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The following notes are designed to aid the speedy processing of scientific contributions to the journal. Authors should comply with them in so far as this is possible.

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2. Diagrams and illustrations should be clearly drawn in black ink on good quality paper. Captions should be written on the back of each illustration. Illustrations, wherever possible, should be drawn in an upright position (x axis narrower than y). The approximate position of diagrams and illustrations in the text should be indicated in the margin.

3. Tables should not be incorporated in the body of the text, but should be submitted separately at the end (one table per page). Their approximate position in the text should be indicated in the margin.

4. Nomenclature, symbols and abbreviations should follow convention. The metric system should be used throughout.

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EDITORIAL

Land Hunger

The policy of the Forest and Wildlife Service on the establishment of plantations is quite clear. The annual planting target is 10,000 hectares. It has been so for many years. Unfortunately, plantings have fallen short of this target in recent years. From almost 9,000ha planted in 1975, the annual figure has fallen in each succeeding year to less than 7,000ha in 1980. The shortage of plantable land is a major reason why the target is not being met. The reserve of land available to the Forest and Wildlife Service for planting is lower now than in any year since 1974. Land acquisition took a sharp downward turn just when land prices had begun to fall. In fact, the total area of land acquired in the past two years is considerably less than that required for one year's planting. Why has this situation developed? Annual reports of each minister responsible for forestry since 1975 have expressed dissatisfaction at the rate of land acquisition. It has been clear for many years that a situation was developing which would make it impossible to achieve the planting target.

This is so contrary to sound forest planning that it demands explanation. Of course money is in short supply, but the programme of acquisition and planting must be considered top priority. It should be adhered to consistently through good times and bad until revised on the basis of rational decision.

The failure of the Forest and Wildlife Service to implement a major component of its policy is cause for serious concern. Will it be able to cope any better with the challenges of the coming years, the problems of fulfilling major supply contracts, of marketing timber surpluses? This may be the time to critically examine the service, its internal management structures and its relationship to government and to society.

The Society of Irish Foresters

The Society of Irish Foresters was founded in 1942 to advance and spread in Ireland the knowledge of forestry in all its aspects.

The main activities of the society centre around:

(a) Annual study tour

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Submissions to the journal will be considered for publication and should be addressed to: Dr. E. P. Farrell, Editor, Irish Forestry, Department of Agricultural Chemistry and Soil Science, University College, Belfield, Dublin 4. The attention of contributors is drawn to "Notes for the Assistance of Contributors" on page 60.

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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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A Yield Model for Unthinned Sitka spruce

(*Picea sitchensis* (Bong.) Carr)

Plantations in Ireland

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SUMMARY

Over the past few decades the construction of yield models has progressed from the graphical through mathematical and biomathematic approach. The development of a biomathematical growth model for Sitka spruce plantations is described. It is suggested that this technique can serve as a basis for general yield model construction of plantation species in Ireland.

INTRODUCTION

The terms 'yield model' and 'yield table' are synonymous although the former reflects the greater flexibility in construction and application which is offered by computers. Yield models are applied in a general sense to presentations of expected growth of forest stands based on growth measured or inferred. They consist of variables such as volume, basal area, height, dbh and number of stems per unit land area for stands of various densities and ages on sites of different productive capacities.

Yield models are used in forestry for production forecasting, for yield control, for valuation and for the evaluation of economic alternatives or management strategies (Hamilton and Christie 1973). They also provide guidelines for solving many forest management problems and for testing various alternatives in decision making at local, regional or national levels. Yield models are currently in use, such as the yield models for forest management

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by Edwards and Christie (1981) which replaced the British Forestry Commission Forest Management Tables (Hamilton and Christie 1971).

In the Republic of Ireland no yield tables have been produced for the management of Sitka spruce plantations. The Forest and Wildlife Service of the Department of Fisheries and Forestry uses BFC Management Tables for the management of these plantations. These tables are now regarded by many forest managers as being inadequate for Irish conditions (Gallagher 1972). Kilpatrick (1978) has also reported that unthinned Sitka spruce stands in Northern Ireland have higher basal area growth rate than is indicated in the BFC Yield Tables. This inadequacy of BFC Yield Tables for the management of Sitka spruce plantations in Ireland has been accentuated by the recent advances in silviculture such as site amelioration, increased planting espacement, respacing or no thinning regimes. Thus, yield models are urgently required in Ireland for the intensive management of plantations.

This paper presents a method based on Richards' Growth Function which has been developed for the construction of yield models for unthinned S.S. plantations of different initial espacements throughout the country.

DEVELOPMENT OF YIELD MODEL CONSTRUCTION

Yield tables were used in Europe before the end of the eighteenth century; the first yield table is said to be produced by Hennert in 1791 (Gallagher 1965). Since the idea of yield table construction was first conceived, its basic functions remain the same. Major developments, however, have occurred in the construction over the years.

Foresters in the 18th and 19th centuries assembled their data in the form of tables which were based on graphically produced relationships between crop characteristics. This procedure was, however, found to be rather subjective so forest scientists started to look for mathematical expressions to depict the growth of forest trees. The qualities of mathematics (precision, predictive ability, abstract in decuctive logic or argument, medium of communications unaffected by barriers of human language) backed by the advent of electronic computer facilities influenced the shift from the graphical and tabular technique of yield model construction to the mathematical models of the 1950s and 1960s. During this period when scientifically designed growth studies became operative, various regression techniques were used. The conventional yield models obtained by these regression procedures are of limited use however because their predictive capability of growth does not take into account the biological complexities of tree growth, silvicultural practices and environmental factors. Therefore, these models are now being replaced by improved growth and yield functions.

Growth Functions

Prodan (1968) discusses fully the many attempts by forest scientists to establish growth and yield functions for the growth prediction of forest trees. Examples of these functions are the exponential, allometric, Backmans etc. All of these are deterministic functions where given sets of conditions yield expected definite results. Stochastic models which are functional equations, where random variables are introduced were also tried by foresters. The Markov chain, Weibull distribution, logistic, Langevins etc., are some of the frequently tried stochastic functions for forest tree growth studies. These deterministic and stochastic functions still do not adequately describe the growth processes in forest trees because the biological complexities of tree growth are not taken into full account.

Pienaar and Turnbull (1973) pioneered a systematic approach of combining the biology of forest tree growth with mathematics. Their work was based on the research results of Von Bertalanffy (1951, 1957) and Richards (1959). The work of these two is well documented in the literature and is also detailed by Pienaar and Turnbull (1973). Because of its applicability to the study of tree growth, Richards' growth function is used to generate mathematical expressions of biological growth processes for Sitka spruce plantations in the Republic of Ireland.

Data Collection

The data used for this study were obtained from three sources within the country:

(a) From a survey of Sitka spruce plantations over the age of ten years carried out by the personnel of the Forest and Wildlife Service in 1966. In all, 198 temporary plots were measured in 16 countries covering over 36 forests (Gallagher 1972).

(b) From controlled thinning trials and spacing experiments established by Forest and Wildlife Service, Research Branch. Age of the plots range from 12 to 21 years. These data covered 13 counties in 27 forests. Lynch (1980) gives a comprehensive outline of these experiments.

(c) From two espacement trials at Drumhierney Plantation, Co. Leitrim. This plantation is owned by Mr. A. O'Rahilly and the experiment was established in collaboration with Professor Clear of University College, Dublin, in 1954. Various measuremets have been taken periodically since 1970.

In all cases, trees 7cm dbh and above were girthed with steel tape. A number of dominant trees were measured for top heights using the Blume Leiss hypsometer. Volumes of sample trees were computed from sectional measurements. The number of surviving stems, basal area, mean dbh and volume per plot were calculated. These were later converted to a per hectare basis.

Model Construction

Growth and yield studies over the years have led to the collection of much empirical evidence of the growth processes in relation to forest crops. This has been consolidated into theories or so called 'laws' which have formed the basis of yield model construction. Examples are Möller's theory of 1954 and Eichhorn's Law of 1901 (Assmann 1970) which state respectively that the volume increment of a stand does not vary over a wide range of stocking levels and that the total crop yield without exception is a function of height. As more information became available, those relations have been modified and refined to accommodate new data. An example of this is the inclusion of production classes as subdivisions of yield classes to cater for the fact that the relationship between cumulative volume production and top height is semi-stochastic rather than functional and varies to some extent with site conditions. Nonetheless, these original 'laws' have stood the test of time and continue to serve as an essential starting point of model construction particularly when data are limited or not available over the range required for detailed analysis. In the absence of adequate date, recourse must be made to growth 'laws' such as those earlier mentioned. This study is no exception and considerable use is made of two well established relationships:

1. Top height in relation to age is a good indicator of site productivity.
2. Top height is not significantly affected by stand density.

In constructing the growth model the first step is to relate top height to age irrespective of stocking density.

Therefore, all the top heights of the available data irrespective of their sources and espacements are plotted on age. By visual inspection, those top height-age points that follow a pattern in ascending order of growth are joined together. Thus, abstract growth series are obtained since growth has not been measured directly but is estimated from the differences between plots of various ages. This is the usual procedure in growth model construction when permanent sample plot data are not available.

Research workers are unanimously agreed that spacing affects dbh, basal area, volume and mortality. In order to quantify the effects of spacing upon these stand characteristics, the data were sorted into square spacing categories (1.6, 1.8, 2.4 and 4.0 meter) and the growth characteristics (vol/ha, ba/ha and mean dbh/ha) for each espacement were then plotted against top height as independent variable.

The growth model chosen for use in this study is based on the Von Bertalanffy growth function (1951, 1957) as modified by Richards (1959).

In its modified form the equation is:

$$W = A(1-be^{-kt})^{1/1-m}$$

where W = dependent variable (e.g. vol/ha)

t = independent variable (e.g. top height)

A = Asymptotic value of the growth characteristic under investigation (e.g. the maximum expected value of, say, vol/ha).

b = constant which is biologically unimportant.

k = rate constant which determines the average steepness of growth curve along the x-axis.

m = coefficient responsible for location of point of inflection on the curve and exclusively determines the shape of the curve.

e = base of Naperian logarithm.

The method used to fit the data to the Richards' function is that of Stevens (1951). Stevens' method solves the equation $Y=A+B.R^x$ by the method of least squares and determines the parameters A, B and R. This involves replacing $W^{(1-m)}$ by 'Y', $A^{(1-m)}$ by 'A', $-A^{(1-m)}$. b by 'B' and e^{-k} by 'R' respectively to present the Richards' function in the same form as that of Stevens.

Because of the detailed computational procedures involved in fitting Richards' function to data by the Stevens method, a computer package consisting of four programmes was developed for this study. The programmes used are as follows:

1. RICHAD.FOR which consists of a main programme and three principal sub-programmes.
2. BMD programme. (Biomedical Computer Programs, California).
3. CURVE.FOR which consists of a main programme and three sub-programmes.

YIELD.FOR which is made up of a main programme and a sub-programme.

Using the available data the first programme generates a number of growth equations for the establishment of relationships between top height and age over the range of site types as shown in Table 1[1]. The programme is then used to establish relationships between each of the crop characteristics vol/ha, ba/ha and mean dbh/ha and top height for each of the four espacements under investigation (Tables 2, 3 and 4). In this way growth models for the different growth characteristics for each espacement are obtained. The computer outputs which are generated are stored on files which are readily accessible to the other two computer programmes.

The second programme performs asymptotic regression analyses of the form $Y=P+QR^x$ (1)

where Y=Asymptotic 'A' values for the growth characteristics generated by Richards Growth Function Programme.

X=Common log of stand density.

P, Q, R=Parameters estimated by the programme.

In this study, the 'A' parameters of each growth characteristic (vol/ha, ba/ha, mean dbh) for the different stocking densities are regressed on the common logarithm of their initial stocking densities. Tables 5 and 6 show the input data and computer output respectively for the different growth characteristics.

The third programme processes the parameters. 'b', 'k' and 'm' generated by the first programme to give third degree polynomial equations for each parameter and spacing. Each parameter of the growth characteristic is regressed on the common logarithm of the stocking densities. Tables 7 and 8 show the input and output data respectively for the various growth characteristics and parameters.

'Adjusted' values of the Richards function growth parameter 'A' in relation to each planting espacement are obtained for the various

1 For all tables see pages 84 to 93.

growth characteristics using the equations generated by the asymptotic regression programme. Similarly, 'adjusted' values of the parameters 'b', 'k' and 'm' were obtained from the polynomial regression equations. Thus, for any given espacement a unique set of 'A', 'b', 'k' and 'm' parameters for each crop characteristic are calculated. When these values were inserted into the Richards' function, $W=A(1-be^{-kt})^{1/(1-m)}$, tabular values for each crop characteristic, for each espacement, were obtained. Thus, a single equation (Table 9) for each growth characteristic is generated and this single equation may be regarded as the biomathematical growth equation for Sitka spruce in Ireland. This biomathematical growth equation permits interpolation of values for those parameters where no data are available. Extrapolation beyond the range of data is also possible.

Yield Table Construction from the Biomathematical Growth Models

The fourth computer programme developed for this study consists of a main programme and a sub-programme called 'Forest'. 'Forest' uses the asymptotic and polynomial regression equations to generate 'adjusted' values of the parameters 'A', 'b', 'k' and 'm'. These adjusted values are inserted into the Richards' Growth Function, $W=A(1-be^{-kt})^{1/(1-m)}$, to generate yield table values. Compilation of the actual tables is done by the main programme. This follows the orthodox procedure of first relating top height to age and then relating the various growth characteristics to top height over the range of stocking densities.

To illustrate this procedure an example may be taken of a stand with a stocking density (variable X) of 3,000 stems per hectare (Table 10). The common logarithm of this number (3.4771) is substituted for the variable X in the biomathematical growth equations by means of sub-programme 'Forest' and the 'adjusted' parameters 'A', 'b', 'k' and 'm' are generated for each crop characteristic (Table 11). For a selected asymptotic height category the main programme computes top heights for given ages and then calculates the values for the different growth characteristics associated with each top height. The main programme also directs the printing of the values in tabular format (Table 12). For the asymptotic height category selected, a series of unique tables can be generated by altering the initial spacing (variable X) within the range 600 to 5,000 stems per hectare.

Validation of the Model

In the validation procedure the values computed by the Richards' function compared with the original field data using a 't' test analysis. A one-way analysis of variance was also used for the same purpose but with three sets of data (Original, Richards', Biomathematical). The results indicated that there were no significant differences (95% level) between the original data and the data generated by the model.

Discussion

Mathematical fitting of growth curves is a common practice in modern forest growth investigations. In the past, most of the functions employed were essentially artificial because the basis of these functions (linear, parabolic, logarithmic) were usually algebraic or geometric (Turnbull, 1963). In consequence they could only represent portions of growth curves. Biomathematical growth equations however have a biological interpretation and therefore can describe total growth curves.

In this study, the Richards' Growth Function was used in conjunction with data available to generate yield models for unthinned Sitka spruce plantations in Ireland. The potential of this method of yield model construction is only limited by the number of initial stocking densities and height categories selected. Since the original data available for Sitka spruce plantations of different espacements in Ireland were extremely limited the tables produced can be considerably refined as more data become available. Nonetheless, the statistical analyses carried out showed that the tables generated by this process were accurate. This high degree of accuracy was attributed to the fact that the 'm' values generated by the computer programme, although varying greatly among and within growth characteristics and espacements, were always less than unity. This ensured that the original significance of the function was maintained.

The models given in this paper are directly applicable only to unthinned Sitka spruce plantations in Ireland with stocking densities ranging from 600-5,000 stems per hectare. However, the growth rate in a thinned stand is identical with that of an unthinned stand of the same age and same basal area for a wide range of thinning regimes (Pienaar and Turnbull 1973). Thus, the models developed should also be applicable to thinned Sitka spruce stands. Similarly, where plantations are respaced before the onset of competition it should be possible to use the developed models.

This study has demonstrated that the effect of initial espacement on the growth of unthinned Sitka spruce stands can be adequately depicted by the Richards Growth Function. This should greatly facilitate research work on the growth of other plantation species in Ireland. There are indications from this work that volume production in Ireland is higher than in Britain for the same top height. However, more growth data are necessary over a wide range of sites to quantify this conclusively.

It is hoped that the result of this study will greatly enhance further research in the use of Richards' Growth Model for the study of growth and yield of man-made forests.

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TABLE 1

Value of the Parameters A, b, k and m
for Richards Function $W = A(1 - be^{-kt})^{1/(1-m)}$
for Top Height and Age.

A	b	k	m
26.4767	1.0000	0.0319	0.5300
30.2367	1.0000	0.0306	0.4900
40.6958	1.0000	0.0197	0.3100
39.8395	1.0000	0.0243	0.3500
37.7746	1.0000	0.0351	0.5000
39.0250	1.0000	0.0344	0.4500
40.3514	1.0000	0.0362	0.4500
41.9092	1.0000	0.0375	0.4500
42.4380	1.0000	0.0413	0.4800
42.8787	1.0000	0.0459	0.5200
43.4904	1.0000	0.0547	0.5600
46.5831	1.0000	0.0447	0.4900

TABLE 2

Value of the Parameters A, b, k and m
for Richards Growth Function $W = A(1 - be^{-kt})^{1/(1-m)}$
for the relationship between Volume Per Hectare and Top Height
for different spacings.

Spacing	Richards growth function parameters			
	A	b	k	m
1.6m	2002.5703	0.8506	0.0574	0.7100
1.8m	1873.0627	0.7375	0.0648	0.7900
2.4m	1640.1812	0.9590	0.0745	0.7700
4.0m	1602.7793	0.8851	0.0652	0.8000

TABLE 3

Value of the Parameters A, b, k and m
for Richards Function $W=A(1-be^{-kt})^{1/(1-m)}$
for the relationship between Basal Area Per Hectare
and Top Height for different spacings.

Spacing	Richards function growth parameters			
	A	b	k	m
1.6m	97.6943	0.6411	0.0785	0.4600
1.8m	84.8862	0.6755	0.1375	0.7500
2.4m	82.7402	1.0000	0.0878	0.4700
4.0m	71.0600	1.0000	0.1059	0.6900

TABLE 4

Value of the Parameters A, b, k and m
for Richards Function $W=A(1-be^{-kt})^{1/(1-m)}$
for the relationship between Mean DBH and Top Height
for different spacings.

Spacing	Richards function growth parameters			
	A	b	k	m
1.6m	38.1838	0.5206	0.0686	0.7500
1.8m	52.4082	0.6419	0.0424	0.6100
2.4m	51.4572	0.5198	0.0464	0.6500
4.0m	52.7102	0.3569	0.0662	0.8000

TABLE 5

Value of the 'A' Parameter calculated by the RICHAD. FOR. of each Growth Characteristic for four different spacings (Crop Density). (Input for BMD Programme).

Growth Characteristic	Log_{10} density	'A' values
Volume/ha	3.5642	2002.5703
	3.4771	1873.0627
	3.2388	1640.1812
	2.7959	1602.7793
BA/ha	3.5642	97.6943
	3.4771	84.8862
	3.2388	82.7402
	2.7959	71.0600
Mean DBH	3.5642	38.1838
	3.4771	52.4082
	3.2388	51.4527
	2.7959	52.7162

(Note: The above log densities represent spacing of 1.6, 1.8, 2.4 and 4.0 metres).

TABLE 6

Value of the Parameters P, Q and R of the
Asymptotic Regression Equation $Y=P+QR^x$
for each growth characteristic calculated by BMD Programme.
(Y='A' values from Richards Function and X=Log Density.)

Growth Characteristic	Growth Parameter	Final Estimates
Volume/ha	P	1585.5625
	Q	0.000002
	R	203.90686
Basal area/ha	P	68.5115
	Q	0.0020
	R	14.2892
Mean DBH/ha	P	–56.0625
	Q	151.1494
	R	0.8942

TABLE 7

Values for the b, k, and m Parameters of Richards Function for four different spacings (density) of each Growth Characteristic used as input for CURVE. FOR. Programme.

Growth Characteristics		Log Density	Growth Parameters b	k	m
Vol/ha	1	3.5642	0.8506	0.0574	0.7100
	2	3.4771	0.7375	0.0648	0.7900
	3	3.2388	0.9590	0.0745	0.7700
	4	2.7959	0.8851	0.0652	0.8000
Ba/ha	1	3.5642	0.6411	0.07850	0.4600
	2	3.4771	0.6755	0.1375	0.7500
	3	3.2388	1.0000	0.0878	0.4700
	4	2.7959	1.0000	0.10590	0.6900
Mean DBH	1	3.5642	0.5206	0.0686	0.7500
	2	3.4771	0.6419	0.0424	0.6100
	3	3.2388	0.5198	0.0464	0.6500
	4	2.7959	0.3569	0.0662	0.8000

1=3666* stems/ha (1.6m spacing)
2=3000 stems/ha (1.8m spacing)
3=1733 stems/ha (2.4m spacing)
4= 625 stems/ha (4.0m spacing)

* Figures exclude mortality up to 5m top height.

TABLE 8

Regression coefficients of the Richard Function Parameters b, k and m on respective Log Density for each Crop Characteristic.

Growth Characteristics	Growth Paras.	Regression coefficients b_0	b_1	b_2	b_3
Vol/ha	b	–251.67194	237.91143	–74.295295	7.6937755
	k	0.9831683	–1.1445837	0.4509529	–0.0568714
	m	98.721554	–93.204607	29.44918	–3.0901535
BA/ha	b	–60.673875	54.885367	–15.983722	1.5175977
	k	33.356622	–31.458282	9.8719758	–1.0280109
	m	180.27699	–168.12044	52.203013	–5.381726
Mean DBH/ha	b	61.074745	–59.466576	19.25527	–2.0579483
	k	–8.8622199	8.9257488	–2.9546853	0.3235010
	m	–48.388036	49.405919	–16.408052	1.7990441

TABLE 9

Biomathemathical Growth Equations for the calculation of "adjusted" values of the Richards Function Parameters (A, b, k and m) for each Growth Characteristic at a range of initial espacements.

Growth Characteristics	Growth Parameters	Equations
Vol/ha	A	$1585.5625+0.000002(203.90686)^x$
	b	$-251.67194+237.91143X-74.295295X^2+7.6937755X^3$
	k	$0.9831683-1.1445837X+0.4509529X^2-0.0568714X^3$
	m	$98.721554-93.204607X+29.44918X^2-3.0901535X^3$
BA/ha	A	$68.5115+0.002(14.2892)^x$
	b	$-60.673875+54.885367X-15.983722X^2+1.5175977X^3$
	k	$33.356622-31.458282X+9.8719758X^2-1.0280109X^3$
	m	$180.27699-168.12044X+52.203013X^2-5.381726X^3$
Mean DBH/ha	A	$-56.0625+151.1494(0.8942)^x$
	b	$61.074745-59.466576X+19.25527X^2-2.0579483X^3$
	k	$-8.8622199+8.9257488X-2.9546853X^2+0.3235010X^3$
	m	$-48.388036+49.405919X-16.408052X^2+1.7990441X^3$

$X=\log_{10}$ of density

TABLE 10

Input data for YIELD. FOR. generated by RICHAD. FOR, BMD and CURVE. FOR.

1

1585.5625	0.000002	203.90686	251.67194	237.91143	
74.295295	7.6937755	0.9831683	1.1445837	0.4509529	
0.0568714	98.721554	93.204607	29.44918	3.0901535	
68.5115	0.002	14.2898	60.673875	54.885367	Biomathematical
15.983722	1.5175977	33.356622	31.458282	9.8719758	Growth
1.0280109	180.27699	168.12044	52.203013	5.381726	Equations
56.0625	151.1494	0.8942	61.074745	59.466576	
19.25527	2.0579483	8.8622199	8.9257488	2.9546853	
0.323501	48.388036	49.405919	16.408052	1.7990441	

3000.0 (Initial stocking density)

A	k	m			
26.4767	0.0319	0.5300		24.0	
30.2367	0.0306	0.4900		28.0	
40.6958	0.0197	0.3100		32.0	
39.8395	0.0243	0.3500		36.0	
37.7746	0.0351	0.5000	Top height/age growth models	40.0	Age
39.0250	0.0344	0.4500		44.0	
40.3514	0.0362	0.4500		48.0	
41.9092	0.0375	0.4500		52.0	
42.4380	0.0413	0.4800		56.0	
42.8787	0.0459	0.5200		60.0	
43.4904	0.0547	0.5600			

1333.6367 2319.8584 0.9391 (Surviving stems equation).

TABLE 11

Adjusted values for A, b, k and m Parameters for the different initial stocking densities (output of 'Forest').

A, B, K, M = parameters for Vol/ha
AA, BB, KK, MM = parameters for Ba/ha
AAA, BBB, KKK, MMM = parameters for mean DBH
AX = Initian stocking densities at 5.0m top height.

AX	A	B	K	M
5000	2283.0703	1.2064	0.0412	0.5005
3666	1926.1977	0.8380	0.0573	0.7144
3000	1799.9525	0.7611	0.0646	0.7803
2350	1707.5405	0.7866	0.0707	0.8047
1733	1645.9316	0.9227	0.0743	0.7810
1100	1606.6935	1.1232	0.0734	0.7211
770	1594.8347	1.0749	0.0689	0.7354
625	1591.2895	0.8870	0.0652	0.7992
AX	**AA**	**BB**	**KK**	**MM**
5000	105.9602	0.4568	0.0371	0.2930
3666	94.6729	0.6126	0.0957	0.5510
3000	89.2700	0.7194	0.1110	0.6096
2350	84.1682	0.8457	0.1125	0.6024
1733	79.5250	0.9819	0.0987	0.5278
1100	75.0266	1.0983	0.0750	0.4336
770	72.8267	1.0764	0.0808	0.5163
625	71.9026	1.0026	0.1043	0.6816
AX	**AAA**	**BBB**	**KKK**	**MMM**
5000	43.8833	0.4133	0.0993	0.9127
3666	45.4011	0.5542	0.0635	0.7214
3000	46.3938	0.5901	0.0503	0.6541
2350	47.6162	0.5894	0.0428	0.6198
1733	49.1611	0.5412	0.0431	0.6318
1100	51.5097	0.4297	0.0545	0.7118
770	53.3893	0.3635	0.0641	0.7792
625	54.5040	0.3538	0.0667	0.8027

TABLE 12

Yield Tables for an initial stocking density of 3000 stems/ha.

AX	A	B	K	M	
3000	1799.9525	0.7611	0.0646	0.7803	(1) = Vol/ha/top height equation
AX	AA	BB	KK	MM	
3000	89.2700	0.7194	0.1110	0.6096	(2) =Ba/ha/top height equation
AX	AAA	BBB	KKK	MMM	
3000	46.3938	0.5901	0.0503	0.6541	(3) = Mean DBH/top height equation

Stems	Age	TopHt	DBH	BA	Mean Volu.	Volume	MAI	
2828	24.0	7.0	9.8	31.9	0.03	88.4	3.7	Yield table for
2681	28.0	8.6	11.5	39.0	0.05	133.4	4.8	the first top
2553	32.0	10.2	13.2	45.5	0.07	185.9	5.8	height age model
2441	36.0	11.8	14.8	51.2	0.10	243.1	6.8	
2346	40.0	13.2	16.3	56.0	0.13	302.2	7.6	(A = 26.4767)
2264	44.0	14.5	17.7	60.0	0.16	360.8	8.2	(B = 1.0000)
2195	48.0	15.8	18.9	63.4	0.19	417.3	8.7	(K = 0.0319)
2136	52.0	16.9	20.0	66.2	0.22	470.4	9.0	(M = 0.5300)
2085	56.0	17.9	21.0	68.5	0.25	519.5	9.3	
2043	60.0	18.9	21.9	70.4	0.28	564.3	9.4	(Table 10)

Harvesting: Its Effect on the Physical Properties of Soils[1]

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SUMMARY

A project on the effect of harvesting by tractor skidder on the physical properties of a soil was carried out on a surface water-gley. Skidding significantly increased bulk density and reduced total porosity under wheel ruts. To minimise damage on vulnerable sites careful consideration should be given to the methods and timing of extraction.

INTRODUCTION

The use of heavy machinery to skid logs over the site exerts large pressures on the soil. This may result in soil damage on up to 25% of the area being harvested (Steinbrenner and Gessell 1955, Dryness 1965). The short term manifestation of this damage is seen in the bogging of skidders. Productivity of the subsequent crop may be adversly affected by the influence of compaction on soil pore space, gas exchange and water movement and by a deterioration in fertility following soil disturbance and organic matter losses. Any increase or decrease in pore volume is reflected in corresponding changes in bulk density (the mass of soil per unit bulk volume i.e. the volume of soil particles + pore space). Increases in soil bulk density following harvesting have been observed in a number of studies (Steinbrenner and Gessell 1955, Dryness 1965, Dickerson 1976, Mace 1970 and Moehring and Rawls 1970). While bulk density provides an indication of the severity of compaction, the relationship is complicated by other factors such as particle density and more particularly by organic matter content which markedly influences bulk density. Soil organic matter content on extraction paths may be displaced

1 This article is based on a final year elective project by the senior author for the B.Agr.Sc.(For) degree.

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by machinery and the rate of oxidation may be increased due to disturbance and mixing with mineral material. The particle density of soil organic matter is about 1.35-1.5g per cm^3 (soil minerals range in particle density from 2.5-2.8g per cm^3) so that variation in this component produces wide variation in bulk density. The bulk density of forest soils range from 0.2g per cm^3 in the organic layers to 1.9g per cm^3 in some sandy subsoils.

The recovery of soils from compaction is slow. Mineral soils often take up to 12 years to recover their initial bulk densities and porosities (Dickerson 1976). Timber volume losses of up to 15% have been recorded as a result of soil compaction during previous rotations (Greacen and Sands 1980). In an experiment on a gley soil with indurated material in Scotland, mean height of a replanted crop after six seasons on severely damaged plots was less then 70% of that in undamaged plots (D. G. Pyatt, Forestry Commission, Edinburgh, personal communication, 1982).

The objective of this study was to quantify the changes that occur in a moderately fine textured soil following harvesting by skidder. Bulk density, total porosity and organic matter content were measured along an extraction path used for thinnings.

METHODS

The extraction path was located along the contour of a drumlin, in a 28 year old Sitka spruce (*Picea sitchensis* (Bong.) Carr.) stand, in the O'Rahilly plantation, Drumhierney, Co. Leitrim. The soil, belonging to the Garvagh series (Bulfin, Gallagher and Dillon, 1973), is classified as a surface water gley and texture varies from a clay loam in the solum to a clay at greater depth. A modified agricultural tractor was used to skid thinnings over the site. Samples were collected at 24m intervals on three cross-sections of the extraction path. At each cross-section samples were taken at three points.

1. Undisturbed, 4m from the centre of the path.
2. Under the wheel rut.
3. At the centre of the extraction path midway between the two wheel ruts.

Since extraction may have caused inversion of the soil in wheel ruts it was considered preferable to sample by arbitrary depth classes. Intact clods were taken at four depths 0-5, 5-10, 10-15 and 15-20cm. An inversion of organic material was found at one point, a layer of soil having been thrown up over the organic matter. This layer of organic material was rejected in sampling for bulk density or particle density determinations. Such inversion was not observed at other points. Bulk density was determined by the clod method. Organic matter content was determined by combustion. Particle density was determined from the weight of the soil sample and its volume. Total porosity was calculated from bulk density and particle density.

RESULTS

The bulk density of 0.7g per cm^3 (Table 1) was due to the influence of organic matter in the sample referred to above. Although a layer of organic matter was rejected from the sample some mixing of organic and mineral material had occurred within the sampled clods. The bulk density under wheel ruts at 5-10cm and 10-15cm were significantly greater than the bulk densities either of the undisturbed area or of the area between wheel ruts (Table 1). Compaction resulted in a 45% increase in bulk density at the 5-10cm depth and a 15% increase at 10-15cm depth. No increase in bulk density occurred in the areas between wheel ruts.

Total porosity was reduced at the 0-5, 5-10 and 10-15cm depths under the wheel ruts. These actual reductions in porosity compared to the undisturbed soil were 12, 32 and 16% respectively.

Reduction in organic matter was only significant at the 5-10cm depth under the tyre ruts. Organic matter at this point was 25% lower than in the undisturbed soil at the same depth.

Table 1. Bulk densities on and off the extraction path (g per cm^3).

Depth	Treatment Means			SE of
cm	Undisturbed	Wheel rut	Path centre	Location mean
0- 5	0.83ab	1.02a	0.70b	0.028
5-10	0.93a	1.36	0.94a	0.004
10-15	1.26a	1.45	1.14a	0.033
15-20	1.33a	1.39a	1.30a	0.043

Values at each depth bearing same letter are not significantly different (5%) from each other.

Table 2. Total porosity % on and off the extraction path.

Depth	Treatment Means			SE of
cm	Undisturbed	Wheel rut	Path centre	Location mean
0- 5	61.03a	53.34	65.49a	1.55
5-10	60.60a	40.79	59.51a	2.05
10-15	47.86a	39.83	51.88a	1.31
15-20	46.40a	41.56a	45.91a	1.24

Values at each depth bearing the same letter are not significantly different (5%) from each other.

Table 3. Organic matter % on and off the extraction path.

Depth	Treatment Means			SE of
cm	Undisturbed	Wheel rut	Path centre	Location mean
0- 5	16.02a	11.02a	18.80a	2.77
5-10	10.76a	7.85	11.17a	0.62
10-15	7.39a	6.42a	7.85a	0.47
15-20	6.61a	5.81a	6.40a	0.34

Values at each depth bearing the same letters are not significantly different (5%) from each other.

DISCUSSION

The results show that extraction of thinnings by skidder can cause soil compaction. The bulk densities measured in the 5-10 and 10-15cm zone under the wheel rut, may be close to the maximum values attainable under prevailing moisture conditions on a soil of this texture and organic matter content. (Bodman and Constantin 1965).

Total porosity in forest soils varies from 30-65% (Pritchett 1979), so the reduction shown in Table 2 may not seem critical. However, changes in non capillary porosity were not measured in this study so that the type of pores lost through compaction and the consequent effect on soil air and water movement could not be assessed. This deterioration of the soil is due in part to organic matter losses which also represent a decrease in the nutrient capital of the site.

The use of a tractor skidder has been detrimental to the site. During thinning this damage is confined but in clearfelling up to 25% of an area may be traversed and the loads carried will be greater. Serious soil damage can result from even a few passes over a path. Hatchell, Ralston and Foil (1970) found that only 7% of the sites they studied required more than four trips to reach their final bulk densities. The soils of the Garvagh series are extensive in Co. Leitrim (27,277ha) and are among the most productive in the country (Bulfin et al 1973). Our results demonstrate the vulnerability of these poorly drained clay loams. It is important that foresters recognise the risk of damage particularly in wet weather. Careful consideration should be given both to the methods and the timing of extraction on these sites.

ACKNOWLEDGEMENTS

Samples were collected from the O'Rahilly plantation Co. Leitrim.

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Letter to the Editor

Dear Sir,

In this centenary year of the birth of James Joyce readers of *Irish Forestry* may be interested in the following short passage from *Finnegans Wake,* published in 1939.

'. . . sweet gum and manna ash redcedera which is so purvulent there as if there was howthorns in Curraghchasa which ought to look as plane as a lodgepole to anybody until we are introduced to that pinetacotta of Verney Rubeus where the deodarty is pinctured for us in a pure stand . . . ' (p. 160)

There are at least four references in these few lines to matters which are currently of interest to Irish foresters.

Curragh Chase, Co. Limerick, ancestral home of the two Aubrey de Veres, is at present being developed as a forest park and major amenity area by the Forest and Wildlife Service.

Lodgepole pine, as the common name for *Pinus contorta,* came into widespread use in the Republic of Ireland in 1975.

'Verney Rubeus' may be presumed to carry a reference to the poplar variety *vernirubens,* bred by Professor Augustine Henry in Dublin, together with *P. generosa,* the first two artificial forest tree hybrids ever to be produced.

'deodarty . . . in a pure stand' must remind us of the rare pure stand of *Cedrus deodara* at Glengarra Forest, Co. Tipperary, and described by O. V. Mooney in *Irish Forestry,* 8 (1), 1951, pp 3-7. That account includes the statement that the species 'is not generally found naturally in pure stands'.

To show that Joyce's knowledge of forestry may have extended even to instruments and natural forest succession we also find (p. 235) 'The hypsometers of Mount Anville is held to be dying out of arthataxis but, praise send Larix U' Thule, the wych elm of Manelagh is still flourishing in the open, because its native of our nature and the seeds was sent by Fortune'.

Yours faithfully,
Niall O Carroll,
12 Mapas Road, Dalkey, Co. Dublin.

P.S. A passage from Joyce's *Ulysses* (1922), based almost entirely on the names of trees, was reprinted in *Irish Forestry,* 27 (1), 1970, p. 37.

OBITUARY

James J. Maher (1916-1982)

It is with great sadness that we have to record the passing of Jim Maher only eight months after his retirement from the Forest and Wildlife Service. He took his forestry degree in U.C.D. in 1942 and spent the following seven years in direct charge of field operations in a wide variety of forest conditions. This combination of science and practical experience was to be the foundation of an outstanding career which contributed uniquely to the expansion and success of Irish forestry.

From 1949 to 1954, in his first assignment as inspector, he had acquisition responsibility for "opening up the west" from Sligo to the Shannon, setting the pattern for the now thriving western forest estate. The following decade he spent in district management in the south where he will be especially remembered for the rehabilitation of Ballyhoura Forest. There followed nine years in charge of the Bray Division, seven years as Senior Inspector (Management South) and finally two years as Assistant Chief Inspector (Management).

With his scientific and practical background, Jim never accepted the experts' text without stringent testing in the crucible of his own experience. But he welcomed and applied the tested results of research and he fostered close and direct communication between researchers and field staff. He will be remembered as a pioneer in three aspects of forestry. The first was the new approach to site assessment in the light of emerging mechanical and chemical techinques, followed up by their practical application to establishment. The second was his unfettered approach to stand management and especially the introduction of line thinning. The third was his enthusiastic tackling of harvesting problems and planning to co-ordinate output with industrial expansion, reconciling inventory forecasts with local management requirements.

To end on this note would be to omit Jim's greatest contribution. He was one of the great "characters" in Irish forestry. His passion for trees was exceeded only by his interest in his fellow man and his great generosity of spirit. He looked on himself not as the Government Inspector but as the friend and collaborator of all who worked in his chargeship. His knowledge of their foibles and their strengths, their family circumstances and their connections, was legendary. No one will ever know how often he used this comprehension to save people from "the slings and arrows of outrageous fortune". His dedication to his profession and his regard for his fellow man provided an inspiring example to us all. That is his great legacy to Irish forestry.

To his wife, Kathleen and his children, the Society extends its deep sympathy.

T. McEvoy

Book Reviews

CONIFER LACHNIDS

C. I. Carter and N. R. Maslem. 75pp. Forestry Commission Bulletin 58, 1982. H.M.S.O., London. Price UK£3.50.

This bulletin brings together recent information on the various species of conifer-feeding aphids belonging to the family Lachnidae that are known to occur in Britain and a number of Irish records are included. Few of the species dealt with are of particular economic importance but several are of common occurrence and their exact identification is of interest to foresters and ecologists generally. Keys are provided for both living and prepared specimens. These are well constructed and easy to use as they are generously supplemented by sketches and photographs. In addition to the morphological keys, a field key is provided in which the species occurring on various coniferous hosts are described in non-technical terms. This will be much appreciated by amateur collectors and by those denied access to sophisticated optical equipment. Individual accounts for each species include descriptions of feeding sites, host plants, life history, economic importance and distribution. A comprehensive and up-to-date list of references is also provided.

P. A. Brennan

FOREST AND WOODLAND ECOLOGY

F. T. Last and A. S. Gardiner (Editor) Institute of Terrestrial Ecology, Cambridge 1981. 158 pp. ISBN 0 904281 511. Price UK£5.00.

The Institute of Terrestrial Ecology (ITE) was established in 1973 from the former Nature Conservancy's research stations and staff. It is one of fourteen sister institutes which make up the Natural Environment Research Council (NERC). NERC finances most of its work which is conducted at seven stations located throughout Great Britain. This volume is an account of research being done in ITE. It contains 33 short papers providing a valuable update of current thinking on a wide range of topics of interest to all foresters. Most of the papers are easy to read, although the style is rather uneven. They are pitched at a level capable of understanding by those not expert in the field of specialisation discussed. To some, the research topics pursued by ITE may appear somewhat academic and irrelevant to the needs of British forestry. There is a place for the type of research done at ITE, complementing the more applied nature of Forestry Commission research.

There is a great deal in this book to stimulate the thinking forester. The suggestion that Sitka spruce stands can induce moisture deficits in previously moist sites within fourteen years of planting is food for thought. I found Cannall and Cahalan's detailed descriptive analysis of the components of shoot growth of conifers most interesting, opening up for me, as it did, an area of the literature of which I was only dimly aware. Growth is discussed at a different level by Ford in a paper covering tree structure under plantation conditions. To say that other useful papers cover a discussion of the cost benefit of hedgrows, the role of buried seed in the recovery of ground vegetation in coppice wood and ongoing research on grey squirrel damage and management is to indicate the diversity of this publication and the scope of ITE research.

I would recommend this attractive publication to all foresters. It includes 26 plates, 21 of them in colour, it is well presented, with an extravagant use of space for a total of 59 figures. It is a particularly useful volume for students, providing the starting point for a host of valuable seminar topics and projects.

E. P. Farrell

A FORESTRY CENTENARY
THE HISTORY OF THE ROYAL FORESTRY SOCIETY OF ENGLAND, WALES AND NORTHERN IRELAND

N. D. G. James
Basil Blackwell, Oxford 1982, ISBNO631 130152.

This book outlines the work and activities of the above society over the century since its formation in 1882. Its author is one of the most accomplished writers on forestry and as a member of the society for 50 years and past President is perhaps uniquely qualified for the task. As one would expect the result is a highly readable book detailing the history of the society from a wealth of letters, records and photographs. The book is likely to be of greatest interest to members of the society whose history it tells. The author has adhered closely to the remit of writing a history of the society without including more than an absolute minimum of material on the general forestry "scene" in Great Britain during the period in question. While this avoids overlapping with other recently published works it does limit the book's appeal to the general reader. The material available to the author is naturally of a highly factual nature and there is a lack of more personal and anecdotal information which would have allowed the reader to appreciate the personalities of the leading characters and the spirit of the society generally.

To anyone involved in the organisation of a forestry society the achievements of the Royal Forest Society of England, Wales and Northern Ireland must be viewed with enormous respect and there is much to be learnt from the work described in this volume. The early realisation by the society that presidents and other officers should be chosen for their capacity to work at their posts rather than their social position, is one problem at least which our own society has not experienced!

John Phillips

THE FORESTERS COMPANION

N.D.G. James. Third Edition. Basil Blackwell, Oxford. 1982. 381 pp.
ISBN 0631 127976. Price UK £9.50.

The works of N.D.G. James need no introduction to the vast majority of those interested in forestry and this third edition of the Foresters Companion is an essential text book for all practical foresters and students of forestry. The new edition has been completely revised and brings up-to-date many aspects of forestry which have been developed since the publication of Mr. James' previous edition in 1965. To quote one example, there is mention of Major General Moore's revolutionary concept of Oceanic Forestry. Metrication, of course, has been introduced in recent years and this has been dealt with very comprehensively, dare I say, too comprehensively. Is there for instance a significant difference between a planting espacement of 2 metres and 2.1 metres (7 feet) ?

This volume is a must for all those involved in day-to-day forestry and provides in a compact and very readable form a comprehensive guide to all aspects of forestry from seed to sawdust — or perhaps more topically, wood ash. It is difficult to be critical of such a volume but perhaps in his enthusiasm and eagerness to cover all aspects of forestry, Mr. James has allowed his pocket volume to become slightly larger than pocket size. My old and battered second edition measures seven inches by four and three-quarters by three-quarters even with a hard cover, whereas the new paperpack third edition measures seven and a half inches by five by seven-eights. The new edition contains 30 extra pages. It is not easy to say what, if anything, could have been omitted to reduce the size but perhaps for instance such a specialised and obsolescent subject as coppice and underwood could have been left out.

For the reader in the Republic there are naturally some aspects covered which do not apply such as the chapters on the law, grants, felling licences, taxation etc., but this is unavoidable and is only a comparatively small proportion of the whole. The volume lends itself particularly to the landowner in Ireland involved to a greater or lesser extent in forest management. Mr. James' previous edition has been my "companion" for the past fifteen years and I have no hesitation in recommending the latest edition to all interested in *practical* forestry.

C. B. Tottenham

DECISION MAKING IN FOREST MANAGEMENT

M. R. W. Williams
Research Studies Press, John Wiley & Son Ltd. 1981. 143 pp.
ISBN 0 471 100978. Price UK £11.80.

Decision-making consists of two components: the generation of alternative courses of action and the selection from these of the best course of action. To aid in this selection process certain criteria are used. Generally these are of an economic nature and readily lend themselves to quantitive methods of analysis. Probably the oldest such criteria in forestry are the 'land expectation value', proposed by Martin Faustmann more than a century ago, and the related 'financial yield'. Although the approach has been modified somewhat, and the terms 'net discounted revenue' and 'internal rate of return' are now more familiar, the principle remains essentially the same.

The author is Lecturer in Forestry at the Cumbria College of Agriculture at Newton Rigg. His expressed hope is to present the material in a simple and explicit form and in this he has succeeded. In his introduction he lists the types of decisions a forest manager has to make, such as: How much to pay for land? What species of tree to grow? Should money be spent on ground-preparation, fertiliser application, brashing, high-pruning? What is the optimum rotation? The reader is then taken through a number of chapters which explain the intricacies of compounding/discounting in relation to various time scales plus the preparation of price size gradients and money yield tables. This leads to structuring of the two criteria, net discounted revenue and internal rate of return. The remaining chapter deals with the application of those two criteria to the type of forestry problem mentioned above.

Treatment of the material is meticulous and detailed, but the large number of tables and figures can sometimes lead to confusion. As a primer for the forestry student or woodland manager anxious to grasp the essentials of compounding/discounting and the application of net discounted revenue to valuation and appraisal problems, the book is extremely useful. However, the absence of any attempt to computerise routine calculations of net discounted revenue and internal rate of return is disappointing in a book published in 1981. Following on the basic calculations with the aid of discount factors, this would have removed much of the boredom associated with repetitive discounting with varying rates.

The author acknowledges the contribution made by the "thoughts, ideas and inspirations from 'classical' German foresters, from W. E. Hiley and Messrs. Johnston, Grayson & Bradley". Those who have read "Economics of Plantations" and "Forest Planning" will find nothing new in this book and indeed there are aspects of decision-making in "Forest Planning" which scarcely get mention. The emphasis on decision-making conveyed in the title evokes an image of sophisticated analytical procedures using maximisation and simulation models, but the reader will look in vain for any mention of such. Neither is there any reference to decision-making criteria where "unpriced values" such as recreation and amenity are involved. Any serious text on modern decision-making methods in forest management must take account of such techniques. Their omission limits the scope of application to one of investment appraisal and land evaluation by traditional criteria.

The book is sponsored by the Royal Forestry Society of England, Wales and Northern Ireland, and is the first in the Forestry Research Studies Series. From the sales point of view it is somewhat unfortunate that it duplicates much of the subject material covered in "Investment Appraisal in Forestry" (R. J. N. Busby and A. J. Grayson) which sells at £3.75 sterling (see *Irish Forestry*, Vol. 38, No. 2, p. 102 for review).

P. M. Joyce

APPRECIATION

Every scientific journal has to call on specialists to review papers submitted for publication. These referees remain, by custom, anonymous, they receive neither reward nor recognition for their services. Often, they spend a great deal of time working on the papers sent them, correcting errors, pointing out ambiguities, suggesting improvements. As a result, the quality of the articles and thus of the journal, is enhanced. To the following, who have acted in this capacity, some on several occasions, over the past six years, a word of thanks:

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Thanks are due also to Eric Joyce, proof-reader over much of the past six years. Through his careful reading of proofs he has contributed greatly to the standard of presentation of the journal.

Editor

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