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METHODS FOR PREPARING YIELD TABLES.

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Preface.

Owing to the fact that several inquiries have been made especially from America concerning the methods applied in preparing the yield tables now used in Suomi (Finland) we have printed in this paper a short account of the preparation of the present Finnish yield tables in English. It commences with a short review of the methods generally employed in preparing yield tables in Central Europe, pointing out the main defects in these methods. Finally the employment of the present Finnish yield tables will be briefly touched upon. The form and the headings in these yield tables are given and on the basis of the figures embraced in these tables the differences between the different forest types are illustrated by some diagrams.

Preparation of Yield Tables in Central Europe.

An accurate determination of yield is far more difficult in forestry than in any other branch of economy for the reason that in most cases the rotation, from the regeneration year up to the age of exploitability, is very long and considerably exceeds the human age. The proper treatment and solution of very many problems of forestry, however, presuppose a thorough insight into the active laws of the growth and yield of stands. Hence, as early as the origins of rational forestry, the need was felt for some practical aids in the accurate determination of the yield of forests. For this purpose so-called yield tables were invented in Germany over a hundred years ago. These tables record the general laws of forest growth, indicating accordingly the different kinds of growth and yield on an average in stands that have been normally developed, but are of different age, classifiable with respect to the quality of forest soil in the same group, and growing on a rather extended and continuous region.

During the last century, as well as during recent years, tables of this kind have been prepared in several countries, especially in Central Europe, endeavours having been made to correct in the later yield tables the defects detected in the earlier ones. By this means yield tables have been prepared for most of the forest-forming species of trees of Europe.

These yield tables prepared in Central Europe indicate for each species of tree separately at the different age-grades, generally of 5 or 10 years' length, the volume and the volume increment in cubic metres (feet), the number of stems and the basal area, all per hectare, the mean height, the mean diameter, and other similar factors in unmixed, evenaged and normally developed stands, all the factors being, as a rule, specified for the principal as well as for the dominated crop.

These tables have generally been based on observations on sample plots with an average area of a quarter of a hectare, measured in considerable number in stands of different age, but of a fairly normal character. For each sample plot all the requisite factors have been determined, and from these again, mostly by graphical methods, the mean smoothed curves representing the development, with advancing age, of the volume, the number of stems, the mean height, etc. have been derived.

The methods employed in the preparation of yield tables have been very manifold, some leading to results comparatively rapidly, others after a longer lapse of time. One of the most difficult, but at the same time one of the most important tasks has always been to find out which of the sample plots chosen as the basis for investigations have to be referred to the same growth series for which the mean yield values have to be calculated. In nature there is an exceedingly great number of different fertility grades of the site, and for this reason it is impossible to set up a different growth series for each fertility grade. But on the other hand one single series of yield numbers does not suffice for each species of tree. It has therefore appeared necessary, in preparing yield tables and for their employment, to group the stands under observation, in a comparatively small number of fertility or quality classes (Bonitätsklasse) and to calculate the series of mean yield figures for each species of tree in these classes.

A simple method of setting up growth series, but impracticable, because requiring too much time, would be to make the investigations on the same permanent sample plots during a whole rotation (see Heyer 1846). Then it would be necessary to arrange in each quality class(Bonitätsklasse) several permanent sample plots and to compute the mean growth series from the data afforded by them. This method, however, requires too much time, in the course of which even the principles of management might change, and, perhaps, fire, storm and insects etc. might inflict so much damage as to render the final results more or less uncertain. Instead of this direct method impermanent sample plots are measured in stands of every age on various sites and all such plots are correlated as evidently belong to the same growth series, deriving the mean series from them.

One of the earliest methods employed in preparing yield tables is the method based upon an indicating stand, »index method» (Weiserverfahren). In the application of this method a certain number of older, exploitable normal stands are taken as indicating stands, in which, by stem analysis, it is determined what the volume, diameter height, etc. of certain stems has been in these stands at the earlier age. Those of the younger stands in which the sample trees show, at the same age, the same course of growth as the corresponding stems of the indicating stand, are brought together into the same growth series.

The earliest form of the index method is that set forth by Huber (1842). He analysed the mean sample tree of the indicating stand and referred to the same growth series as it those of the yonger stands whose mean stem, at the corresponding age, had the same dimensions as the mean sample tree of the indicating stand. The assumption on which this method rested, *i.e.* that the average tree of an exploitable stand should also have been the average tree of the stand in its youth, is not, however, correct, on the contrary, the average tree of an exploitable stand generally has in its earlier age belonged to the thickest diameter classes. In this way the method of Huber has only a historical significance.

THEODOR and ROBERT HARTIG (1847 and 1865, 1868) remedied the defect in the method of Huber, mentioned above, by dividing the trees of the indicating stand into diameter classes (by means of the »Bestandesaufnahmenverfahren» of Hartig) and by analysing the mean sample trees of the latter. In young stands a number of the thickest trees, equalling that of the trees of the indicating stand, was set apart and grouped in classes, within which again the mean sample trees were analysed. If the growth of the latter average stems showed the same characteristics as that of the indicating stand at the corresponding age, the stands were brought together in the same growth series. It is, however, by no means sure that the average stems thus selected would correspond to the average stems of the indicating stand analysed. Moreover, Hartig himself points out as a drawback to this method that the growth of individual trees depends on the silvicultural system applied, thinning grades, etc.

The index method has been further developed by several authors. WAGENER (1875) based it on a greater number of indicating stands,segregated 150 to 200 of the thickest dominant trees per hectare, calculated their average tree and felled several sample trees with the latter's diameter. These were analysed with regard to the development of the height and breast-height diameter. Further the volumes of the earlier age were determined by the aid of the Bavarian volume tables. Whenever, in young stands, the factors thus determined were found to be the same as in the indicating stand at the same age, they were referred to the same growth series.

The equality in the growth between an indicating stand and young stands has been investigated by many other methods. SCHWAPPACH (1893) arranged groups of 100 stems, and, among them, he used the average height of such trees as belonged, when measured at the thicker end, to the second group (101—200), the so-called »Oberhöhe», as an indicator of the correspondence existing among the individual stands. LOREY (1884) brought into the same growth series all the stands in which 500 of the thickest trees had the same volume and showed the same course of growth. BLOCK (1889) grouped, according to diameter, the trees of a sample stand in classes equal as to the number of trees, the average tree of which was calculated and analysed. If, in young stands, the course of growth, basal area and mean height at the end of each 10 years' period were the same in the different classes as in the corresponding classes of the indicating stand at that age (i.e. if the graphic increment curves of the corresponding classes coincided), and in addition the ages of the stands differed from each other by about one thinning period, moreover if an examination of the soil, and so forth, authorised one to assume that the yield capacity under consideration would permanently remain the same, the stands were presumed to belong to the same growth series.

Some of these latter methods partly approach the so-called directing curve and strip methods. The directing curve method (Leitkurvenverfahren) was originally invented by CARL and EDUARD HEYER (1846 and 1857, 1877). E. HEYER arranged permanent sample plots in stands which apparently belonged to the same site class, but differed only in regard to age, the youngest age, for instance, being a_1, the next ages, a_2, a_3 etc. In these the volume and the increment were calculated for the time being and again after the lapse of certain periods until a stand of a_1 years had reached the age of a_2, that of a_2 years the age of a_3, etc. The growth of each stand was graphically recorded in the same system of co-ordinates, and the short curves or broken lines were suitably combined into one single increment curve separately for each quality class. HEYER held it to be possible to prepare reliable yield tables in 20—30 years by this method.

In more recent times many investigators and forest research institutes have availed themselves of the directing curve method, but in a form more fully developed in many respects. Numerous permanent sample plots have been arranged in stands belonging to different age-classes and growing on all sorts of sites, and the investigators, accordingly, do not rest content, as Heyer did, with one sample plot in each age-class and on each quality class. The volumes, diameters, etc. of the sample plots are re-examined after certain periods, generally after the lapse of 5 years, and by recording graphically the data thus obtained, a great number of short curves or broken lines are secured. These fragments of curves are then combined in the same system of co-ordinates into greater directing curves, on which in their turn the definite mean curves for the volume, etc. are based.

In the preparation of yield tables recourse is had in Central Europe to a very large extent to the so-called strip method (Streifenverfahren), which also rests on graphical methods and has been set forth by BAUR (1877, 1888 and 1891) and KUNZE (1878). According to HUFFEL (1893) an analogous method was invented by DE PERTHUIS as early as 1788.

When preparing yield tables for spruce, BAUR (1877) employed the strip method, taking the mean heights of the sample stands as a basis, but subsequently, in his tables for beech (1881), he substitued the volume for the mean height. After sample plots have been taken in sufficient number on all sorts of forest soil, special note having been taken of the best and the worst site class, and the volumes of the sample plots have been measured, the volumes are entered as points in a system of co-ordinates in which the abscissa stands for the age, and the ordinata for the volume of the stand. As long as the stands are young the points which represent the volume lie in the vicinity of the origo (zero position) and close together, but with advancing age and at a greater distance from the origo they spread wider like rays, rising higher at the same time. By drawing two curves suitably, one through the upper and the other through the lower points, Baur obtained the mean limits between which the overwhelming majority of the points fall, and between which the yield of normal stands of the different age-classes ranges during the period from the regeneration years up to exploitability. Baur argues then, that, because it is desirable that the different quality classes should stand at equal distances from each other, in the graphic diagram, the zone between the upper and lower limit curve should be divided into five uniform strips, parallel to the limit curves. According to the strip, whether the first, second, etc., counting from the top downwards, within which the point representing the volume of a certain stand falls, the quality class of the sample plot is determined. Thus the mean yield curve is ascertained for each quality class, and from this the mean yield values are deduced for the yield tables by drawing a new curve in the direction of the limit curves, through the middle of a strip representing a quality class. In the application of the yield tables thus prepared, the quality class had to be deduced from the mean height of the stand, and, for this purpose, the mean height curves had to be found out by a graphic method analogous to that described.

An examination of the methods used in Central Europe in the preparation of yield tables, reviewed above, discloses many advantages, but also many defects. Leaving out of account some defects common to all of them, the index method can be said frequently to offer a good means for ascertaining which of the sample plots belong to the same growth series. The method, however, requires the utmost accuracy and judgment and yet is easily misleading. The trees to be analysed have to be chosen from amongst the dominant trees, which, in all probability, have been allowed to grow more unchecked than the rest throughout the age of the stand.

It may on the other hand also happen in this case, that a tree analysed has previously grown in the shade or its top has been broken, and so forth. Furthermore, it is indispensable that the stand should have been treated, from the very beginning under the same silvicultural system, that it should have been equally dense throughout its development, and so forth. If the method is applied as it generally has been, i.e. choosing only one indicating stand on each quality class, it is a matter of mere chance that it should be normal in all respects. If it happens to border on the normal, a growth series is found for a quality class which does not represent the average, but a limit. Apart from this, the stem analysis in broadleaf forests, for instance, or in coniferous forests, growing very slowly, is often beset with difficulties.

The directing curve method, in the employment of which observation of the growth on the sample plots is extended over a longer period of time, is, of course, more reliable than a method which rests on a mensuration only performed once. It is the more reliable the longer the period is in which the sample plots are measured over and over again. If the number of the sample plots is sufficient, measurements extended over 30 to 50 years will secure quite reliable directing curves. If, on the other hand, the sample plots are few in number and the pieces of curves or broken lines are very short, it happens very easily that sample plots of different growth series are brought under the same directing curve. Accordingly, the directing curve method is vitiated particularly by the drawback that the yield tables will only be completed after a long lapse of time. Further, it is difficult to decide (see for instance, Baur 1881, pp. 34—35), whether the stands that have been brought under the same growth series, really belonged originally to the same quality class, whether they have regenerated in the same manner, with equal density, etc. and, lastly, whether they have developed in the same way and under the same silvicultural treatment. Furthermore, the results obtained by the directing curve method may be unfavourably affected in the cours of investigations by meteorological factors (see Schwappach 1893, p. 62).

On a superficial examination, the strip method appears to be very simple and quick, but a closer inspection shows it to be founded in many respects on a very weak basis, as has often been pointed out. Thus G. Heyer (1877, p. 196) and Borggreve (1888, p. 94) have proved that just the stands that function as limits, i.e. those of the very best and very worst growth, on which the method is entirely based, are very rare, existing often in a few age-classes alone. For want of sufficient material the limit curves, as well as the other increment curves deduced from them, will be drawn on very uncertain grounds (for instance, EICHHORN 1902). It is also very doubtful, whether the curves for the medium quality classes can be deduced directly from the limit curves. For instance, the increment curves for spruce forests drawn by BAUR himself appear, indeed, fine and harmonious, but a closer examination and a comparison with the data afforded by the sample plots, reveal that the increment curves have been drawn summarily, the lower one, for instance, having been drawn on the basis of a couple of points only. It is by no means certain that the points correlated are referable to the same growth series. It is quite possible that they belong to different series, which may cross one another (see FLÜRY 1907, pp. 48—49 and v. GUTTENBERG 1903, p. 45). The growth series of this schematic type, drawn exactly at equal distances from each other, are accordingly quite artificial.

Although the index method and the directing curve method often render useful service in determining which of the sample stands are referable to the same growth series, they, however, necessarily presuppose that the quality classes have been determined and limited beforehand by some method or other. The earlier yield tables excepted, the classification of site has almost always been more or less exclusively based on site classes deduced earlier by the strip method or, the quality classes have been calculated in each individual case by the strip method.

The defect attached to the earlier yield tables, viz. that, based as they were on various methods of determining the quality class they could not be compared with each other even with regard to the same species, was to some extent — not, however, wholly, for instance with regard to the different growth regions — removed by the Association of the German Forest Research Institutes by adopting a special scheme for determining the quality classes for the principal species of trees on the basis of the yield (see for instance, WEBER 1891, p. 135). But as these modes of classifying sites also rest on grounds which are different for each species of tree and wholly independent of each other, and entirely ignore the soil, the following objections must be made even against the recent yield tables of this type (see CAJANDER 1909 pp. 162—163). First, that the quality classes given in them for the different species of trees do not correspond to each other. It is, therefore, impossible in these yield tables to compare the yields of different species of trees on these quality classes. And secondly, their quality classes and growth series are very artificial products. The artificiality inherent in these growth curves, even in the very latest yield tables, is clearly proved among other things by the fact that the increment curves for the different quality classes have such a schematically uniform course that it cannot possibly correspond to the real and natural course of growth in normal stands on the different quality classes (see p. 8 and CAJANDER 1909, p. 163).

The application of the yield tables prepared in Central Europe, i.e. the estimate of the quality of the site, is mostly based on the mean height of the stand. BAUR admits (1877, p. 16) that in certain cases it is apt to be misleading in the estimate of site, when the stand is young. GREBE (1872, p. 331) pleads for the employment of the mean height only conditionally and for convenience sake. SCHUBERG (1882, p. 137 and 1888, p. 86) finds it necessary to take into account, in addition to the mean height, many other factors, such as the number of stems, the mean diameter, etc. BORGGREVE (1888, p. 91) approves of employing the mean height as a reliable basis for estimating the quality of the site only in stands of exploitable age. WALTHER (1884) requires as a condition for the employment of the mean height that the stands should be perfectly normal. HENZE (1902) has obtained, with regard to the mean height, results which are very unfavourable in many respects. FLURY (1903) and CAJANUS (1914) determine the close dependence of the mean height on the method at the formation of the stand and on the silvicultural system.

If it be taken into account: 1) how the mean height assumes very different values according to the principle on or formula by which it has been calculated or estimated; 2) how the mean height changes — without the least change, in reality, in the quality of the site — after every thinning and differently according as the thinning has been different, similarly after every selection cut, by which the biggest and, at the same time, the highest trees are removed from the stand, while the smallest and shortest trees are left standing; 3) how, for instance, in Suomi (Finland) the pasture-land forests, which, as forest soil, are exceedingly good, classified by the mean height method fall, being sparsely stocked and therefore short-boled, into too low a quality class; and, otherwise, a forest land of the self-same kind may, on account of the present casual condition of the stand, be brought in different cases into entirely different quality classes; 4) how, for instance, that part of the same dry heath which is covered with pine, has to be classed, if estimated by the mean height method, in a quality class far higher than a part usurped by the spruce, which, as a rule, grows on such a soil at a rate considerably slower than the pine, while the same quality class will comprise widely different forest lands; for instance, the worst class will comprise heaths of the driest type, rocky grounds, swamps of poor growth, etc.; and , finally, if it be taken into account, 5) how a forest land is to be assessed, by the method under consideration, which itself is quite clear as well as the surroundings; the conclusion is inevitable that at least in Suomi (Finland) the mean height is inapplicable in the estimate of the quality of the site by the application of the yield tables, and accordingly unsuitable as a basis for the preparation of yield tables.

In North Europe the yield tables in existence are very few in number, and in the preparation recourse has been had to the same methods as in Central Europe (for instance: AF STRÖM 1846, SEGERDAHL 1852 and 1868, MAASS 1911, STALSBERG 1882, VARGAS DE BEDEMAR 1849, etc.)

Preparation of Yield Tables in Suomi (Finland).

The earlier attempts and the new fundamental principles.

The first attempts at yield tables in Suomi are those made by BÖCKER 1829, and GYLDÉN 1853. The first yield tables in the strict sense of the word are those prepared by BLOMQVIST in 1872. These are set out on principles, which are entirely different from those used in the preparation of yield tables in Central Europe, viz. the former set out from the kind and the quality of the soil of the site and its suitability for different species of trees. As these yield tables, which contain the results of investigations that were singularly farreaching and thorough for those times, are antiquated in more than one respect under present conditions, and as their application is consequently beset with difficulties, the Society of Forestry in Suomi (Finland) started work with a view to producing new yield tables for the most important species of trees of the country. The research work for this purpose was begun in 1916 and was carried on for about four years without interruption.

The two main points in which the new Finnish yield tables were planned to run on lines different from those customary in Central Europe, were as follows: 1) On every sample plot, already at the time as it is measured, the quality of the site should be assessed on the spot and independently from the standing crop covering it. Thus the sample plots of each site class in setting up the growth series can from the very beginning be treated as independent groups. And thus the quality classes will consequently be the same for all species of trees. 2) In determining which of the stands of the same site class belong to the same growth series endeavours should be made to achieve results by the mathematical-statistical methods. By means of these the mean stem distribution series (frequency series) should be deduced and recorded in the yield tables for each species of tree on each site class at each age-grade. These series are indispensable for calculating the financial value of the stand, and they are, as representing the mean number of stems for each diameter class, of special significance for a country like Suomi (Finland), in which the prices vary widely for trees of different diameters.

With regard to both these points mentioned, the further work could start from the foundation laid by the earlier investigations carried out in Suomi; in regard to the first point, by resorting to the Finnish system of forest types, worked out by Cajander (1909, 1921 and 1926), and in regard to the second point, by having recourse to the applications of the mathematical-statistical methods invented by Cajanus (1914).

Cajander had proved that forest sites can be naturally grouped in some definite types which, in cultivated tracts, can best be characterised chiefly on the basis of the vegetation surface-cover (undergrowth). In nature the plant species generally occur grouped in some regular plant-communities which are more or less clearly distinguished from one another and each of which has some very distinct demands with regard to the site. Since the quality of a site is an expression of the capacity of a site to group sites according to the vegetation characteristic of them, consequently to group forest sites according to the plant-communities of forests. In the same forest type all those stands are included, the vegetation of which, at the age of maturity for felling or approximately so and in normally dense condition is characterised by a more or less similar floristic composition and ecological-biological nature and all those stands the vegetation of which differs from the so determined one only for reasons, which are to be considered as accidental or temporary, in any case not permanent (such as the age of the stand, felling, etc.). The lands belonging to the same forest type are to be regarded biologically as of equal value [1].

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[1] The types are named after one of their most characteristic plants or groups of plants and abbreviated names are formed from their initials, e.g. the ling or Calluna type (CT), the cowberry or Vaccinium type (VT), the blueberry or Myrtillus type, (MT) etc.

The work started by Cajander has been carried on by many Finnish investigators, and numerous recent works have contributed to the elucidation of the importance of the forest types in silviculture and forest estimation and valuation. The result has been that the forest types have already in a short period attained a very wide application in both theoretical research and practical work, as a basis for an objective assessment of the quality class of forest sites.

The investigations of CAJANUS showed that the methods of mathematical statistics furnish us with an excellent means for the solution of many problems in forest estimation. Thus, the stem distribution series or frequency series, derived from the breast-height diameter, which can be characterised with sufficient precision by a few parameters, comparatively easily attained can be made use of in examining which of the older and younger stands belong to the same and which to different growth series. It is very difficult to elucidate the character and development of the stem distribution series — whose general form appears form the figure 5 — by examining and comparing the series themselves; but, on the other hand, this is well effected by means of the characteristics of these distribution series: the mean diameter, dispersion (coefficient of variation) and number of stems, often also the asymmetry and sometimes the excess, all of which together practically determine a distribution series completely.

Preparation of the latest Finnish Yield Tables.

After the fundamental principles referred to had been sufficiently investigated and made clear, the preparation of new yield tables was commenced in Suomi (Finland).

The investigations for this purpose were started by taking during three summer seasons 467 sample plots in different parts of the southern half of the country, for which the universal yield tables were planned. In order to secure uniform material, these plots with an area of, on an average, a quarter of a hectare were located in stands that were regular, fully-stocked and pure, and unthinned, i.e. »nature normal».

On the sample plots the trees were first measured at breast-height, i.e. at a height of 1.3 metres from the ground, using for stands older than 30 years the diameter classes of 2 centimetres, for the younger ones those of 1 centimetre. Having done this, the trees to be removed in thinnings were counted. In order to find out the mean height for the different diameter classes the mean height curve was traced for the stand on the basis of numerous height measurements carried out. With a view to volumetric measurements, on each sample plot at least 5 sample trees were felled and these equally from different diameter and height classes. The measurement of volume was effected by pieces, the pieces being in length 1 meter for stems shorter than 12 metres, and 2 metres for longer ones. Mereover, the age, the diameter of the stump, the diameter at breast-height and at the height of 6 meters, the thickness of the bark, the solid contents up to 10 and 7 centimetres at the smaller end, the branchless part of the stem, the maximum width of the crown and its height from the ground were measured. At last, in order to gain a thorough insight into the growth of the dominant trees of the stands, the biggest of the sample trees, the mean sample tree of the 100 thickest trees per hectare, was subjected to a complete stem analysis.

A detailed description of the surface vegetation was made for each sample plot, using NORRLINS scale (degrees 1—10, see CAJANDER, 1918) in recording the frequency of occurrence; in this manner the forest type was described in detail. In addition, on the sample plots, notes were taken concerning the quality of the soil and the stand, and samples of the soil were taken for chemical soil analysis from the different strata.

The material of sample plots thus collected was further dealt with during the winter seasons. On the volumetric data derived from the sample trees measured, a volume curve (Massenkurve, KOPETZKY 1902) or a straight volume line was traced for each sample plot separately by entering the breast-height diameter (in centimetres) raised to some of the powers 1.0 to 3.0 (for instance 1.5, 1.8, 2.0, 2.2, 2.4 etc.) as the abscissa, and the corresponding volumes of the sample trees (in cubic metres) as the ordinata (in power 1.0). The drawing of the volume curve (in power 1.0) is often, especially if the sample trees are few in number, rather uncertain and arbitrary, except for quite young stands, in which the sample trees do not differ very much with regard to their diameter. On this account for middle-aged and old stands a straight volume line was deduced by first experimenting as to which power of the abscissa gave the volume line more straightness then applying this power of the abscissa and guiding by the eye, consequently, without mathematical smoothing calculations, an essentially straight line was drawn on the basis of the points representing the volumes. The volume of each sample plot was calculated by its own volume line.

For the different forest types the number of the sample plots was large enough to secure a fairly complete elucidation of the growth and yield of the following species of trees: the birch (*Betula odorata* and *B. verrucosa*) on the Oxalis-Majanthemum (or Oxalis) type, the Scots pine (*Pinus silvestris*), Norway spruce (*Picea excelsa*) and birch on the Oxalis-Myrtillus type as well as on the Myrtillus type, the pine and birch on the Vaccinium type, and finally the pine on the Calluna and Cladina types. It is just of these forest types and species of trees that the commonest and most important forest forms in Finland consist.

Previous to the examination of the growth and yield on the basis of the material derived from the sample plots the question which sample plots of the same forest type and the same species of tree belonged to the same growth series, was proved, as has already been mentioned on page 12, by means of the nathematical-statistical methods through the instrumentality of the characteristics of the stem distribution series. For, having been originated by natural seeding, the stands of the sample plots may have been different from the very beginning, even on the same forest type, and with the same species of tree, according to the success of the seeding and so forth.

The characteristics of the stem distribution series: the mean diameter, dispersion, (coefficient of variation), number of stems, further the asymmetry and excess were computed for the sample plots by a special scheme (see Y. Ilvessalo, Investigations on the importance of forest types — —, pp. 68—69).[1]

The mean diameter was calculated as a weighted arithmetic mean from the breast-height diameters of the trees of the sample stand.[2] All the values for the mean diameters of the same forest type and the same species were entered as points in the same system of co-ordinates, in which the abscissa stood for the age and the ordinata for the mean diameter. On the basis of these points a mean curve could be drawn which yielded the smoothed mean values for the mean diameters in each age. When the mean diameter of a sample plot deviated at most about three times its standard error from the smoothed mean diameter of the same age, the sample plot

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[1] In the work of the mathematical-statistical calculations the following works were consulted in the first instance: Charlier 1906 and 1910, Davenport 1904, Elderton 1906, Johannsen 1913, Žižek 1908, Yule 1912.

[2] Formula: $D = D_0 + b$, and formula for the standard error: $\varepsilon\,(D) = \frac{\sigma}{\sqrt{N}}$, in which D = mean diameter, D_0 = provisory mean diameter (chosen to facilitate calculations), σ = dispersion, and N = number of the stems of the sample plot.

could be regarded, in regard to the mean diameter, as belonging with sufficient accuracy to this mean growth series of the type.

The dispersion (and the coefficient of variation) together with their standard errors were calculated in the same way, and it was examined on which sample plots the dispersion and the coefficient of variation did not deviate materially from the corresponding smoothed mean values more than treble their standard error, and consequently in these respects belonged to the mean growth series of the type.[1] On the basis of the numbers of the trees of the sample plots smoothed mean curves representing the reduction, as the stands advance in age, of the number of the trees, were traced also for each forest type and species of tree.

In addition, the last two characteristics of the stem distribution series, the coefficient of asymmetry and the excess, as well as their standard errors, were calculated, and from them the mean values for each species of tree on each forest type were deduced.[2] The significance, from the point of view under consideration, of these higher characteristics for the stem distribution series were found to be so small that no sample plots were removed from any mean growth series on account of deviation shown by them.

With respect to the different characteristics several sample plots deviated from the corresponding mean value by more than the allowed ratio (± 3 × standard error). In setting up the growth series it was, however, found neither advantageous nor necessary to eliminate all the sample plots thus deviating from the mean value, for in many cases the

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[1] Formula for the dispersion: $\sigma = \pm \sqrt{\frac{\Sigma\, p\, a^2}{N}} - b^2$, for the standard error of the dispersion: $\varepsilon\,(\sigma) = \pm \frac{\sigma}{\sqrt{2\,N}}$, for the coefficient of variation: $V = 100\,\sigma : \mathrm{D}$, for the standard error of the coefficient of variation $\varepsilon\,(V) = \frac{V}{\sqrt{2\,N}} \left\{ 1 + 2 \times \left(\frac{V}{100} \right)^2 \right\}^{1/2}$; in these formulas: $\sigma =$ dispersion, $p =$ number of observations (= number of the trees) in the diameter class, $a =$ deviation of the class from the provisory mean value (chosen to facilitate the calculation), $b =$ deviation of the provisory mean value from the arithmetic mean, $N =$ total number of trees on a sample plot.

[2] Formula for the coefficient of asymmetry: $\beta_3 = -\nu_3 : 6\,\sigma^3$, for its standard error: $\varepsilon\,(\beta_3) = \frac{1.9325}{3\sqrt{N}}$; for the excess: $\beta_4 = {}^1/_{24}\,(\nu_4 : \sigma^4 - 3)$, and its standard error: $\varepsilon\,(\beta_4) = \frac{0.6124}{3\sqrt{N}}$. (See Y. ILVESSALO, Investigations on the importance of forest types — — — p. 68).

deviation exceeded the ratio allowed only very little, in other cases again such sample plots deviated only with regard to one or two of the characteristics, being quite regular in every other respect. Moreover, since the stands under consideration had sprung up and developed in a state of nature, all the sample stands of the type were referred to the same growth series of the type except those 1) of which the mean diameter, the dispersion and the coefficient of variation deviated by more than treble the standard error and the number of stems by more than 20 per cent, or 2) the mean diameter of which deviated by six times the standard error and the number of stems by 30 per cent (these, on the whole, proved to be anomalous in other respects, too), or 3) which in two respects deviated by more than six times the standard error (the number of stems by more than 30 per cent) and in some third respect more than three times the standard error (the number of stems by more than 20 per cent).

Although quite a number of sample plots were thus excluded from the calculation of the mean growth series, their number, nevertheless, did not reach 20 per cent of the total number of the sample plots. For the sake of comparison it may be mentioned that CAJANUS (1914), when deducing the corresponding growth series, from material in a Swiss yield table, had to put aside 20 per cent on account of the deviations shown by the dominant height (Oberhöhe), and from the rest 45 per cent had to be excluded because of the great deviations shown by the characteristics of the stem distribution series. This would seem to testify to the superiority of the forest types to artificial site classes, the more so as the Swiss sample stands have mostly been managed under a uniform silvicultural system, while the sample stands of this investigation have grown up under widely varying conditions and in a state of nature.

When it had thus been elucidated which sample plots of the same site class, i.e. of the same forest type, and of the same species of tree belonged to the same growth series, the calculation of the series of mean values for the growth and yield, for the yield tables, was begun. This was carried out mainly by graphic methods.

First, a new smoothed mean curve for each forest type was traced, representing the development of the mean diameter as the stands advance in age. This supplied the yield tables with the series of values for the mean diameter. Then, new values for the dispersion were computed in the same way and the curves, expressing the reduction of the number of stems according as the stands grow older, were deduced, which, in their turn, furnished the yield tables with the mean number of stems for each age. And further, when the coefficient of asymmetry and the excess had been consulted, from all these mean values of the characteristics of the stem distribution series, the mean stem distribution series for each species of tree on the different forest types and at the different age-grades could be deduced, expressing how many trees and of what diameter, on an average, there were in a stand at this age.[1]

On the basis of the volumes of the sample plots the mean volume curves, smoothed graphically, were drawn, also treating now the sample plots of each species of tree and each forest type individually and separately. The curves were drawn by making use of ocular adjustment and at several points once more weighing the reliability in this respect of each sample plot separately. These graphic curves furnished the yield tables with the mean values for the volume. By an analogous operation the yield tables were furnished with the series of values for the basal area and the mean height of the stand.

Finally, on the basis of the stem analysis carried out the growth in height, diameter and volume of the dominant trees of the stand was examined and the different forest types were compared with each other in this respect.

In this preparation of yield tables one of the main problems was to see, whether yield tables could be based on the so-called forest types instead of the artificial quality classes used in Central Europe. The answer to this problem obtained in the investigations, was as follows:

Each forest type possesses a characteristic surface-vegetation (undergrowth) of its own and for different forest types this surface-vegetation is widely different. A forest type can be comparatively easily determined by its surface-vegetation;

for each species of tree and at every age the mean diameter of the stand is greater, the better the forest type is;

the dispersion of the stem distribution series is on the whole greater, the better the forest type is (with regard to the coefficient of asymmetry and the excess no distinct differences are discernible);

for each species of tree the number of stems of a stand, at least from 20 years onwards, is greater, the more unfertile the forest type is;

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[1] As to the formulae and the tables vide CHARLIER 1906, CAJANUS 1914, YRJÖ ILVESSALO 1920, pp. 89—92 and LÖNNROTH 1925, pp. 115—129. — More easily than by the aid of mathematical-statistical methods the final mean stem distribution series for the yield tables can be constructed by graphic methods, but the construction may then be more subjective.

on the basis of the characteristics of the stem distribution series and by using the forest types as site quality classes, it is possible to calculate, by the aid of the mathematical-statistical methods, the mean stem distribution series for the different age-grades; these series differ considerably for the different forest types: the decrease of the number of trees in the smaller and the increase in the greater diameter classes takes place more rapidly and more completely, the better the forest type is;

the volume, the basal area and also the mean height of a stand — the latter varies widely in individual cases — are greater in regular stands for all species of trees at each age, the better the forest type is;

the height of the dominant trees (Oberhöhe), as well as the breast-height diameter and the volume of the dominant trees are on the whole very decidedly greater at the same age, the better the forest type is;

the same forest type, with regard to all the aspects of growth, is in every respect very similar in the different parts of the southern half of Suomi (Finland);

the conclusions to be drawn from these facts are: since on the whole all the aspects of growth are different for the different forest types, while for the same forest type they differ within comparatively narrow limits, the forest types, being uniform and natural, comparatively easily distinguishable quality classes, are capable of serving as the basis for the classification of forest sites and valuation investigations in general and for yield tables in particular.

Some of the most important aspects of growth have been graphically set forth in diagrams 1—11 from which the mean differences between the different forest types may be seen.

The yield tables (YRJÖ ILVESSALO 1920 b) that were the fruit of this research work contain the series of values of the growth and yield for the different species of trees and the different forest types separately in tables of the form shown on the page 20 and the stem distribution series in tables of the form shown on the page 21.

Employment of the Yield Tables.

The Finnish yield tables worked out as reviewed above, afford an important basis for the solution of many problems of forestry. Based on regular and fully stocked stands, they express the highest values of growth and yield, showing accordingly the yield capacity of forest sites.

As forests of this kind as a whole do not occur in wider areas these tables cannot be applied without further work for every individual stand; on the contrary, if the value for the volume, for instance, is to be estimated by the tables, the »quality of the stand» (Bestandsbonität) has to be determined first, i.e. how much the stand differs from a regular and fully stocked stand, and the values recorded in the tables have to be reduced accordingly. — Since it can be made out by the aid of the yield tables, how much the forest lands of the different types are able to produce by growing definite species of trees, it is possible to calculate on their basis which species of tree is the most economical to grow, on a specified forest site, and how long a rotation in each case will best serve the interests of economy. — By the aid of the yield tables, and using the methods of forest valuation, the yield value of the forest land can be determined; they afford a basis for a real assessment of the quality of forest land. Similarly, on the basis of these yield tables the value of unexploitable and young forests can be assessed — an operation frequently needed. Accordingly they can serve as a basis in the estimation of damages by fire and so forth, and when a forest has to be valued in connection with expropriation, insurance, granting of credits, agricultural book-keeping, and so forth; similarly, they are of great use in estimating forests in connection with sales and purchases. — These yield tables serve as a básis in calculations, as to whether it would be more economical to use a piece of land for agricultural purposes or as forest land. — And it is only by yield tables of this kind that the remunerativeness of the draining of a swamp can be calculated, for it is possible, as the investigations carried out in Suomi (Finland) have shown, to determine beforehand into what class of forest land, i.e. into which forest types, the different kinds of swamp will be transformed, when drained. By the aid of the stem distribution series, which are part of these tables, calculations of the financial value of the forests are most expediently effected, and also local money yield tables calculated.

The headings in the Growth and Yield Tables are as follows (A table of this kind was constructed for every species of tree on every forest type):

Species of tree ......; Forest type ......

Age, years	Volume of the stand										Volume-increment (Bark excluded)			Number of stems		Basal area (Bark included)					Mean diameter (Bark included)				Mean height				Height of the dominant trees (Oberhöhe)			Age, years
	Principal crop			Self-thinning crop 1)			The self-thinning crop in all. cbm.		The total yield														5-years' increment									
	Volume (Bark excluded), cbm.	Wood having over 10 cm in Diameter at the smaller end (Bark excluded), cbm.	Volume (Bark included), cbm.	Volume (Bark excluded), cbm.	Wood having over 10 cm in Diameter at the smaller end (Bark excluded), cbm.	Volume (Bark included), cbm.	Bark excluded	Bark included	Bark excluded	Bark included	Current annual, cbm.	Mean annual, cbm.	Current annual, per cent.	Principal crop	Self-thinning crop	Principal crop, sq. m.	Self-thinning crop, sq. m.	Principal crop + Self-thinning crop, sq. m.	Current annual increment, sq. m.	Mean annual increment, sq. m.	Principal crop, cm	Self-thinning crop, cm	Current, cm	Mean, cm	Principal crop	Self-thinning crop	Current annual increment, cm	Mean annual increment, cm	Principal crop	Current annual increment, cm	Mean annual increment, cm	
	Per hectare																															
10																																10
15																																15
20																																20
25																																25
----																																----

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[1] These tables refer to »naturally normal», i.e. unthinned forests.

The headings in the Tables of the Stem Distribution Series are as follows:

Species of tree . . . . .; Forest type . . . . . .

Age of the stand	Breast-height diameter (Bark included) cm	Principal crop				Self-thinning crop in 10 years, from ... to ... years	
		Number of stems in the diameter class	Total solid volume of the class (Bark excluded), cbm.	Mean heigh of the class m	Wood over 10 cm per cent of the total solid volume (Bark excluded)	Number of stems in the class	Total solid volume of the class (Bark excluded), cbm.
		Per hectare					
	1						
	3						
	5						
	7						
	9						
	11						
	13						
	15						

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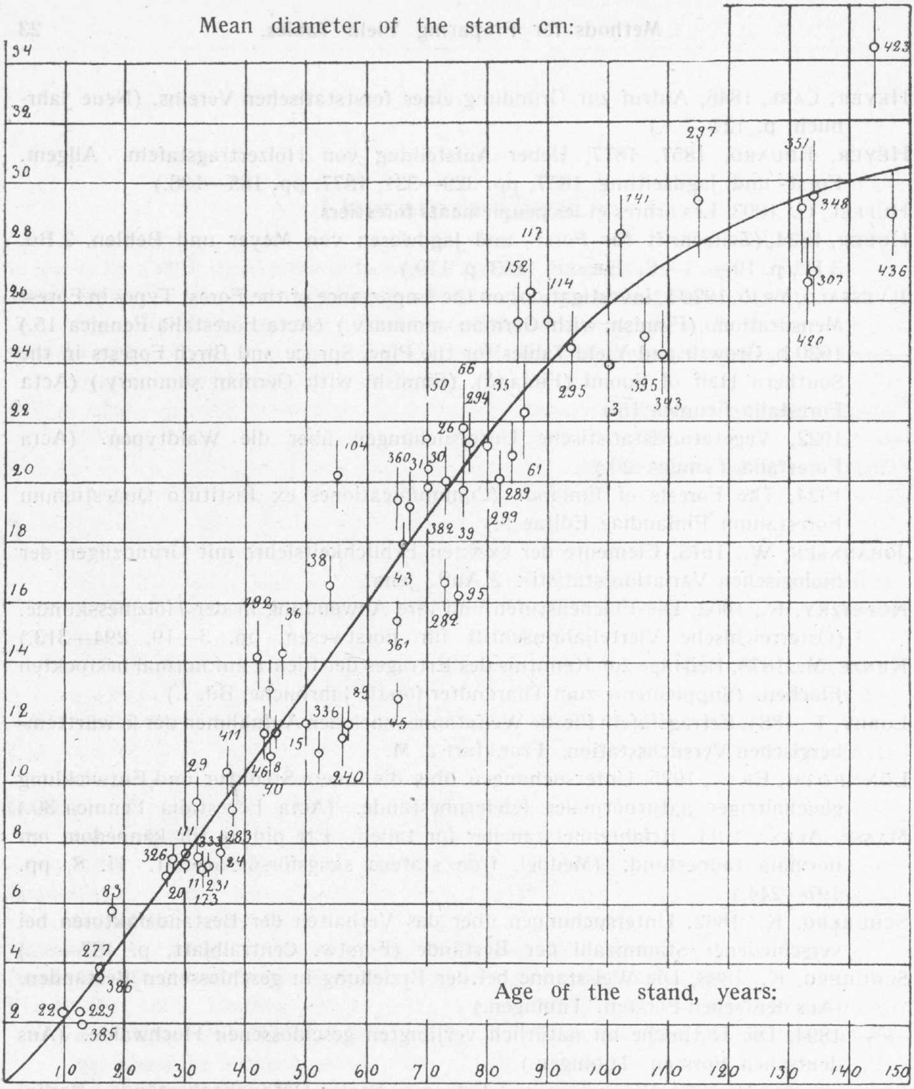

Diagram 1. Pine forest, Myrtillus type.

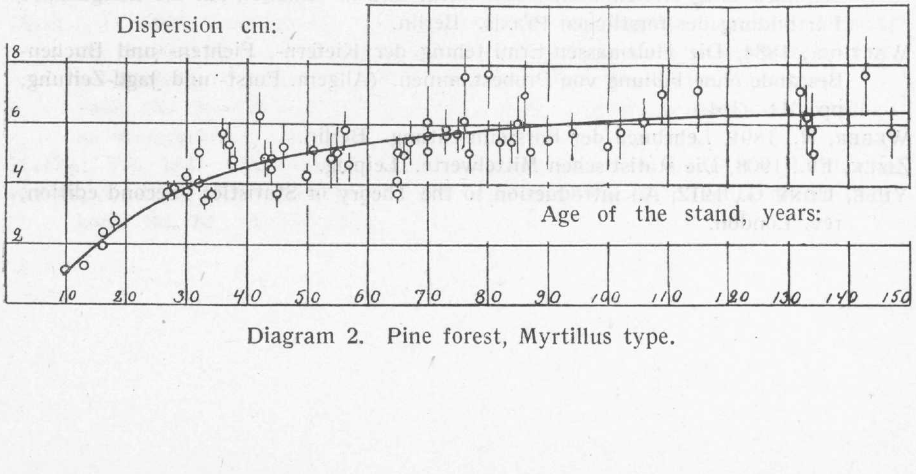

Diagram 2. Pine forest, Myrtillus type.

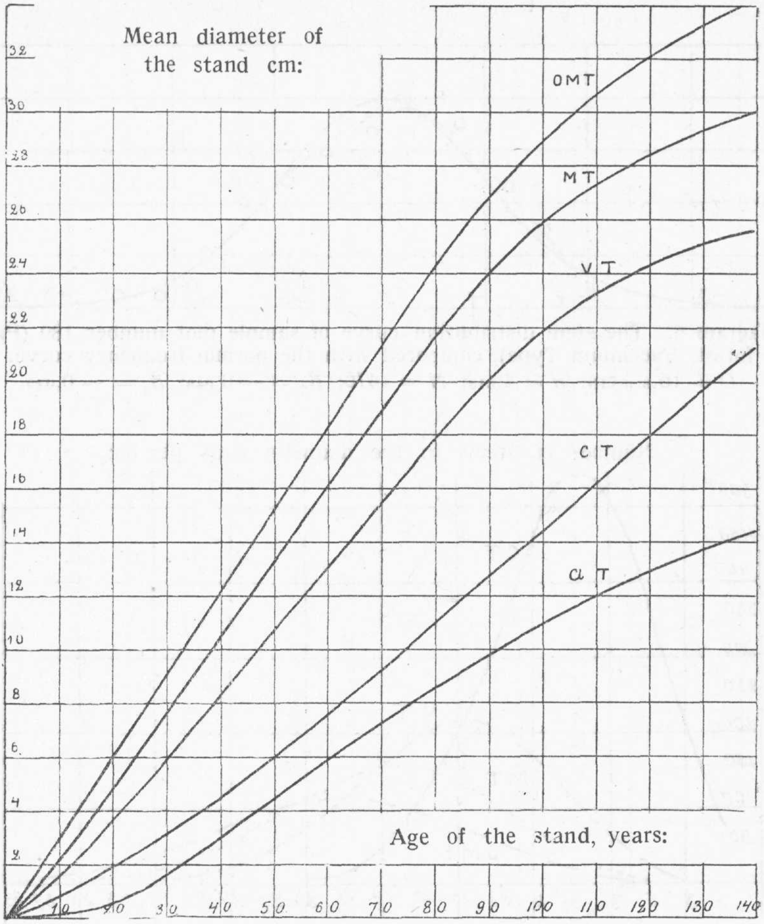

Diagram 3. Pine forest on the different forest types.

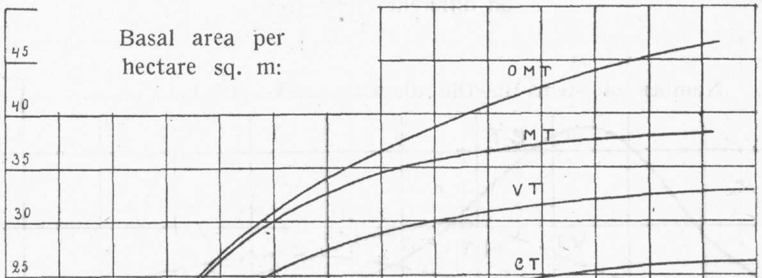

Diagram 4. Pine forest on the different forest types.

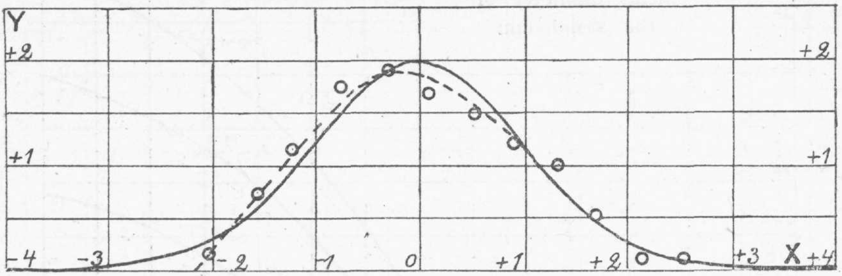

Diagram 5. The stem distribution curve of sample plot number 189 (Pine forest, Vaccinium Type), compared with the normal frequency curve. $D = 16{,}620$ cm; $\sigma = 4{,}812$; $N = 1475$; $\beta_3 = -0{,}040$; $\beta_4 = -0{,}022$.

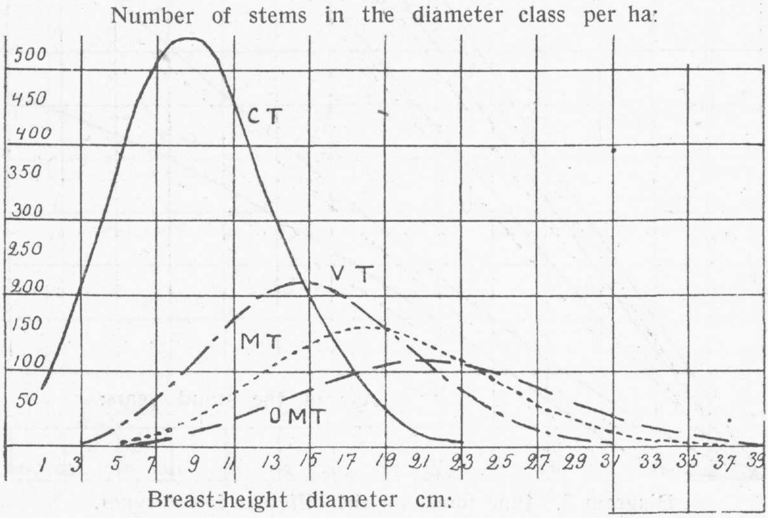

Diagram 6. Mean stem distribution series in 70-years pine forest on different forest types.

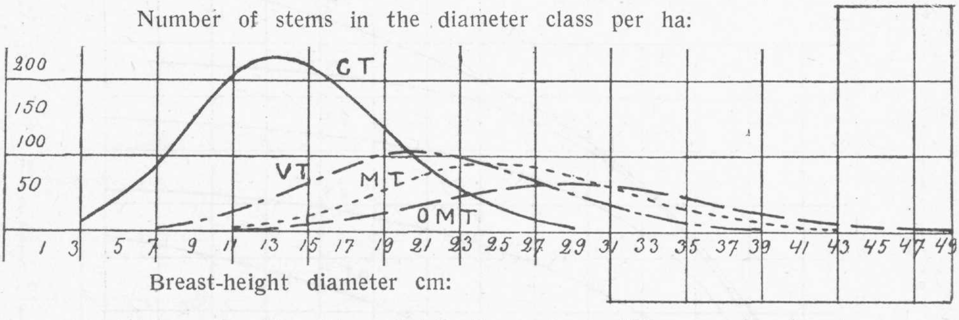

Diagram 7. Mean stem distribution series in 100-years pine forest on different forest types.

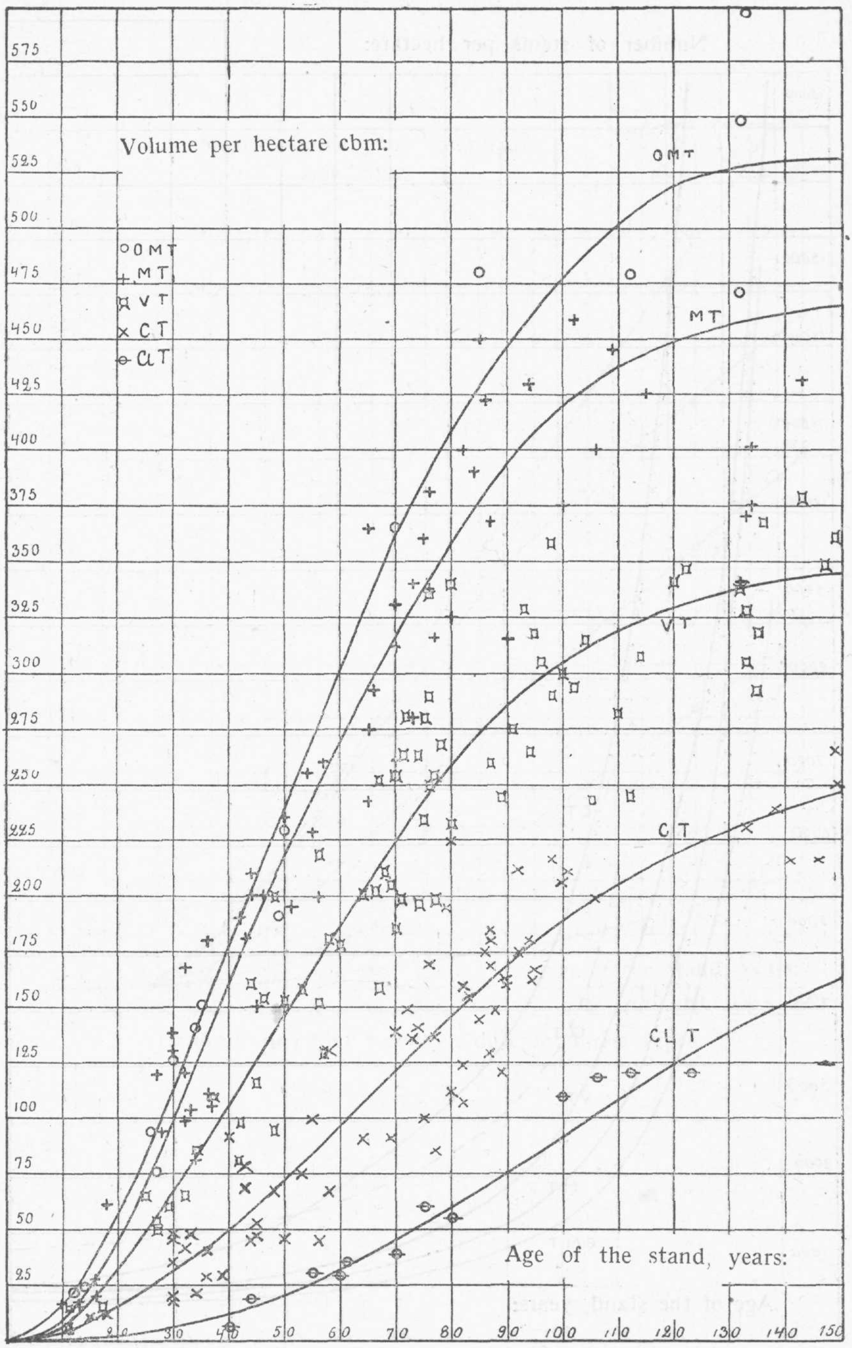

Diagram 8. Pine forest on different forest types.

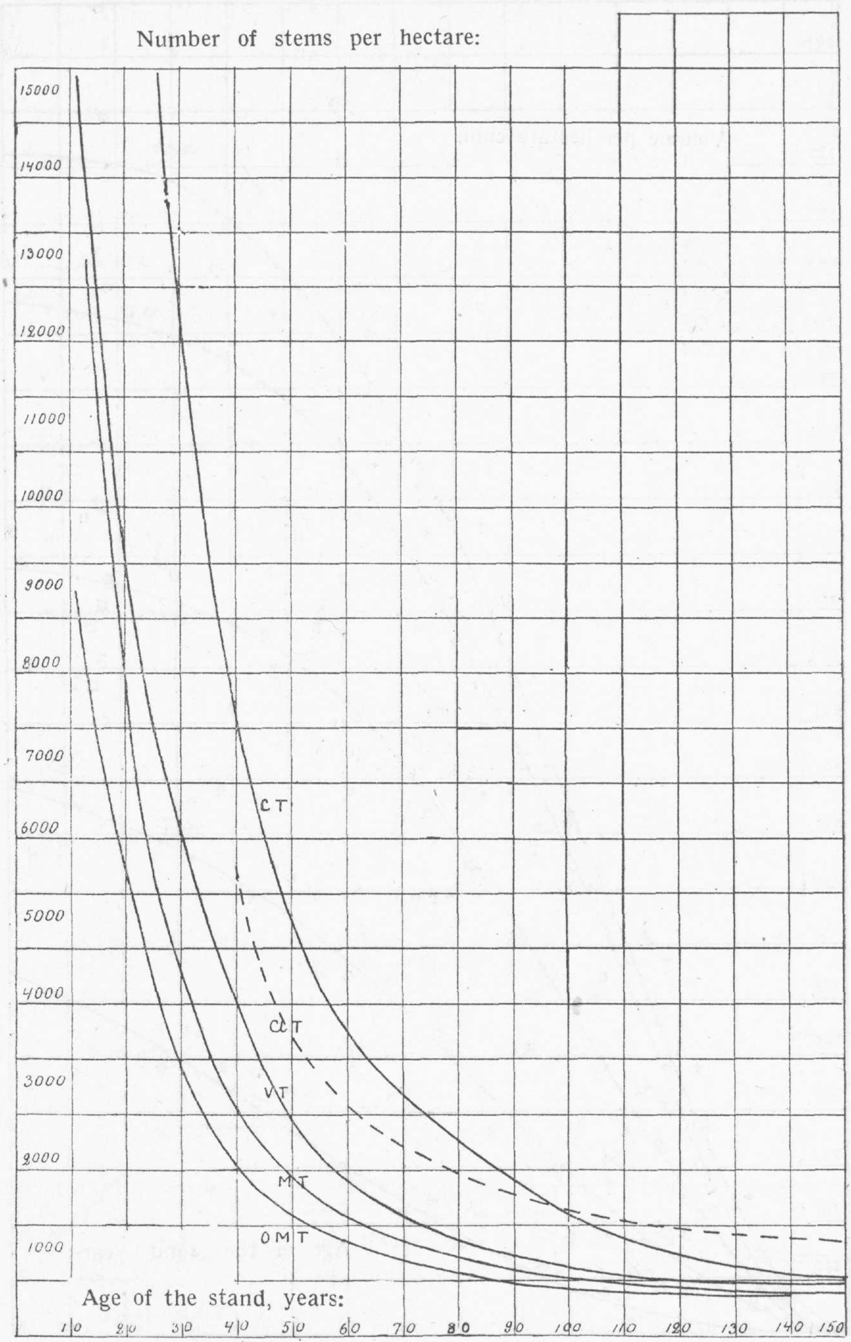

Diagram 9. Pine forest on the different forest types.

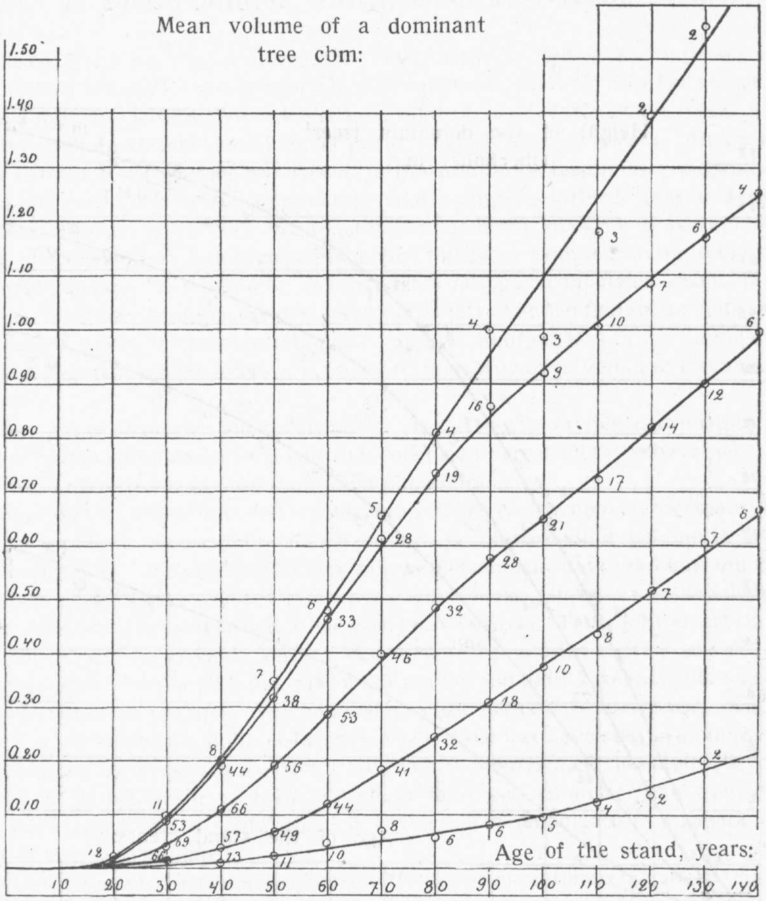

Diagram 10. Pine forest on different forest types.

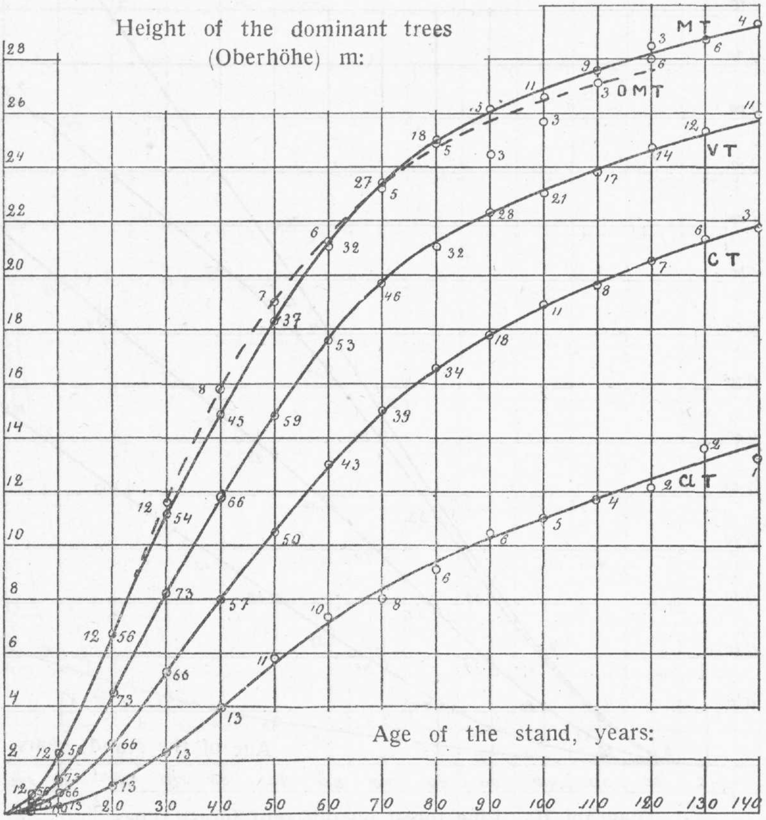

Diagram 11. Pine forest on different forest types.

Kasvu- ja tuottotaulujen laatimisessa käytetyistä menetelmistä.

Pääasiallisesti sen johdosta, että Amerikasta käsin on tiedusteltu Suomessa nykyisin käytännössä olevien kasvu- ja tuottotaulujen laatimisessa noudatetuista menetelmistä, joista ei millään yleisellä sivistyskielellä ole ollut riittävää yhtenäistä esitystä olemassa, on tässä julkaisussa englanninkielellä esitetty lyhyt selostus asiasta. Aluksi luodaan lyhyt katsaus Keski-Euroopassa kasvu- ja tuottotaulujen laadinnassa yleisesti käytettyihin menetelmiin ja osotetaan niiden huomattavimpia puutteellisuuksia. Sen jälkeen selostetaan kasvu- ja tuottotaulujen laatimista Suomessa, ensiksi varhaisempia kokeita, sitten uusia Suomessa kehitettyjä perusteita tällaisten taulujen laatimiseksi ja sitten uusimpien suomalaisten taulujen valmistamista ja lopuksi tällaisten kasvu- ja tuottotaulujen käyttöä. Taulujen yleinen muoto on esitetty kahden taulukon avulla ja kasvu- ja tuottotaulujen ilmaisemien läpimitta-, pituus-, kuutiomäärä- y.m.s. arvojen perusteella on muutamissa piirroksissa kuvattu eri metsätyyppien välillä esiintyviä eroavaisuuksia.

Kun puheena olevien suomalaisten kasvu- ja tuottotaulujen laatimisesta ja käytöstä sekä itse tauluista on suomenkielellä olemassa perusteelliset selvitykset [1], rajotutaan tässä mainitsemaan vain muutamia pääkohtia.

Niinkuin Cajander jo v. 1909 teoksessaan »Über Waldtypen» on osottanut, haittaavat uusimpiakin keski-eurooppalaisia kasvu- ja tuottotauluja pahimmin seuraavat puutteellisuudet: Eri puulajeille on niissä metsämaan hyvyysluokat muodostettu toisistaan riippumatta erikseen ja eri perusteilla, jonka vuoksi eri puulajeille erotetut saman nimiset hyvyysluokat eivät ole toisiaan vastaavia. Tästä johtuu, että tällaisten taulujen perusteella ei voida verrata keskenään eri puulajien tuottoa saman nimisten hyvyysluokkien mailla eikä päättää, mikä puulaji kullakin kasvupaikalla on edullisin. Toiseksi tällaisten taulujen hyvyysluokat ja niille perustetut kasvusarjat ovat kaavamaisia ja keinotekoisia, niillä ei tarvitse olla mitään vastaavaisuutta luonnossa.

Suomessa on kasvu- ja tuottotaulut pyritty perustamaan luonnolliselle pohjalle. Niinpä jo Blomqvistin v. 1872 laatimissa tauluissa on metsämaan hyvyysluokkia muodostettaessa otettu lähtökohdaksi kasvupaikan maanlaatu ja maaperä sekä sen soveltuvaisuus eri puulajeille.

Ryhdyttäessä v. 1916 Suomen Metsätieteellisen Seuran toimesta valmistamaan uusia kasvu- ja tuottotauluja Suomen eteläpuoliskon metsille, suunniteltiin niiden laatiminen varsinkin seuraavassa kahdessa pääkohdassa keski-eurooppalaisista menetelmistä poikkeavalla tavalla: 1. Jokaisella koealalla olisi metsämaan hyvyysluokka määrättävä jo koealaa otettaessa itse paikalla ja metsiköstä riippumattomalla tavalla, niin että jokaisen hyvyysluokan koealoja voitaisiin kasvusarjoja laadittaessa käsitellä alusta lähtien itsenäisenä ryhmänä ja että hyvyysluokat olisivat yhteiset kaikille puulajeille. 2. Tutkittaessa, mitkä saman hyvyysluokan metsiköt kuuluvat samaan kasvusarjaan, olisi kokeiltava päästä tuloksiin n.s. matemaattis-tilastollisten menetelmien avulla.

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[1] Yrjö Ilvessalo, Tutkimuksia metsätyyppien taksatoorisesta merkityksestä. (Acta forestalia fennica 15. Helsinki 1920.)

Yrjö Ilvessalo, Kasvu- ja tuottotaulut Suomen eteläpuoliskon mänty-, kuusi- ja koivumetsille. (Acta forestalia fennica 15. Helsinki 1920.)

Näitten perusteella olisi myöskin koetettava johtaa tauluihin — kullekin puulajille jokaisessa metsämaan hyvyysluokassa ja kaikissa tarvittavissa ikäasteissa — raha-arvolaskelmia varten välttämättömät keskimääräiset runkojakaantumissarjat. Tällaisilla kunkin läpimittaluokan keskimääräistä puulukua esittävillä lukusarjoilla on erikoisen suuri merkitys, syystä että eri vahvuisten puitten hinta on hyvin erilainen. Kummassakin tässä mainitussa pääkohdassa voitiinkin alottaa Suomessa aikaisemmin tehdyissä tutkimuksissa luodulla pohjalla, edellisessä turvautumalla Cajanderin (1909 y.m.) metsämaitten luokittelussa käänteen tekevään metsätyyppijärjestelmään ja jälkimäisessä Cajanuksen (1914) uraa uurtaviin matemaattis-tilastollisten menetelmien sovellutuksiin.

Uusia kasvu- ja tuottotauluja varten kerättiin eri osista Suomen eteläpuoliskoa vuosien 1916—1918 kuluessa aineisto, joka käsitti lopuksi kaikkiaan 467 koealaa. Nämä keskimäärin 1/4 ha suuruiset koealat otettiin yhtenäisen aineiston saamiseksi säännöllisesti kasvaneista, harventelemattomista ja puhtaista metsiköistä. Paitsi tavanmukaisia maata ja metsikköä koskevia selityksiä ja mittauksia, tehtiin jokaisella koealalla Norrlinin 10-jakoista runsausasteikkoa käyttäen kuvaus kasvipeitteestä ja otettiin eri maakerroksista maanäytteitä analysoimista varten. Kerättyä aineistoa muokattiin edelleen talvikausina ja v. 1920 valmistuivat uudet kasvu- ja tuottotaulut. Suoritetut tutkimukset osottivat, että yleisesti kaikki kasvusuhteet ovat eri metsätyypeillä erilaiset ja samalla tyypillä taas verraten suppeissa rajoissa vaihtelevat, joten metsätyypit yhtenäisinä, luonnollisina ja suhteellisesti helposti eroteltavina hyvyysluokkina soveltuvat sangen hyvin kasvu- ja tuottotaulujen pohjaksi. Matemaattis-tilastollisten menetelmien käyttäminen osottautui tarjoavan erittäin suuria etuja kasvu- ja tuottotaulujen laatimisessa ja saattavan laskelmat entistä varmemmalle perustalle.

Etuina keski-eurooppalaisiin tauluihin verraten näissä kasvu- ja tuottotauluissa huomataan erityisesti: 1. Koska taulut osottavat, kuinka paljon saman hyvyysluokan (s.o. tässä metsätyypin) metsämaa mitäkin puulajia käyttäen kykenee tuottamaan, käy niiden perusteella mahdolliseksi laskea, mitä puulajia minkinlaisella maalla on taloudellisesti edullisinta kasvattaa. 2. Koska tauluissa esiintyvät metsämaan hyvyysluokat ovat luonnossa todella esiintyviä, voidaan taulujen avulla laatia käytäntöön soveltuva, todellisuuden mukainen metsämaitten jyvitysasteikko. 3. Taulut voidaan ottaa laskelmien pohjaksi määrättäessä, onko edullisempaa käyttää jotakin maa-aluetta metsätalouteen vaiko maanviljelystarkotuksiin. 4. Tällaisten taulujen perusteella voidaan laskea soitten ojittamisen kannattavaisuus, kun edeltäpäin saatetaan päättää, kuten Suomessa tehdyt tutkimukset ovat osottaneet, minkälaiseksi metsämaaksi, s.o. metsätyypiksi kukin suolaatu kuivatettuna muuttuu. 5. Tauluihin liittyvien runkojakaantumissarjojen perusteella voidaan edullisesti suorittaa metsän raha-arvoa koskevia laskelmia sekä laatia paikallisia rahatuottotauluja, tunnettaessa erilaatuisten puutavarain yksikköhinnat sekä sopivimmat katkaisu- ja sahaustavat.