THE DEVELOPMENT OF A MODEL FOR THE EVALUATION OF SILVICULTURAL REGIMES FOR *PINUS RADIATA*

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ABSTRACT

This paper describes work undertaken by the Forests Commission, Victoria, in developing a computer-based model for evaluating silvicultural regimes for **Pinus radiata**. Following a discussion of the value of such work, the model is described according to its four sequential modules which relate respectively to stand growth, estimation of produce, evaluation and cash-flow analysis. Various auxiliary studies are also outlined in order to indicate the breadth of the project and its current state of development. Some early results of the work are discussed briefly.

INTRODUCTION

The Forests Commission, Victoria, is currently reviewing management practices for the predominant plantation species, *Pinus radiata* D. Don, and this work involves the examination of silvicultural regimes. To aid in this work, the Research Branch was requested to develop a computer-based model to predict the outcome of various regimes, and what follows is an account of the progress made.

Cost-Benefit Considerations

The production of a model to predict the outcome of various silvicultural regimes in terms of woodflows and cashflows could obviously develop into a task of considerable size. The concept of a silvicultural regime can readily and reasonably be broadened to include such treatments as site preparation, nutrition, and weeding. Each treatment can be carried out in various ways. There are an infinite number of combinations, each yielding a different woodflow or cashflow. Moreover, the outcome of any given treatment combination will depend upon all sorts of factors—natural (e.g. site quality), economic (e.g. market state) and technological (e.g. manufacturing method).

Given that the cost of developing a comprehensive accurate model could be very high, how much effort is warranted? Some idea can be obtained from consideration of the possible applications, which are seen to be in:

1. *National Planning*

For even the broadest levels of planning it is essential to have a thorough appreciation of certain "details". In warfare, for example, some aspect of technology may prove to be crucial. The same applies in forestry, and if, to take a highly pertinent example, we can judge from the discussions of a national forest policy for New Zealand, it would

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appear that specialised regimes are one such aspect. If it is important to consider the role of specialised regimes at this level, the research worker should surely supply the best possible information on costs and benefits.

2. *Regional Planning*

In optimization the quality of the solution depends, among other things, upon the pertinence of the options provided, and the accuracy of the data. Thus the procedure for optimizing the management of a broad forest region should be based upon a sufficient choice between alternative regimes for each stand, together with realistic costs and benefits for each regime. What constitutes "sufficient choice" is, of course, highly conditional. In some cases, such as where the entire resource is overmature, perhaps the only regimes that need be considered in the short term will be of the form "complete harvest in χ years". But as the management of such a resource evolves, the number of alternative regimes worthy of consideration will tend to increase.

3. *Stand-level Management*

Broad planning, however thorough, can only provide guidelines and set general constraint levels. It is then up to the local forester to do his best within these constraints. The quality of the work carried out at this level can have a great bearing on profitability *in toto*. If the result is good enough, be it in relation to either reducing costs or increasing production, it can even cause re-casting of the higher level plans.

This brief discussion is sufficient to indicate that, at each level of forest management, accurate evalution of alternative silvicultural regimes is important. The payoffs should be high enough to justify at least a few man years of effort in development.

AIM

In view of the possible applications it was felt that the *P. radiata* model should be as versatile and accurate as possible. The main aspects of versatility sought were:

1. The broadest view of a silvicultural regime should be adopted, namely all treatments that may be given to a stand throughout its life. In other words, the stand model was seen as the ultimate vehicle for integrating all studies of factors affecting tree growth.

2. The model should apply to all localities.

3. The woodflow data should be well detailed in all respects that influence end-use and value.

There were, however, constraints on time and funds for development. A reasonably accurate working model was required at once. The aim therefore was to produce a working model as soon as possible, but with a structure that would allow of continual improvement in respect of versatility and accuracy.

THE MODEL

The model consists of four modules in series, as follows:

Module 1: predicts stand development for any given regime.

Module 2: converts harvested trees to volumes of produce by size classes.

Module 3: makes a monetary evaluation of the produce.

Module 4: carries out cash-flow analyses.

Separate modules allow of independent development, testing, and operation. Independence is particularly important in relation to operating costs, because it is envisaged that the users will often wish to vary only the late-stage input such as costs and product values.

Each module is designed so that inputs and outputs can be in either metric or imperial units.

Module 1: Prediction of Stand Growth

1. *The Basic Algorithm*

It was decided at the outset to base the yield model on STANDSIM (Opie, 1972), a Fortran-coded program for non-stochastic time-based simulation of a unit area of an evenaged monospecific stand of more or less evenly spaced trees (*Eucalyptus regnans*).

The chief advantages in choosing STANDSIM were seen to be:

a. The operators were familiar with it.

b. It was reasonably well suited to developmental work, being easy to modify, and fairly efficient in terms of computer hire, at least in comparison with most stand models offering similar detail.

c. It would be a move towards standardization in that STANDSIM models for other important species have been developed. Discussion with the intending users indicated that standardization would be most welcome.

The chief disadvantages were seen to be:

a. The model would be costly to operate on a regular basis as a standard management tool.

b. There was doubt that the model, being based on the assumption of even spacing, would be satisfactory for the study of row thinning or highly rectangular spacing.

c. Other models are already available for *P. radiata.*

Perhaps because the originator of STANDSIM was also the study co-ordinator, it was held that the advantages greatly outweighed the disadvantages. Means are being devised to overcome the first two disadvantages of high operational cost and the assumption of even spacing. The third disadvantage is at best highly contentious—the other *P. radiata* models have been designed for somewhat different aims and growing conditions, they are of unfamiliar form, and they introduce an unwelcome diversity.

The basic algorithm (i.e. the general framework of STANDSIM) as originally published has been examined by several worker's who have modified it variously.

The *Eucalyptus regnans* version has been examined by Pope[1] in relation to mortality, Campbell (1974) in relation to various biases (concerning e.g. height-age relationships. mortality, and net increment of basal area) and Opie (unpublished report) in relation to diameter distributions. These studies resulted in considerable alteration to the specific functions (i.e. those dealing with *E. regnans* in particular) and some changes in the algorithm so as to improve the distribution of mortality and increment.

Incoll (1974) in working on a model for *Eucalyptus sieberi* improved the algorithm in respect of speed and accuracy. By re-writing the sorting routines and shortening certain loops he halved the time required to simulate young stands. He improved precision by altering the procedures for distributing increment among trees, for estimating and distributing mortality, and for generating initial diameter distributions.

He also expanded the model to include three effects of fire: bark loss, growth depression, and mortality.

White[2] has also worked on the model. He has modified the algorithm for greater speed by storing tables of evaluated functions and by reducing the area base for young stands. He has also redefined the *E. regnans* functions to suit Tasmanian conditions.

In the research branch of the Forests Commission, Aberli[7] is conducting a thorough examination of the STANDSIM algorithm. He aims to produce an updated version—hopefully the standard operational version for at least the next few years—incorporating several of the improvements mentioned above, plus a good many other features that should increase its flexibility, accuracy, efficiency and ease of operation. This work is still at an early stage.

2. *Modelling* P. radiata

This work is being undertaken mainly by Aeberli and the author. To meet short-term commitments we have concentrated on data directly applicable to one or another Victorian region. Even within this limitation there is a great quantity of information, so much indeed that it would be unwieldy to detail all the sources in the brief account below. We wish, however, to acknowledge our debt to the following organizations for various useful publications: Forestry and Timber Bureau, Forest Research Institute, Woods and Forests Dept. of South Australia, and A.P.M. Forests Pty Ltd.

The main points of interest in the model are as follows:

a. Generalizing between localities:

Site index, usually defined as mean dominant height at some given age, is a common measure of productivity, and within a limited locality may well be a sufficient measure. When dealing, however, with stands from widely separated localities, and somewhat different climates, site index may be far from sufficient. Wright (1967) found this for *P. radiata* in Victoria; at one particular site index, the volume production at age 16 for Aire Valley was almost twice that for Myrtleford. The usual approach to this problem is to stratify by locality, which proliferates the number of models required. Our approach has been to generalize the model between localities by using, in addition to site index, indices for basal area production. We define basal area index as the total production per unit area of basal area overbark at given age for a stand specified in respect of initial density and subsequent treatment. Currently we are using two indices, coded B7 and B15, for the two ages 7 and 15 years, specifying unthinned stands with an initial density of 1682 trees/ha. These ages were selected because this region of the growth-age function is particularly important. The other specifications were selected because suitable stands could be found in all localities. In the model the height-age curve is forced to pass through the stipulated value of site index at the appropriate age, unless other factors such as extremes of stand density are operative. A similar forcing is made in the case of the basal area indices, except that allowances for other factors, and in particular stand density, must be made more generally.

The use of basal area index raises some interesting possibilities. It is possible that a cross-classification of stands by site index and basal area index will be of predictive value in relation to other factors known to vary between localities after allowance for site index, such as taper, green level, bark thickness and stem straightness. It is possible, too, that the two basal area indices will be of value in simulating the effects of certain factors that accelerate crop growth (e.g. fertilizing, weeding) or decelerate it (e.g. disease).

If this approach of using basal area indices in a similar way to site index proves to be successful (and results to date are promising) the next step, of an Australia-wide or even a world-wide model for *P. radiata* should surely be considered. It may also be of value to relate our admittedly empirical approach to the more fundamental studies of similar intent, as for example the work of Jackson and Gifford (1974).

b. Fertilizing:

As the result of nutrition studies by various workers in Victoria (e.g. Craig, 1971; Bren and Craig, 1972; Craig *et al.,* 1974) a good deal has been learned about the response of *P. radiata* to fertilizers, and specially superphosphate, at various ages. Accordingly the growth model has been elaborated to incorporate the option of applying superphosphate. Whilst we think that we have modelled the main effects of the fertilizer reasonably well, many matters still require attention, such as site-fertilizer interactions and eventual effects on stand structure.

c. Stand density:

The model provides wide options for the manipulation of stand density. Any initial density can be nominated, and there can be up to five thinnings. For each thinning any type (e.g. from above, from below, row thinning) or degree can be specified by reference to the proportion of trees to be removed from each diameter class. This approach, based on FORSIM (Gibson *et al.,* 1971) was adapted for the model by Campbell. Simpler input options for standard thinning regimes are also provided.

Unfortunately the options available are considerably broader than the current data base. The effects of initial density have not yet been defined for anything like the full range of site qualties and localities. Our modelling has been based mainly on the one study, that of Cromer and Pawsey (1957). It is anticipated, however, that useful data from Nelder designs with seed orchard stock in various localities (Opie and Incoll, internal reports) will become available in the next few years. Better data on thinning should also become available as various studies, such as those initiated by Wright (internal reports) in several localities, approach maturity.

d. Departures from even spacing:

Because they offer certain operational advantages, rectangular spacing and row thinning are important options. There is doubt that STANDSIM, being based on the assumption of even spacing, can accurately model the long-term effects of these treatments on stand structure. Little information is available for examination. The only comprehensive trials of initial density by rectangularity in Victoria (Opie and Incoll, internal reports) are but three years old. The only comprehensive trials of row thinning in Victoria, by A.P.M. Forests Pty Ltd, and reported by Hall[3] are not yet fully mature.

The Evaluation Modules

The evaluation modules (2, 3 and 4), developed by Campbell, are described next.

Module 2: Product Estimation

The growth model (Module 1) provides statistics for every harvesting operation of the regime. These statistics are mean dominant height at time of harvesting, and the number of harvested trees by diameter classes. From this input total stem volume for the tree of mean basal area is calculated. By reference to taper lines (Gray, 1956) this volume is allocated to various produce classes specified by small end diameter underbark and minimum log length. Up to eight classes of small end diameter can be specified, and the minimum log length can be varied. Reductions in the volume of produce are then made to allow for: (1) unmerchantable defect; and (2) miscellaneous harvesting losses such as damage and inaccessible pockets. Both these allowances can be varied. Note: Campbell is currently working on the possibility of replacing the total volume and taper line calculations with taper functions produced by Dargavel (1974).

Module 3: Valuation

The current version simply converts the volume in each size class into dollar values by reference to inputs of value per unit volume. This module will be elaborated when results of the supporting studies mentioned below become available.

Module 4: Cash-flow Analysis

Various standard programs are available, but for ease of interfacing, a special routine was written. Inputs of costs and times, relating to such operations as establishment, tending, supervision and measurement are used, together with an annual maintenance charge, to compute present net worth (both for one and an infinite series of rotations, and a range of interest rates), benefit-cost ratio, and internal rate of return.

Supporting Studies

As is clear from the above, many aspects of costs and values are currently handled by varying the inputs. As the results of certain supporting studies come to hand various of the input options will be replaced by functions or models to provide a more positive approach. The main supporting studies are:

1. *Quality Assessment:*

The effects of locality, site quality and various silvicultural regimes on tree characteristics that influence quality have been studied by Wright (1972). The results of this work are being followed up in the sawlog studies described next.

2. *Sawmill Studies:*

Officers of the Research Branch and Division of Economics and Marketing, in liaison with officers from the Division of Building Research, C.S.I.R.O., are undertaking studies in the sawmilling of radiata pine. This work aims to determine the effects of various environmental factors and silvicultural practices on the value of sawn yield. Sample trees are drawn from strata defined by cross-classification of the following factors: locality (three), age (two classes), site quality (two classes) and regime (unthinned and standard). Various types of pruning regime are to be included in due course. Within each stratum six sample trees covering the widest possible range of DBH have been selected.

Half of the trees within each stratum are sawn by a strategy aimed at maximizing the production of board timber. For the other half the strategy is to maximize the production of structural timber. The results for one locality, Aire Valley in south-western Victoria, are currently being analysed by Waugh[4].

3. *Simulation of Sawlog Conversion:*

Sawmill studies are costly yet are very restrictive for the examination of alternative sawing patterns. The Research Branch is therefore attempting to develop a simulation model. This would facilitate the valuation of stands, the definition of economically efficient silvicultural regimes, and the choice of optimal sawing strategy. This work, commenced by Thompson[5], is based on peeling, an approach originated by Dowden[6] at the School of Forestry, University of Melbourne. Work is still at an early stage.

4. *Stumpage Studies:*

Comprehensive accurate sets of stumpage values will not be available until the quality studies are completed, but preliminary work on methodology and costing has been done, as described e.g. by Thompson (1973), in relation to ash regrowth.

5. *Costing Studies:*

The following is a non-exhaustive list of relevant costing studies that have been undertaken by various officers of the Forests Commission. Documentation is in the form of internal reports except where otherwise indicated.

Site preparation (Weetman, Jack).
Machine planting — density by rectangularity (Opie and Incoll).
Weeding methods (Jack, 1970).
Pruning methods (K. Simpfendorfer, Wright).
Non-commercial thinning (Wright).
Row thinning (L. Simpfendorfer *et al.*).
Aerial application of fertilizers (Dexter and Opie, 1975).
Ground application of fertilizers (Craig).

EARLY RESULTS

The entire model is now working, but has not yet been tested thoroughly. Four regimes that have been examined to date are:

1. Conventional regime: Initial spacing of 2.6 × 2.6 m, and commercial thinnings at ages 12, 20 and 27, and various rotation ages.

2. Conventional regime modified: As above, except for deletion of third thinning, and various rotations beyond age 20.

3. Pulpwood regime: Initial spacing as above but no thinning. Various rotation ages.

4. Clearwood regime: Initial density of 746 trees/ha, three early non-commercial thinnings combined with high pruning, and frequent applications of superphosphate, for various rotation ages.

Each of these regimes was examined for a range of site indices. Basal area indices (i.e. values of B7 and B15) were chosen to represent the Ballarat-Daylesford region.

For the first three regimes it was found that, for similar assumptions of wastage (e.g. harvesting losses), the estimated volumes were approximately 10% less than those indicated from yield tables. The evaluation modules appeared to work satisfactorily.

Using current royalty rates, the conventional and the conventional modified regimes appeared to be much more profitable than the pulpwood regime.

For the clearwood regime the estimated volumes were much smaller than expected—the yield was considerably less than half that obtained at the same age with conventional regimes. There is almost certainly a bias in the model.

Testing the Model

To test the model for the sort of regimes represented by the first three examples above, a co-operative project with the Working Plans Branch has been initiated. The first phase of this study involves comparison of simulated and actual diameter distributions, the actual distributions being obtained from a wide range of C.F.I. plots.

In principle the modelling of a low-density clearwood regime presents few difficulties —the main requirement is to define, for a range of site qualities, the maximal growth of virtually open-grown dominants that have less than their full complement of foliage. This is not much to define, but local data are wanting. Our first estimates have been based on data from completely open-grown trees and very patchy stands. In due course better data will become available from the pilot trials of clearwood regimes established by Wright (internal reports).

CONCLUSION

The perceptive reader may have noticed that the modest achievements reported at the end of this paper do not match up well against the lofty ambitions described at the outset. I hasten to emphasize, however, that this is not a final report—the work is continuing, more and better data are continually coming to hand, and the model is at least a going concern.

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