PREPARATION OF GROWTH AND YIELD TABLES

by

Y. Ilvessalo, D. Ph.

Professor at the Forest Research Institute of Suomi.

On account of the long period of the growth of forests, which often considerably exceeds the age of man, an accurate account of the yield in forestry is more difficult than in many other branches of economy. A proper treatment and correct solution of many problems of forestry, however, presuppose a thorough insight into the laws governing the growth and yield of stands. Fully aware of this the first pioneers of scientific forestry made attempts at creating such expedients as would facilitate an exact determination of the growth and yield of stands. For this purpose as early as over a hundred years ago the first so-called yield tables were prepared in Central Europe. In these tables, as is well-known, an endeavour is made to describe, on the ground of investigations based on representative materials, the general laws of the growth of stands, *i. e.* on an average the different aspects of growth and yield of stands at the different age grades of the forests which on the ground of the fertility of the soil are to be classed with the same comprehensive group, and, occupying a rather large and uniform area, are of as normal a character as possible.

With the progress of forestry reliable growth and yield tables have proved to be indispensable and are the means generally used in every country practising rational forestry. The important position attained by the growth and yield tables in forestry causes ever greater and more manifold demands and requirements to be made on them. Consequently a considerable number of growth and yield tables have been prepared in various countries, but especially in Central Europe, both in the course of the last century and constantly in more recent times, and the latter ones have tried to remedy the shortcomings detected in the earlier. A great number of the forest forming species of trees have been furnished with tables of their own, some of them having been furnished with several growth and yield tables.

The methods and devices employed in the preparation of growth and yield tables have been very varied, and some of them lead to their goal comparatively quickly, others only after a longer lapse of time. One of the most important, but at the same time the most difficult fundamental problem, perhaps in most cases more or less uncertainly solved, has always been in this work to find out which of the sample plots of the same species of trees belong, with respect to the quality of the site (Standortsbonität) and to the quality of the stand occupying that site (Bestandsbonität), to the same growth series and, accordingly, have to be treated together by preparing the common average series of the growth and yield. The methods employed for that purpose have been diverse, but perhaps the most universally used have been the well-known *strip, index* and *directing curve methods* in one form or another. In the course of time, these have been further developed by many compilers of growth and yield tables, who have endeavoured to mould them into as well-adapted instruments as possible.

An examination of those methods and devices reveals in each of them many advantages, but at the same time many deficiencies, which to some extent are common to all of them. The index method, in its more developed forms, may often be a good means of grouping sample plots, on the basis of the quality of stands, into growth series, but it requires the utmost precision and discrimination, especially in the selection of the index trees, which are to be analysed, and the indicating stand itself. The directing curve method, when based on a sufficient number of sample plots and a period of investigation extending over several decades, may render reliable directing curves and, accordingly, certainty as to which of the sample plots belong, in regard to the quality of stands, to the same growth series; but its drawbacks are the length of the period of investigation in particular, further the probable damages and the possible disturbances caused by the meteorological conditions etc., which may affect the sample plot stands in the course of that period. Whilst both the index and the directing curve methods may offer a good means of judging which sample plots, with reference to the quality of stands (Bestandsbonität), are to be referred to the same growth series, they, however, inevitably presuppose that, by one means or another, it has already been ascertained which of the sample plots belong, with respect to the quality of site (Standortsbonität), to the same group. As to this presupposition, in most cases and more or less exclusively, resort has been had to quality classes determined by the strip method.

The advantage of the strip method is its simplicity. Those who have employed it have quickly and mechanically, too, solved the difficult question: which of the sample plots, with respect to the quality of site, belong to the same series. As is well-known, this has generally been effected by marking the volumes of all the sample plots taken for preparing the yield tables in a system of co-ordinates — the sample plots of each species of trees in a separate system of co-ordinates — as ordinates over the corresponding ages as abscissae. At an earlier age the points indicating these volumes collect in the vicinity of the origo and close to one another, and with advancing age they form, to the right from the origo and upwards, an ever widening strip, like the tail of a comet. On the basis of the highest and lowest points of this strip two curves, bounding the tail of points from above and below, are drawn by free hand. When it was desirable to distinguish five quality classes the area thus confined by the limiting curves was divided by corresponding curves into five sub-strips of equal breadth, by which operation the points, *i. e.* the sample plots, were divided into five quality classes according to the strip into which they had fallen. By drawing a mean curve, exactly in conformity with the limiting curves, through each strip, the mean volume curve for each quality class was obtained, from which the volume table was prepared for succeeding years.

But a closer examination reveals a fact which has often been demonstrated, viz., that the strip method rests on a basis that is weak in many respects. Thus, just the limit stands, *i. e.* the best and the poorest of all, on which the method is based, are relatively rare, to be met with mostly in a few age classes only. Under these circumstances the limit curves and along with them other yield curves, too, will be traced, in the absence of sufficient material, on a very uncertain basis. Further it is doubtful, whether it is possible at all to deduce the yield curves of the middle quality classes directly from the limit curves. It may happen, especially when the region investigated is large and variable in altitudes, that the points standing for the volume etc. of the sample plots that have fallen into the same strip do not in reality belong at all to the same growth series, but to quite different growth series which may intersect one another. The method is quite schematic and, the quality classes deduced by its means are graphical abstractions, which have been delimited quite arbitrarily and which, accordingly, have, of themselves, no counterpart in nature.

As to the use of the *mean height* of the wood as an indicator of the quality of site, which has attained to such a universal use in the preparation and application of growth and yield tables as well as in the determination of the quality of the forest site in general, very widely differing views have been advanced in Central Europe as well as elsewhere. As the mean height of the wood depends to a very considerable extent on the method by which it is deduced and on the mode of formation (sowing or planting etc.) and treatment of stands, varying by dint of every thinning cutting and by dint of some modes of regeneration cuttings, as, for instance, selection cutting; as the mean height diverges widely from the normal, when a forest land is used for some special purpose, for instance, as pasture enclosure, and as on its basis the same site, too, will be referred to different quality classes according to the species of tree that occupies the site; whilst, on the other hand, widely differing forest lands: barren heaths, moors, rockbound forests etc., will be included in the same quality class, and whilst the determination of the quality of forest lands that lie treeless is not feasible on its basis, it seems highly improbable that the mean height could serve as a basis for the determination of the quality of sites, either in connection with the preparation of yield tables or otherwise, at least when applied universally and without important reservations.

Since in the yield tables prepared by means of the methods discussed above and in the present-day yield tables almost without exception *the classification of sites has been effected on different principles for different species of trees,* quite independently of one another and without any regard to the soil, they suffer from the common drawback that *the quality classes for the different species of trees in them do not correspond to one another, and, accordingly, it is impossible on the basis of such yield tables to compare the yield of the different species of trees on the same site.* They suffer further from the disadvantage that *their quality classes of sites are based on arbitrarily determined limits, and, accordingly, are as artificial as the growth series constructed in their bounds, for which reason they have no real counterpart in nature.* This artificiality is evident, for instance, from the fact that the growth curves for the different quality classes have such a uniform course and their divergences from one another are so mathematically even and smooth that they can scarcely correspond in nature to the real course of growth in the normal stands of the different sites. In addition to what has been said above it must be regarded as a defect in most of the present-day growth and yield tables that they, as a rule, *do not present numerical series to show how many stems of such and such thickness are to be found, on an average, in the normal stands of the different sites and of the different species of trees at the* *different age grades.* These numerical series are quite indispensable for calculations of various kinds, wherever trees of different thickness have a considerably differing monetary value per unit of volume.

From the above considerations it would seem necessary to undertake the preparation of growth and yield tables on such new principles as would be as much as possible free from the worst defects detailed above and would lead, at least with respect to the latter, to more satisfactory growth and yield tables.

During the last decades an attempt at the realization of this object has been made in Suomi by constructing growth and yield tables for the most important species of trees by processes differing from those employed hitherto. For this purpose a good deal of preliminary research work was carried out, by which the potential methods were investigated and experimented with.

The two principal points in which the preparation of the new growth and yield tables was planned on lines different from the previous ones were as follows:

1) *On each sample plot the quality class of the site had to be determined at the same time as the sample plot was taken, on the spot and independently of the stand occupying the site,* so as to make it possible to treat the sample plots of every different site, in the preparation of growth and yield series, as an independent group from the very beginning, and so that the quality classes should be the same for all the species of trees;

2) *In the investigations for finding out, which of the sample plots of the same quality class belong to the same growth series, an attempt had to be made to probe the applicability of the mathematic-statistical methods for this purpose* and the chances of deducting by their aid the so-called stem distribution series, representing the average number of stems of the different diameter classes, for the different quality classes and the different species of trees, especially at the higher age grades, at which such series are of the greatest importance.

With respect to both these points the work was in a position to depart from the basis created by investigations carried out earlier in Suomi: regarding the former point resort could be had to *the system of forest types* worked out by CAJANDER, and, regarding the latter point, to *the application of the mathematic-statistical methods* worked out by CAJANUS[1]). The system of forest types renders it possible

[1]) A. K. CAJANDER: Ueber Waldtypen (Acta Forestalia Fennica 1; Fennia 28) and The Theory of Forest Types (Acta Forestalia Fennica 29).

WERNER CAJANUS: Ueber die Entwicklung gleichaltriger Waldbestände (Acta Forestalia Fennica 3).

to classify sites on a natural principle and to bring, accordingly, the sample plots, with respect to the quality of their sites (Standortsbonität), into uniform natural groups. The mathematic-statistical methods render it possible to compare, by the aid of some fairly easily determinable parameters, the stem distribution series of different stands, of different age etc., with one another, which is exceedingly difficult directly. Thus the stem distribution series, which reflect the structure of stands very closely, can be taken as the basis for investigations with a view to finding out, which sample plots of the same quality class can be referred, with respect to the quality of stands (Bestandsbonität), to the same growth series.

The procedure in the preparation of growth and yield tables then will in the main lines be as follows.[1])

For investigation a sufficient number of sample plots with an average area of ¼ hectare is taken in the different parts of the area to be investigated, in stands as normal as possible, treated under the same system and unmixed, whilst attention is paid to each sample plot in its entirety belonging to the same forest type, that it in all probability represents as »pure» a type as possible. The sample stands are measured and cubed as usual, observing some precise procedure. It is advisable to subject the mean tree of the dominant trees (of the 100 thickest trees per hectare, for instance) to stem analysis, and the results can be used as auxiliaries, analogously to the index method, in examining whether such and such stands belong to the same growth series. On each sample plot an accurate description of the flora is made in order to make a detailed delineation of the forest type to which the site belongs.

Since the forest type of each sample plot, indicating the quality of the site, is determined at the same time as the sample plots were taken in the forest, the investigation at its later stages need no longer deal with the problem: which of the sample plots belong, with respect to the quality of site (Standortsbonität), to the same group. As is natural, the sample plots of the same forest type, and, within the latter's compass, those of the same species of trees are treated as the same group. Accordingly, the sample plots of each different

[1]) Yrjö Ilvessalo: Tutkimuksia metsätyyppien taksatoorisesta merkityksestä (Investigations on the Importance of Forest Types in Forest Mensuration. Acta Forestalia Fennica 15).

Yrjö Ilvessalo: Kasvu- ja tuottotaulut Suomen eteläpuoliskon mänty-kuusi- ja koivumetsille (The Growth and Yield Tables for Pine, Spruce and Birch Forests in the Southern Half of Suomi. Acta forestalia fennica 15).

site class, *i. e.* the sample plots of a definite species of tree of each different forest type, are treated quite separately, independently of the rest of forest types and species of trees, from the very beginning.

The problem, which of the sample plots belonging to the same forest type and the same species of trees have to be included, with reference to the quality of stands (Bestandsbonität), in the same growth series, is solved by the aid of mathematic-statistical methods with stem distribution series as objects of comparison, as follows.

For each sample plot the characteristics of its stem distribution series: number of stems (frequency), mean diameter (mean value), dispersion (and variation coefficient) are determined, and if necessary, also the higher characteristics: asymmetry and excess. On the basis of the values of the number of stems, mean diameter, dispersion and variation coefficient of the sample plots of the same forest type and, within its compass, of the same species of trees, curves are traced, smoothed either graphically or calculatively, from which the smoothed mean values of the characteristics mentioned are deduced for each age grade. In the same manner, or — unless dependence on age is in evidence — as the simple arithmetical mean the smoothed values for the coefficients of asymmetry and excess are deduced for each forest type and, within its compass, for each species of trees, whenever these values are also held to be of use.

The nearer all the values of characteristics for the individual sample plots of the same forest type and, within its compass, of the same species of trees approach the corresponding smoothed values, the more certainly the sample plots belong to the same growth series in respect to the stands. When the values of characteristics differ from the corresponding smoothed values at most only by about three times their mean error, the individual sample plot may be taken as belonging, according to the mathematic-statistical principles, to this same growth series quite exactly. This theoretically justifiable limit value for deviation (three times the mean error) may not, however, be applicable to such material as comprises stands regarding which, in addition to the principal factors, so many collateral factors may, in the course of the great age of the stands, bring about lesser variations and deviations. But at least all the sample plots whose deviations from the smoothed mean values are worth attention, are subjected to a closer examination, and in any case all such sample plots whose deviations are detected to be caused by a special factor, are left out of account in the deduction of the final mean growth series.

After it has been thus established, which sample stands of the same quality, *i. e.* of the same forest type and, within the compass of the latter, of the same species of trees, may be referred to the same growth series, the mean series of growth and yield values are computed, using either calculative or graphical smoothing methods or both of them together, for the different species of trees and for each forest type separately. The mean stem distribution series are deduced on the basis of the smoothed values of the characteristics mentioned above (number of stems, mean diameter, dispersion [and coefficients of asymmetry and excess]). All the series, of course, may be computed separately, too, for the dominant and dominated parts of stands, in case it is deemed necessary.

The investigations carried out in Suomi by the preparation of the growth and yield tables led to the following results: (1) *All the aspects of growth are different in the different forest types and the same in the same forest type, for which reason the forest types, being uniform, natural and fairly easily distinguishable quality classes, are well adapted to serve as a basis for the classification of forest lands in general and for the growth and yield tables in particular.* (2) *Whether the individual sample plots of the same forest type belong to the same growth series can be very exactly checked by mathematic-statistical methods with the stem distribution series of the sample plots as objects of comparison; in addition to which it is also comparatively easy to deduce, on the basis of the latter, the mean stem distribution series for the different species of trees in each forest type and at each age grade separately.*

Suomenkielinen selostus.

Metsätaloudellisten kasvu- ja tuottotaulujen laatiminen.

Metsätaloudellisia kasvu- ja tuottotauluja, joissa edustavaan aineistoon nojautuvien tutkimusten perusteella kuvataan metsikön kasvun yleisiä lakeja, sen kasvu- ja tuottosuhteita, mahdollisimman säännöllisissä, »normaalisissa» metsissä, on 1700-luvun lopulta lähtien nykyaikaan saakka laadittu eri maissa suuri joukko. Metsätalouden kehittyessä luotettavat kasvu- ja tuottotaulut ovat osoittautuneet välttämättömiksi apuneuvoiksi, joita ilman tuskin missään metsätaloutta harjoittavassa maassa nykyisin katsotaan tultavan toimeen. Tästä syystä tällaisille tauluille on asetettu yhä korkeampia ja moninaisempia vaatimuksia.

Menettelytavat kasvu- ja tuottotaulujen laatimisessa ovat olleet hyvin monenlaisia, mutta ehkä yleisimmin käytettyjä ovat olleet n. s. juova-, osoittaja- ja johtokäyrämenettelyt, jotka ovat esiintyneet useassa eri muodossa. Tärkeimpiä ja samalla vaikeimpia tehtäviä tällaisessa työssä on aina ollut määrätä, mitkä saman puulajin koealat kasvupaikan ja sen puitteissa edelleen metsikön puolesta kuuluvat samaan kasvusarjaan ja ovat siis yhdessä käsiteltävät.

Eri menettelytavoissa huomataan useita hyviä puolia, mutta samalla kullakin niistä on omat puutteellisuutensa. Sitä paitsi miltei poikkeuksetta kaikissa menetelmissä ja niiden perusteella laadituissa kasvu- ja tuottotauluissa esiintyy myöskin yhteisiä puutteellisuuksia. Kun niissä yleisesti kasvupaikkojen jaottelu hyvyysluokkiin on tehty eri puulajeille erilaisilla perusteilla, aivan toisistaan riippumatta ja ollenkaan maaperää huomioon ottamatta, eivät niissä eri puulajien hyvyysluokat vastaa toisiaan, eikä siis tällaisten taulujen perusteella voida verrata keskenään eri puulajien tuottoa samalla kasvupaikalla. Toiseksi niissä on haittana se, että niiden kasvupaikka-hyvyysluokat perustuvat mielivaltaisesti määrättyihin rajoihin ja ovat siis keinotekoisia samoin kuin niille laaditut kasvusarjatkin, joten niillä ei ole todellista vastinetta luonnossa. Lisäksi on useimmissa nykyisissä kasvu- ja tuottotauluissa puutteellisuutena, että niihin ei sisälly sellaisia, raha-arvoa koskevissa laskelmissa tärkeitä lukusarjoja, jotka esittäisivät, kuinka paljon eri vahvuisia runkoja eri kasvupaikka-hyvyysluokkien ja eri puulajien normaalisissa metsiköissä kullakin iällä keskimäärin on.

Suomessa tehtiin uusimmat kasvu- ja tuottotaulut laadittaessa (vv. 1916—1919) yritys taulujen valmistamiseksi sillä tavalla, että ainakin edellä mainitut kasvu- ja tuottotaulujen pahimmat puutteellisuudet vältettäisiin. Kaksi pääkohtaa, joissa uusien taulujen laatiminen suoritettiin entisistä menettelyistä poikkeavalla tavalla, olivat seuraavat: 1) jokaisella koealalla määrättiin kasvupaikan hyvyysluokka jo itse koealalla sitä mitattaessa ja tehtiin se metsiköstä riippumattomalla tavalla, niin että jokaisen eri kasvupaikka-hyvyysluokan koealoja voitiin kasvusarjoja laadittaessa heti alusta lähtien käsitellä itsenäisenä ryhmänä ja että hyvyysluokat olivat yhteiset kaikille puulajeille; 2) tutkittaessa, mitkä saman kasvupaikka-hyvyysluokan metsiköt kuuluivat samaan kasvusarjaan, käytettiin apuna matemaattistilastollisia menetelmiä ja niiden avulla laskettiin myöskin eri läpimittaluokkien keskimääräistä runkolukua esittävät n. s. runkojakaantumissarjat.

Molempiin edellä mainittuihin kohtiin nähden voitiin lähteä Suomessa varhaisemmin tehdyissä tutkimuksissa luodulla pohjalla, edellisessä turvautumalla Cajanderin metsätyyppijärjestelmään ja jälkimäisessä Cajanuksen matemaattistilastollisten menetelmien sovellutuksiin. Metsätyyppijärjestelmä tekee mahdolliseksi kasvupaikkojen luokittelun luonnollisella pohjalla ja siis koealojen viemisen kasvupaikan puolesta yhtenäisiin luokkiin. Matemaattistilastollisten menetelmien avulla taas käy mahdolliseksi muutamien verraten helposti määrättävien tekijöiden perusteella verrata keskenään erilaisten metsiköitten runkojakaantumissarjoja, mikä suoranaisesti on sangen vaikeata. Siten voidaan ottaa metsikön rakennetta hyvin kuvastavat runkojakaantumissarjat perustaksi tutkittaessa, mitkä saman kasvupaikka-hyvyysluokan koealat metsikön puolesta kuuluvat samaan kasvusarjaan.

Puheena olevia kasvu- ja tuottotauluja laadittaessa käytetty menetelmä on yksityiskohtaisesti kuvattu kirjoituksessa: Yrjö Ilvessalo, Tutkimuksia metsätyyppien taksatoorisesta merkityksestä (Acta forestalia fennica 15). Saadut tulokset sisältyvät myöskin mainittuun kirjoitukseen sekä kirjoitukseen: Yrjö Ilvessalo, Kasvu- ja tuottotaulut Suomen eteläpuoliskon mänty-, kuusi- ja koivumetsille (Acta forestalia fennica 15).