Development of Yield Tables

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SUMMARY

The availability of Forestry Commission yield tables has influenced the development of forest management in Ireland particularly in the past decades. This article traces the development of yield studies in the Foresty Commission and outlines the recent publication of yield models for forest management.

INTRODUCTION

A yield table shows the course of development of a stand from an early age up to the maximum rotation which may be adopted. It simulates the growth pattern of the various stand characteristics (volume, height, diameter, etc.) in relation to age on a given site type. The early yield tables developed in Germany more than a century ago were the result of a graphical approach to model construction but during the past two decades mathematical formulae are being increasingly used in conjunction with computers and the tendency is to refer to those as yield models. The two terms are, however, synonymous.

The traditional source of data for yield table construction is the sample plot on which measurements may be taken once (temporary) or over the lifespan of the crop (permanent).

Early models are in all cases based mainly on temporary plot data. It follows that those tables must of necessity be of a provisional nature and will be modified as more data become available from repeated measurements on permanent plots. Accumulating reliable data for yield table construction is, therefore, a long drawn out process which can last for decades. It ends for a particular plot only when the plot is harvested or so extensively damaged to be of no further use.

With the advent of computers the individual tree approach, modelling from the individual tree rather than the stand, to

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modelling became fashionable particularly in Canada and the United States. In Europe, however, the greater availability of growth data from sample plots rather than from individual trees continued to influence the approach to model construction.

Site Classification

While there are many approaches to yield table construction one method in particular is of interest. In its simplest form it can be regarded as a two stage process: (i) site classification and (ii) the construction of yield curves for each site class. Measurement of site quality may be expressed in terms of volume, height, vegetation and environmental factors such as soil and climate.

Vegetation as a means of site classification is useful on unafforested land where the presence of certain indicator plants gives an indication of the forest potential. Apart from Finland, however, few other countries have used it as a means of site classification in established tree crops. Indeed, in most of our coniferous forests an assessment of the natural vegetation could prove difficult. Soil as the source of growth obviously merits attention, but to establish the quantitative relationships between soil properties and growth is often difficult and costly and has not been done successfully on a wide scale. The remaining two methods of site classification, often referred to as growth classifications, are the most commonly used in yield table construction.

Cumulative volume production and its related mean annual volume increment has always been recognised as an excellent measure of site (or growth) classification. It is also the one of most interest to forest managers. Unfortunately, accurate estimates of cumulative volume production (which includes the volume of all thinnings to date) are seldom available. Substituting standing volume for cumulative volume is acceptable only where crop treatment has been absolutely uniformly applied. Obviously, lightly thinned stands will have more standing volume than heavily thinned stands resulting in a confounding of site quality and thinning treatment. Because of the difficulty in determining cumulative volume production and the unreliability of standing volume as a means of growth classification, mean height and eventually top height (mean height of the 100 trees of largest diameter breast height per hectare) in relation to age became the most widely accepted criteria.

VARIABLE DENSITY AND TREATMENT

Having categorised the range of site types by a series of cumulative height growth curves in relation to age the second stage in construction is accomplished by relating the various crop characteristics (e.g. volume, basal area, diameter, etc.) to age or height for each site class. The implication is that those crop characteristics will follow a definite development pattern with age or height growth, but this is true only within certain limits of treatment and stocking density.

The characteristics of a crop of a given age on a given site will vary with treatment such as thinning. They will also vary with initial planting espacement and crops planted at wide spacing can well follow very different growth patterns from those planted at close spacing. This applies also to crops which have become understocked with time. By combining planting espacements with subsequent thinning treatments (including no-thinning) and applying those over a range of site types for each species it will be apparent that the number of tables required to cater for all combinations could run into four figures. Furthermore, those tables will only be realistic if they are based, at least to some degree, on actual data. Obviously, the data requirements for such a range of yield models are formidable and are available only as a result of continuous measurements on sample plots or individual trees.

The task of yield table construction can be greatly simplified if data are confined to fully stocked stands — the so called 'normal' stocking density. Simplification can be brought a stage further if restrictions are placed on the range of initial espacements and if subsequent thinning treatment is also restricted to a particular type and/or grade. This kind of restriction will give rise to a normal yield table applicable to a fully stocked stand established at a particular espacement and thinned according to a particular prescription, in short the type of yield table contained in Forestry Commission Booklet No. 34 — *Forest Management Tables (Metric)* (Hamilton and Christie 1971) with which we are familar. The new issue, Forestry Commission Booklet 48 — *Yield Models for Forest Management* (Edwards and Christie 1981), caters for a range of initial espacements and thinning treatments. It replaces Booklet No. 34 and is the most recent development in an undertaking which started 65 years ago. It is now proposed to outline this development.

EARLY DEVELOPMENTS

Collection of data for construction of the first yield tables in Britain is attributed to Robinson. The work began in 1917 when extensive fellings were in progress all over Britain. Robinson was then with the Agricultural Department but was transferred to the Forestry Commission on its establishment in 1919 where he continued this work (Schlich 1925). In all a total of 1183 temporary plots and subplots were measured up to 1920 including 52 which were measured in Ireland (Anon. 1928). The results of this were published as *Forestry Commission Bulletin* No. 3 in 1920, giving yield tables for European larch, Norway spruce and Scots pine and preliminary tables for Douglas fir, Corsican pine and Japanese larch. Because of the variable treatment received the volume method of growth classification, which was favoured in Germany, was not adopted in Britain. As Schlich (1925) points out; "In these circumstances, the Commission decided to effect the division into quality classes by means of the mean height of the woods, as that is closely connected with the volume production and comparatively little affected by the different methods of treatment. The sample plots were classified according to the height of the crop at a standard age, for which 50 years was selected in the case of coniferous woods . . . .". This method was to remain with only slight modification for the next forty years.

In 1928 the original tables were updated by the inclusion of complete yield tables for Douglas fir and Corsican pine and by a revised preliminary yield table for Japanese larch and a new preliminary table for Sitka spruce. The original tables for European larch, Scots pine and Norway spruce remained unaltered. The updated version was based on measurements of 1118 temporary plots and subplots, augmented by data from 48 permanent plots. The 52 temporary plots in Ireland were excluded. Those new tables were prepared by MacDonald in collaboration with Guillebaud, the Chief Research Officer, under the direction of Robinson who was now Commissioner.

After the war, the 1928 tables were reproduced in booklet form for field use (Anon. 1946) but with the accumulated data now available from permanent sample plots a major revision was in the offing. This took place in 1953 with the publication of "Revised Yield Tables for Conifers in Great Britain" (Hummel and Christie 1953). The main difference between those and previous tables was in the method of growth classification which was based on the "top" height attained at 50 years. Top height was defined as the "average height of the 100 largest trees per acre". Other differences included the source of data, which was based on permanent sample plot records, and the thinning regime which was heavier than that assumed in the older tables.

In constructing the revised yield tables considerable use was made of two observed facts:

(a) "Total volume production per acre is closely correlated with the top height of a stand, and the total volume production reached at a given top height is not influenced appreciably by the rate of growth".

(b) "Volume and basal area increment per acre is similar within a wide range of thinning treatments". (Hummel and Christie 1957).

Those observed phenomena substantiate "laws" or "theories" proviously postulated by Eichorn in 1904 (Assmann 1970) and Möller in 1952 respectively (Heiberg 1954). The first was subsequently to require modification just as Eichorn's "law" had to be extended to cater for site-dependent differences, but at the time they enabled Hummel and Christie to introduce the "master table" concept for the construction of yield tables. This is a table based on top height alone and is applicable to all site classes. It greatly facilitated yield table construction in that all crop characteristics were related to top height regardless of site and it became the corner stone of subsequent yield table construction.

YIELD CLASS

The revised yield tables were, like all yield tables, intended as instruments for broad planning and for comparing the relative profitability of different species by economic analysis. They were not intended to be applied to individual stands and since they represent the average growth pattern they are often not appropriate for a particular site.

In the early sixties it was decided to expand the scope of the tables to meet the need for guidance on aspects of forest management (Johnston and Bradley 1963). This led to the publication of Forestry Commission Booklet No. 16, *Forest Management Tables* in 1966 (Bradley, Christie and Johnston 1966) and its metric equivalent Forestry Commission Booklet No. 34 (Hamilton and Christie 1971). Included were tables on thinning control and production forecasting as well as yield tables. Those had their origin in a concept which, although not entirely new, was now refined to provide a unique approach to yield table and forest management table construction. This was the concept of *yield class*.

From a management standpoint, volume is the variable of most interest to the forest manager. This was recognised in the early methods of yield table construction. The total or cumulative volume production in relation to age is an excellent criterion of site productivity. An analogous measure is the mean annual increment.

Johnston and Bradley (1963) took the value of mean annual increment at its maximum, termed it *yield class,* and used it as a basis for stand classification. However, cumulative volume production of a stand is seldom readily available in practice and even if it were there would still be the difficulty of volume measurement to classify the stand. The problem was overcome by using top height/age as a means of site classification then relating total volume production to top height and dividing by age to obtain mean annual increment. Yield class was determined from a series of mean annual increment curves for the appropriate species. The concept of yield class is a significant contribution to yield studies and from a forest management standpoint it is eminently practical and highly informative.

With the accumulated data from their permanent sample plots, the Forestry Commission was in a position to identify local variations in total volume production for a given top height. To cater for those local growth patterns each General Yield Class was subdivided into three production classes, 'a', 'b' and 'c'. The effect of using production class 'a' or 'c' was to raise or lower, respectively, the General Yield Class by one class. Thus, General Yield Class 16, Production Class 'a', was equivalent to Local Yield Class 18, while Production Class 'c' was equal to local Yield Class 14.

The term 'General Yield Class' was applied where the top height/ age relationship has been obtained. Production class was established from the relationship of top height to either (i) total volume production per ha, (ii) total basal area production per ha or (iii) the mean breast height diameter of the 100 trees of largest breast height diameter per ha. The second and third methods are really substitutes for the first and later, with the preparation of yield models for different thinning and spacing treatment, the third method was dropped completely as it is highly influenced by treatment.

The problem of assessing the yield class of crops which have recovered from an initial period of check and are now growing normally is only too familiar to foresters. The predicted growth rate based on the average growth to date will usually be less than the actual future growth rate. The guidelines recommended in such a situation were to subtract the number of years spent in check from the actual age and subtract also the height growth of that period from actual top height. This notional top height and age was then used to determine yield class. Similarly, where height growth had started to decline, the point and the age appropriate to it should be used. With the availability of improved growth data this procedure was later modified by adjusting the age in relation to current height growth.

Marginal Intensity

The management tables assume a marginal thinning intensity; that is the highest intensity which can be sustained without diminishing total production (Johnston and Bradley 1963). Although this intensity varies with both stocking levels and rate of growth it can, for all practical purposes, be regarded as varying only with rate of growth. This simplifies the position and makes it possible to prepare thinning tables which are applicable to stands of the same rate of growth or yield class irrespective of their stocking levels. In addition the analysis of thinning experiments indicated that the marginal thinning intensity could be expressed in terms of a volume removal of 70% of the yield class. When an allowance of 15% is made for unproductive components this reduces to 60%. The implications of this for thinning control and production forecasting are considerable. Over the normal thinning period for a crop the annual thinning yield (m^3/ha) can be expressed as 70% of the yield class and thinning forecasts are equivalent to 60% of the yield class. To those involved in forecasting this is one of the most outstanding contributions of the yield class method to forest management.

New Yield Models

A revised, metric edition of the Forest Management Tables was produced in 1971 (Hamilton and Christie 1971). With minor exceptions, consisting mainly of small adjustments to the General Yield Class Curves, the content remained unchanged. Christie (1972) describes the method used to construct the tables. The "master table" approach used to produce the Revised Yield Tables for Conifers in 1953 was again adopted, but the growth relationships between the crop characteristics were now expressed in mathematical terms by orthogonal polynomials.

The speed and simplicity of yield table computation by means of computer, when the relationships are expressed mathematically, heralded a new era in the construction of yield models. Hamilton and Christie (1973) present an outline of what is feasible in relation to different thinning and spacing regimes and record that some 600 acceptable models were produced by a programme developed by the Forestry Commission. A selection of those models has now been published for the common species to which various combinations of spacing and thinning treatments have been applied. Spacings range from 0.9m to 3.0m for spruces and pines, extending to 4.5m for Scots and Corsican and up to 7.3m for Poplar. Thinning treatments are low, intermediate, crown, and line thinning, no thinning, thinning at conventional marginal thinning age and thinning with 5 and 10 years delay. Unless stated otherwise all the models are thinned at the marginal thinning intensity and usually on a 5 year cycle. The format of the tables is very similar to that of the Normal Yield Tables in Booklet No. 34 except that the current annual increments and volume assortments have been omitted. The models are supplemented by index cards showing general yield class and production class curves for the common coniferous and broadleaved species. Booklet No. 48 entitled *Yield Models for Forest Management* (Edwards and Christie 1981) completes the presentation.*

The booklet on Yield Models for Forest Management replaces Booklet No. 34 *Forest Management Tables (Metric)* which is now out of print. It reproduces Part I of that publication dealing with the yield class system of classifying growth potential with only slight modifications but covers new ground on the effect of variations in growth rate and different treatments as well as presenting a general coverage of the construction and application of the yield models. The recommended way to deal with changes in growth rate is to combine current growth rate with 'adjusted age'. Tables showing annual top height increment by yield class and top height for the common coniferous species are provided for this purpose. The procedure is also applicable to crops which have responded to fertilising.

It is generally recognised that there is a relationship between total volume production and treatment such as spacing or heavy thinning. Wide spacing reduces total volume production while close spacing will increase it. It follows that the mean annual increment at its maximum will be less for a given species on a given site if it is planted at wider spacing. Since the mean annual increment at maximum determines the yield class does this mean that treatment affects yield class? The answer is no, because yield class is the maximum mean annual increment which a given species can attain on a particular site, *irrespective of treatment.* In the normal yield tables of Booklet No. 34 *Forest Management Tables (Metric)* it was possible to determine yield class by inspection of the mean annual volume increment. This is no longer possible and at the wider spacings the models show mean annual increment at maximum which are considerably lower than the yield class.

* The models, index cards and booklet may be ordered from the Publications Section, Forestry Commission, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, England.

The new yield models will provide a valuable tool for better decision making in relation to silviculture and treatment of the growing stock. This point is well made in the section on the use of yield models. "Before a stand is planted, a forest manager needs to decide the initial plant spacing, or number of trees per hectare, and, once the stand is growing, he needs to decide whether to thin it and if so when, how frequently, how heavily and in what way, and, finally, he needs to decide when to fell the stand". To arrive at a decision will usually involve economic analysis of the various options. It will involve constructing price-size curves giving the value per m^3 for the material produced by the treatments selected and discounting those back to a common date. A table of discounting factors is provided for this purpose.

Guidelines are provided for forecasting production. This requires, for each stand, information on the area of each species by age, yield class, past treatment and proposed future treatment. The presentation is adequate for application to short-term thinning forecasts and stand assortment tables are provided for those who wish to have a breakdown of the predicted volume by top diameter classes.

The yield models catering for various spacing and thinning treatments represent another milestone in growth studies. Future models will likely be based on the growth of individual trees in the stand as this method has the flexibility to simulate the effects of treatment regimes which have not yet been tried in practice. The Forestry Commission have already developed a modelling programme for this purpose. Work is also in progress on modelling the change in diameter distributions as the stands develop and special functions such as the beta (Mood and Graybill 1963, Van Laar 1976) or Weibull (Bailey and Dell 1973) may well be used.

Irish foresters can look forward to many new developments in growth models during the next decade but this does not mean that they should be accepted blindly and without critical examination. Models are intended to simulate a growth process under a certain set of conditions. They are a guide to forest management but should not be allowed to dictate it.

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