	2.75	9.8	28.5	13.3	258
24	15.0	16.0	1 350	27.4	213	299	3.9	29	2.55	8.6	29.0	12.0	317
26	16.4	17.9	1 131	28.7	240	219	3.8	31	2.35	8.0	28.5	11.0	375
28	17.8	19.9	951	29.6	264	186	3.8	33	2.20	7.1	28.0	10.0	434
30	19.1	21.9	805	30.3	285	146	3.7	35	2.10	6.6	27.5	9.1	490
32	20.3	23.9	690	30.9	305	115	3.6	35	1.95	6.1	26.5	8.3	546
34	21.5	25.9	595	31.3	323	95	3.5	35	1.85	5.7	25.5	7.6	598
36	22.6	27.9	517	31.6	339	78	3.4	35	1.75	5.4	24.5	7.0	649
38	23.7	29.9	452	31.8	352	65	3.3	36	1.65	5.0	23.5	6.4	698
40	24.7	31.9	400	31.9	363	52	3.2	36	1.53	4.6	22.2	5.8	745
43	26.1	34.9	338	32.1	379	62	4.4	51	1.40	4.2	20.9	5.2	812
46	27.4	37.9	287	32.3	392	51	4.2	50	1.27	3.8	19.9	4.8	875
49	28.6	40.9	245	32.2	403	42	3.9	49	1.17	3.5	18.9	4.4	935
52	29.8	43.8	211	32.1	414	34	3.8	48	1.10	3.3	17.7	4.0	992
55	30.9	46.7	184	31.8	420	28	3.6	47	1.00	3.1	17.0	3.8	1 045
58	31.9	49.6	162	31.5	426	22	3.3	45	0.90	2.8	16.0	3.6	1 096
61	32.8	52.5	142	31.2	431	20	3.0	43					1 144

Douglas fir
Site Class III
$H_{50} = 26{,}0$

Age years	Stand remaining after thinning					Trees removed in thinning			Current annual increment				Total yield m³ per hectare
	Mean height metres	Mean diameter cm	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	m² per hectare	Increment %	m³ per hectare	Increment %	
18	8.7	8.2	3 641	19.4	95				3.05	13.8	24.0	20.2	112
20	10.3	9.7	2 783	21.5	123	858	4.0	20	2.90	11.9	24.5	16.6	160
22	11.7	11.4	2 253	23.4	149	530	3.9	23	2.75	10.5	25.0	14.4	209
24	13.0	13.1	1 851	25.0	174	402	3.9	25	2.60	9.4	25.5	12.8	259
26	14.2	14.9	1 519	26.4	198	332	3.8	27	2.45	8.7	25.7	11.9	310
28	15.5	16.8	1 253	27.5	220	266	3.8	29	2.20	8.0	25.4	10.9	361
30	16.7	18.6	1 044	28.4	241	209	3.7	30	2.15	7.3	24.8	9.8	412
32	17.8	20.5	883	29.1	260	161	3.6	31	2.00	6.7	23.9	8.8	462
34	18.9	21.4	753	29.6	277	130	3.5	31	1.90	6.2	23.0	8.0	510
36	19.9	24.3	650	30.0	291	103	3.4	32	1.80	5.8	22.0	7.3	556
38	20.9	26.2	565	30.3	303	85	3.3	32	1.70	5.4	21.2	6.7	600
40	21.9	28.0	495	30.5	313	70	3.2	32	1.50	4.8	20.2	6.1	642
43	23.3	30.8	412	30.7	328	83	4.3	46	1.37	4.3	19.2	5.5	703
46	24.5	33.6	347	30.7	341	65	4.1	45	1.23	3.9	18.3	5.1	761
49	25.7	36.4	297	30.6	352	50	3.8	44	1.17	3.7	17.4	4.7	816
52	26.8	39.1	254	30.5	361	43	3.6	43	1.10	3.5	16.8	4.4	868
55	27.8	41.8	221	30.3	369	33	3.5	42	1.00	3.2	15.7	4.1	918
58	28.7	44.5	193	30.1	376	28	3.2	40	0.90	2.9	14.7	3.8	965
61	29.5	47.2	170	29.8	382	23	2.9	38					1 009

Douglas fir
Site Class IV
$H_{50} = 23{,}0$

Age years	Stand remaining after thinning: Mean height metres	Mean diameter cm	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Trees removed in thinning: Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Current annual increment: m² per hectare	Increment %	m³ per hectare	Increment %	Total yield m³ per hectare
20	8.4	7.4	4 361	18.7	89				2.80	13.0	20.0	18.4	105
22	9.7	8.3	3 429	20.5	111	932	3.8	18	2.65	11.5	20.0	15.6	145
24	10.8	10.2	2 712	22.2	132	687	3.7	20	2.50	10.1	21.0	13.7	186
26	11.9	11.6	2 214	23.5	152	528	3.7	22	2.30	9.3	21.5	12.4	228
28	13.0	13.2	1 790	24.5	171	424	3.6	24	2.20	8.7	22.0	11.6	271
30	14.1	14.9	1 460	25.3	189	330	3.6	26	2.10	8.0	21.8	10.8	315
32	15.2	16.6	1 209	26.0	206	251	3.5	27	1.95	7.3	21.3	10.0	359
34	16.2	18.3	1 009	26.5	222	200	3.4	27	1.85	6.8	20.7	9.0	402
36	17.2	20.0	857	26.9	235	152	3.3	28	1.75	6.3	20.0	8.1	443
38	18.1	21.7	735	27.2	247	122	3.2	28	1.65	5.9	19.3	7.5	483
40	19.0	23.4	637	27.4	258	98	3.1	28	1.53	5.3	18.5	6.9	522
43	20.3	25.9	521	27.6	272	116	4.4	42	1.40	4.8	17.6	6.3	578
46	21.5	28.5	433	27.7	284	88	4.1	41	1.30	4.5	16.8	5.6	631
49	22.6	31.1	365	27.8	294	68	3.8	40	1.23	4.2	16.1	5.2	681
52	23.7	33.8	311	27.9	303	54	3.6	39	1.10	3.8	15.6	4.9	729
55	27.7	36.4	267	27.8	312	44	3.4	38	1.00	3.4	14.7	4.5	776
58	25.6	39.0	231	27.6	320	36	3.1	36	0.97	3.1	13.7	4.1	820
61	26.4	41.6	201	27.4	327	30	2.8	34					861

Table 9. Yield tables for Sitka spruce.

Sitka spruce
Site Class I
$H_{50} = 30{,}0$

Age years	Stand remaining after thinning: Mean height metres	Stand remaining after thinning: Mean diameter cm	Stand remaining after thinning: Number of trees per hectare	Stand remaining after thinning: Basal area m² per hectare	Stand remaining after thinning: Volume m³ per hectare	Trees removed in thinning: Number of trees per hectare	Trees removed in thinning: Basal area m² per hectare	Trees removed in thinning: Volume m³ per hectare	Current annual increment: m² per hectare	Current annual increment: Increment %	Current annual increment: m³ per hectare	Current annual increment: Increment %	Total yield m³ per hectare
18	8.2	9.6	3 740	27.4	127				3.20	11.0	26.4	17.3	145
20	9.9	11.4	2 828	29.1	158	912	4.7	22	3.15	9.8	28.4	15.3	198
22	11.5	13.2	2 227	30.7	190	601	4.7	25	2.95	8.8	31.2	14.0	255
24	13.0	15.0	1 792	32.0	224	435	4.6	28	2.75	8.0	32.1	13.1	317
26	14.6	16.9	1 466	33.0	257	326	4.5	31	2.65	7.7	33.0	12.0	381
28	16.1	18.9	1 207	33.9	289	259	4.4	34	2.50	7.1	33.1	10.9	447
30	17.6	20.9	1.008	34.6	319	199	4.3	36	2.35	6.6	33.0	9.8	514
32	19.0	22.9	853	35.1	347	155	4.2	38	2.25	6.2	32.8	9.0	579
34	20.4	24.9	727	35.5	373	126	4.1	40	1.15	5.9	32.5	8.4	645
36	21.8	27.0	624	35.8	397	103	4.0	41	2.00	5.5	32.1	7.8	710
38	23.1	29.1	539	35.9	419	85	3.9	42	1.90	5.2	31.5	7.2	774
40	24.3	31.2	471	35.9	439	68	3.8	43	1.77	4.7	30.5	6.6	837
43	26.1	34.3	390	36.0	466	81	5.2	65	1.60	4.2	29.3	5.9	929
46	27.9	37.3	329	35.9	490	61	4.9	64	1.47	3.9	28.0	5.4	1 017
49	29.5	40.8	281	35.8	512	48	4.5	62	1.33	3.5	26.5	5.0	1 101
52	30.8	43.3	242	35.6	532	39	4.1	60	1.20	3.2	25.1	4.5	1 180
55	32.0	46.1	212	35.4	549	30	3.8	58	1.10	3.1	23.0	4.1	1 255
58	32.8	48.9	189	35.3	563	23	3.4	55	1.03	2.9	21.0	3.6	1 324
61	33.5	51.6	170	35.3	576	19	3.1	50					1 387

Sitka spruce
Site Class II
$H_{50} = 27{,}0$

Age years	Stand remaining after thinning: Mean height metres	Stand remaining after thinning: Mean diameter cm	Stand remaining after thinning: Number of trees per hectare	Stand remaining after thinning: Basal area m^2 per hectare	Stand remaining after thinning: Volume m^3 per hectare	Trees removed in thinning: Number of trees per hectare	Trees removed in thinning: Basal area m^2 per hectare	Trees removed in thinning: Volume m^3 per hectare	Current annual increment: m^2 per hectare	Current annual increment: Increment %	Current annual increment: m^3 per hectare	Current annual increment: Increment %	Total yield m^3 per hectare
20	8.3	9.7	3 602	27.0	122				3.00	10.0	24.5	17.3	140
22	9.8	11.4	2 729	28.5	152	873	4.5	21	2.85	8.9	26.0	14.6	191
24	11.1	13.2	2 151	29.7	180	578	4.4	24	2.70	8.4	27.4	13.2	253
26	12.5	14.9	1 743	30.8	209	408	4.3	26	2.60	8.1	28.4	11.8	308
28	13.9	16.7	1 441	31.8	237	303	4.2	28	2.45	7.4	29.0	11.4	362
30	15.4	18.6	1 199	32.6	265	242	4.1	30	2.30	6.8	29.2	10.3	420
32	16.7	20.5	1 001	33.2	291	198	4.0	32	2.20	6.4	29.4	9.6	478
34	18.0	22.4	857	33.7	316	144	3.9	34	2.11	6.1	29.2	8.8	537
36	19.3	24.3	736	34.1	339	121	3.8	35	2.00	5.7	28.7	8.1	595
38	20.5	26.2	639	34.4	360	97	3.7	36	1.90	5.4	28.4	7.6	652
40	21.6	28.1	558	34.6	380	81	3.6	37	1.73	4.7	27.4	6.9	709
43	23.3	30.7	470	34.8	407	88	5.0	55	1.57	4.3	26.6	6.2	791
46	24.9	33.4	397	34.8	432	73	4.7	55	1.43	4.0	25.8	5.6	871
49	26.5	36.1	339	34.7	455	58	4.4	54	1.37	3.8	24.5	5.1	948
52	27.8	38.8	293	34.7	475	46	4.1	53	1.23	3.4	23.3	4.7	1 022
55	28.9	41.4	257	34.7	494	36	3.7	51	1.10	3.1	21.3	4.2	1 092
58	29.8	43.9	229	34.6	510	30	3.4	48	1.00	2.8	19.3	3.7	1 156
61	30.5	46.2	206	34.6	522	25	3.0	45					1 213

Sitka spruce
Site Class III
$H_{50} = 24{,}0$

Age years	Stand remaining after thinning					Trees removed in thinning			Current annual increment				Total yield m³ per hectare
	Mean height metres	Mean diameter cm	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	m² per hectare	Increment %	m³ per hectare	Increment %	
20	6.8	8.6	4 271	24.6	91								106
22	8.2	10.2	3 189	26.2	115	1 082	4.4	18	3.00	10.9	21.0	18.9	150
24	9.4	11.9	2 435	27.6	140	754	4.4	20	2.90	10.0	22.6	16.4	196
26	10.6	13.7	1 950	28.8	166	485	4.2	22	2.70	9.1	23.8	14.7	243
28	11.8	15.4	1 609	29.9	191	351	4.1	24	2.60	8.6	24.7	13.8	292
30	13.1	17.1	1 339	30.8	216	270	4.0	25	2.45	7,9	25.0	12.2	342
32	14.4	18.7	1 146	31.5	241	193	3.9	26	2.30	7.2	25.3	10.9	393
34	15.6	20.4	984	32.1	263	162	3.8	28	2.20	6.8	25.5	9.9	444
36	16.7	22.1	847	32.5	284	137	3.7	30	2.10	6.7	25.5	9.2	495
38	17.9	23.9	731	32.8	304	116	3.6	31	1.95	5.8	25.3	8.6	546
40	19.0	25.5	646	33.0	322	85	3.5	32	1.85	5.5	25.0	7.9	596
43	20.6	28.0	438	33.2	349	108	4.8	47	1.70	4.8	24.7	7.1	670
46	22.1	30.4	461	33.5	375	77	4.5	47	1.60	4.6	24.3	6.5	743
49	23.5	32.8	399	33.8	400	62	4.1	46	1.47	4.2	23.5	6.0	814
52	24.7	35.2	348	33.9	422	51	3.9	45	1.33	3.7	22.6	5.4	881
55	25.6	37.5	307	34.0	441	41	3.5	43	1.20	3.4	20.8	4.7	944
58	26.5	39.8	274	34.1	457	33	3.2	42	1.10	3.1	19.3	4.2	1 003
61	27.2	42.0	247	34.1	470	27	3.0	40	1.00	2.9	17.6	3.7	1 058

Sitka spruce
Site Class IV
$H_{50} = 21{,}0$

Age years	Stand remaining after thinning: Mean height metres	Mean diameter cm	Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Trees removed in thinning: Number of trees (per hectare)	Basal area m² (per hectare)	Volume m³ (per hectare)	Current annual increment: m² per hectare	Increment %	m³ per hectare	Increment %	Total yield m³ per hectare
22	6.5	9.0	3 916	24.9	83				2.75	10.0	18.5	18.3	94
24	7.6	10.5	3 068	26.3	106	848	4.1	14	2.60	9.0	19.6	15.5	121
26	8.8	12.0	2 422	27.4	129	646	4.1	16	2.45	8.2	20.6	13.7	160
28	9.9	13.5	1 975	28.3	152	447	4.0	18	2.35	7.7	21.7	12.1	211
30	11.1	15.1	1 622	29.1	174	353	3.9	20	2.25	7.5	21.9	11.7	253
32	12.2	16.7	1 361	29.8	196	261	3.8	22	2.15	7.0	22.1	10.6	297
34	13.3	18.3	1 162	30.4	216	199	3.7	24	2.05	6.5	22.3	9.8	341
36	14.4	19.8	1 001	30.9	236	161	3.6	25	1.95	6.1	22.4	8.9	386
38	15.4	21.4	870	31.3	255	131	3.5	26	1.80	5.6	22.2	8.3	431
40	16.6	23.0	760	31.5	272	110	3.4	27	1.70	5.1	22.0	7.5	475
43	17.9	25.1	643	31.8	296	117	4.8	42	1.57	4.7	21.5	6.9	541
46	19.2	27.2	552	32.1	319	91	4.4	42	1.43	4.3	20.8	6.1	606
49	20.6	29.3	479	32.3	340	73	4.1	41	1.33	3.9	20.0	5.6	668
52	21.5	31.3	421	32.5	360	58	3.8	40	1.20	3.5	18.6	5.0	732
50	22.6	33.3	372	32.6	378	49	3.5	38	1.10	3.2	17.4	4.4	788
58	23.4	35.2	332	32.7	394	40	3.2	46	1.03	2.9	16.0	3.9	840
61	23.9	37.1	301	32.7	408	31	2.9	34					888

II. Douglas fir growth and growing conditions

Morphology, taxonomy and range

Douglas fir is usually regarded as a Pacific coast species although it has a range extending over large areas of the continent of North America. Certainly, Douglas fir here reaches maximum development and it is of great economic significance west of the Cascade Range in the states of Oregon and Washington and in south-west British Columbia. This area, called »The Douglas Fir region», contains two-thirds of the total Douglas fir volume. However, Douglas fir is also found east of the Cascade Range and in even more continental climate regions such as the states of Arizona and Colorado. The most southerly points of the Douglas fir range are located in Mexico in the mountains east of the town of Monterrey, as well as in the easterly offset of the Sierra Madre west of the town of Chihuahua. The northerly boundary of the range runs through northern British Columbia and Alberta (Fig. 24).

Douglas fir was discovered in 1791 by the Scottish naturalist Archibald Menzies at Nootka Sound on Vancouver Island. This island was named after Captain Vancouver, leader of the expedition of which Menzies was a member. In 1803 the tree was first described as Pinus taxifolia by the Scottish botanist Aylmer Bourke Lambert. Lambert was a close friend of David Douglas, another Scottish scientist, who studied the range and growth of the species in America and introduced the first Douglas fir seed lot to Europe. The tree was named after him (Harvey 1947).

Douglas fir was previously ranged in the Pinus, Abies, Picea and Tsuga genera. The French botanist, Jean Poiret, called the species Abies taxifolia when he described it in 1804. It is admittedly true that the shoot formation closely resembles those of the Abies species. The same also holds good for the flat, bilaterally directed needles, which lack pronounced peduncles. The buds, on other hand, are much more pointed than in the case of Abies. The cones display great dissimilarity, and furthermore, as distinct from true fir, Douglas fir has pendulous cones.

The morphological differences are clear also in comparison with Picea. Among other things Picea (like Tsuga), as distinct from Pseudotsuga, has

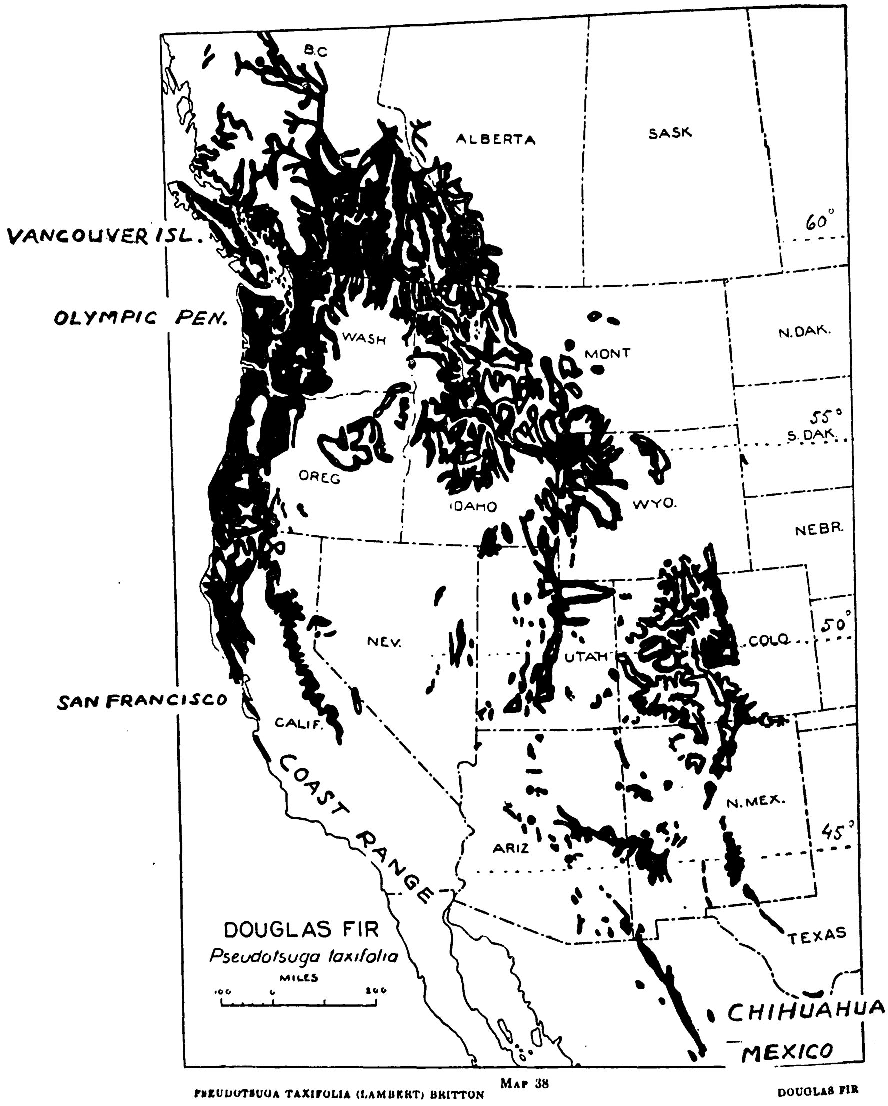

Fig. 24. The range of Douglas fir (Pseudotsuga taxifolia) after Munns (1938).

needle-clad branches. Another difference is that as a rule Picea has needles with quadrangular cross-section.

Pinus, which belongs to another sub-family, is morphologically quite different from Douglas fir. One of the reasons for this confusion of names may possibly have its origin in the terminology used in sawmills. Thus, Douglas fir timber is still rather generally known as Oregon Pine, although the official name is now Red or Yellow Fir.

It was Carriere who first placed it into a new genus 1857 when he called it Pseudotsuga Douglasii. In 1889 Britton suggested Pseudotsuga taxifolia. According to Little (1954) the name should be Pseudotsuga menziesii.

Belonging to the sub-family Abietoideae, the Pseudotsuga genus comprises 6 living species, two of which are indigenous to North America and 4 to East Asia as follow:

In North America: Pseudotsuga taxifolia. Britton, and Pseudotsuga macrocarpa, Mayr, which occurs mainly in southern California under the name Bigcone Spruce (Sudworth 1908). This is a smaller tree than Pseudotsuga taxifolia and has a conical crown. At times it has been regarded as a variety of Pseudotsuga taxifolia.

In Japan: Pseudotsuga japonica, Beiss, and Pseudotsuga Wilsoniana, Hayata.

In China: Pseudotsuga sinensis, Dode, and Pseudotsuga Forrestii, Craib.

Furthermore, fossilized occurrences of the Pseudotsuga genus have been found in Europe (Silesia). These are considered to have been more closely related to the Asiatic species than the American ones (Kock 1924, 1927).

Species ranging under largely varying climatic conditions naturally display great physiological and morphological variability. At 80 years of age the Douglas fir reaches a height exceeding 60 metres in the favourable climate of the sheltered valleys on the western slopes of the Cascade Range and the Coast ranges. In the dry, continental areas behind the Sierra Nevada, however, they hardly reach 20 metres.

European botanists such as Engler-Prantl (1926), Beissner-Fitschen (1931) and others, have used morphological differences for a separation of Pseudotsuga taxifolia into a number of species.

The American scientists do not consider this warranted, but they have differentiated between a coast type and a mountain type (Frothingham 1909). This division into varieties was later developed further by Schenck (1939). Even though Schenck's somewhat sketchy division was subject to criticism (e.g. Peace 1948), it is today generally accepted and embraces the following three varieties:

1. Pseudotsuga taxifolia viridis (the coast or the green type) is ranging from the coast to the Sierra-Cascade Range.[1] It has green, long and soft needles, which point levelly to the sides and the parenchymata do not generally possess sclereids. The mature cone is relatively large and the scales are persistent. The lateral branches are horizontal except in old specimens, where they are sometimes declinated. Young bark is almost smooth but later it grows crusty, with longitudinal fissures. The bark of old trees is soft and has a light brown tone. According to Krutina (1929), the terminal buds

[1] Although Cascades and Sierra Nevada are different in origin, for phytogeographic purposes they are sometimes referred to as Sierra-Cascade range.

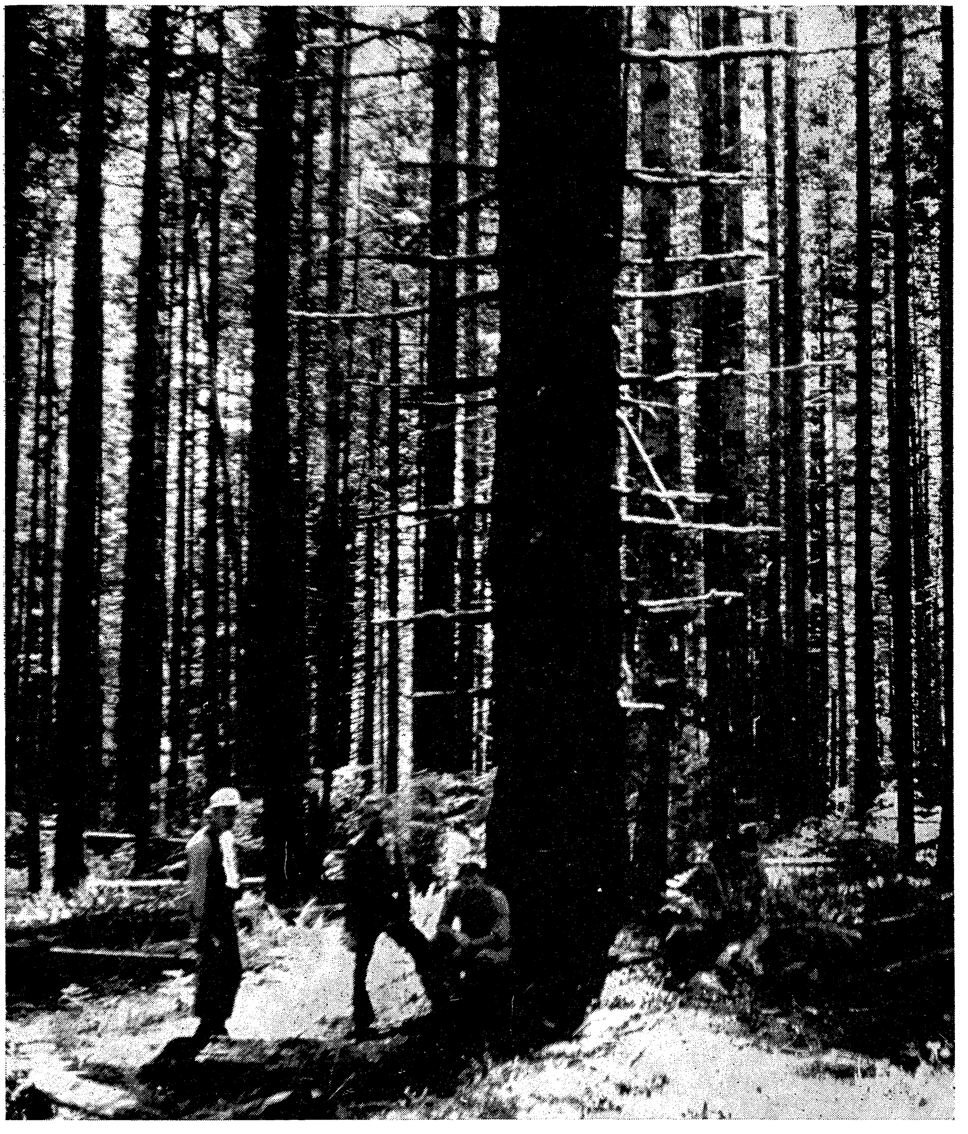

Fig. 25. A good stand of Douglas fir at St. Helen's Tree Farm, Washington, U.S.A. (Weyerhaeuser Timber Co. Green Mt. study area No. 4). The stand is even-aged, 58 years. Developed from a dense reproduction, it is of good quality. The limby tree in the foreground, however, is older than the others, 110 years, and has been growing as a solitary tree.

of young seedlings of the coast type are partly enveloped in needles, while those of the mountain type are bare. This difference could be regarded as a dormancy phenomen, however.

2. Pseudotsuga taxifolia glauca (the mountain or the blue type) is ranging the central parts of U.S.A. and Mexico. A coating of wax lends the needles a somewhat blue or silvery appearance. The cones are smaller than those of the coast type and the free parts of the bracts are dilated. The lateral branches are generally slightly raised. Young bark is coarse.

3. Pseudotsuga taxifolia caesia (the grey type) is a transition type and it is mainly ranging in central British Columbia and the North American states east of the Cascade Range and above the 39th parallel.

There are no distinct boundaries between the ranges of the subspecies. Transition types occur in large areas, and grey varieties are found in areas where the green types are pre-dominant and vice versa.

Naturally, growth conditions vary even in »The Douglas Fir Region». For this reason Mc Ardle (1930) has divided the coast forests into three types according to composition and climate. This division, however, omits the California part although Douglas fir represents the largest volume of commercial timber in this state.

1. The fog-belt type occurs as a narrow strip along the coast. Precipitation is high, and wet fogs roll in from the Pacific even during the summer months. Picea sitchensis and Tsuga heterophylla here succeed well in competition with Douglas fir.

2. The Douglas Fir type proper occurs in the Puget Sound-Willamette-basin, in the Coast ranges and at the foot of the Cascade Range. These forests are composed almost exclusively of Douglas fir, with light intermixture of Tsuga heterophylla, Thuja plicata, Abies grandis and occasionally Abies amabilis, Abies nobilis and Pinus monticola. The most common deciduous trees here as in the fog-belt are Alnus rubra, Acer macrophyllum and circinatum, Populus trichocarpa and Quercus garryana.

3. The upper-slope type occurs from the intermediate heights to the upper reaches of the Cascade Range, where, however, Douglas fir gradually is replaced by Thuja plicata, Tsuga heterophylla, Pinus monticola, Abies nobilis, Abies amabilis, Abies lasiocarpa, Tsuga mertensiana and Chamaecyparis nootkatensis.

Douglas fir provenances

Since David Douglas had his headquarters in Fort Vancouver on the Columbia River, it is highly probable that the seed first introduced into Europe originated from these tracts (Booth 1903, Sudworth 1918, Syrach Larsen 1927, 1947). Trees from the original plantations still exist in Scotland e.g. at the Murthly Estate (Karlberg 1955). It is now considered less likely that the first seed was taken from Sierra Nevada (Opperman 1915).

Seed from these Scottish parent trees has since been used for several experimental plantations on the European continent (Booth 1887, 1903, 1907). According to Fabricius (1926) and Syrach Larsen (1947) there is also reason to assume that the old Douglas fir stands in Denmark (e.g. on Langesö and Linaa) originated from these Scottish trees, and consequently from the Fort Vancouver area.

According to Opperman (1922), the old Douglas fir on Bornholm and possibly even on Gunderslevsholm (plot No. 58 in the list on page 118) came from Booth's nursery at Flottbeck, Hamburg. Because of Booth's Scottish connections it is possible that this seed, too, came from Scotland.

Although this information on the origin of the old stands is of great silvicultural and historical value, it is naturally too vague to be used in a discussion regarding the importance of provenance. Unfortunately, it must be stated, that even in the case of the young stands included in this yield investigation, provenance data are so vague, that they cannot be used as a basis of discussion. Nevertheless, an attempt has been made to clarify the matter of provenance by means of a compilation of the results of some earlier and more extensive experiments.

The first planned experiments with various strains of Douglas fir were carried out by Schwappach (1914). The seed was sown at Eberswalde in 1911, and the seedlings were planted at Chorin in 1915. Simultaneously, an experiment was carried out at Kaiserlautern in Pfalz by Münch (1923 and 1936). The experiments include the viridis, caesia and glauca sub-species. However, no less than three strains of the viridis type are from California, while the fourth originates from Snoqualmie, Washington (150—180 metres altitude).

The plots have been revised on several occasions, i.a. by Liese (1932, 1935 and 1936), who studied the resistance of various strains to frost and fungal attacks. Liese investigated especially the reaction of the tree to the needle cast, Rhabdocline pseudotsuga. This fungus was brought to Europe about 1925 and it was discovered in Sweden in 1931 (Lagerberg 1942). It generally attacks 15—20 year old stands. The viridis type of Douglas fir, however, has proved practically resistant to Rhabdocline (Liese 1938). The damage is minor if a proper strain has been introduced. Although common in America the fungus causes negligable damage only. Trees infected by Rhabdocline and Rhabdogloeum are easily found in the Puget Sound Region.

Much more serious is the damage caused by Phaecryptopus gäumanni. The majority of the thirteen stands in Skåne, examined by Witte (1948), were seriously affected. In Denmark (Buchwald 1940, Holm 1944) and Germany (Liese 1938) the attacks were so severe that further cultivation of

Douglas fir was strongly questioned. Whether or not certain provenances show greater resistance than others has not yet been proved in Denmark (Thulin 1949). Between 1946 and 1947, where the attack reached climax in Denmark, the increment of the stands was barely half the normal (Lundberg 1952) for at least two years. It should be emphasized, however, that the stands generally recovered remarkably soon.

The severity of the attacks in 1946 and 1947 was probably due to a combination of conditions which were favourable to the fungus and unfavourable to the trees (i.a. extremely cold winters with subsequent frost damage). Furthermore, a great number of stands were of an age when they were particulary susceptible to attack. A study of the frequency of attacks made in conjunction with this yield investigation showed that dense stands between 15—35 years of age are easily attacked. Very young open plantations and old stands remain unaffected. It might easily be assumed that mainly dense, young stands create the micro-climate that is suitable to the fungus (Hvass 1952). In certain stands trees under shelter were attacked more than open-grown trees in the same stand. This was also observed in a mixed stand of Douglas fir and Chamaecyparis, where the Douglas fir was spaced well apart with its healthy, green crowns above the Chamaecyparis canopy. An adjacent dense stand of pure Douglas fir of the same origin and age was badly affected by Phaeocryptopus.

The yield performance on the same plots has been studied by Kanzow (1936 and 1937). This investigation showed the Snoqualmie strain (150—180 metres altitude) to be considerably superior to the others, not only with respect to resistance to frost and fungal attacks, but also regarding increment. On the basis of Schwappach's sample plots and others, Kanzow (1927) concluded that, so far as Germany is concerned, the highest yield would be produced by strains originating from those parts of the climax region, where the monthly mean temperature is most equal to that of the German locality. In the state of Washington this would include the western slopes of the Cascade Range from 170 to 500 metres altitude. In Oregon and along the lower reaches of the Fraser River in British Columbia, seed could be collected from somewhat greater heights. In the case of the more northerly situated Fraser River, the higher sites have been recommended according to Kanzow, because the meteorological stations in this area (at 170 to 500 metres altitude) are located in narrow valleys that are potential frost pockets. Outside these valleys there are strains that are more sensitive to frost. For this reason seed from the Fraser River should be collected in higher sites. Kanzow is certainly correct when warning against extensive extrapolation of values obtained from scattered meteorological stations. The local variations are extraordinarily pronounced and erratic due to topographic conditions. However, the climate in the dells of the Cascade

Range is strongly influenced by the Pacific Ocean and is decidedly maritime. In my opinion, therefore, they cannot be regarded as extreme frost localities.

In the Netherlands, where great interest has been displayed in Douglas fir and where the area covered with this species now amounts to over 4.000 hectares, extensive provenance experiments have been pursued from 1923 (de Hoogh 1925). The latest revision of the material (Veen 1951) comprised no less than 35 provenances each represented in several parts of the country. The highest yield was shown by the strain from Chilliwack (BC), a location 100 km. from the mouth of the Fraser River and 540 metres above the sea level, and from Columbia National Forest (Washington) from an unknown altitude on the western slopes of the Coast Range. These results agree well with those of the German investigations, which showed that the coast type produced outstanding results. The investigation also showed that the bud bursting of the most maritime strain (Pacific Coast) was late, and the buds were consequently unaffected by spring frost. On the other hand, caesia seedlings originating from the areas with continental climate and high altitude (over 1.000 metres) developed early and were damaged by spring frost.

In Denmark, where the acreage of Douglas fir now exceeds 1.000 hectares, provenance experiments were started at the time of the first World War. New sample plots have been added successively. A compilation and report of the experiments was first presented by Opperman as early as 1929. The provenance experiments have later been described by Holm (1940). Even the Danish experiments clearly show that the viridis type is superior in growth and less susceptible to attacks by Rhabdocline than other types.

A further report on the Danish provenance experiments with Douglas fir has been published by Lundberg (1957). It deals with all experiments pursued by the Danish Forest Experiment Station from 1918 until 1940. The results closely agree with earlier ones and particularly with those reported by Veen (1951). The best provenances in the experiments have been Louella (Olympic Nat. Forest, Wash.), 300—400 metres altitude, Snoqualmie Pass (Wash.), 1.650 metres altitude, Howe Sound (Coast Range, BC), 150—600 metres altitude and Lower Frazer River Valley (BC), 120 metres altitude. Lundberg (l.c) also shows, however, that the superiority of the strains from west of the Cascade Range increases with respect to frost resistance and thus growth at increasing latitude of origin. For this reason Lundberg suggested that Douglas fir from more northerly regions of British Columbia should be tested. Progeny from the Danish stands dealt with in the investigation (Linaa and Lerchenborg) equal the best American progeny.

It is evident from the experiments mentioned, that the viridis (coast) type of Douglas fir is the only one which should be considered for introduction into southern Scandinavia. Naturally, the specifications regarding the provenances of Douglas fir are different in other parts of northern Europe. Investigations by Kujala (1937) showed that the viridis type is unsuitable in the Finnish climate. The same experience was made in Esthonia (Livland) by von Berg (1912), where Douglas fir from Snoqualmie suffered severely from frost. In the Norwegian experiments described by Hagem (1931) the best results were obtained when seed from the Fraser Valley and Salmon Arm was used. According to Hagem (l.c) these strains are most closely related to the green (coast) type. At least with respect to the Salmon Arm strain this statement is hardly compatible with current conception. As far as western Norway is concerned, the green type from northerly and high localities would appear to be the most suitable one. This was confirmed to a certain extent by a visit to Norway in 1955, when the author had opportunity to see several beautiful young stands of the green type of Douglas fir.

Douglas fir is obviously sensitive to changes of climate. Langlet (1938) classified Douglas fir as a »provenance tree». This is also confirmed by these experiments and by results from several forest plantings in U.S.A. (Isaac 1949). Consequently, there is every reason to attempt a strict delineation of the area where seed suitable for southern Scandinavia should be collected, even though this may be wrought with difficulties. In some of the investigations mentioned above the information regarding origin could not be regarded as completely reliable. In other instances pertinent data are lacking. Site conditions, forest type, the type and composition of the stand etc., are extremely valuable complements to the information regarding climate. Moreover, many of the experiments are unreplicated and thus largely subject to chance occurrences. Since, however, the experiments are so numerous, their value for the specification of Douglas fir cannot be underestimated.

Although a complex set of factors determines the boundaries of a species' spontaneous distribution, eventual comparisons within the area concerned can in this case certainly be limited to the temperature curves. Several experiments show that there is reason to define the localities, where temperature and growing season are equal to those prevailing in the new environment. In the case of Douglas fir, spring frosts may be disastrous, and the risk is directly related to the time of bud bursting. It is also essential to get a strain, the growth of which terminates in time. Douglas fir provenances with temperature conditions similar to those in southern Scandinavia should not be difficult to find, for instance on the slopes of the Cascade Range (Syrach Larsen 1947).

Existing experiments, however, provide a rather good basis for the specification of areas with strains of Douglas fir suitable in southern Scandinavia. It may thus be suggested that the collection of seed should currently be confined to a region located between the Columbia River in the south

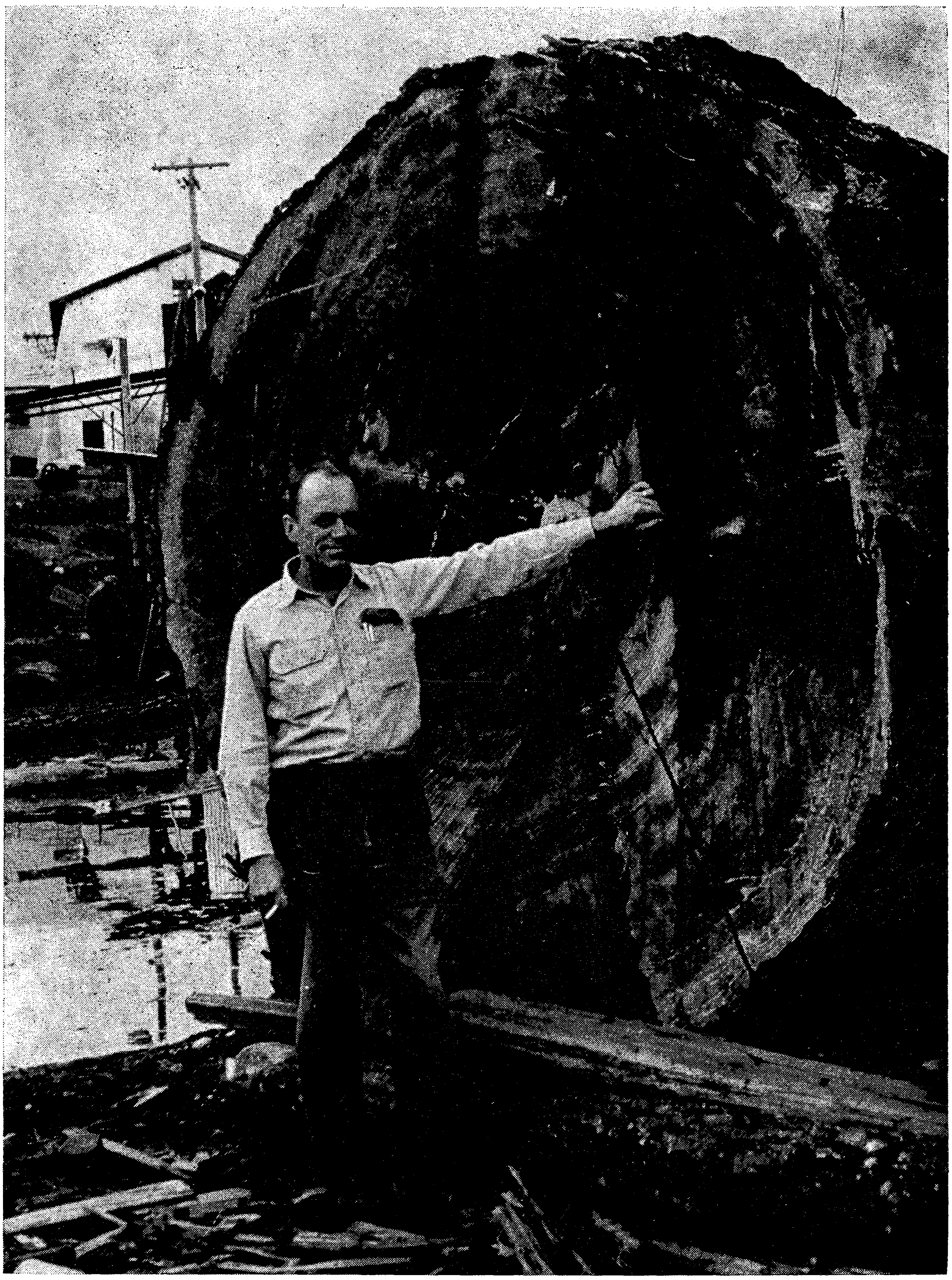

Fig. 26. Veneer log at a Darrington factory, Wash., U.S.A. It shows 330 annual rings at the butt-end.

and a line not far north of the Fraser River. The altitude of the area bounded by the two rivers is varying from 200—800 metres. There is, moreover, every reason to locate strains which have proved themselves superior in earlier experiments. Domestic seed of good quality should be used, if possible.

Nevertheless, the Douglas fir provenance has been the subject of speculation in several countries, e. g. Denmark (Juncker 1949, Heilman 1950, Schulze 1951 and others). Since the Douglas provenance experiments have now reached such an advanced stage, there should be no reasons to try a delineation of the areas suitable for seed-collection by means of a formula based on climatic observations.

Accompanied by Mr Leo Isaac, who is an expert on Douglas fir, the author had the privilege in the summer of 1951 to become more acquainted with some well-known Douglas fir localities. Among places visited were Louella on the Olympic peninsula, which is the source of several beautiful stands in Europe e.g. in Denmark. Since there is a sparsity of old forests, the impression of the place is not overwhelming, however.

Darrington and Granite Falls, the almost classical places referred to in the provenance literature, are located in the Mount Baker National Forest. The forests are very impressive because of the great variety of species and the topographic conditions. A. relatively limited area here may certainly provide a wealth of material for provenance studies. Following a route from Darrington (200 metres altitude) to Granite Falls over White Church, and along the Sauk River via Bedal and Barlow Pass (1.000 metres altitude), the author became well aquainted with this interesting area. Even in the pass, where snow remained in the beginning of July, there were impressive trees of Douglas fir. Some attractive stands at Granite Falls, where the growing season starts about one month earlier were also visited. Obviously, it is reasonabel to expect a high degree of physiological variation in this area.

The area surrounding the Fraser River in British Columbia also appeared to be a region with strains that would succeed in our climate. Near the town of Chilliwack, which is well known in the provenance literature, large areas on the mountain slopes above Sardis are covered with beautiful forests.

The term »provenance», synonymous with the German »Herkunft», has consistently been used in the foregoing pages. The meaning of provenance is origin, in this context the tract or habitat, from which the seed was collected. The term is generally used until experiments have shown whether the population concerned is an ecotype, i.e. whether it possesses characteristic or distinct physiological traits. Naturally, it is doubtfull in certain transition cases, whether a strain is a climatic race (ecotype) of one species, or a mixture of closely related species. Modern experimental taxonomy should then be able to provide an answer by an analysis of fertility and progeny. Ecotype will here be used as equivalent to race, and climatic races are ecotypes that are adjusted to the climate. The ecotype is consequently a product of natural selection, and the unit within a species that is adapted to survive a special set of environmental conditions. It is also generally true that the ecotype is unable to survive in circumstances which are essentially different from those prevailing in its natural habitat.

Climatic races are not uniform as regards their genetic composition, and they have fully interchangeable genes. When two ecotypes of the same species from climatically different habitats cross, the progeny may be able to succeed in a more diversified climate than either of the two parents. This phenomenon may explain the reason for the results of experiments with Douglas fir obtained by Munger and Morris (1936, 1942). They showed that trees originating from the areas of Darrington and Granite Falls (about 200 metres altitude) grew better than trees of other Douglas fir strains in the experiment (13 provenances) on various experimental sites below 1.500 metres.

Hybrids with superior growth properties have also been produced experimentally from widely separated climatic races. The experiments carried out with separate climatic races of Potentilla glandulosa (Clausen, Keck and Hiesey 1939, Clausen 1949) are fundamental. Similar results have also been obtained in the case of forest trees; e.g. by crossing Pinus ponderosa from the Rocky Mountains with Pinus ponderosa from California (Duffield 1950).

Differentiation into ecotypes is much more common in species with a wide distribution than in the case of local or endemic species. As far as Douglas fir is concerned, therefore, there is reason to assume that a number of widely different ecotypes occur within a limited area. It would naturally be of immense value to ascertain the degree of genetic variation for geographic rases occurring on the slopes of the Cascade Range.

Douglas fir growth on the Pacific Coast and in southern Scandinavia

Douglas fir attains large dimensions in its natural range. Thus, the height development in America (Mc Ardle 1930) is superior to that of the present material. Wind exposure is undoubtedly one of the reasons why Douglas fir in southern Scandinavia displays a retarded height development at increasing age. Möller (1951) stated that the height development of trees is checked by persistent wind. This was found for Douglas fir as well (Abell 1954). Stunted tops worn by the wind and crowns with a strongly retarded height growth were recorded during the examination of sample plots in several old stands. Thus, the crowns of the 87 year-old stand at Gunderslevholm, (Plot No. 58), were very flat.

At Buderupholm, (Plot. No. 55, 72 years) and Silkeborg, (Plot. No. 81, 68

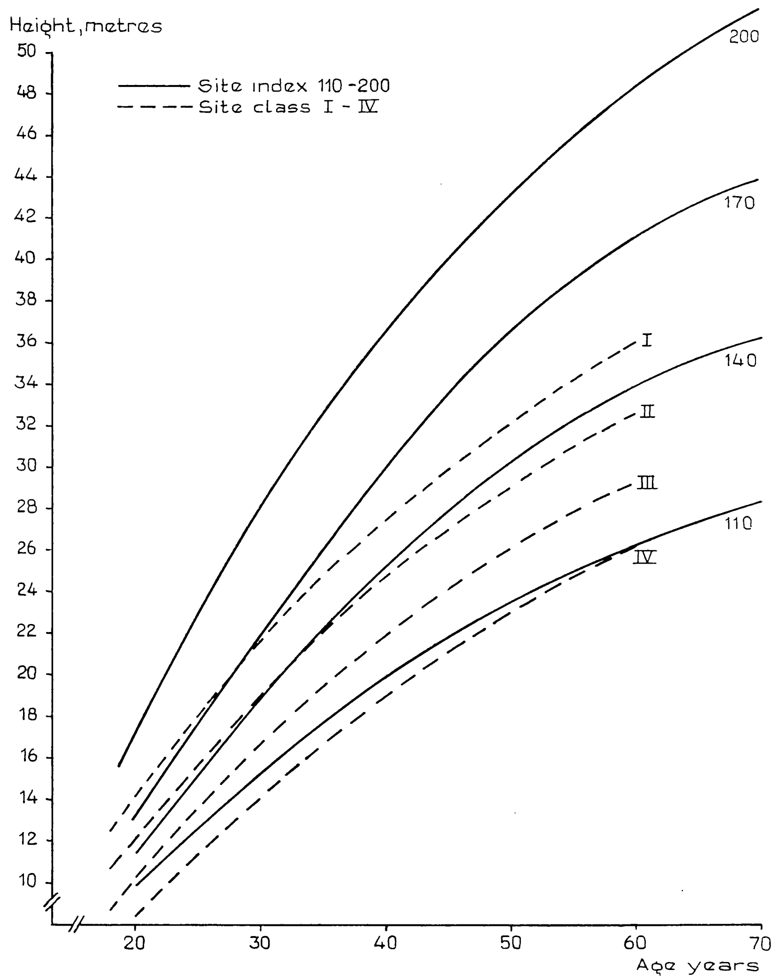

Fig. 27. Comparison between the height development of Douglas fir according to this investigation (site class I—IV, — — — — — — dashed line) and according to Mr Ardle (1949) on the Pacific coast (site index 200—110, ———————— full line). Site index indicates the height in feet at 100 years for dominant and codominant trees.

years), too, the tops were badly worn by wind. According to the former forest supervisor H. H. Biilman this was also observed in the old Douglas fir stands at Frijsenborg. Naturally, a height index is then a less suitable means of expressing site quality.

However, the great differences between the height development of Douglas fir in its native habitat according to Mc Ardle (1949) and that shown by this material, naturally cannot be caused by wind alone. The conditions for Douglas fir growth in the Pacific Coast region are decidedly more favourable above all on account of heavier rainfall, higher mean temperature, longer

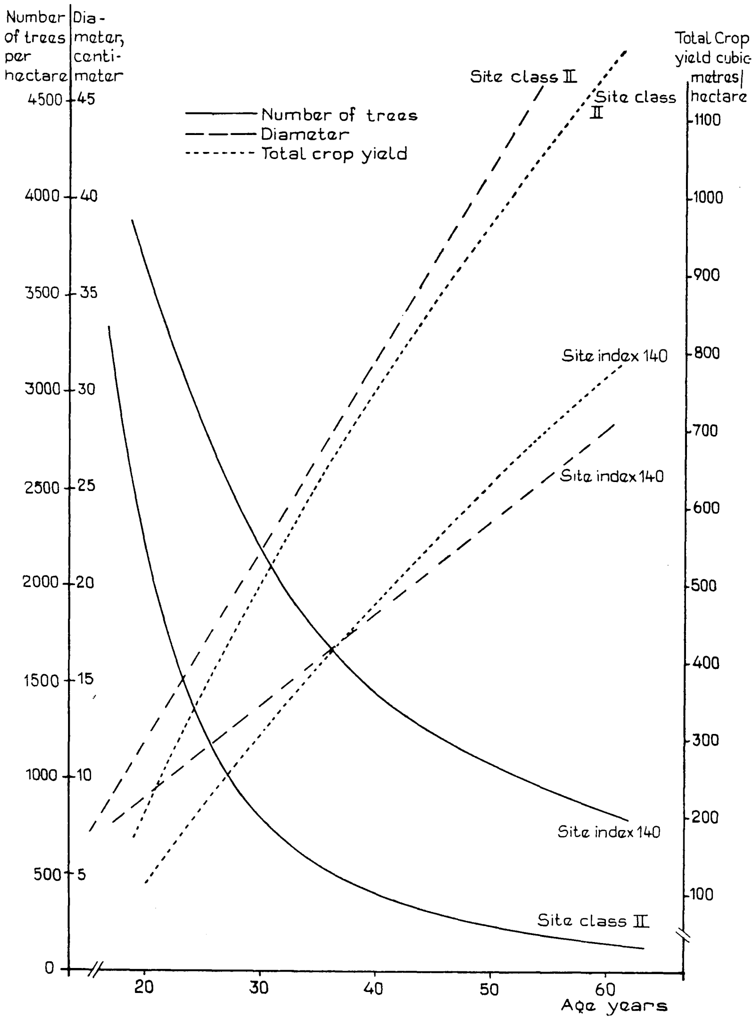

Fig. 28. Comparison between the number of trees per hectare (———— full line), diameter (— — — — — — dashed line) and total yield per hectare (....... dotted line) for site index 140 (Mc Ardle 1949) and for site class II in this material.

growing season etc. The best sites on the Pacific Coast (Site index 200) are also appreciably superior to Site class I in southern Scandinavia. According to fig. 27, the difference in height amounts to 11 metres at a stand age of 50 years.

In Mc Ardles investigation (1949) height in feet at a stand age of 100 years is used as a site index. The interval between site indexes is 10 feet, and three site indexes constitute a site class. The material was obtained from observations in representative stands distributed over 261 areas, and

Fig. 29. The biggest Douglas fir in Sweden is growing in a small stand at Rössjöholm in Skåne (Plot No. 74 in the sample plot list). In 1955 at an age of 66 years the mean height of the other 25 trees was 28.2 metres. This tree was 34.0 metres high and measured 94.0 cm at breast height.

from revisions of sample plots (a total of more than 2.000 revisions). The region investigated contained tracts with precipitation up to 2.500 mm. All types of soil are represented from sea-level to 1.000 metres altitude. The stands were all unthinned. Nevertheless, it may be of interest to compare certain data for the American and the Scandinavian stands.

A comparison of this kind is made in Fig. 28, where curves for the number of trees, diameter and total yield are shown. The comparison is made for site index 140 (Mc Ardle 1949) and site class II, which have approximately the same height development (c.f. Fig. 27).

The curve describing the number of trees of the thinned stand (Fig. 28) is quite different from that of the unthinned stand, where the number of trees is reduced only by mortality. Thus, when the thinned stand has 142 stems per hectare at 60 years, the unthinned stand still has 830. This naturally affects the diameter growth. The mean diameter of the thinned stand (Site class II) is 52 centimetres, whereas that of the unthinned stand (Site index 140) is only 28 centimetres.

The curves representing the total yield have been derived from the yield tables and are shown in the same graph. For Douglas fir, site class II, the total yield at 60 years is 1150 m^3 per hectare, whereas for site index 140 it is only 775, i.e. a difference of 375 m^3. However, no less than 720 m^3 of the total yield in site class II has been removed in thinnings. In the case of site index 140, approximately 2.900 trees have been lost by mortality before contributing to the yield. The approximate volume of these trees, may be estimated to the difference in yield between the stands, i.e. 375 m^3 (Burger 1951, Möller 1952, 1953). This comparison between thinned and unthinned stands elucidates the great values that can be saved by means of proper stand management. As the supply of virgin forests in north-west America is gradually diminishing, the importance of second growth management has increasingly been realized.

Based on comparisons with European stands, views of this considerable yield problem have been presented by e.g. Briegleb (1952). An outline of the potential development of managed domestic stands has been attempted by Heiberg and Haddock (1955) on the basis of European experience and sample plot material from several thinned stands.

Douglas fir growth according to this and other European yield investigations

The Douglas fir yield conditions have been investigated in England by Hummel and Christie (1953) and in Germany by Kanzow (1937).

The English yield tables of 1953 are a revision of the previous yield tables published by the Forestry Commission in 1928. Similar to the old tables, the new ones have been constructed by graphic methods. The new tables, however, are entirely based on permanent sample plot records. Volumes and form quotients pertain to measurements over bark, and the term »top» height has been introduced in addition to mean height. The top height at a stand age of 50 years is the basis of site classification and the interval between quality classes is 10 feet, i.e. in the case of Douglas fir the height of Quality class I = 110 ft., Quality class II = 100 ft. etc.

Since the tables cover seven different conifers, comparisons are possible. It must be borne in mind, however, that the same quality class does not signify the same height at a stand age of 50 years for all the species. Quality class I shows the best height development for the species concerned. Thus, for an age of 50 years, quality class I shows a height of 60 ft. for Scots pine, 80 ft. for Norway spruce, 110 ft. for Douglas fir etc. To avoid misunderstanding, it is therefore usual in practice to refer to »the 60 ft. class», »the 70 ft. class» and so on.

The German material (Kanzow 1937) is divided into two site classes, »I and II Ertragsklasse» with a mean height at an age of 50 years of 28 and 23 metres respectively. Kanzow's site class tables are also used as a basis when Wiedemann (1939) compiled a material that covered a further ten years, i.e. a maximum stand age of 60 years. The German tables are based partly on sample plots established by the Prussian Research Institute, 17 of which were laid out by Schwappach in 1911 (see page 54) and 12 about a year later. The tables also contain data from 59 plots in Braunschweig, Baden, Switzerland and Holland. The material has been analyzed by graphical methods similar to those used by Wiedemann in »Die Rotbuche» (1931).

Fig. 30 displays the height development according to the German, English and present tables. The figure shows that the curves agree relatively well. The height curves for Douglas fir in southern Scandinavia describe courses that are generally similar to those representing Douglas fir in Great Britain and Germany.

Quality class III, which is in the middle of the English material, has been used for a further comparison concerning the numbers of trees, diameter, basal area and current basal area increment per hectare. Showing a height of 26.4 metres at a stand age of 50 years, the corresponding height curve in the German material is placed approximately mid-way between Ertragsklasse I and II and slightly above site class III in the present tables. Data regarding number of trees, diameter etc. for the corresponding height have been caluculated by interpolation in the German and in the present tables.

Fig. 31 shows a comparison between the yield tables with respect to number of trees, diameter and basal area. Regarding the number of trees, the German material consistently has clearly higher values. To a certain extent, however, the present opinion in Germany (Hennig 1951) is, that thinning according to these tables is too light, and that Douglas fir should be thinned more heavily in the young ages. The number of trees in the English tables is lower than that shown by the present material in the young ages. On the other hand, the number of trees is higher after 35 years of

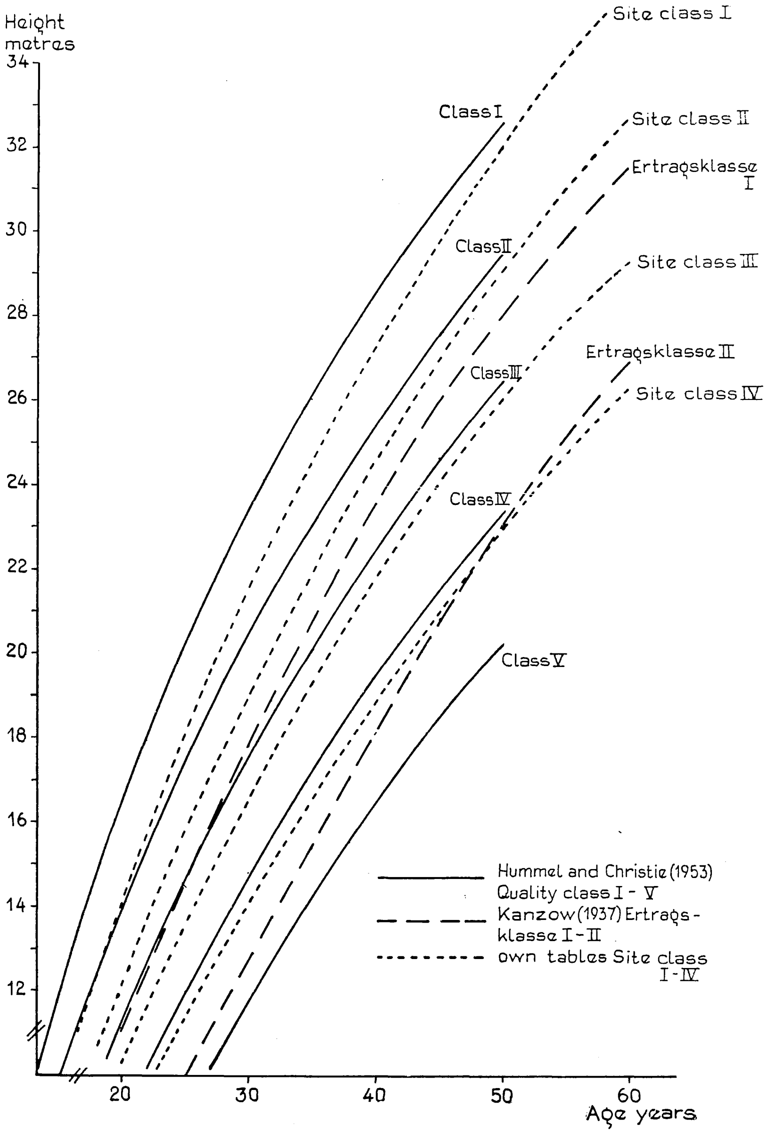

Fig. 30. The mean height of Douglas fir according to: Kanzow (1937) Ertragsklasse I and II, respectively, dashed lines — — — —, Hummel and Christie (1953) Quality classes I—V, full line ———— and present material. Site classes I—V, dotted lines - - - - - -

age. The diameter growth of the mean basal area tree in the remaining stand is nearly constant in the present tables, and diminishing in the others as a result of the lower grade of thinning. The basal area of the remaining stand, which is a product of the number of trees and the mean basal area, should be rather equal in the German and English material. The present

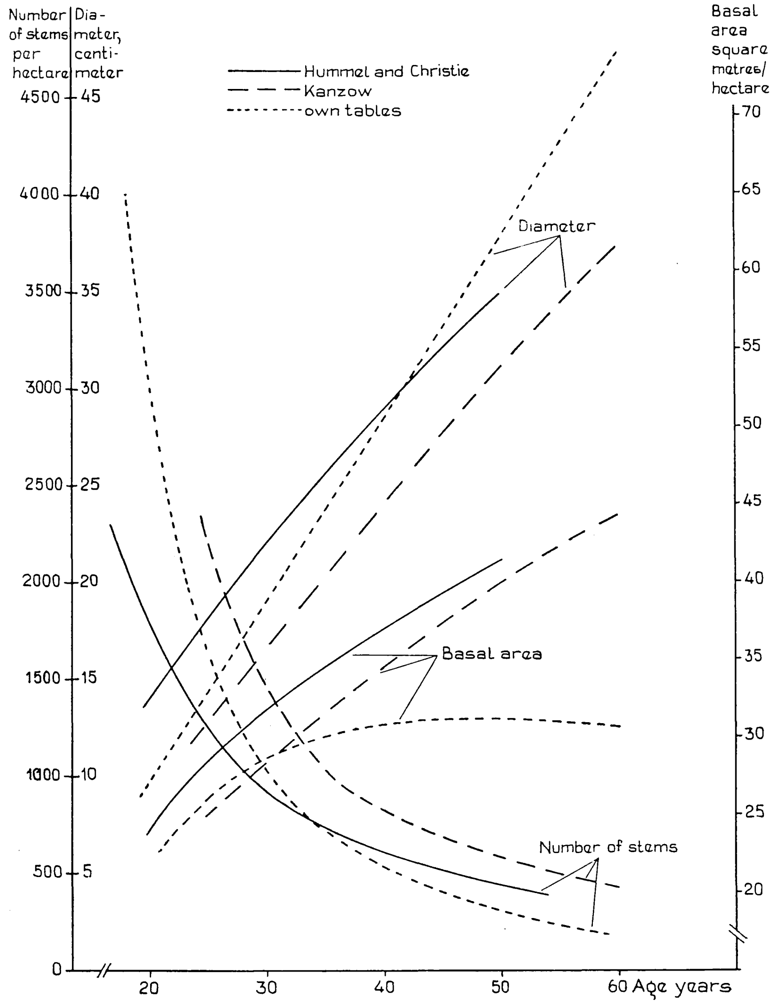

Fig. 31. Diameter of the remaining stand, number of trees and basal area per hectare at equal mean hight (H_{50} = 26.4 m) according to Kanzow (1937) (— — — — dashed lines), Hummel and Christie (1953) (———— full lines) and own tables (- - - - - dotted lines).

tables, however, deviate by showing a relatively low basal area in the high ages.

The same tendencies regarding the basal area of the stand appear when comparisons are made between Scandinavian and other European yield tables for Norway spruce. Thus, if the Danish tables (Möller 1933) are compared with the German (Wiedemann 1949) and the English (Hummel and Christie 1953) tables, it will be seen that the Danish tables show a considerably lower basal area.

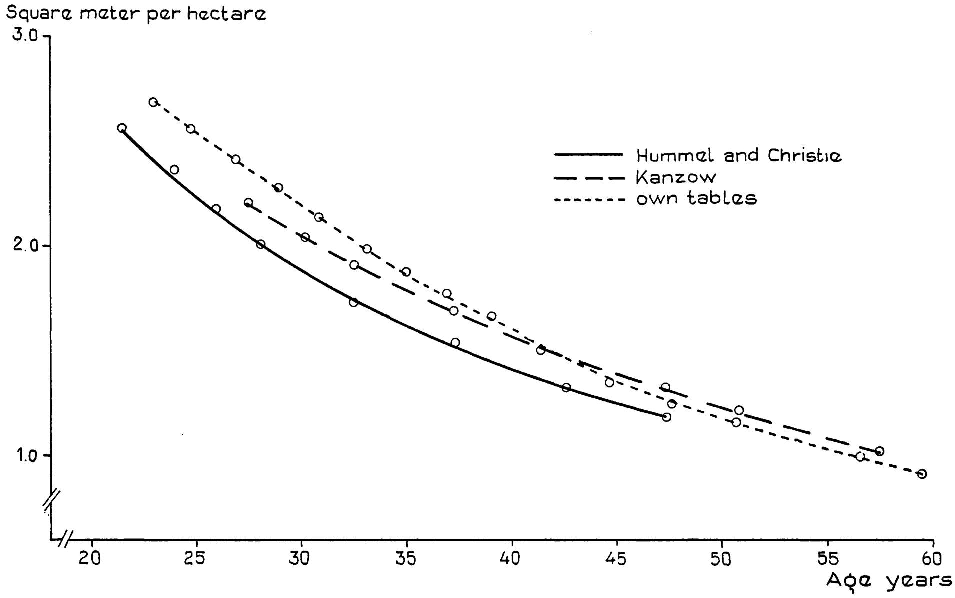

Fig. 32. Current basal area increment for the height curves representing H_{50} = 26.4, according to Hummel and Christie, quality class III (——————— full lines). Kanzow (———— dashed lines). Own tables (- - - - - dotted lines).

Regarding yield capacity, the current basal area increment has been considered most suitable for comparison. Values have been obtained from tables representing the height curves for H_{50} = 26.4. Due to differences in representation (German — »Derbholz» vs English — volume of trunk below 3″ top diameter vs present — total trunk volume) it has not been advisable to compare current volume increment. Thus, the difference in increment between total volume and volume below 3″ top is considerable, especially in youth when many of the trees are smaller than 3″ at breast height. In the present material it has been advantageous to calculate the current basal area increment since it has appeared relatively independent of the site. This was also found in the German investigation, so no extensive interpolations were necessary.

Since, as already pointed out, it may be assumed that increment is unaffected by the degree of thinning, within relatively wide limits it has been considered permissible to ignore the possible differences in stocking in the yield comparisons made.

The basal area growth development according to the tables is shown in Fig. 32. The differences in basal area increment are apparently relatively slight.

It may be pointed out in this context, that with respect to total yield the differences between the tables are very small. The English material is certainly slightly lower, but this partially depends on differences in the mode of presenting the yield.

The growth and yield performance of Douglas fir in relation to that of Norway spruce (Picea Abies).

Interest in exotic species is chiefly centred on the yield capacity in relation to that of indigenous species. In this case it was natural to compare the growth of Douglas fir with that of Norway spruce (Picea Abies).

To secure a valid comparison between Douglas fir and Norway spruce in this respect, the material was collected from places where the species were growing adjacent to each other. These stands were required to be comparable with respect to level, topography and exposure, and, as far as could be judged, hydrological conditions. Stands unsuitable for comparisons owing to previous calamaties were excluded. In certain cases the age differences were considerable (cf Table 10), but the material would have been altogether too scanty for a comparison, if equal age had been required. Mostly it has been possible to obtain information on the history of the stands from the records kept by the local forest management authorities.

The requirements of comparison fulfilled, the soil type was tested in each case by simple methods. After a classification into morain soils and deposits, the soil structure was determined according to methods described by Ekström (1951). This included a smoothing test,[1] a determination of the colour of the dry soil, and a roll test. The thickness of the roll of soil in the latter test indicates the degree of cohesion of the soil, i.e. its clay content. If the stands were of equal age, the soil conditions were recorded in agreement with current terminology (Tamm 1940). The profile was described for podzolized soils. The occurrance of lesser vegetation has been recorded to supplement the picture regarding the biochemical activity of the humus layer. It has also been noted, whether the stands have been affected by high water table.

If the stands could be considered comparable on the basis of these investigations, the site classes were determined for each stand according to the method already described.

Because of the strict requirements placed on the comparability of the stands, only 33 locations were found where the conditions could be considered equal. A detailed account of these stands is presented in Table 10. Owing to variations, the limited material did not permit an extensive scrutiny of the significance of the individual site factors. The site class may be considered a collective expression of these factors.

[1] A dry sample of the soil is smoothened between the fingers. The amount remaining on the fingers indicates the adhesion of the soil.

Table 10. Summary of Douglas fir and Norway spruce stands included in the comparison.

Douglas fir							Norway spruce			
Plot number	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
4	Gisselfeld, Denderup Vænge, Avd 202	I	39	26.5	Medium heavy clayey moraine	Crumbly mor. Oxalis acetosella. Planted on abandoned field	II	58	22.2	F[1]=3 cm melted mor. Attacked by Fomes annosus. Site class II according to a survey at the age of 44 years
16	Næsbyholm, Østerskov, Avd 37	I	29	20.8	Sandy-clayey moraine	Crumbly mor with Oxalis acetosella and Urtica dioeca. Light low thinning. Attacked by Phaeocryptopus.	I	23	10.5	Crumbly mor
1	Gisselfeld, Hesede, Avd 147	II	49	29.2	Loamy-clayey moraine	Crumbly mor with Rubus idaeus and Calamagrostis sp.	II	85	26.0	Site class II according to a survey in 1938
7	Gisselfeld, Denderup Vænge, Avd 258	II	47	27.9	Medium heavy clayey moraine	Mull. Oxalis acetosella and Rubus idaeus. Scattered snow-bent trees.	II	58	24.3	Site class I—II according to a survey in 1938 (44 years 20,0 metres)
78	Linaa, Vester-skov, Avd 32 e	II	44	26.3	Sandy moraine on 30 cm deep, loamy moraine with mica	Crumbly, loose mor. F=2 cm, H= 4 cm. Hylocomium sp.	II	51	21.0	15 cm thick matted mor
48	Mejlgaard, Avd 106 b	II	37	22.6	Sandy moraine. Slightly clayey	Mor. Oxalis acetosella	II	74	23.7	According to information, the stand deviates from the tables (Möller). The height curve beeing more level after 40—50 years, this plot is put in site class II

[1] F = Decomposition layer
H = Humus substance layer

Douglas fir							Norway spruce			
Plot number	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
49	Mejlgaard, Avd 134 a	II	35	21.1	Sandy moraine	Mor. Oxalis acetosella and Rubus idaeus	II	64	22.3	Site class II according to remark for plot No. 48
50	Mejlgaard, Avd 273 a	II	38	24.6	Sandy moraine	Mor. Oxalis acetosella	II	59	23.3	
51	Mejlgaard, Avd 413 b	II	37	23.2	Sandy moraine	Mor. Oxalis acetosella	II	69	23.0	Site class II according to remark for plot No. 48
67	Langesø, Ruehed, Avd 8	II	47	28.7	Loamy-clayey moraine	Crumbly mor. Planted on abandoned field	II	47	19.5	Mor
69	Langesø, Moridskov, Avd 6 c	II	75	35.8	Clayey sandy moraine	Crumbly mor. Rubus fruticosus and Rubus idaeus, Oxalis acetosella and exceptional Lamium sp., Acer and Ulmus. Supplementary group planting after beech. Unexposed location. F=2 cm, H=7 cm	I	75	31.5	Mor. Supplementary group planting in a beech stand. Attacked by Fomes annosus
99	Langesø, Moridskov, Avd 6 b	II	25	16.6	Clayey-sandy moraine	Crumbly mor	I	25	13.1	Crumbly mor
3	Gisselfeld, Hesede skov, Avd 127	III	28	16.0	Sandy moraine	Mull. Oxalis acetosella and Deschampsia sp. F=2 cm, H=1 cm	II	50	20.0	
22	Petersgaard, Stensby skov Avd 106	III	30	16.7	Medium heavy clayey moraine	Mor. Urtica dioeca and Rubus idaeus. Provenance Upper Fraser River. South slope	I	29	15.5	Mor

Douglas fir							Norway spruce			
Plot number	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
19	Petersgaard, Langebæk, Avd 26	III	31	16.8	Sandy-clayey moraine	Crumbly mor. Douglas fir canopy over Chamaecyparis Lawsoniana. No attacks by Phaeocryptopus	I	31	15.5	Mor
20	Petersgaard, Stensby skov, Avd 22	III	33	19.0	Sandy-clayey moraine	Mor. Urtica dioeca and Rubus idaeus	I	33	16.1	2 cm thick undecomposed needle layer. The spruce heavily attacked by Fomes annosus. Fruiting bodies on the ground
5	Gisselfeld, Nygaard Vænge, Avd 46 N.V.	III	42	22.5	Sandy moraine	1—3 cm thick layer of needles. The stand planted on abandoned field	II	42	17.2	Mor. The spruce heavily attacked by Fomes annosus
54	Buderupholm, Tøtteruphus, Avd 130	III	61	30.4	Sandy moraine	Mor. Oxalis acetosella, Deschampsia sp., Pteridium aquilinum, Juncus effusus Slightly podzolized Dense regrowth of Douglas fir	II	61	23,0	Mor
34	Randbøl, Gødding Skov, Avd 1	III	21	10.4	Sandy moraine	Crumbly mor with evidently good activity in the humus layer. No vegetation. Phaeocryptopus attacks in 1947—1949	III	30	8.9	Mor

Douglas fir							Norway spruce			
Plot number	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
81	Silkeborg, Vesterskov, Avd 331	III	80	33.9	Sandy-clayey moraine	Crumbly mor, F=½ cm, H=1½cm, Oxalis acetosella, Natural regrowth of Douglas fir and Norway spruce. Crowns stunted by wind	III	80	26.6	Mor
161	Silkeborg, Nordskov, Avd 126	III	33	17.2	Sandy moraine	Crumbly mor	IV	37	11.0	Mor
32	Palsgaard, Avd 98 g	III	43	24.1	Sandy moraine	Mor	II	43	17.7	Mor
63	Wedellsborg, Balsløv, Avd 6	III	32	17.9	Sandy moraine, slightly rocky	Crumbly mor. F=1 cm, H= 4 cm. Scattered occurrence of Rubus ideaeus and Pteridium aquilinum. Northwest slope	II	32	13.2	Crumbly mor. The average height curve of the Norway spruce is somewhat lower than that in Möller's quality class II up to 25 years, but then it descends to III—IV, due to, among other things, Fomes annosus
64	Wedellsborg, Rendebjerg, Avd 15	III	39	21.5	Gravelly moraine with a few boulders	Crumbly mor. F=3 cm, H=1 cm. Evidently good activity in the humus layer. Scattered occurrence of Oxalis acetosella and Rubus idaeus	II	32	13.2	
79	Linaa, Vesterskov, Avd 10	IV	65	28.0	Sandy moraine	Mor layer 5 cm. Height growth nearly finished. Dense regrowth of Douglas, Abies and Picea	III	65	21.6	Heavy mor

Douglas fir							Norway spruce			
Plot number	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
52	Buderupholm, Tøtteruphus, Avd 93	IV	61	26.3	Sandy moraine	Crumbly mor	III	71	23.1	
55	Buderupholm, Skelhus Skov-part, Avd 190	IV	72	30.7	Sandy moraine	Mor. Oxalis acetosella and Juncus effusus. Good water conditions. Crowns stunted by wind	II	70	26.8	Mor
33	Ranbøl, Gødding Skov, Avd 18	IV	21	9.4	Sandy moraine	Mor. Stand planted after Norway spruce under shelter of birch	III	21	6.9	Mor
139	Silkeborg, Avd 328 b	IV	58	27.1	Sandy moraine	Crumbly mor	II	58	24.4	Mor
28	Palsgaard, Gludsted Pl., Avd 9 m	IV	28	11.5	Sandy moraine	Mor	IV	26	6.4	Mor
27	Palsgaard, Gludsted Pl., Avd. 116	IV	22	8.3	Sandy moraine	Planted on original heath after one generation of Norway spruce	IV	68	18.5	
82	Langesø Ruehed, Avd 8 b	IV	63	27.0	Sandy moraine	Crumbly mor	III	65	21.5	Mor

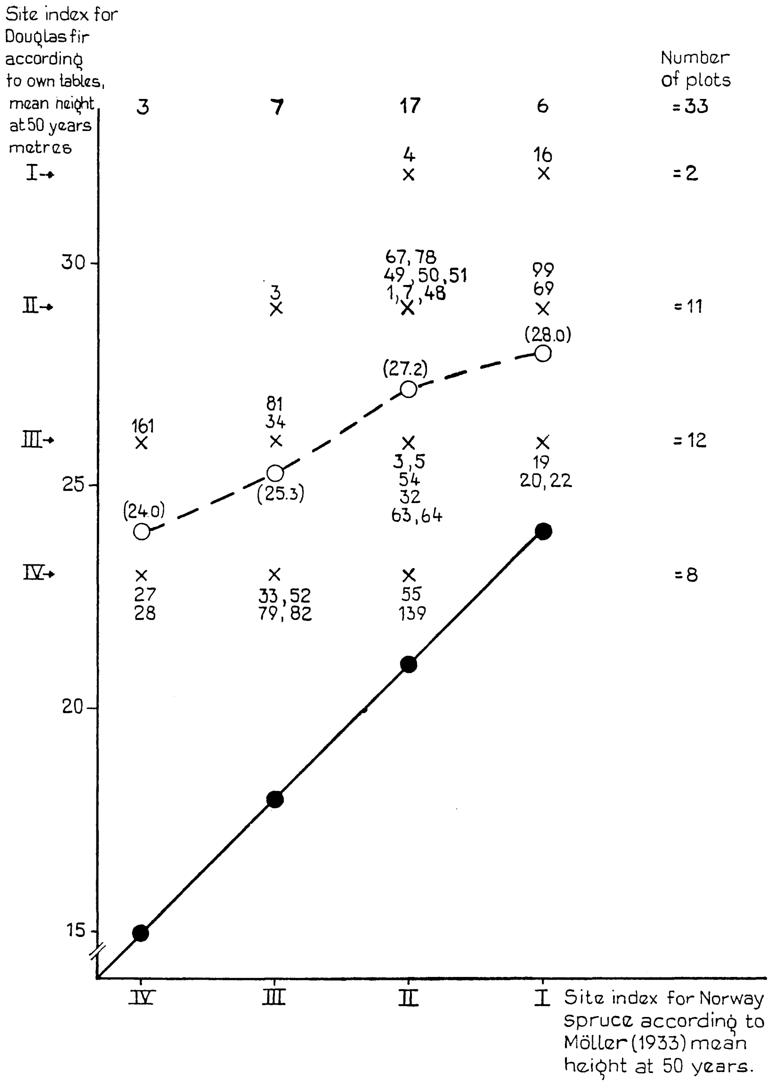

Fig. 33. Height development of Douglas fir (———— dashed line) compared with that of Norway spruce (———— full line) in the corresponding Norway spruce site class. The figures refer to the list of sample plots in table 10. The figures within the brackets (28,0) indicate the mean height of all Douglas fir stands in this Norway spruce site class.

The result of the comparison between Douglas fir and Norway spruce with respect to height development on equal sites is presented in Fig. 33 and Table 11. The comparison refers to 50-year old stands.

In the figure the site classification for Norway spruce according to Möller (1933) has been marked on the X-axis. Height and the corresponding site class for Douglas fir have been marked on the Y-axis. The height develop-

Table 11. A comparison between the height development of Douglas fir and that of Norway spruce on various Norway spruce site classes.

	Site class I	Site class II	Site class III	Site class IV
The height of Norway spruce at an age of 50 years according to Möller (1933), metres	24.0	21.0	18.0	15.0
The height of Douglas fir on equivalent sites according to the present investigation material, metres	28.0	27.2	25.3	24.0
Difference in height, metres	+ 4.0	+ 6.2	+ 7.3	+ 9.0
Difference, per cent	+17	+29	+41	+60

ment of Norway spruce in the various site classes has been denoted with a full line. Observations regarding the height of Douglas fir in the various Norway spruce site classes were then plotted according to site classes and marked with their plot numbers. The mean height of Douglas fir in each Norway spruce site class was calculated and a curve (dashed line) drawn through the plotted values.

Fig. 33 shows a great difference in height between the species in corresponding Norway spruce site classes. The dispersion of values is certainly considerable, but all the mean heights of Douglas fir are greater than the height of Norway spruce in corresponding site class. The difference is so marked, that even Douglas fir in the lowest site class shows a height approximately equalling that of Norway spruce in the highest site class. Variations in the growth of Douglas fir within each Norway spruce site class may be caused by the variability of the strain, climate when planted as well as minor differences in the site conditions. The superiority of Douglas fir is more noticeable in the low Norway spruce site classes.

On the basis of survey reports obtained from the forest districts where Douglas fir is well represented, it has previously been possible to establish considerable differences in height development between the species. The curves (height in relation to age) showed, that the Douglas fir height curve for the districts examined — Langesø, Silkeborg and Bornholm — was situated above that of Norway spruce. Merely indicating tendencies, however, this method cannot be used for a direct comparison between the species. Further, no information is obtained regarding the mutual relationship on equal sites.

A numerical presentation of the differences is given in Table 11, which shows that the height difference between the species in Norway spruce site class IV is no less than 60 %. The table also shows that the difference in height between the site classes I—IV for Norway spruce is 9 metres, whereas for

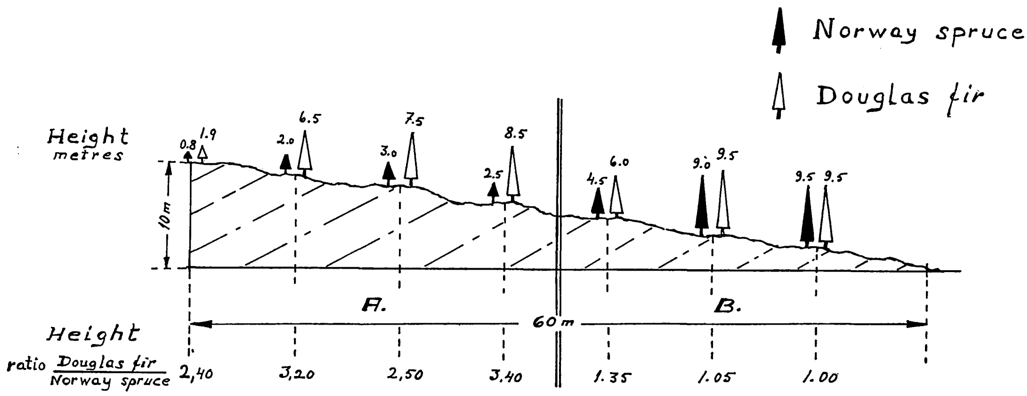

Fig. 34. Profile of a slope in the Silkeborg state forest district with simultaneously planted Douglas fir and Norway spruce. The height of the species in metres is given above the trees in the diagram. The ratio between the height of Douglas fir and that of Norway spruce is given at the bottom of the diagram.

Douglas fir it is only 4 metres. This may indicate that Douglas fir is less specific than Norway spruce with respect to site quality.

The following investigation which was carried out in the Silkeborg state forest district (department 275 b Sønderskov), is a good example of the relationship between the growth of Douglas fir and that of Norway spruce under various site conditions. The author visited the experimental area in 1952 accompanied by the Danish forest officer, Mr. E. Oksbjerg, who kindly made the results of his 1956 height measurements available.

Mixed individually, Douglas fir and Norway spruce were planted on a slope, the profile of which is shown in Fig. 34. The area was cultivated prior to planting. In the upper part of the slope (A in the diagram) most of the morain soil, which had been turned in cultivation, disappeared because of sand movement. The trees were rooted in a deep layer of leached sand. The lesser vegetation consisted of heather only.

In other lower part of the slope (B in diagram) the ridges of soil between the furrows remained, and the trees were rooted in a layer of morainic gravel. The lesser vegetation chiefly consisted of grass.

In all places of measurement, marked with trees on the diagram, the height of 5 Douglas firs and 5 Norway spruces were measured. The height figures noted on the diagram are the mean values of these observations rounded off to the nearest half metre. The figure shows that the height of Norway spruce declines rapidly as the ground level increases, i.e. at decreasing site quality. The height of Douglas fir, however, remains relatively stable.

The great adaptability of Douglas fir has been emphasized by i.a. Tarrant (1949), Gessel and Lloyd (1950). On the basis of experience from Denmark

Holm (1940) claims that the use of Douglas fir in forestry will be of greatest importance on the poor sites.

German investigations, too, show that the height of Douglas fir is considerably greater than that of Norway spruce. Thus, Jahn (1954) reported that the height of Douglas fir in 47 out of 69 comparable cases, was greater than that of Norway spruce. The mean difference was 20 %.[1]

In the remainder of the comparison between the species, chief interest is attached to the total yield. The total yield of Norway spruce at an age of 60 years in the site classes I—IV (Möller), were obtained by adding the volume of the remaining stand at this age to the volume removed in thinning. The total yield at an age of 60 years in the corresponding Douglas fir site classes, i.e. with heights of 28.0 m, 27.2 m, 25.3 m and 24.0 m respectively at 50 years, were obtained by interpolation in the column for total yield in the Douglas fir tables. A comparison between the total yield of Norway spruce and that of Douglas fir in the corresponding site classes is shown in Table 12.

The table shows that the total yield of Douglas fir at an age of 60 years is lower than that of Norway spruce in site class I, although Douglas fir is considerably superior as regards height. In the other Norway spruce site classes, however, Douglas fir yields decidedly more; this is particularly the case in Norway spruce site class IV, where the difference is no less than 64 %. On this site, Douglas fir yields almost as much Norway spruce in site class II.

In comparison with Norway spruce, Douglas fir displays relatively slight differences in total yield between the various Norway spruce site classes. While the difference in total yield between the site classes I and IV is as much as 600 m³ for Norway spruce, the corresponding difference for Douglas fir is as small as 180 m³, i.e. the yield ratio approximately equals

[1] The difference in height development between Douglas fir and Norway spruce is an important factor to consider when mixed stands are being established. It is rather common to mix Douglas fir and Norway spruce with for example every fourth tree a Douglas fir (Hesmer 1952, Karlberg 1952). This ratio is chosen to reduce the costs of expensive Douglas fir seedlings. Since Norway spruce usually shows high survival after planting, the risk of failure, too, is reduced.

To prevent the Douglas fir from completely outgrowing the Norway spruce, the former is usually planted later. Abell (1954) suggests the following interval on the basis of experience obtained from Fyn in Denmark:

Norway spruce, site classes (Möller l.c.)	better than I½	Simultaneous planting of Douglas fir and Norway spruce
—»—	I½—II½	Douglas fir is planted 2 years after Norway spruce
—»—	below II½	Douglas fir is planted 3—4 years after Norway spruce

It should be borne in mind, however, that severe frost sometimes may reduce a plantation to a pure Norway spruce stand.

Table 12. The total yield of Douglas fir at an age of 60 years in the Norway spruce site classes I—IV (Möller) in comparison with that of Norway spruce on equivalent sites.

	Site class I	Site class II	Site class III	Site class IV
The total yield of Norway spruce, m³	1 150	930	730	550
The total yield of Douglas fir on equivalent sites, m³	(H_{50} = 28.0) 1 080	(H_{50} = 27.2) 1 040	(H_{50} = 25.3) 970	(H_{50} = 24.0) 900
Difference i yield, m³	— 70	+ 110	+ 240	+ 350
Difference in per cent	— 6	+ 12	+ 33	+ 64

the height ratio of the species. As already pointed out, this is the result of the fact that the basal area increment is relatively independent of site class for both Douglas fir and Norway spruce. Total yield consequently becomes a function of height.[1]

The yield capacity of Douglas fir in relation to that of Norway spruce has been investigated by e.g. Schwappach (1920). The result of his investigation, presented in Table 13, also shows that the total yield of Douglas fir is considerably greater than that of Norway spruce.

Table 13. Comparison between Douglas fir and Norway spruce with respect to height development and total yield according to Schwappach (1920). The material is obtained from 16 sample plots in Norway spruce »Standortsklasse» I and II.

Douglas fir			Age	Norway spruce		
Height m	Volume per hectare m³	Total yield per hectare m³		Height m	Volume per hectare m³	Total yield per hectare m³
Standortsklasse I						
11.2	147	147	20	6.8	25	25
17.9	237	368	30	11.6	125	134
21.3	328	474	40	16.6	262	305
Standortsklass II						
7.0	48	48	20	—	—	—
13.5	128	171	30	8.3	71	74
17.6	209	327	40	12.8	175	195

[1] The physiological reason for the greater yield of Douglas fir has been examined by e.g. Polster (1955). Investigating the carbondioxide assimilation of the species, he concluded that Douglas fir, by virtue of its greater assimilation capacity and a larger number of needles, produces twice as much organic substance as Norway spruce.

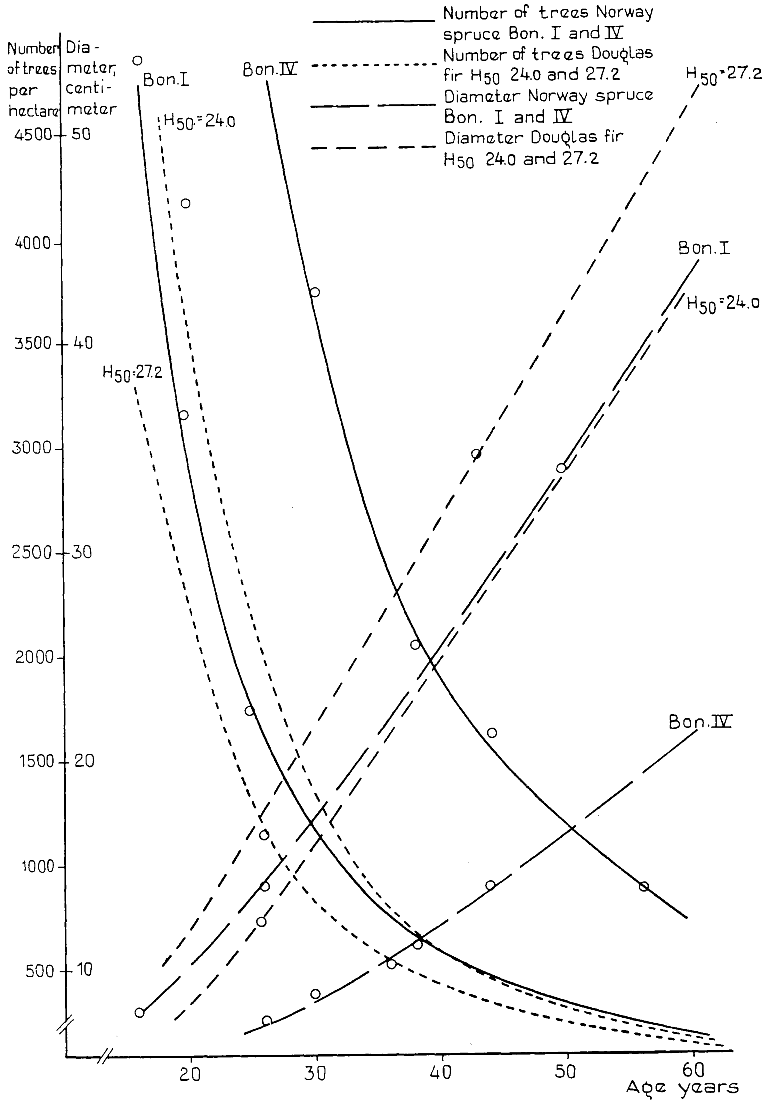

Fig. 35. Development of the number of trees and diameter for Norway spruce. Site classes I and IV (Möller) (in the figure called Bon) and for Douglas fir on equivalent sites. (H_{50} = 27.2 and 24.0, respectively).

Similar experience was later reported by Seibert (1949), who found the yield of Norway spruce on equal sites to be 45—64 per cent less than that of Douglas fir. Fabricius (1950) suggested that Douglas fir produces 30 % more than Norway spruce on normal Norway spruce sites.[1]

[1] There are certainly investigations which show the opposite, as for example those presented by Cieslar (1920), Harrer (1925) and Zacharias (1931). However, in addition to lack of provenance data, the stands concerned are established in places that are altogether too high and continental for Douglas fir.

Since Douglas fir displays the greatest superiority in total yield in the lowest Norway spruce quality classes, i.e. in this case site class IV, it would have been desirable to compare the relationship in the site classes V and VI as well. Material for an extended comparison, however, was not available.

It is not only the magnitude of the yield, which is of interest in a comparison between species, but also the composition of yield with respect to the diameter of the trees. Fig. 35 shows a comparison between Norway spruce and Douglas fir as regards the number of trees and diameter on equivalent sites, i.e. Norway spruce site classes I and IV and Douglas fir H_{50} = 27.2 and 24.0, respectively. (vide Fig. 33.)

Fig. 35 shows that Douglas fir, which in Norway spruce site class I equals the yield of Norway spruce, has a lower number of trees and a superior diameter development. Thus, when 60 years old Norway spruce has a mean diameter of 43 cm, Douglas fir has a diameter of 51 cm at the same age. The prospect of attaining large sizes of Douglas fir relatively quickly on good sites, perhaps justifies the introduction of this species on this site, too. However, the great resistance of old Douglas fir to attacks of root-rot (Fomes annosus), may be of even greater significance when choosing between this and other species.[1]

In the case of Norway spruce site class IV, however, Douglas fir and Norway spruce differ greatly with respect to number of trees and diameter development. Thus, the mean diameter of 60-year old Douglas fir is twice that of Norway spruce at the same age. In this context it is also clear that Douglas fir, because of its superior height growth, must be thinned more heavily than Norway spruce.

In this respect it is also of interest to compare Norway spruce and Douglas fir with regard to the number of trees and diameter in Norway spruce site class I and Douglas fir H_{50} = 24.0, since both these table stands have equal height at an age of 50 years (vide Fig. 35). This comparison shows that the number of trees and diameter development are approximately equal in both cases. Dengler (1930) furthermore claimed, that Douglas fir and Norway spruce are similar as regards light requirements.[2]

To outline the soil requirements of Douglas fir in relation to those of

[1] In the 187 stands contained in the entire investigation, Fomes annosus was found in two cases only, i.e. one on the isle of Fyn and one at Silkeborg. The attacks were not serious. Of the 33 stands contained in the yield comparison, 5 Norway spruce stands were heavily damaged by Fomes annosus, while the nearby Douglas fir stands were unaffected. The ability of Douglas fir to withstand Fomes annosus attacks has been pointed out by i.a. Fabricius (1926), Holm (1940) and Henriksen (1955).

[2] Cieslar (1920) classified Douglas fir as a light-demanding species on account of the early culmination of height growth. Harrer (1921), too, was of the opinion that Douglas fir is a typical light-demanding tree. Liese (1938), however, regarded Douglas fir as a shade tolerant tree. His opinion was presumably based on the observation that Douglas fir can tolerate shade under favourable site conditions. It is also an established fact that the seedlings grow well under a light shelter.

Table 14. Comparison between the total yield of Douglas fir and that of Norway spruce in various soil types.

	Soil groups	Douglas fir, total yield at 60 years	Norway spruce, total yield at 60 years	Ratio of total yield Douglas fir/Norway spruce
Very low clay content	Coarse soils without clay Fine, sandy soils Slightly clayey soils	940 m³	640 m³	1.47
Moderate clay content	Clayey soils Loamy clays Medium clays	1 120 m³	1 010 m³	1.11

Norway spruce, the material used for yield comparison has been classified into soil groups. A division into two groups, soils with very low clay content and soils with moderate clay content, produced the results shown in Table 14.

As already pointed out, the material does not allow a more detailed differentiation into soil groups. The table clearly shows, however, what has already been implied, i.e. that the difference in yield between Douglas fir and Norway spruce is most pronounced on the poor soils.

Regarding the soil requirements of Douglas fir, the comprehensive literature agrees very well with the findings of this investigation. Thus, Schwappach (1881, 1920), Holland (1921), Opperman (1929), Dengler (1930) and others claimed, that Douglas fir displays a high yield capacity in almost all kinds of soils. Several investigations show good results even for very poor soils, e.g. Hennig (1951). According to Fabricius (1926), old forest soils are only exceptionally too poor for Douglas fir. Similar experience was recorded by Henriksen (1955), who emphasized the great value of Douglas fir in areas where the soil is poor and precipitation low, and where the success of Norway spruce plantation is erratic. Analyzing in detail the soil requirements of Douglas fir on the isle of Fyn in Denmark, Abell (1954) concluded that Douglas fir thrives relatively well in a wide range of soil types.

The majority of investigations show, however, that Douglas fir fails on swampy sites, in soils with stagnant water and in heavy clays. Fabricius (1926) pointed out that Douglas fir mostly shows poor growth in heavy clay. This agrees well with results of this investigation (cf. sample plots 19 and 22 in Table 10). Thus, Douglas fir develops poorly in Bregentved's (Sjælland) heavy clays, whereas oak shows excellent growth.

The influence of Douglas fir on the soil conditions can be regarded as favourable. The soil conditions prevailing in the Douglas fir stands included in the yield investigation are generally better than those in the adjacent Norway spruce stands. Similar findings are reported by Wittich (1933), who showed that the humus conditions in Douglas fir stands are similar to those found in deciduous stands. Fabricius (1926) emphasized the favourable influence of Douglas fir on the soil conditions. Holm (1940) concluded on the basis of an investigation of Douglas fir in Denmark that Douglas fir is effecting great improvements in the soil.

III. Sitka spruce growth and growing conditions

Morphology, taxonomy and range

The following common names of Picea sitchensis (Bong.) Carr. are used in North America: Sitka spruce, Yellow spruce, Western spruce, Coast spruce and Tideland spruce. Sitka spruce is named after one of the places, where it was first encountered, the island of Sitka in Southern Alaska. Archibald Menzies, who discovered Douglas fir, first described it in 1792.

The general habitus of Sitka spruce is rather different from that of Norway spruce (Picea Abies). In the juvenil stage it has often a wide crown and erect, upturned main branches. The main branches of Sitka spruce often have several long, drooping, lateral branches. Since the needles with the two wide bands of stomata are turned upwards, the foliage appears to be somewhat lighter in colour than that of Norway spruce. The needles gradually taper off to a sharp point. The cones are small and have thin, somewhat irregular scales. The seeds, which are small, average 500,000 per kilo. The bark is light brown and thicker than that of Norway spruce, and large flakes of loose bark form at the base of old trees (fig. 36). Characteristics of old Sitka spruce are also the butt-flare, which is often quite pronounced, and the occurrence of epicormic branches.

Under optimum conditions Sitka spruce grows to very big sizes. At Quinault Lake, on the Olympic peninsula in the state of Washington, the author has seen trees exceeding 70 metres in height. Sitka spruce is a markedly maritime tree and its natural range constitutes a narrow belt along the Pacific Coast of Northt America from Alaska (Kodiak Island 60° lat.) to northern California (40° lat.). Generally restricted to the so-called fog-belt (see page 53) it is seldom found on places situated more than 300 kilometres from the coast. In such cases it occurs in the main river valleys, where the humid sea winds reach inland (Kay 1922, Hopkinson 1931). The old name, »Tideland spruce», (Sudworth 1908, Cary 1922) also hints at the restricted occurrence along the coast.

On the western side of the Olympic peninsula, Sitka spruce grows at an altitude below approximately 800 metres. Hardly forming stands at this altitude the trees are stunted and limby. The boundary below which Sitka

Fig. 36. Old Sitka spruce at Linaa Vesterskov, Jylland, Denmark, with large flakes of bark and characteristic butt-flare.

spruce is economically significant has previously been placed at an altitude of 400 metres (Cary 1922).

Being relatively insensitive to sea winds, Sitka spruce occasionally grows even on the sea side of sand dunes on the coast of Oregon. The ability of Sitka spruce to withstand saline winds has been investigated in Denmark by Oksbjerg (1952). In Europe, however, Sitka spruce is not considered wind-firm in dense stands (Cheyney 1942).

In North America, two types of Sitka spruce are distinguishable on the basis of their occurrence (Cary 1922): the bottomland type and the slope type. Trees belonging to the bottomland type are often limby and characterized by pronounced butt-flare and taper. They occur individually or in small groups, often in mixture with broad-leaved species such as Alnus rubra, Populus trichocarpa, Acer macrophyllum etc. (cf. the Douglas fir fog-belt type page 53). The development of Sitka spruce on bottomland sites closely resembles that of Norway spruce on good pasture-land and in rich stream bottoms, where it often occurs individually, limby and wide-crowned, interspersed chiefly with birch and alder.

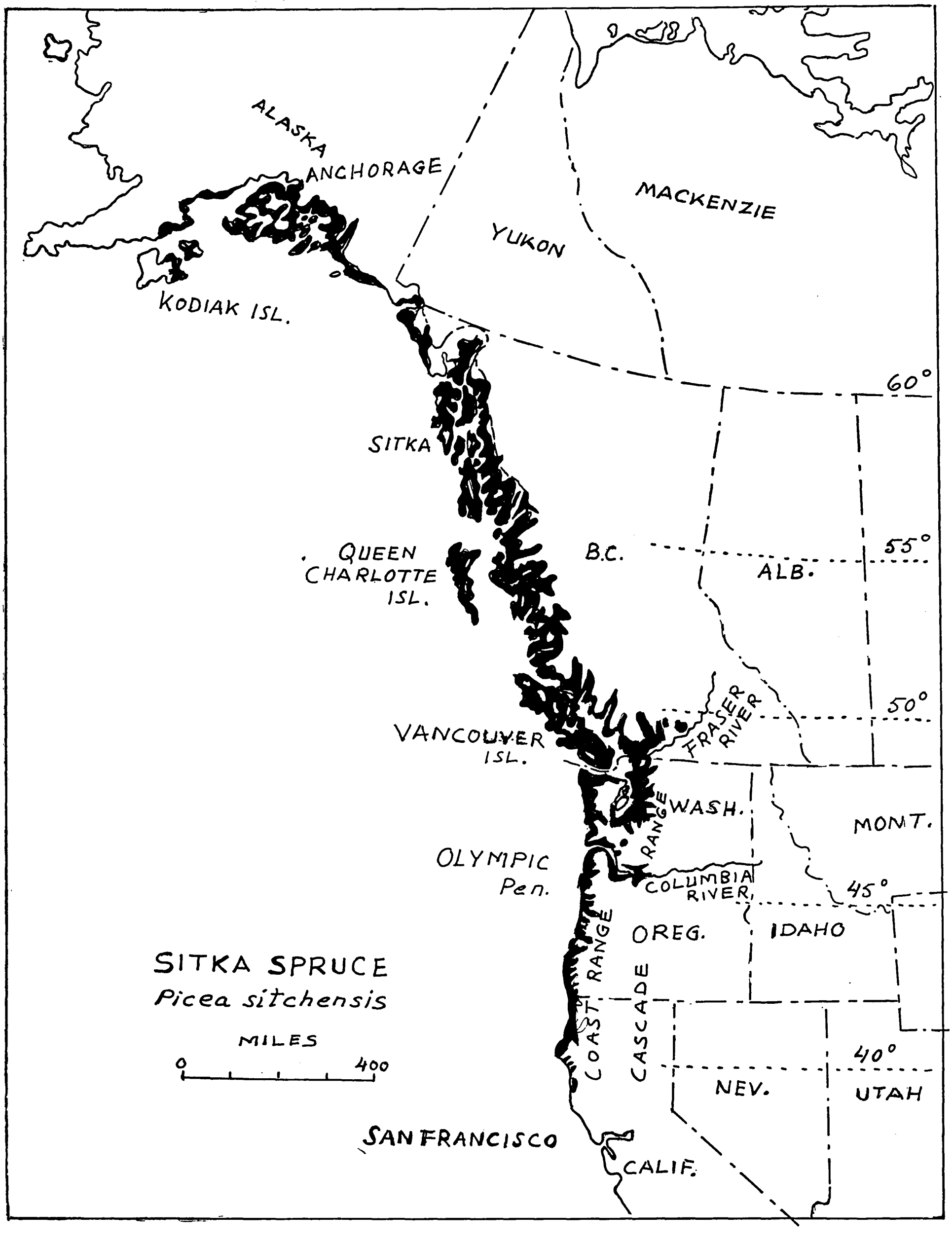

Fig. 37. The range of Sitka spruce (Picea sitchensis) after Munns (1938).

When Sitka spruce is growing on the well drained western slopes (the slope type) it is tall and has a clean bole. The stands are dense and usually interspersed with other species; pure stands are fairly rare. On account of its intermixture with Tsuga heterophylla a particular forest type is distinguished: »The Sitka spruce-Western hemlock type» (Meyer 1937). The composition of mixed stands usually includes other trees such as Pseudotsuga taxifolia, Thuja plicata, Abies grandis, Chamaecyparis lawsoniana or Chamaecyparis nootkatensis in proportions that depend on the location within the range.

Differences in development between the slope type and the bottomland type are not only of a genetic nature, but they can also be regarded as ecological, i.e. a result of environmental influence.

It seems indisputable that climatic variations occur within the latitudinal section (approximately 20°) embraced by the narrow range. Evidently no geographical varieties have ever been described. On the other hand, spontaneous hybrids between Sitka spruce and other spruce species have been encountered and described. Thus, hybridization easily takes place where Sitka spruce meets White spruce (Picea glauca) i.e. in the Chugach Mountains in Alaska and on the Kenai peninsula (Little 1953).

Spontaneous hybrids between Sitka spruce and White spruce are also common in Denmark and were commented upon as early as 1892 in Pinetum Danicum by C. Hansen, and described in detail by Fabricius (1926). Thaarup (1945) considered the spontaneous hybridization to be disturbing and warned against the use of hybrids as they do not appear to posses any advantages over pure Sitka spruce. This opinion has also been expressed by other Danish foresters (Larsen 1947). Thus, there appear to be no genetic barriers preventing hybridization between these two species.

Owing to close relationship, spontaneous hybrids between Sitka spruce and P. Engelmannii occur in Denmark according to Wright (1955). It also hybridizes with P. jezoensis, the most probable link between the spruce of the old and the new worlds. Moreover, Sitka spruce is still considered to have grown on the Aleutian Island in pre-Pleistocene times (Wright 1955).

It is amazing that P. sitchensis and P. Abies which have grown geographically far apart for a great length of time do not seem to have developed genetical differences that prevent hybridization. Thus Dr. Langner of the Institut für Forstgenetik in Germany has informed me that successful crossing experiments with these species have produced a couple of hybrids.

Sitka spruce provenances

Since the range of Sitka spruce is long, narrow and limited to a relatively low elevation, the matters concerning provenance are not so complicated as in the case of Douglas fir. The testing of strains has instead been restricted almost entirely to progeny from different latitude, or rather climatic regions, since not even in this case latitude and climate are exactly correlated.

The first seed lot of Sitka spruce was brought to Europe by David Douglas as early as 1831 (Dallimore and Jackson 1948). The major portion of seed subsequently introduced to Europe seems to have been collected in the state of Washington.

Complete experiments with strains of different provenances are of relatively recent date. The greatest interest is centred on the results of the Danish experiments, according to which Opperman (1929) stated that seed suitable for Danish conditions could be collected from areas as far south as British Columbia and the state of Washington. Superior results had been obtained with seed from Tongass (53°33). This strain surpassed the more northerly ones, from places with altogether too short growing season, as well as the southerly ones originating from places where the height growth is checked by frost. The experiments show that the strains differ from each other not only regarding hardiness but also concerning form and growth.

The experiments in western Norway (Hagem 1930) provide a clear relationship between the frequency of frost damage to 1 and 2 year-old seedlings and the latitude of provenance. It was further shown that certain strains are suitable for the Norwegian climate. However, those from the state of Washington are not sufficiently hardy. Similar experience was reported in Great Britain by Mc Donald (1927).

Following a warm month of March, the severe spring frost repeatedly occurring in Denmark in April 1938 caused extensive damage to Sitka spruce over large areas, particulary among the more northerly strains. Recently, opinion regarding suitable provenances has changed, and the use of seed from Washington is now recommended (Tulstrup 1950). It has also been pointed out that the once so popular Sitka spruce from the Queen Charlotte Islands has failed partly because its buds burst about 8 days earlier than those of Sitka spruce from Washington. The height growth of Sitka spruce from the Queen Charlotte Islands, however, terminates approximately 3 weeks sooner than Sitka spruce from Washington. Moreover, seed from the Queen Charlotte Islands has produced a disproportionate number of slow-growing, poorly formed individuals, which bear cones precociously. However, in other parts of Denmark, particularly northern Jutland, Sitka spruce from Washington is claimed to be severely attacked by autumn frost and rigorous winter cold. The Queen Charlotte strain is therefore to be preferred. The considerable local variations in climate, which occur in Denmark, are certainly causing the controversy regarding the most suitable provenance.

It should be pointed out, however, that the Queen Charlotte Islands comprise a rather large and mountaineous area. It is therefore quite important to know where the seed was collected. According to a forest officer, who had participated in cone harvesting on the Queen Charlotte Islands, vast quantities of cones were picked by Indians in canoes from trees lining the shores of fiords and rivers. This was found to be the cheapest method since the trees had long, thick branches stretching out over the water. It is essential to know whether the seed was collected from such trees or from good trees growing at higher elevations. The state of Washington, too, is altogether too vague as a provenance description since, apart from its large size, this state has height variations of up to 500 metres in the area where the collection of Sitka spruce cones is considered feasible.

In northern Washington, in British Columbia and on the Queen Charlotte Islands, there are tracts with temperature conditions similar to those of certain places in southern Scandinavia. The choice of strains to be used in a habitat, where damaging spring frost or autumn frost is frequent, depends on the local conditions. Since it appears advisable to collect seed from areas with moderate rainfall, the slope type of Sitka spruce should be given consideration.

Sitka spruce growth on the Pacific Coast and in southern Scandinavia

The growth of Sitka spruce in its native habitat has already been discussed briefly in conjunction with its range and taxonomy. Occasionally attaining extremely large dimensions, trees exceeding 100 metres have been encountered on the Queen Charlotte Islands (Harlow 1937). No exceptional heights have been recorded in the current investigation as the material is comparatively young. In Scotland, on the other hand, there are trees of about 50 metres (Karlberg 1955).

Since, for reasons already given, no real yield tables for pure stands of Sitka spruce are available in North America, no direct yield comparisons are possible. The American tables (Meyer 1937), which may be used for a comparison, refer to mixed stands of Sitka spruce and Western hemlock (Tsuga heterophylla) where the hemlock generally occurs as undergrowth. In the highest site class, site index 200, the height of 50-year old Sitka spruce exceeds 40 metres. In the present tables the height is 30 metres on the best site at the same age.

A relationship between age and height was presented by Cary (1922) on the basis of material comprising over 500 dominant trees selected from stands without consideration to site quality. The height curve of these trees is closely similar to that representing Site class II in this material. As the diameter was measured 15 ft. above the ground to avoid the butt-flare, no further comparisons are possible. Cary also found that the yield of Sitka spruce may equal that of Douglas fir under favourable conditions.

Although direct comparisons are impossible due to the lack of yield tables, it seems that Sitka spruce cannot be offered growth conditions in southern Scandinavia that are as favourable as those prevailing in its native habitat (heavy rainfall and mild climate).

Sitka spruce growth according to this and other European yield investigations

Sitka spruce yield tables have been compiled by Hummel and Christie (1953) in Great Britain and by Henriksen (1956) in Denmark. Limited growth investigation have previously been carried out by among others Fabricius (1926) in Denmark and Penschuck (1937) in Germany.

The origin and construction of the tables published by Hummel and Christie (1953) have been reviewed in conjunction with the description of the Douglas fir tables (page 64).

The Danish tables, which were complied by H. A. Henriksen, are partly based on the sample plots established by the Danish Forest Experiment Station. The tables comprise four site classes and were published as a preliminary appendix to »Praktisk Lommehandbog» (1956). A more detailed report came in 1958, when Henriksen published his investigations about »The Increment and Health Condition of Sitka Spruce in Denmark». His report (371 pages) deals particularly with the increment-health-disease relationships. The growth and yield of Sitka spruce has been investigated in various parts of Denmark and in different environmental types. Besides mensuration many stands have also been investigated with respect to soil. The report presents several interesting data about the growth conditions of Sitka spruce in Denmark. Since this paper was already written when his report was published, the findings of Henriksen have not be referred to.

Height in the Henriksen tables corresponds to the mean basal area, and the volume of the stand has been calculated on the basis of the whole trunk. The author emphasized the fact that great differences in volume increment occur in the same site class.

Fig. 38 shows the height curves according to English, Danish and the present yield tables. The height development is obviously rather similar. The curves representing this material rise somewhat more sharply than the English ones. This difference can most likely be attributed to dissimilarities in thinning and stand development. It is obvious that the agreement between the height curves according to Henriksen (1956) and those pre-

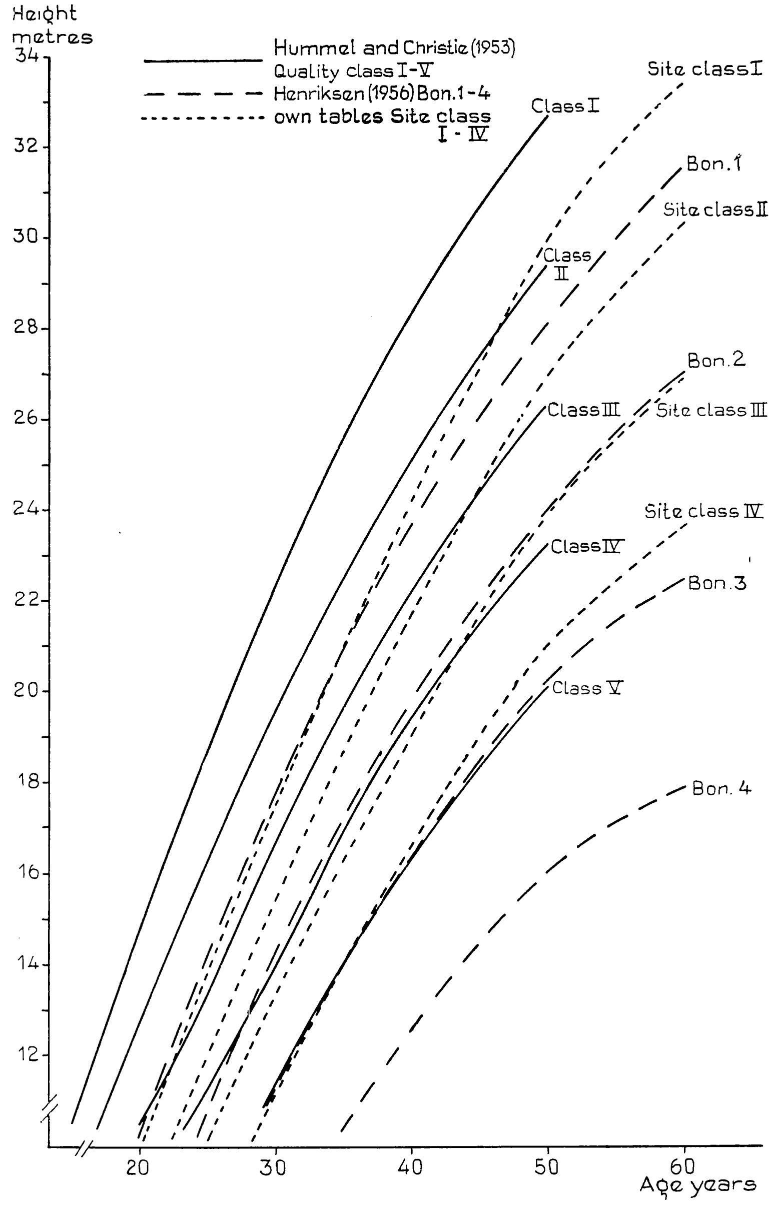

Fig. 38. Development of the mean height of Sitka spruce according to Hummel and Christie (1953), Henriksen (1956), and the present tables.

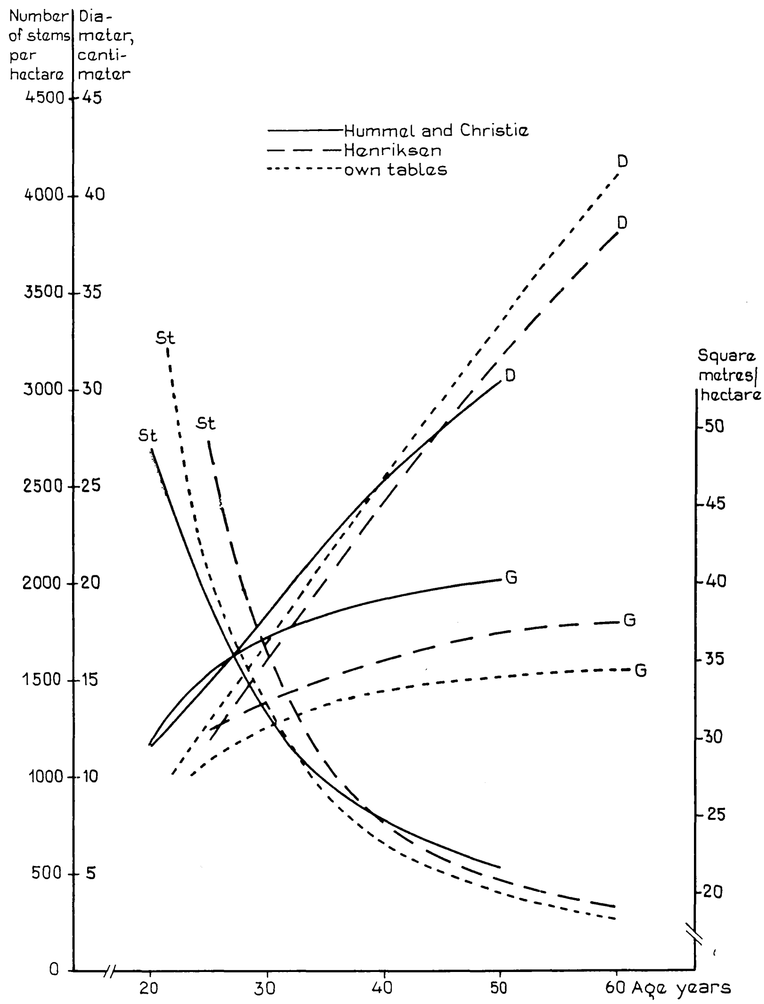

Fig. 39. Comparison between various investigations with respect to diameter (D), number of trees (St) and basal area per hectare (G) for the Sitka spruce height curve for H_{50} = 24.0. Hummel and Christie (——— full line), Henriksen (1956) (— — — — dashed line), Present tables (- - - - dotted line).

sented here should be close, since both are partly based on sample plots established by the Danish Forest Experiment Station.[1]

The further comparison is based on site class II (Bon 2) (Henriksen), which shows the same height as the present Site class III at a stand age of 50 years, e.i. 24.0 metres (fig. 38). This height indicates a site quality

[1] Of the 42 sample plots with a large number of observations supporting the height curves, 15 are managed by the Danish Forest Experiment Station.

slightly over class IV in the English material, and corresponding values regarding the number of trees etc. have been obtained by interpolation in the table.

The curve representing the number of trees in the English table (Fig. 39) starts below the corresponding curves for the other tables and ends above. The curve representing this material lies somewhat below the curve shown by Henriksen. Corresponding to the low number of trees in the young ages the English table also shows the largest diameter and a more rapidly decreasing diameter increment. In this respect the other two tables agree rather well with each other. The basal area standard is therefore considerably larger in the English material. The basal area according to the present data is slightly less than that shown in the Henriksen table. This may depend on the relatively heavy grade of thinning applied in plots, which have not been managed by the Danish Forest Experiment Station.[1]

Current annual volume increment has been chosen for yield comparison. Whereas the total trunk volume is the basis of yield compution in this and in the Danish investigation, the trunk volume above 3″ diameter has been used in the English investigation. This entails considerable differences in volume increment (cf. page 68). To compensate for this discrepancy, the values shown in the English table have been raised by 11 %. This allowance was obtained after comparisons with the Norway spruce tables (Möller 1953), where site class I also shows a height of 24.0 metres for a stand age of 50 years. The difference between the total trunk volume and the trunk volume above 7 cm diameter with respect to volume increment is there consistently 11 % for the ages concerned.

Fig. 40 shows certain differences in the yield development. Although volume increment in this material never reaches the maximum value shown by the Henriksen investigation, it is more sustained. It is impossible to determine whether this is caused by omitting stands attacked by root-rot (Fomes annosus) from the present study. The total yield between 25 and 60 years of age, however, is approximately 800 m³ in both cases.

After adjustment the English table displays relatively good agreement with the other tables as regards the beginning of the increment period, only to show clearly lower values for the later stages. Similar experience has been reported in the case of Douglas fir, i.e. increment in the British material was slightly lower.

Möller (1951) showed that the same differences also apply to Norway spruce. Danish tables consistently display average increment values that

[1] Currently, young stands are treated with a heavier grade of thinning than that applied 20—30 years ago. Old stands, however (this applies also to Douglas fir and other exotics) do not always seem to be managed according to current silvicultural praxis but are left as show stands as long as possible.

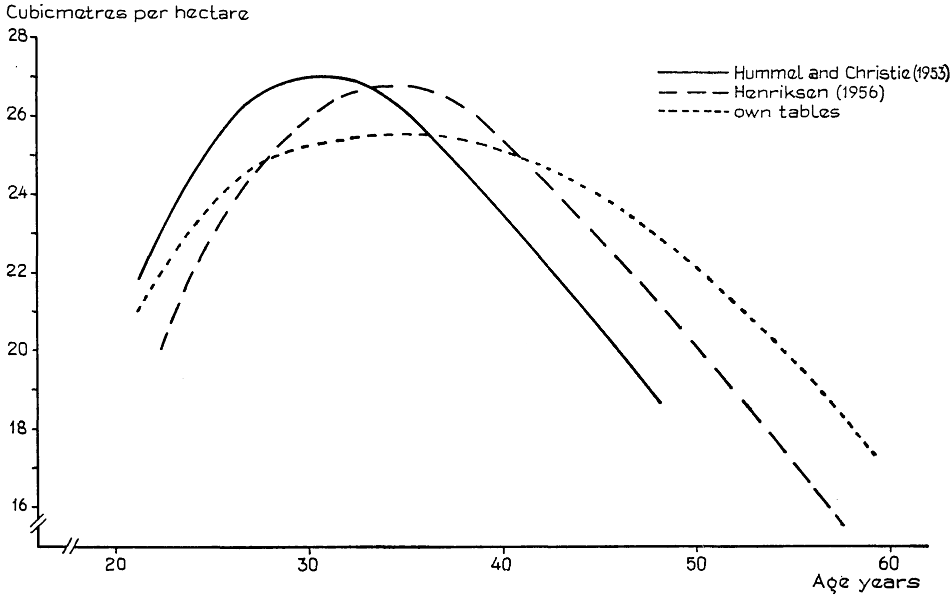

Fig. 40. Current annual volume increment representing the same height curves for $H_{50} = 24.0$ according to: Hummel and Christie (1953) (——— full line), Henriksen (1956) (— — — dashed line), Present tables (- - - - - dotted line).

are greater than those shown by Wiedemann (1936), the British Forestry Commission (1928) and Flury (1907) for the same height and age.

The growth and yield performance of Sitka spruce in relation to that of Norway spruce (Picea Abies)

The procedure used for the comparison between Norway spruce and Douglas fir with respect to yield (cf. page 69) has also been applied for a corresponding comparison between Sitka spruce and Norway spruce. However, it was more difficult to find stands on comparable sites, as Sitka spruce mostly grows on places which are more moist and situated at a lower level than that of adjacent Norway spruce sites.

A total of 35 Sitka spruce stands are included in the comparison. A description is presented in Table 15. Figure 41 shows the difference in height development between Sitka spruce and Norway spruce under similar conditions at an age of 50 years. The figure was constructed on the same principle as that used for Figure 33.

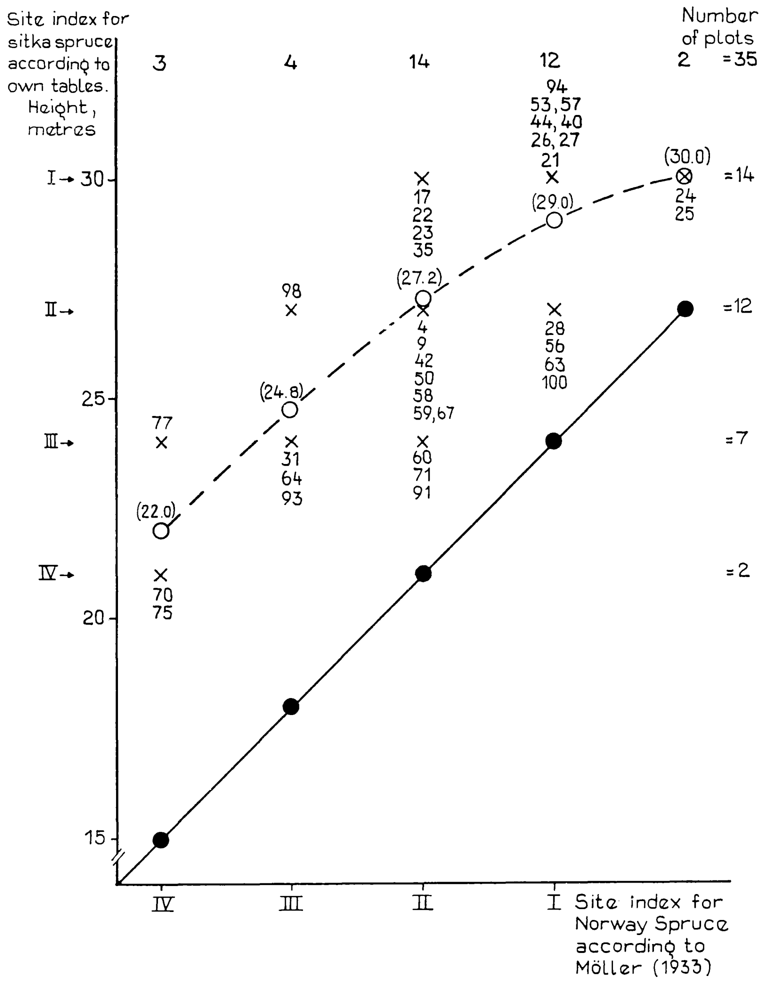

Fig. 41. Height development of Sitka spruce (———— dashed line) compared with that of Norway spruce (———— (full line) on equivalent sites. The figures refer to the list of sample plots in Table 15. The figures within brackets (29.0) indicate the mean height of all Sitka spruce stands in the corresponding Norway spruce site class.

Table 15. Summary of Sitka spruce and Norway spruce stands included in the comparison.

Sitka spruce							Norway spruce			
No	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
53	Frijsenborg, Lystskoven, Avd 58	I	49	31.8	Sandy-clayey moraine	Crumbly mor, F=3 cm, 15 cm, leached layer, Oxalis acetosella, Rubus idaeus, Deschampsia sp.	I	49	24.6	
57	Frijsenborg, Borridsø, Avd 5	I	43	27.5	Sandy-clayey moraine	Mull with Oxalis acetosella, Rubus idaeus and Pteridium aquilinium. Light Fomes annosus attacks	I	43	21.8	Avd 8. Light Fomes annosus attacks
35	Mejlgaard, Avd 85 a	I	35	21.9	Sand	20 cm old peat	II	35	15.6	Avd 85 B
44	Mejlgaard, Avd 256 a	I	35	20.5	Sand		I	45	20.1	Avd 256 b. Site class I according to remarks in Table No. 10
17	Glorup, Dyrehaven, Avd 95	I	45	28.9	Sandy-clayey moraine	Mor, F=1 cm. Oxalis acetosella, scattered Pteridium aquilinium	II	38	17.3	
21	Hvidkilde, Amalienlyst, Avd 5	I	23	13.1	Heavy clayey moraine	No lesser vegetation. Dense Mercurialis outside the stand	I	23	11.8	
22	Hvidkilde, Amalienlyst, Avd 6	I	25	15.2	Heavy moraine clay	No vegetation	II	27	11.4	Old stand of spruce attacked by Lophodermium
23	Hvidkilde, Paulinelund, Avd 9 a	I	21	12.4	Heavy moraine clay	No vegetation	II	36	15.2	According to Abell the spruce grows well in youth but the height growth is heavily retarded after 30 years of age

Sitka spruce							Norway spruce			
No	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
24	Hvidkilde, Folehave, Avd 2	I	42	25.1	Sandy-clayey moraine	Rubus idaeus and fruticosus. Oxalis acetosella	0	39	22.0	Site quality is essentially better than site class I (Møller), i.e. site class 0
25	Hvidkilde, Folehave, Avd 2	I	39	22.8	Sandy-clayey moraine	Scattered Pteridium aquilinium	0	39	22.0	Site quality is essentially better than site class I (Møller), i.e. site class 0
26	Hvidkilde, Faarehave, Avd 12	I	42	24.8	Sandy-clayey moraine	F=1 cm, Oxalis acetosella, occasional Pteridium aquilinium. Attacks by Fomes annosus on felled trees	I	34	15.9	Norway spruces with scattered Douglas fir
27	Hvidkilde, Trillinghave, Avd 4	I	39	23.5	Sandy-clayey moraine	1 cm needle layer, Oxalis acetosella, Sambucus racemosa, scattered Rubus idaeus	I	39	17.9	
94	Wedellsborg, Vestermark, Avd 11 b	I	29	17.0	Sandy-clayey moraine	F=1 cm; abandoned field with favourable soil water status; no vegetation. Mercurialis outside the plot in a beech stand	I	29	15.3	Near the sea-side the spruce height growth is often retarded, and the old spruce show lower site class according to height
102	Wedellsborg, Rendebjerg, Avd 18	I	40	23.4	Sandy moraine	Rich humus. No vegetation. Occurrence of Fomes annosus in one corner of the sample plot	I	40	17.9	The spruce grows well until 40 years age, but is subsequently at-attacked by Fomes annosus. This is also applicable to the Sitka spruce

Sitka spruce							Norway spruce			
No	Location and department	Site class	Age years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
9	Bregentved, Ganneskov, Avd 62	II	43	22.9	Sandy-clayey moraine	Oxalis acetosella, Rubus idaeus, Sambucus racemosa, Mercurialis and various grasses	II	28	13.9	Avd 48, Norway spruce planted in 1927. As the spruce here is diseased as early as at the age of 40 years, the rotation is short
4	Gisselfeld, Nygaard Vænge, Avd 27	II	37	20.1	Sandy moraine		II	41	18.1	
63	Buderupholm, Tveden Skov, Avd 280	II	63	32.0	Sandy-clayey moraine	Favourable soil water status, Oxalis acetosella, Calamagrostis and Juncus effusus. The stand cut lightly	I	65	27.8	
56	Frijsenborg, Grolsted, Sønderskov, Avd 92	II	41	23.1	Sandy-clayey moraine	Good humus condition. There were fruiting bodies of Fomes annosus observed on stumps and roots in 1936	I	44	22.0	
58	Frijsenborg, Gejlund Bakker, Avd 19	II	29	13.5	Sandy-clayey moraine	The stand planted on abandoned field. No vegetation	II	29	12.5	
59	Frijsenborg, Gejlund Bakker, Avd 4	II	31	16.0	Sandy-clayey moraine	No vegetation. Scattered attacks by Fomes annosus	II	31	13.5	
42	Mejlgaard, Avd 219 b	II	40	22.7	Sand		II	69	23.5	Avd 220 c. Site class III according to table but classified as site II with regard to the above

Sitka spruce							Norway spruce			
No	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
50	Mejlgaard, Avd 307 a	II	35	18.0	Sand		II	54	22.3	Avd 311 a
67	Skærbæk Plantage, Avd 128	II	47	26.9	Sandy-clayey moraine	Planted on abandoned field. Rumex acetosella, Hieracium, Scleropodium and Mnium sp. Heavily attacked by Fomes annosus	II	47	20.4	According to classification of 1945 14,8 metres at 40 years, i.e. site class III
98	Wedellsborg, Haare, Avd 36	II	40	22.5	Sandy moraine	Sand mixed with peat	III	40	15.1	
100	Wedellsborg, Ørsbjerg, Avd 56	II	41	23.4	Clayey sand	Oxalis acetosella, scattered Rubus idae- and Rubus fruticosus	I	57	24.1	Site class II according to table. This has been corrected, however, as it does not follow the height curve
28	Hvidkilde, Raarud, Avd 3 b	II	59	29.4	Sandy-clayey moraine	Oxalis acetosella, scattered Rubus idaeus and Rubus fruticosus. A few attacks by Fomes annosus	I	55	25.9	
64	Buderupholm, Tveden, Avd 307 SW	III	53	25.2	Sandy moraine		III	53	19.4	
60	Frijsenborg, Hagsholm, Avd 40	III	44	22.9	Sandy moraine	Rubus idaeus, various grasses. Planted on abandoned field. Last classification in 1948. Attacked by Fomes annosus after 1948 (Last revision)	II	41	20.7	Hagsholm, Avd 39. Heavily attacked by Fomes annosus

Sitka spruce							Norway spruce			
No	Location and department	Site class	Age, years	Height, m	Soil type	Remarks	Site class (Møller)	Age, years	Height, m	Remarks
31	Mejlgaard, Avd 34 a	III	26	12.8	Sand		III	74	19.9	Avd 33 a
71	Palsgaard, Gludsted, Avd 70	III	66	29.0	Sandy-clayey moraine		II	66	24.2	Actually site class II—III.
77	Randbøl, Gøding Skov, Avd 28	III	45	21.8	Sany-clayey moraine		IV	45	13.4	
93	Rye Nørreskov, Avd 10	III	44	22.4	Sandy moraine	F=4cm, H=13 cm. No vegetation, scattered Hylocomium	III	50	17.6	
91	Skåne, Rössjöholm, Avd 223	III	50	23.5	Sandy-clayey moraine		II	50	21.0	
70	Palsgaard, Gludsted, Avd 10 d	IV	26	7.3	Sandy moraine		IV	26	6.4	
75	Palsgaard, Snabegaard, Avd 112 b	IV	49	20.6	Sandy moraine		IV	49	16.3	

Table 16. The total yield of Sitka spruce at an age of 60 years in the Norway spruce site classes I—IV (Möller) in comparison with that of Norway spruce on equivalent sites.

	Site class I	Site class II	Site class III	Site class IV
The total yield per hectare of Norwa spruce, m³	1 150	930	700	550
The total yield per hectare of Sitka spruce on equivalent site, m³	(H_{50} = 29.0) 1 380	(H_{50} = 27.2) 1 200	(H_{50} = 24.8) 1 080	(H_{50} = 21.0) (930)
Difference in yield, m³	230	270	380	(380)
Difference, per cent	20	27	54	—

Other investigations also show that the height development of Sitka spruce is superior to that of Norway spruce. Thus, 70 per cent of the 101 Sitka spruce stands contained in the Penschuck (1937) material from the maritime climate region in north-western Germany, displayed a greater height than that of Norway spruce in site class I (Schwappach), 26 % showed a height indicating a Norway spruce site quality between the classes I and II and only 4 % a height corresponding to the site classes II and III. Similar relationships between the height development of the species can also be ascertained in Great Britain by comparing the species according to the English yield tables compiled by Hummel and Christie (1953).

Total yield at 60 years has been chosen as the basis of a comparison between the species. For Norway spruce the total yield has been calculated by means of tables (Möller 1933) according to methods already described (page 78). The values for Sitka spruce on equivalent sites have been obtained by interpolation in the Sitka spruce tables. The result of this comparison is given in Table 16.

The yield of Sitka spruce is consistently 20—50 per cent greater than that of Norway spruce. Similar results were obtained by Mayer (1906), who claimed that the yield of Sitka spruce is frequently superior to that of Norway spruce. On the basis of extensive German material Penschuck (1937) stressed the superiority of Sitka spruce in maritime climate. He also showed that Sitka spruce in 50 years produced 100 % more than Norway spruce in the best German site class, i.e. Schwappach's Ertragsklasse I (1902), in the coastal areas of northern Germany. Fabricius (1926) stated that according to extensive, young Danish material the increment of Sitka spruce is approximately 50 % greater than that of Norway spruce under the same conditions.

The stand development of Sitka spruce in relation to that of Norway

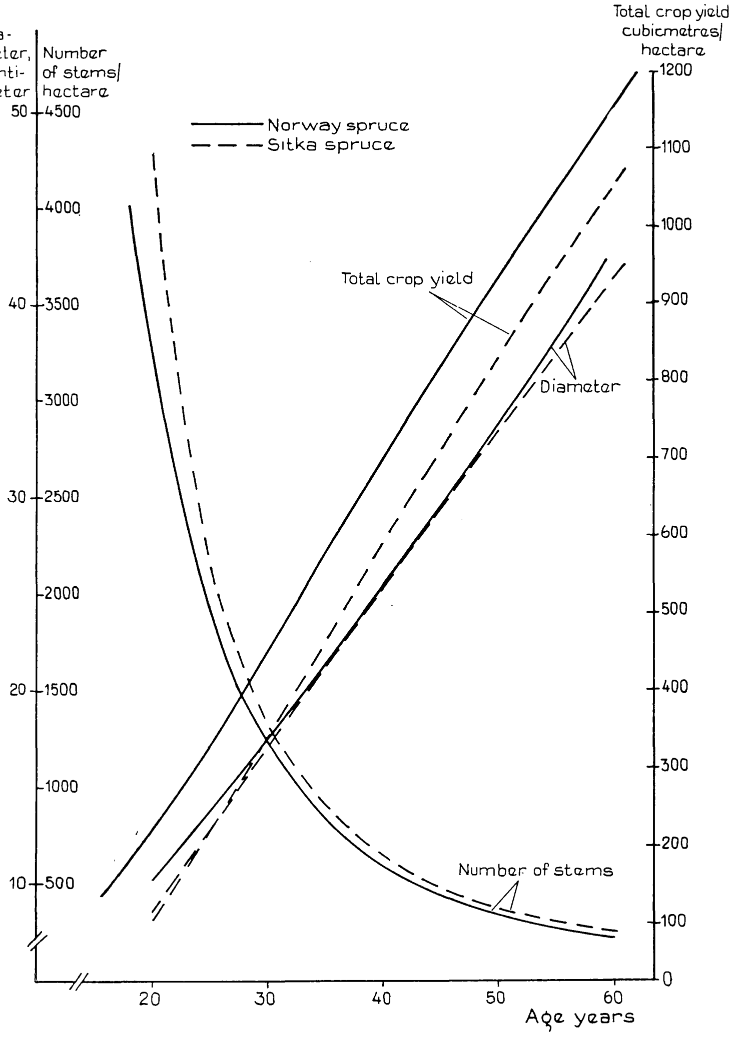

Fig. 42. Comparison between Sitka spruce and Norway spruce with respect to diameter, number of trees and total yield. Sitka spruce, site class III (— — — — dashed line). Norway spruce, site class I (———— full ine) with equal mean stand height at the age of 50 years, 24.0 metres.

spruce otherwise shows the same trend as that of Douglas fir, i.e. on equivalent sites Sitka spruce shows a superior diameter development. While, for instance, a Norway spruce stand in site class II has 339 trees per hectare and a mean diameter of 29 cm at 60 years, corresponding site class in the Sitka spruce table (H_{50} = 27,2) shows 229 trees per hectare and a mean diameter of 44 cm.

In this context, however, it has been considered warranted to compare the species on the basis of stands with equal height at the age of 50 years, to detect potential differences in stand treatment and stand development. Sitka spruce site class III and Norway spruce site class I (Möller), which both show a height of 24.0 metres at 50 years, have therefore been chosen. Fig. 42 displays the total yield, the development of diameter and the number of trees for the species.

The number of trees for Norway spruce is consistently lower than that of Sitka spruce, but the difference is so slight that it may have occurred by chance.[1] Diameter development is also relatively similar, and the minor differences that occur in the beginning and in the end of the rotation period merely reflect differences in the number of trees.

The curves showing total yield are parallel. The curve representing Norway spruce rather consistently displays 100 m^3 higher values than those shown by the Sitka spruce curve. This difference, however, is partly caused by the dissimilarity between the Norway spruce tables, which are based on thinning already at an age of 16 years, and the Sitka spruce tables, which are based on thinning from a stand age of 20 years. The difference is reduced by half, i.e. to 50 m^3, if the total yield of Norway spruce is compiled from an age of 20 years.

A comparison between Sitka spruce in site class IV and Norway spruce in site class II (Möller), which both display a height of 21.0 metres at 50 years, also shows that the differences regarding the mean diameter, number of trees and total yield are negligible.

Thus, Sitska spruce, which has the same height as Norway spruce at the age of 50 years, generally shows equal total yield. Moreover, Sitka spruce is regarded similar to Norway spruce with respect to thinning requirements, since the number of trees and mean diameter are generally almost identical in stands of the same height.

For the purpose of discussing differences in the soil requirements, the material has been classified into soil groups. For reasons already given, this division was very rough and limited to soil types with very low clay content and those with moderate clay content. The total yield of each species is listed in table 17. The mean site class has first been calculated for each species and soil group, after which the total yield at 60 years for corresponding site class has been obtained from the yield table.

The table shows a slight difference in the ratio of the total yield of Sitka spruce and Norway spruce in the various soil groups. The difference in the

[1] It may be mentioned that young Sitka spruce sometimes is coarse-limbed and poorly shaped in relation to Norway spruce (Mayer 1906, Andersen 1951). The stands should therefore be kept dense in the young ages. On account of a tendency to develop epicormic branches, it would perhaps be advantageous to keep a relatively large number of trees at the end of the rotation period.

Table 17. Comparison between the total yield of Sitka spruce and that of Norway spruce at an age of 60 years in various soil groups.

	Soil groups	Sitka spruce, total yield at 60 years	Norway spruce, total yield at 60 years	Ratio of total yield Sitka spruce/ Norway spruce
Very low clay content	Coarse soils without clay Fine sandy soils Slightly clayey soils	1 180 m^3	900 m^3	1.31
Moderate clay content	Clayey soils Loamy clays Medium clays	1 280 m^3	1 060 m^3	1.21

yield of Sitka spruce between various soil groups is less than that of Norway spruce, i.e. certain differences, which were not so noticeable when the species were compared on equal site classes, can be discerned. The differences may have occured due to the fact that the estate of Mejlgaard is well represented in the material (Table 15). The soils are here sandy, but Sitka spruce, in contrast to Norway spruce, enjoys favourable growth conditions.

The list of sample plots shows that the Sitka spruce stands at Mejlgaard grow on good sites. A comparison between the Norway spruce and Sitka spruce stands on Mejlgaard on the basis of data contained in the forest survey figures for 1952, reveals that the mean height of Sitka spruce at 50 years is 26.0 metres and that of Norway spruce 18.5 metres. Suitable water table and high air humidity appear to be chief reasons for the good growth of Sitka spruce on Mejlgaard. However, an annual rainfall of about 600 mm is not exceptional.

This indicates the soil requirements of Sitka spruce. Summarizing these requirements, Löfting (1933) concluded, that sandy or gravelly sites without supply of subsoil water or without underlying fine material are unsuitable sites for Sitka spruce plantation. The same also applies to clayey sites with stagnant water, where young Sitka spruce is severely attaced by root-rot. These site requirements naturally apply to Norway spruce as well, but in the author's opinion, not so pronounced as in the case of Sitka spruce. This is also shown by other investigations (Penschuck 1937) which illustrate the exceptionally good growth of Sitka spruce in the moist, diluvial sand of northwest Germany.

Moisture is consequently one of the prerequisites for Sitka spruce growth, either as ample supply of moving subsoil water, as heavy rainfall, or as a high air humidity.[1] A comparison between the range of Sitka spruce and that of other West American species indicates the relative moisture requirements. The location of suitable Sitka spruce sites in relation to the range of Picea Abies on the continent of Europe also provides similar information.

Regarding the influence of Sitka spruce on soil conditions, there are no investigations that conclusively show whether Sitka spruce differs from Norway spruce. Stephan (1923) mentioned, however, that the needles appear to decompose more rapidly on a Sitka spruce forest floor than in the case of Norway spruce. Fabricius (1926) found that the pH-value of the forest litter was occasionally lower in stands of Norway spruce than that observed in adjacent Sitka spruce stand.

1 The resistance of Sitka spruce to fungal attacks should probably also be seen against this background, since Fomes annosus has occasionally attacked stands very heavily. Severe attacks have occurred chiefly on sites which are unfavourable to Sitka spruce and particularly in stands with deficient moisture conditions. It is consequently difficult to say whether Sitka spruce is more suspectible to root-rot than Norway spruce under comparable conditions. The resistance of Sitka spruce to Dendroctonus micans attacks, too, may be considered accordingly. Löfting (1950) thus stated that Sitka spruce (in Denmark) had been planted on sites which are altogether too dry. This leads to reduced vigour and invites bark beetle attacks. A primary attack can admittedly be made by Dendroctonus micans, but the most extensive attacks usually occur in conjunction with other calamities such as root-rot (Petersen 1952). It may be suggested, however, that this bark beetle is especially attracted to Sitka spruce. Since Dendroctonus micans is a very big (the biggest in Europe) bark beetle (Petersen 1952), breeding must occur in trees with thick bark. As Sitka spruce soon reaches large dimensions with thick bark, the high frequency of attacks experienced by Sitka spruce, especially in the young ages, may depend on the bark thickness.

IV. Conclusions

The aim of the present work is to elucidate the growth and yield conditions of Douglas fir and Sitka spruce, particularly with respect to the potential use of these species in southern Sweden.

Since the major portion of the material is of Danish origin, there is reason to question whether the results are applicable to conditions in South Sweden as well. This is actually the case since climate, soil and silvicultural conditions prevailing in the two areas are highly comparable. Furthermore, forest seed and seedlings of Danish origin have long been used succesfully in southern Sweden.

Moreover, the Douglas fir stands from South Sweden, which are included in the investigation, do not differ from the rest in such a way as to suggest systematic differences. Dissimilarities in the stand development certainly occur, but the basal area increment generally agrees well with the yield tables.

The investigation presents results and conclusions on the basis of the treated material. This prompts the question as to the extent to which the results can be generalized, i.e. what discrepancies can be expected in the case of another sample selected at random from the same population. Comparison with the yield tables for Sitka spruce in Denmark (Henriksen 1956), provided a fair answer to this question by showing negligible differences only. The present material, however, cannot be regarded as a random selection from a population free from systematic tendencies since the investigation was not intended to produce a statistical presentation of the yield development of a commonly occurring species. The aim was to make forecast which will be reasonably accurate if current knowledge of provenance and site conditions is applied. Since the vast majority of yield summaries are based on specially selected and successful sample plots, the development presented must be regarded as optimum rather than normal. The yield in practice must consequently be reduced on account of losses and calamities etc. Naturally, the risk of such loss or discrepancy is greater for relatively unknown exotics than it is in the case of familiar indigenous species. Several plantations of Douglas fir and Sitka spruce have also failed as a result of faulty strain or unsuitable site. Furthermore, it is quite certain that less successful stands have been liquidated and replaced by other species. This shows that the present material is a selection.

As far as Sitka spruce is concerned, stands were excluded from the investigation if Fomes annosus occurred to such an extent that development was affected. In the case of Douglas fir, too, the investigation has been limited to stands whose development was regarded as acceptable. Stands where unsuitable strains were causing abnormal development have consequently been excluded. This subjective selection, however, is no depreciation of these important questions. The risk of calamities has been considered in the yield analysis of the species. On the other hand, it should be possible on the basis of our present knowledge of the provenance conditions and site requirements of these species to greatly reduce or even avoid repetitions of failures. This is accomplished by a careful selection of suitable Douglas fir strains and by choosing right plantation sites for Sitka spruce.

The variation in each site class is still extensive in spite of this selection, particularly with respect to Douglas fir. The material cannot therefore be regarded as a true population, since the variation is considerable and mainly genotypical in the Douglas fir site classes due to differences in provenance. This naturally brings up the question, whether the variation due to genetical, climatological and geological differences in addition to the chance variation, was of such a magnitude as to entail bias. Comparisons with German and English yield summaries serve as a guide in this respect. However, the comparisons displayed no differences which suggested the occurrence of appreciable systematic deviations. It can therefore be concluded that the tables present a true mean yield development since the material was collected objectively with regard to certain conditions. The material also provides an idea of the variation of this mean development.

A final decision as to the silvicultural value of Douglas fir and Sitka spruce is formed after weighing and evaluating pertinent factors. This decision, which is strongly subjective, has been left out for natural reasons. The aim of the investigation was instead to create an objective foundation as a solid basis for this subjective decision.

In addition to presenting the relevant facts, it has been considered desirable to conclude by discussing some questions, where the material was insufficient to provide strictly scientific evidence. This is particularly the case regarding certain views on the stand treatment. As already pointed out, the present yield tables for Sitka spruce and Douglas fir are based entirely on the stand development of the sample plot material, i.e. the thinning programme applied in such stands. In praxis, however, economic conditions usually justify different thinning regimes, and even if the tables cover only 61 years of stand development no opinion has been formed regarding the suitable lenght of rotation period.

Comparisons between the present tables for Sitka spruce and Douglas fir and other European yield tables show that the grade of thinning used in this material is appreciably higher than that applied in other European countries. However, since volume increment has appeared to be unaffected by the grade of thinning within relatively wide limits, it has been considered permissible in the yield comparisons to ignore the differences in stand density. For the same reason it should be possible to choose within rather wide limits the stand treatment program considered to produce the best financial result — as along as no special biological complications arise. In the case of Douglas fir its light requirements and susceptibility to Phaeocryptopus in overstocked stands favour heavy thinning in the young ages. This is particularly reflected in the British tables. The possibilities of utilizing the wood in the cellulose industri should also justify early thinning, and most likely promote the establishment of pure Douglas fir stands, instead of the present mixed stands with Norway spruce. The inferior natural pruning occurring in stands that have been treated with heavy thinning in the young ages, may be counteracted by artificial pruning (Benson 1932, 1947, 1950, Weck 1938, Shaw and Staebler 1950, Holck 1953). Douglas fir then becomes a particularly fast growing producer of large sizes of clean timber.

To be saleable on the timber market, a species must be available in large quantities of good quality. Douglas fir can, however, be expected to become of greatest importance for large-scale forestry in southern Sweden. Extensive areas of root-rot infested Norway spruce sites, where a generation of broad-leaved trees is now consirered necessary as a sanitation measure, may prove suitable projects for Douglas fir plantations. Great resistance to Fomes annosus and favourable influence on the soil condition are Douglas fir characteristics that should make this species a good substitute for less profitable broad-leaved species, particularly on poor sites. Since the investigation has shown that Douglas fir is tolerant with respect to site requirements, it should also be able to compete successfully with inferior Scots pine (Pinus silvestris) on a number of sites.

The comparison shows with minor exceptions that the treatment generally accepted for Sitka spruce is similar to that suitable for Norway spruce. For sitka spruce the English and German tables show considerably higher standards for the number of trees and the basal area than that of the material investigated. According to views recently expressed in Denmark, thinning in Sitka spruce should be made lighter than before because of the risks of attacks by bark beetle (Dendroctonus micans) and root-rot (Fomes annosus) (Henriksen 1955). The risks would then be reduced, since it was assumed that dense stands are relatively insensitive to drought spells. Furthermore, according to the Risbeth theory (1951), the risk of attack by root-rot would be reduced if thinning is light because of the small number of stumps. According to other views, however, the economical effects of root-rot may be reduced by short rotation periods and heavy thinning. A final opinion must be formed on the basis of local conditions, however.

So far as southern Sweden is concerned, there are reasons to consider Sitka spruce as material for the pulp industry rather than the sawmill industry. If the Sitka spruce plantations are confined to well drained soils and areas with high precipitation, the matter of suitable stand treatment should be easily settled.

V. Enclosures

Appendix 1. Sitka spruce sample plot material

The Sitka spruce investigation includes a total of 119 revisions divided as follows:

Sample plots established and recorded by:

The Danish Forest Experiment Station and the Swedish Forest Research Institute	20
The Danish Regulation Department of State Forests	28
The forest administration authorities (controlled or revised by the writer)	20
The writer	51
Total	119

Sample plot location, stand age and year of revision.

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
1	Gisselfeld (Sjælland) Nygaard Vænge. Avd 25	48	28.6	38.1	I	1952	21
2	» » » » » 4	53	28.7	41.4	II	1952	20
3	» Gl. Dyrehave. Avd 457	69	30.2	82.9	III	1953	22
4	» Nygaard Vænge. Avd 27	37	20.1	21.0	II	1933	2
6	» Denderup Vænge. Avd 241	19	9,1	9.6	I	1950	
7	Vibygaard (Sjælland)	39	25.0	22.5	I	1952	
8	Bregentved (Sjælland) Boelskov. Avd 39 c	40	21.3	27.5	II	1952	
9	» Ganneskov. Avd 62	43	22.9	29.4	II	1952	
10	» Nyskov. Avd 4	33	19.4	21.4	I	1952	
11	Gavnö (Sjælland) Fe Plantage. Avd 50	47	25.2	31.4	II	1952	
12	Rosenfeldt (Sjælland) Knudskov II:4	18	9.4	10.1	I	1953	
13	Petersgaard (Sjælland) Stenby. Avd 22	21	10.1	11.1	I	1947	
14	» Viemose. Avd 33	23	12.5	12.7	I	1947	
15	» Nørrehave. Avd 5 a	49	25.6	34.6	II	1952	
16	Glorup (Fyn) Dyrehaven. Avd 77	38	23.6	25.4	I	1952	
17	» Dyrehaven. Avd 95	45	28.9	31.1	I	1952	11
19	» Dyrehaven. Avd 95	23	17.3	16.9	I	1952	
21	Hvidkilde (Fyn) Amalienlyst. Avd 6	23	13.1	14.0	I	1952	
22	» Amalienlyst. Avd 6	25	15.2	15.9	I	1952	
23	» Paulinelund. Avd 9 a	21	12.4	12.0	I	1952	
24	» Folehave. Avd 2	42	25.1	28.1	I	1952	8
25	» Folehave. Avd 2	39	22.8	23.9	I	1952	
26	» Faarehave. Avd 12	42	24.8	27.5	I	1952	9
27	» Trillinghave. Avd 4	39	23.5	26.7	I	1952	
28	» Raarud. Avd 3 b	59	29.4	36.8	II	1952	
29	Mejlgaard (Jylland). Avd 12	37	20.9	24.8	II	1952	
30	» Avd 14	26	15.1	17.1	I	1952	
31	» Avd 34 a	27	12.3	13.2	III	1952	
32	» Avd 63 a	37	23.1	31.3	I	1952	
33	» Avd 76 a	32	15.4	15.7	III	1952	
34	» Avd 78 b	34	22.0	25.4	I	1952	
35	» Avd 85 a	35	21.9	26.2	I	1952	

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
36	Mejlgaard Avd 106 a	37	24.2	30.8	I	1952	
37	» Avd 127	44	24.2	24.8	II	1952	
38	» Avd 148	23	12.6	13.8	I	1952	
39	» Avd 210 a	69	32.4	43.1	I	1952	39
40	» Avd 210 b	42	25.3	30.2	I	1952	
41	» Avd 211 a	41	22.9	32.1	II	1952	
42	» Avd 219 b	40	22.7	27.0	II	1952	
44	» Avd 256 a	35	20.5	23.7	I	1952	
45	» Avd 275 a	26	13.7	13.5	II	1952	
46	» Avd 280 a	35	23.5	26.0	I	1952	
48	» Avd 459 b	35	21.1	23.1	I	1952	
49	» Avd 477 b	34	23.0	24.1	I	1952	
50	» Avd 307 a	35	18.0	20.2	II	1952	
51	Frijsenborg (Jylland) Havrum. Avd 34	45	28.3	34.6	I	1952	
52	» Havrum. Avd 38	22	10.2	11.7	II	1952	
53	» Lystskoven. Avd 58	49	31.8	43.9	I	1952	
54	» Kildedal. Avd 13	29	15.9	18.3	II	1950	4
55	» Grolsted Sønderskov. Avd 92	23	12.9	14.6	I	1951	4
56	» Grolsted Sønderskov. Avd 92	41	23.1	27.9	II	1950	14
57	» Borridsø, Avd 5	43	27.5	35.0	I	1952	10
58	» Gejlund Bakker. Avd 19	29	13.5	12.9	II	1952	4
59	» Gejlund Bakker. Avd 4	31	16.0	16.6	II	1952	4
60	» Hagsholm. Avd 40	44	22.9	26.9	III	1948	17
61	» Hagsholm. Avd 40	42	24.3	26.2	II	1946	20
62	Lindenborg (Jylland) Rold Østerskov. Avd 199	39	23.6	27.5	I	1952	
63	Buderupholm (Jylland) Tveden, Avd 280	63	32.0	49.7	II	1952	8
64	» Tveden. Avd 307	53	25.2	35.1	III	1952	
65	» Tveden. Avd 262	48	27.4	35.2	II	1952	
66	» Tveden. Avd 202	66	31.3	49.6	II	1952	
67	Skarbæk Plantage (Jylland). Avd 128	47	26.9	30.9	II	1952	7
68	» » Avd. 204	39	16.9	20.6	IV	1952	7
69	Palsgaard (Jylland) Gludsted. Avd 32	53	15.7	19.5	IV	1952	
70	» Gludsted. Avd 10 d	36	7.3	8.6	IV	1952	
71	» Palsgaard Skov. Avd 70	66	29.0	37.8	III	1952	6
72	» Palsgaard Skov. Avd 96 c	58	22.7	32.2	IV	1952	

SITKA SPRUCE

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
73	Palsgaard (Jylland) Velling. Avd 174 b	62	34.3	41.2	I	1952	
74	» Velling. Avd. 177 c	62	32.1	34.3	II	1952	
75	» Snabegaard. Avd. 112 b	49	20.6	25.1	IV	1952	
76	» Snabegaard. Avd 125 c	50	17.0	21.8	IV	1952	
77	Randböl (Jylland) Göding Skov. Avd 28	45	21.8	23.1	III	1951	2
78	Høllund Søgaard (Jylland). Avd 81	58	23.8	36.5	IV	1952	
79	Bornholm. Avd 142 a	32	15.7	16.3	II	1948	
80	» Avd 349 f	50	24.9	35.0	III	1948	
81	» Avd 304 g	50	25.8	35.2	II	1948	
83	Silkeborg (Jylland). Avd 352 g	60	33.2	45.0	I	1951	
84	» Avd 214 b	25	13.2	12.8	I	1951	
85	» Avd 43 c	50	20.6	21.3	IV	1951	
86	» Avd 182 c	59	18.3	23.0	IV	1951	
87	» Avd 195 c	35	14.1	14.0	III	1951	
88	» Avd 195 h	35	14.1	14.0	IV	1951	
89	» Avd 328	48	24.9	31.0	II	1934	4
90	Sorø 2 distr. (Sjælland). Avd 31 c	38	22.0	23.8	I	1952	
91	Rössjöholm (Skåne). Avd 223	50	23.5	32.5	III	1950	
92	» Avd 157 (Stat. Skogsf.inst.)	45	24.0	25.0	II	1956	6
93	Rye Nøreskov (Jylland). Avd 10	42	22.4	20.6	III	1952	
94	Wedellsborg (Fyn) Vestmarkskov 11 B	29	17.0	18.1	I	1953	
95	» Nyskov 16	42	24.8	30.8	I	1953	15
96	» Nyskov 17	25	15.3	14.8	I	1953	
97	» Nyskov 17	30	18.0	20.1	I	1953	
98	» Haare. Avd 36	40	22.5	25.7	II	1953	15
99	» Lystskoven. Avd 49	51	27.5	38.9	II	1953	15
100	» Ørsbjerg. Avd 56	41	23.4	26.4	II	1953	
101	» Ørsbjerg. Avd 72	27	16.7	18.9	I	1953	
102	» Randebjerg. Avd 18	40	23.4	22.7	I	1953	12
103	Klitdirektoratet Vejers Klitplantage (Jylland)	38	9.4	13.9	IV	1941	4
104	» Vrøgum Klitplantage	35	13.4	19.2	IV	1930	2
105	» Tornby Klitplantage	35	15.0	17.8	III	1948	9
107	» Bosdrup Klitplantage	70	20.3	33.7	IV	1953	

SITKA SPRUCE

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
	Sample plots etablished by The Danish Forest experiment Station						
GJ	Vilsbøl Klitplantage (Jylland)	36				1926	8
GK	Vrøgum » »	44				1935	17
GL	Høllund Søgaard Plantage (Jylland)	43				1930	13
HGa	Rosenfeldt (Sjælland)	52				1947	14
HGb	» »	47				1947	24
GQ	Frijsenborg (Jylland)	42				1933	14
GS	» »	43				1926	6
GU	Palsgaard (Jylland)	61				1948	27
GM	Gisselfeld (Sjælland)	33				1930	13
ID	Giesegaard (Sjælland)	45				1941	20
IK	Klelund Plantage (Jylland)	38				1943	12
IP 6	Bregentved (Sjælland)	22				1936	3
IP 7	» »	21				1936	3
IP 10	» »	21				1936	
IP 11	» »	22				1936	2
MA	Silkeborg Vesterskov (Jylland)	58				1949	24
MB	Nystrup Plantage (Jylland)	40				1951	16
MB	» » »	42				1951	16
MB	» » »	47				1951	16

Appendix 2. Douglas fir sample plot material

The Douglas fir investigation includes a total of 187 revisions divided as follows:

Sample plots established and recorded by:

The Danish Forest Experiment Station and the Swedish Forest Research Institute	24
The Danish Regulation Department of State Forests	14
The forest administration authorities (controlled or revised by the writer)	28
The forest administration or by the Regulation Department of State Forests, (used only as a basis for site classification)	79
The writer	42
Total	187

DOUGLAS FIR

Sample plot location, stand age and year of revision.

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
1	Gisselfeld (Sjælland) Hesede. Avd 147	45	29.2	42.9	II	1952	7
2	» Hesede. Avd 147	36	20.2	20.4	III	1952	11
3	» Hesede. Avd. 124	28	16.0	17.4	III	1952	
4	» Denderup Vænge. Avd 202	39	26.5	20.8	I	1952	14
5	» Nygaard Vænåe. Avd 46 NV	41	22.5	29.9	III	1952	
6	» Nygaard Vænge. Avd 46 NV	25	13.8	14.6	III	1952	2
7	» Denderup Vænge. Avd 258	47	27.9	35.1	II	1952	
8	» Gl. Dyrehave. Avd 453	34	24.6	32.1	I	1952	
9	» Hesede. Avd. 124	25	14.5	16.7	III	1950	
10	» Nygaard Vænge. Avd 31	25	14.5	15.4	III	1950	
11	Bregentved (Sjælland) Boholte V:1	39	23.8	35.3	II	1952	
12	Farum (Sjælland) Ganløse. Eget avd 148	25	13.1	12.7	III	1952	7
13	Penarpsgården, Förslöv (Skåne). Avd 146	43	23.6	29.9	III	1952	
14	Skjoldenæsholm (Sjælland) Mortenstrup Skov.						
15	Avd. 165	27	19.0	21.7	I	1934	8
	» Mortenstrup Skov. Avd 83	36	22.0	27.0	II	1948	6
16	Næsbyholm (Sjælland) Østerskov. Avd 37	29	20.8	25.0	I	1952	
17	» Østerskov. Avd 37	41	26.1	29.7	II	1952	27
18	» Storskov. Avd 104	41	28.9	35.3	I	1952	
19	Petersgaard (Sjælland) Langebæk. Avd 26	31	16.8	28.6	III	1952	
20	» Stensby. Avd 22	33	19.0	22.3	III	1952	
21	» Stensby. Avd 33	26	18.0	18.8	II	1947	
22	» Stensby. Avd 16 d	30	17.7	20.9	III	1952	
23	» Stensby. Avd 16 d	30	16.5	18.0	III	1952	2
24	» Stensby. Avd 26 c	34	18.3	23.4	III	1952	4
25	» Stensby. Avd 26 a	41	23.9	32.0	II	1952	5
21	» Hestehave. Avd 12	56	34.5	44.1	I	1952	19
27	Palsgaard (Jylland) Gludsted Plantage.						
	Avd. 116	22	8.3	8.5	IV	1952	
28	» Gludsted Plantage. Avd 10 i	28	11.5	12.1	IV	1952	
29	» Gludsted Plantage. Avd 72 d	41	24.5	26.9	II	1952	
30	» Gludsted Plantage. Avd 73 d	41	23.7	25.3	II	1952	

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
31	Palsgaard Gludsted Plantage. Avd 82 e	43	32.1	25.8	III	1953	
32	» Gludsted Plantage. Avd 98 g	43	24.1	28.4	III	1952	
33	Randbøl (Jylland) Gødding Skov. Avd 18	23	9.4	9.5	IV	1949	2
34	» Gødding Skov. Avd. 1	21	10.4	9.4	III	1952	2
35	» Tykhøj. Avd. 137	23	9.9	9.5	IV	1949	
36	Frijsenborg (Jylland) Havrum. Avd 21	43	23.2	28.2	III	1952	
37	» Sølunden. Avd 13	37	24.5	31.4	I	1952	22
38	» Borridsø. Avd 16	37	20.5	26.1	III	1949	
39	» Norringure. Avd 8	51	28.7	40.5	III	1952	26
40	» Norringure. Avd. 24	66	31.6	52.7	III	1952	
41	» Norringure. Avd 22 b	43	26.7	35.2	II	1952	
42	» Norringure. Avd 22 b	35	21.5	25.8	II	1951	
43	» Norringure. Avd 22 b	39	23.3	31.0	II	1952	
44	» Tinning. Avd 10 b	42	24.2	34.8	II	1952	15
45	» Tinning. Avd 15 b	44	26.5	36.1	II	1952	24
46	Glorup (Fyn) Dyrehaven. Avd 95	45	29.5	41.6	I	1952	
47	» Dyrehaven. Avd 79	39	23.8	30.8	II	1952	
48	Mejlgaard (Jylland). Avd 106 b	37	22.6	30.5	II	1952	
49	» Avd. 134 a	35	21.1	27.0	II	1952	
50	» Avd 273 a	38	24.6	29.1	II	1952	23
51	» Avd 413 b	37	23.2	28.0	II	1952	
52	Buderupholm (Jylland). Avd 193	61	26.3	37.2	IV	1952	
53	» Avd 193	56	24.1	39.2	IV	1952	
54	» Tøtteruphus. Avd 130	61	30.4	53.1	III	1952	11
55	» Skelhus Skovpart. Avd 190	72	30.7	58.6	IV	1952	12
56	» Avd 191	61	31.0	49.8	III	1952	
58	Gunderslevholm (Fyn) Tvede Vænge. Avd 21	87	34.0	71.6	IV	1952	
59	Wedellsborg (Fyn) Kongeskoven. Avd 31	33	19.8	26.6	II	1952	
60	» Westmarskov. Avd 9	36	21.2	27.1	II	1952	
61	» Westmarkskov. Avd 7	26	12.4	14.0	IV	1952	
62	» Balslev. Avd 7	27	13.4	14.3	IV	1952	
63	» Balslev. Avd 6	32	17.9	22.3	III	1958	
64	» Rendebjerg. Avd 15	39	21.5	27.7	III	1952	
65	Börringekloster (Skåne) Kellingsberg	46	25.4	33.3	III	1952	5
66	Langesø (Fyn) Mørkemose. Avd 3 f	32	23.4	25.1	I	1952	4

Plot No.	Locality and department	Age when last revised	Height, m	Diam, cm	Site class	Last year of revision	Length of observation period, years
67	Langesø Ruehed 8 d	47	28.7	33.5	II	1952	14
68	» Morudskov 4 e	32	24.6	29.8	I	1952	
69	Langesø (Fyn) Morudskov 6 c	75	35.8	58.3	II	1952	4
70	» Stjernebjerg. Avd 7 a	72	35.2	55.6	III	1951	13
72	Holstenshuus (Fyn)Enemærket 14 b	41	29.1	36.4	I	1951	7
73	Rössjöholm (Skåne) Avd 144 (Stat. skogsf.inst.)	39	18.0	18.2	IV	1958	
74	» Avd 67 (Stat. skogsf.inst.)	66	28.2	64.1	III	1955	5
75	Hvidkilde (Fyn) Hedeskoverne. Avd 102	28	15.5	15.7	III	1950	8
76	Hensbacka Skogsvårdsgård (Bohuslän)	36	17.5	18.8	IV	1952	
77	Valborup (Sjælland). Avd 75	37	19.6	24.3	III	1952	4
78	Linaa Vesterskov (Jylland). Avd 32 e	44	26.3	37.2	II	1952	
79	» » Avd 10	65	28.0	47.7	IV	1949	5
80	Silkeborg Vesterskov (Jylland). Avd 327	47	25.9	30.6	III	1951	22
81	» » Avd 331	80	33.9	46.5	III	1950	
82— 99	Langesø (Fyn). Results from the forest survey in 1948						
100—107	Bornholm. Results from the survey 1946						
108—161	Silkeborg (Jylland). Results from the forest survey in 1950						
162	Vejle kommuneskov (Fyn)	32	22.5	25.7	I	1945	
163	Skärsnäs krp (Skåne)	47	24.6	32.7	III	1957	9
164	Tommarp 1:3 (Skåne) Österlövs sn	47	28.4	42.3	II	1957	
165	Vittsjö (Skåne) 500 m s.v. kyrkan	52	27.5	37.9	III	1957	
166	Oxhult krp (Halland) (Stat. skogsf.inst. no 45)	53	20.7	27.1	IV	1958	
167	» » (Stat. skogsf.inst. no 46)	53	28.7	21.8	IV	1958	

DOUGLAS FIR

Sample plots managed by the Danish Forest Experiment Station.[1]

Plot No.	Locality and department	Age when last revised	Length of observation period, years
GA	Boller Skovdistrikt (Jylland)	69	43
GB	Københavns Distrikt (Sjælland)	69	44
GC	Valbygaard (Sjælland)	51	24
GE	Frijsenborg (Jylland)	70	43
IB	Giesegaard (Sjælland)	45	27
IC	Silkeborg (Jylland)	67	25
PA—a	Nødebo (Sjælland)	24	10
PA—b	» »	25	5
PA—c	» »	23	10
PA—d	» »	24	8
PA—e	» »	23	8
PA—f	» »	21	8
PA—g	» »	23	8
PA—h	» »	23	8
PA—i	» »	23	8
PA—k	» »	23	8
PA—m	» »	25	8
PA—o	» »	23	8

[1] A number of measurements have also been made at the Bromme plantation (sample plot GD). Since this plantation was spoiled by windthraw it is no longer used by the Experiment Station. Similar records have also been kept for some of the early Douglas fir sample plots (IN) established by the Experiment Station in the Bregentved district. Sample plot II in the Giesegaard district (established by the Experiment Station) was omitted from the investigation since it contained the grey variety of Douglas fir, i.e. the caesia form.

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D.F.F	means	Det Forstlige Forsøgsvæsen i Danmark
D.S.T.	»	Dansk Skovforenings Tidsskrift
D.D.G.	»	Mitteilungen Der Deutschen Dendrologischen Gesellschaft
A.F.u.J.	»	Allgemeine Forst- und Jagdzeitung
Z.F.u.J.	»	Zeitschr. für Forst und Jagdwesen

VII. Abstract in Swedish

Douglasgranens och sitkagranens produktion och växt i södra Skandinavien och i nordvästra Amerika

Inledning (sid. 5—6)

Föreliggande undersökning har utförts under åren 1950—1957. Avsikten har varit att bringa ökad klarhet om douglasens och sitkagranens växt och produktionsförhållanden med särskild hänsyn till dessa trädslags möjligheter i södra Sverige.

I. Materialinsamling och detaljbearbetning (sid. 7—48)

Materialets insamling (sid. 7—9)

Då bestånd i tillräcklig omfattning för en fullständig analys saknats i Sverige, har huvudparten av materialet insamlats i Danmark, vars klimat ej väsentligt avviker från södra Sveriges. Underlaget består dels av provytor, som lagts ut genom egen försorg, och dels av provytematerial, som ställts till förfogande av de privata skogsförvaltningarna, Det forstlige Forsøgsvæsen i Danmark, Den danska Statsskovreguleringen och Statens Skogsforskningsinstitut i Sverige. Inalles ingår 187 douglasytor och 119 sitkagranytor. Provytematerialet redovisas i bilaga 1 och 2 på sid. 111—120.

Bonitetsindelning för sitkagranen (sid. 9—14)

Vid bonitetsindelningen har endast sådana ytor, som blivit föremål för uppskattning under en längre följd av år, använts. Härvid har den grundytevägda medelhöjden hos beståndet efter gallring lagts upp över åldern. Konstruktionen av kurvorna har skett med stöd av den normala fördelningsfunktionen Φ (x), där $\Phi \, x = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{t^2}{2}} dt$. På basis av denna har funktionen $h = A \, \Phi \left(\frac{{}^{10}\log t - m}{\sigma} \right)$ uppställts. Härvid betecknar h höjden i meter och A högsta höjd vid oändlig ålder och t åldern i år.

Bestämning av de båda obekanta storheterna m ($^{10}\log$ för åldern vid halva höjden) och σ (standardavvikelsen) har skett grafiskt på sätt som närmare beskrives på sid. 10 och i tabellerna 1 och 2.

Den aktuella ekvationen för sitkagranen har därvid erhållit följande utseende: $h_t = 2\, h_{50}\, \Phi \left(\frac{^{10}\log t - 1.6990}{0.21 + 0.0066\, h_{50}}\right)$ där h_t är höjden vid t år och h_{50} höjden vid 50 år.

Bonitetsindelningen har skett efter höjden vid 50 år och omfattar fyra bonitetsklasser (I—IV) enligt följande definition:

Bonitet	I	Bestånd, som nått eller antages nå 30 meters (28½—31½) medelhöjd vid 50 år
»	II	Bestånd, som nått eller antages nå 27 meters (25½—28½) medelhöjd vid 50 år
»	III	Bestånd, som nått eller antages nå 24 meters (22½—25½) medelhöjd vid 50 år
»	IV	Bestånd, som nått eller antages nå 21 meters (19½—22½) medelhöjd vid 50 år

Bonitetsindelning för douglasen (sid. 14—17)

Liksom vid bonitetsindelningen för sitkagranen har endast ytor, som blivit föremål för upprepade inventeringar, använts. Konstruktionen av kurvorna har också här skett med hjälp av den normala fördelningsfunktionen Φ x. Den för douglasen aktuella ekvationen erhöll därvid följande utseende:

$$h_t = h_{50}\, \Phi\, \frac{(^{10}\log t - 1.6990)}{0.24 + 0.0088\, h_{50}}$$

Definitionen av de fyra bonitetsklasserna för douglasgranen är följande (sid. 14):

Bonitet	I	Bestånd, som nått eller antages nå 32 meters (30½—33½) medelhöjd vid 50 år
»	II	Bestånd, som nått eller antages nå 29 meters (27½—30½) medelhöjd vid 50 år
»	III	Bestånd, som nått eller antages nå 26 meters (24½—27½) medelhöjd vid 50 år
»	IV	Bestånd, som nått eller antages nå 23 meters (21½—24½) medelhöjd vid 50 år

För såväl douglas- som för sitkagransmaterialet råder synnerligen god överensstämmelse mellan materialets höjdkurvor och de konstruerade bonitetskurvorna (fig. 3 och 5, sid. 13 och 16).

Produktionsöversikterna (sid. 17—20)

För vidare bearbetning av materialet har grafisk utjämning ansetts vara mest lämpad. Liknande metodik vid framställning av produktionstabeller har på senare tid använts bl. a. av Wiedemann (1931 och 1936), Möller (1933), Schober (1949), Hummel och Christie (1953) m. fl. Såsom framgår nedan är ett det ett flertal observationer som blivit föremål för grafisk utjämning. Uträkningarnas tyngdpunkt har dock lagts på den direkt mätbara grundytan per hektar. De olika kurvorna har fått stödja varandra och kontroll har företagits på sätt som närmare beskrives på sid. 18 ff.

A. *Stamantal per hektar* (sid. 20—22)

Observationerna, som avser tillståndet efter gallring, har lagts upp bonitetsvis över ålder och utjämnats grafiskt, varvid de olika boniteternas kurvor fått stödja varandra. Resultatet redovisas i figurerna 6 och 7 och på sid. 21 och 22.

B. *Grundytemedelstammens diameter* (sid. 23—24)

Grundytemedelstammens diameter hos beståndet efter gallring har lagts upp bonitetsvis och blivit föremål för grafisk utjämning på liknande sätt som stamantalet. Resultatet redovisas i figurerna 8 och 9 på sid. 23 och 24.

C. *Grundyta per hektar* (sid. 24—26)

Värdena för grundytan per hektar hos beståndet efter gallring har lagts upp över åldern bonitetsvis och blivit föremål för utjämning. De olika boniteternas kurvor har härvid fått stödja varandra. Spridningen på grundytan är såsom framgår av figurerna 10 och 11 på sid. 25 icke oväsentlig. För att erhålla ytterligare stöd vid konstruktionen av grundytekurvorna har dessa också konstruerats genom att multiplicera det utjämnade stamantalet med grundytemedelstammens grundyta, erhållen från den utjämnade grundytemedelstammens diameter.

D. *Formhöjd* (sid. 26—27)

Formhöjden har dels beräknats på det formtalsmaterial, som insamlats i samband med undersökningen och dels på det material, som ställts till förfogande av Det forstlige Forsøgsvæsen i Danmark. Formhöjden för samtliga boniteter har lagts upp över höjden, varefter grafisk utjämning skett. Såsom framgår av figurerna 12 och 13 på sid. 26 och 27 är spridningen kring den närmast med en rät linje överensstämmande medelkurvan mycket liten.

E. *Kubikmassa per hektar* (sid. 28—30)

Kubikmassan omfattar hela stammens volym på bark. Den har erhållits genom att multiplicera provytans grundyta per hektar med formhöjden. Erhållna värden, som hänför sig till tillståndet efter gallring, har lagts upp över åldern och blivit föremål för grafisk utjämning bonitetsvis. En ytterligare kontroll på de olika kubikmassekurvorna har skett genom att beräkna kubikmassan som en produkt av den utjämnade grundytan per hektar och formhöjden. Exempel på några kubikmassekurvor redovisas i figurerna 14 16 och 17 på sid. 28 och 29.

F. *Det utgallrade virkets diameter* (sid. 30—31)

Härmed avses det utgallrade virkets grundytevägda medeldiameter. Denna har beräknats för det utgallrade virket och satts i relation till den grundytevägda diametern för kvarvarande bestånd. Sambandet framgår av figurerna 16 och 17 på sid. 30 och 31.

G. *Det utgallrade virkets höjd* (sid. 31—33)

Sambandet mellan det utgallrade virkets grundytevägda medelhöjd och det kvarvarande beståndets har erhållits på liknande sätt och resultaten återfinnes i figurerna 18 och 19 på sid. 32 och 33.

H. *Grundytetillväxten per hektar* (sid. 32—38)

Beståndets årliga löpande grundytetillväxt har beräknats med hjälp av de tillväxtuppgifter, som erhållits från ytor, som följts med mätningar under flera år, samt från borrkärnematerialet.

För douglasens vidkommande lades de beräknade värdena på tillväxtprocenten upp över åldern och blev föremål för utjämning. Resultaten framgår av fig. 20 sid. 36. När de utjämnade värdena på tillväxtprocenten sedermera sattes i relation till grundytorna i tabellerna visade det sig, att den löpande grundytetillväxten för de fyra boniteterna, frånsett vissa skillnader i yngre åldrar, icke företedde några väsentliga skillnader (se produktionstabellerna sid. 41 ff).

Tillväxtberäkningarna för sitkagranen utfördes därför genom att sätta den löpande grundytetillväxten i relation till åldern. När grundytetillväxterna samlats för samtliga boniteter i ett diagram låg observationerna, frånsett vissa differenser i yngre åldrar, där boniteten påverkat grundytetillväxten, oregelmässigt blandade med varandra. (Fig. 21 sid. 37.)

I. *Kubikmassans tillväxt per hektar* (sid. 39—40)

Den årliga löpande tillväxten på kubikmassan har erhållits direkt ur tabellerna som en skillnad mellan tillståndet före gallring och tillståndet efter närmast föregående gallring dividerad med gallringsintervallet. En kontroll på kubikmassetillväxten har utförts genom att jämföra den i tabellerna beräknade kubikmassetillväxten med den som hämtats direkt ur provytematerialet. En sådan kontroll redovisas i figurerna 22 och 23.

J. *Totalproduktion per hektar* (sid. 40)

Den totala produktionen har erhållits genom att summera kubikmassan per hektar vid första gallringen och den årliga kubikmassetillväxten.

Produktionstabellerna (sid. 41—48)

De data, som beräknats och kontrollerats på sätt som ovan beskrivits har överförts i tabellform. Produktionstabellerna för båda träslagen omfattar 61 år.

II. Douglasgranens växt och växtvillkor (sid. 49—83)

Utbredning, morfologi och systematik (sid. 49—53)

Douglasen betraktas allmänt såsom ett nordligt västamerikanskt trädslag fastän dess utbredning omfattar stora delar av den nordamerikanska kontinenten (fig. 24, sid. 50). Man brukar skilja på tre varianter, nämligen den vid kusten förekommande viridisformen samt de två kontinentala formerna glauca (den blå eller bergsformen) och caesia (den grå formen), (sid. 51). Den enda variant, som är av intresse för södra Sveriges vidkommande, är viridisformen.

I de skyddade dalarna på Kaskadbergens västra sluttningar når douglasgranen mäktiga dimensioner. Arten har bytt namn ett flertal gånger och senast från Pseudotsuga taxifolia till Ps. menziesii (sid. 51).

Pseudotsuga utgör ett släkte (sid. 51) tillhörande underfamiljen Abietoideae och är således varken gran eller ädelgran i egentlig bemärkelse. Det kan därför anses något inkonsekvent att på svenska kalla trädet för douglasgran. Därför användes här emellanåt benämningen douglas i likhet med vad som ofta är fallet i Danmark och Tyskland.

Proveniensförhållanden (sid. 53—60)

»The Douglas Fir Region», som i huvudsak omfattar staterna Oregon och Washington väster om Kaskadbergen, uppvisar stora variationer i klimat etc. Douglasens proveniensfråga har därför stor betydelse. Föreliggande material är emellertid inte tillräckligt för att belysa proveniensproblemet. I proveniensfrågan kan dock de omfattande undersökningar, som utförts i Danmark, Tyskland, Holland och England lämna anvisningar. Av dessa undersökningar kan dragas den slutsatsen, att för södra Skandinavien lämpat frömaterial är att finna i staten Washington och södra British Columbia inom ett område som i söder begränsas av Columbiafloden och i norr av Frazerfloden. Lämpligaste höjdläge inom detta område ligger mellan200—800 meter med den högre siffran huvudsakligen gällande för sydligare delar av området.

Douglasgranens växt på Pacifickusten och i södra Skandinavien
(sid. 60—64)

Douglasen uppnår i sitt hemland väsentligt större höjder än vad man vågar hoppas på för södra Skandinaviens vidkommande. Denna skillnad i höjdutveckling torde bero på de mera optimala växtbetingelser douglasen har i sitt hemland, såsom högre medeltemperatur, längre vegetationsperiod etc. Således är douglasen på bästa bonitet på Pacifickusten redan vid 50 år 11 meter högre än vad den är på bästa bonitet i föreliggande undersökning (fig. 27, sid. 61).

Jämföres bestånd som nått samma höjd vid 50 år, visar det sig, att de sydskandinaviska bestånden har ett väsentligt lägre stamantal och därmed större medelgrundytediameter än de ogallrade amerikanska (fig. 28, sid. 62). Genom att gallringsvirket tillvaratages här och ingår i produktionen, erhålles en väsentligt större totalproduktion än i de amerikanska bestånden, där undertryckta stammar få självdö (fig. 28, sid. 62). Ökad efterfrågan på virke för den nordvästamerikanska skogsindustrien har emellertid skapat förutsättningar för rationellare genomhuggningar av bestånden.

Douglasgranens växt enligt andra produktionsundersökningar i Europa
(sid. 64—69)

Jämföres douglasens växt i föreliggande undersökning med den, som redovisas i England och Tyskland visar det sig, att douglasen väl hävdat sin ställning längre norrut. Visserligen är höjdtillväxten i England liksom även produktionen något större på bästa engelska bonitet än på den bästa i undersökningen (fig. 30, sid. 66). Jämföres däremot tillväxten hos bestånd med samma medelhöjd i de engelska, tyska och föreliggande produktionstabellerna förekommer inga skillnader av betydelse (fig. 32). Såsom framgår av fig. 31 gallras de sydskandinaviska bestånden hårdare än de tyska och även de engelska och redovisar därmed lägre grundytor. Liknande skillnader i beståndsutvecklingen erhålles om danska produktionstabeller för gran jämföres med tyska (sid. 67).

Douglasgranens växt och produktion i jämförelse med den vanliga granens (Picea Abies), (sid. 69—83)

Det skogliga intresset för ett främmande trädslag är i första hand knutet till dess produktionsförhållanden i relation till befintliga trädslags. Jämförelser har därför gjorts i sådana fall, där douglasbestånd och bestånd av vanlig gran stått intill varandra och betingelserna i de angränsande bestånden bedömts likartade. Inalles har 34 douglasbestånd blivit föremål för sådana jämförelser med intilliggande granbestånd (tabell 10 sid. 70). Därvid framgick att douglasen vid 50 år har genomgående högre höjd än granen. Höjdskillnaderna, som redovisats i tabell 11 och fig. 33, är störst på Möllers granbonitet IV (9,0 meter) och minst på granbonitet I (4,0 meter). Granens höjdskillnad mellan Möllers bonitet I och IV är avsevärt större än douglasens höjdskillnad mellan ifrågavarande granboniteter. Denna tendens hos douglasen till mindre specifika krav på ståndorten än granen framgår också av en utförd specialundersökning (sid. 77 och fig. 34).

Jämföres totalproduktionen vid 60 år, visar det sig, att douglasen på Möllers granbonitet I trots större medelhöjd producerar något mindre än granen (—6 %). På granbonitet IV producerar douglasen däremot väsentligt mera än granen (+64 %) (tabell nr 12 på sid. 79).

Då douglasen har genomgående kraftigare höjdtillväxt än gran på motsvarande mark, gallras den där kraftigare än granen och når snabbare grova dimensioner (fig. 35, sid. 80).

Jämföres däremot stamtals- och diameterutvecklingen hos douglas- och granbestånd, som nått samma höjd vid 50 år, förekommer inga större skillnader vare sig med avseende på stamantal eller diameter (sid. 80 fig. 35). För bestånd, som har sammanfallande höjdutveckling, är beståndsbehandlingen i praktiken således likartad för de båda trädslagen.

De olikartade markförhållandena och det relativt begränsade materialet har icke tillåtit en mera ingående penetrering av de enskilda ståndortsfaktorerna. Däremot har en uppdelning av materialet för produktionsjämförelsen kunnat göras på lerfriare respektive lerhaltigare jordartsgrupper. Enligt tabell 14 på sid. 82 är förhållandet mellan douglasens och granens totalproduktion större på de lerfriare jordartsgrupperna (1,45) än på de lerhaltigare (1,10). Detta resultat står i god överensstämmelse med tidigare undersökningar beträffande douglasens markanspråk, nämligen att douglasen spänner över vitt skilda jordarter, men att dess överlägsenhet gentemot granen är mera framträdande på de svagare. Av undersökningsmaterialet framgår att äldre douglas påverkas föga av rotröta (Fomes annosus). Redovisade iakttagelser, att douglasen är en markförbättrare och ger ett humustillstånd, som påminner om lövträdens, bekräftas av andra undersökningar, (sid. 83).

III. Sitkagranens växt och växtvillkor (sid. 84—105)

Utbredning, morfologi och systematik (sid. 84—87)

Sitkagranen är en utpräglat maritim art och dess utbredningsområde utgöres av ett smalt bälte längs Nordamerikas Stillahavskust (fig. 31, sid. 82). Den intar en särställning inom släktet Picea genom att dess utbredning är begränsad till lägre höjder över havet.

Sitkagranen når i sitt hemland kraftiga dimensioner och kan under goda betingelser bli över 100 meter hög. Som ung är den som regel mera bredkronig än den europeiska granen (Picea Abies) och har något uppåtriktade grenar. Barrskruden verkar ljusare och barren smalnar långsamt till en vass spets. Äldre exemplar har ofta kraftig rotansvällning och brun tjock bark med löst sittande barkflagor. Förekomst av vattenskott är icke ovanlig (fig. 36, sid. 85). P. sitchensis hybridiserar lätt med P. Engelmanni, P. glauca och P. jezoensis. Däremot torde endast ett fall vara känt, där man lyckats korsa P. sitchensis med P. Abies (sid. 87).

Proveniensförhållanden (sid. 87—89)

Genom att sitkagranens utbredningsområde är begränsat till en med avseenden på klimatet ganska likartad kuststräcka och till mindre höjd över havet, är proveniensfrågan ej så komplicerad som hos douglasen. Även om man skiljer på olika typer av sitkagran allt efter dess växtplats (sid. 85) har inga geografiska varianter beskrivits.

Såväl i norra Washington som i British Columbia och på Queen Charlotte Islands finns områden, som med avseende på temperatur visar god överensstämmelse med södra Skandinavien. De extremt fuktiga lägena längs kusten bör dock undvikas för fröinsamling. Sitkagran från Queen Charlotte Islands börjar sin skottsträckning tidigare än sitkagran från staten Washington och bör hos oss undvikas i lägen, som är utsatta för vårfrost. I gengäld slutar de sydligare provenienserna sin tillväxt några veckor senare än de nordligare.

Sitkagranens växt på Pacifickusten och i södra Skandinavien (sid. 89—90)

Då det inte finns några tabeller för rena sitkagranbestånd i U.S.A. saknas möjligheter till produktionsjämförelser. Däremot finns tabeller för blandbestånd av P. sitchensis och Tsuga heterophylla, vilket möjliggör jämförelse av höjdutvecklingen i Amerika och Skandinavien (sid. 89). Bästa bonitet i de amerikanska tabellerna (site index 200) redovisar för sitkagran en höjd av drygt 40 meter vid 50 år, medan höjden för bästa bonitet i föreliggande undersökning är 30 meter vid motsvarande ålder. Sitkagranen kan tydligen i likhet med Douglasen icke erbjudas lika goda växtvillkor i södra Skandinavien som i sitt hemland med dess högre nederbörd och blidare klimat.

Sitkagranens växt enligt andra produktionsundersökningar i Europa (sid. 90—94).

Bästa bonitet i de brittiska produktionstabellerna (Quality class I) har en större beståndsmedelhöjd vid 50 år än bästa bonitet i de danska (Bonitet 1) och i de föreliggande produktionstabellerna (Site class I) (fig. 38, sid. 91). I övrigt visar höjdkurvorna god överensstämmelse.

Beträffande beståndsutvecklingen är grundytorna genomgående större i det brittiska materialet (fig. 39, sid. 92).

Jämföres den löpande kubikmassetillväxten för bestånd med samma höjd vid 50 år (H_{50} = 24,0) föreligger inga väsentliga skillnader mellan de danska och de föreliggande tabellerna. Däremot avviker de brittiska tabellerna något, med större tillväxt i yngre åldrar och mindre mot slutet av omloppstiden (fig. 40, sid. 94).

Sitkagranens växt och produktion i jämförelse med den vanliga granens (P. Abies) (sid. 94—105)

Metodiken har varit densamma som vid jämförelsen mellan douglas och vanlig gran. Antalet sitkagranbestånd, som ingår i jämförelsen är 35 (tabell 15). Som framgår av figur 41 (sid. 95), där bestånd som står på likartad mark jämföres, har sitkagranen genomgående större höjder än granen vid 50 år. Höjdskillnaderna är ungefär lika stora på samtliga granboniteter (4—5 meter), varav torde framgå, att sitkagranens ståndortskrav avviker föga från den vanliga granens. Spridningen på sitkagransmaterialet inom respektive granboniteter är mindre än för douglasmaterialet. Detta har tolkats så, att skillnader i proveniens spelat en mindre roll här än vid douglasundersökningen.

Vad avser jämförelsen mellan de båda trädslagens totalproduktion vid 60 år är denna genomgående större hos sitkagranen (20—50 %), såsom framgår av tabell 16. På motsvarande granbonitet gallras den högre sitkagranen hårdare än vanlig gran och når därmed kraftigare dimensioner än denna. Jämföres däremot sitkagranbestånd med granbestånd, vilka båda nått samma medelhöjd vid 50 år, är såväl stamtals- som diameterutveckling överensstämmande (fig. 42, sid. 102). Bestånd av respektive trädslag med likartad höjdutveckling, genomhugges tydligen efter samma normer i praktiken. Av samma jämförelse framgår också, att sitkagranbestånd, som vid 50 år har samma medelhöjd som vanlig gran, i stort sett redovisar samma totalproduktion som denna.

Delas produktionsjämförelsens material upp på lerfriare respektive lerhaltigare jordartsgrupper är förhållandet mellan sitkagranens och den vanliga granens totalproduktion ganska likartat i båda fallen (1,31 resp. 1,21), (Tabell 17 sid. 104). Alla undersökningar, som gjorts över sitkagranens växtvillkor, framhåller nödvändigheten av fuktighet i en eller annan form, såsom rikligt förekommande rörligt grundvatten, hög nederbörd eller hög luftfuktighet.

IV. Granskning av materialet och slutsatser (sid. 107—109)

Genom att huvudparten av materialet för denna undersökning insamlats i Danmark uppstår följdenligt frågan, huruvida erhållna resultat också är helt tillämpliga för sydsvenska förhållanden. För att så är fallet talar den omständigheten att såväl klimat som mark- och skogsskötselförhållanden visar god överensstämmelse inom respektive områden. En annan faktor, som talar för likartade betingelser är, att de sydsvenska bestånd, som ingår i undersökningen, icke avviker från de övriga på sådant sätt att anledning finnes förmoda systematiska skillnader.

Beträffande undersökningen i sin helhet gäller resultat och slutsatser det behandlade materialet. Ur jämförelserna med de danska produktionstabellerna för sitkagran erhålles ett svar på frågan hur stora avvikelser, som kan påräknas för ett annat slumpmässigt uttaget stickprov ur samma population. Skillnaderna härvid har bedömts såsom obetydliga.

Undersökningen har emellertid inte syftat till att statistiskt klarlägga produktionsförloppet hos några allmänt förekommande trädslag, utan i stället till att ställa prognoser, som bygger på, att vår nuvarande kännedom om proveniens, ståndortsanspråk m. m. väl tillvaratages. Undersökningen har av den anledningen begränsats till bestånd, vars utveckling bedömts vara god (sid. 12).

Trots det urval som skett, är variationen inom respektive bonitetsklasser relativt stor. Detta gäller framför allt för douglasen. Materialet kan därför icke betraktas som en ren population utan sannolikt föreligger här en genotypisk variation på grund av skillnader i proveniens. Den omständigheten aktualiserar naturligtvis frågan, huruvida en sådan variation utöver den äkta slumpvariationen, d. v. s. på grund av genetiska och kilmatologiska olikheter, förekommit i sådan omfattning, att den medfört systematiska avvikelser. Jämförelser med tyska och engelska produktionsöversikter visar emellertid inga skillnader, som ger anledning förmoda förekomsten av sådana avvikelser. Sammanfattningsvis kan därför sägas, att de föreliggande produktionstabellerna ger medelutvecklingen hos det använda materialet.

Ett slutgiltigt ställningstagande till douglasgranens och sitkagranens produktionsbetingelser innebär en avvägning och en värdering av alla de faktorer som har inflytande. Detta ställningstagande, som medför ett starkt subjektivt värderingsmoment, har av naturliga skäl utelämnats i undersökningen.

Utöver de mere relevanta fakta som här redovisats, kan det dock vara befogat, att avslutningsvis något perifert beröra en del frågor, där materialet inte kunnat bidraga med vetenskapligt verifierbar bevisning. Detta gäller framför allt synpunkter på beståndsbehandling och odlingsmöjligheter.

Såsom framgår av de jämförelser, som gjorts med andra europeiska produktionstabeller är den gallring, som redovisats här, genomgående kraftigare för såväl douglas som sitkagran.

Odlingen av douglas i södra Skandinavien har dock hitintills i huvudsak siktat på produktion av grövre kvalitetsvirke. Nuvarande möjligheter att använda virket inom cellulosaindustrien kan emellertid motivera andra gallringsformer och eventuellt medföra en tendens mot anläggningar av rena douglasbestånd i stället för nuvarande inblandning med gran. Den mindre goda kvistrensning som kan bli följden av glesare förband och kraftigare ungskogsgallringar kan möjligen kompenseras med stamkvistning (sid. 108). Då massatillväxten synes vara oberoende av gallringsstyrkan inom relativt vida gränser, saknas sannolikt icke möjligheter att välja det skötselprogram, som bedömes ge bästa ekonomiska utbyte.

Om douglasens virke skall röna god efterfrågan torde såväl relativt stora kvantiteter som goda kvaliteter erfordras. Det är emellertid huvudsakligen för produktion i större sammanhang, som douglasen kan påräknas lämna det största bidraget till sydsvenskt skogsbruk. Detta gäller inte minst på de arealmässig omfattande rötinfekterade granmarker, där det ofta anses nödvändigt låta en generation lövträd efterträda granen. Douglasgranens stora motståndskraft mot Fomes annosus och dess markförbättrande egenskaper torde göra den till ett gott substitut för den mindre lönsamma lövträdsodlingen på svagare granmarker. Då douglasen, som framgått av undersökningen, spänner över ett förhållandevis stort register av ståndortsförhållanden, torde den också på en del marker kunna konkurrera med i södra Sverige förekommande tall av mindre god kvalitet.

Sitkagranen har också en produktion, som under vissa omständigheter är väsentligt större än den vanliga granens. Sitkagranens starka krav på god vattentillgång torde emellertid begränsa dess odlingsmöjligheter i vårt land.

Den i södra Skandinavien accepterade gallringsformen för sitkagran står, såsom framgått av jämförelsen, i god överensstämmelse med skötseln av den vanliga granen. De engelska och tyska produktionsökningarna för sitkagran visar emellertid avsevärt större stamantal och grundytor än i denna undersökning. På senare tid har också synpunkter framförts i Danmark, att med hänsyn till barkborrehärjningar (Dendroctonus micans) och rotröta

(Fomes annosus) söka gallra sitkagranen svagare. En svagare gallring skulle också kunna motverka det förhållandet att sitkagranen på de allra bästa ståndorterna genom sin kraftiga diametertillväxt producerar ett ganska löst virke. Om odling av sitkagran begränsas till väl genomsilade marker och höga nederbördsområden, där den hör hemma, torde gallringsstyrkan kunna varieras inom relativt vida gränser utan biologiska komplikationer.