AN ECONOMIC COMPARISON OF ALTERNATIVE SILVICULTURAL TREATMENTS IN *PINUS RADIATA*

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ABSTRACT

Economic comparisons have been made of a number of alternative silvicultural regimes in **Pinus radiata** plantations in New South Wales. These comparisons, done with the aid of computer simulation, have indicated that relatively severe thinning regimes are financially preferable to those incorporating light and frequent thinnings, and that optimal financial rotations over a wide range of forest conditions are in excess of 45-50 years. The critical factors influencing the profitability of silvicultural regimes are shown to be the effective discount rates used and the price size gradient of harvested wood. Other factors which influence profitability are also discussed. For large plantation owners such as the Forestry Commission of New South Wales it is not feasible to treat plantations by one optimal silvicultural regime. Meeting aggregate wood demands requires application of a number of alternative silvicultural regimes, some sub-optimal, so that maximum benefits are obtained from the total plantation in a defined geographical zone.

INTRODUCTION

Silviculture is the tool used by the manager of a *Pinus radiata* plantation to accommodate all the demands put upon the plantation by the various sectors of the community. Silviculture covers a large number of variables in plantation management and discussion here is limited to the consideration of thinning. Thinning in this context is the removal of a number of trees from the plantation at some point in time.

The number of options open to a plantation manager range from no trees removed to all trees removed, at any point in stand life. To effectively choose between these a number of important factors need to be taken into account. This can be done intuitively or with intuition sharpened by the application of economic analysis. If all knowledge was available and all interactions known then silvicultural operations in a plantation would express the long term preferences of the community. However, all knowledge is not available and managers of plantations must make a number of assumptions so that analyses showing the most suitable silvicultural treatments may be carried out.

This paper describes the analytical procedure that is being used for *P. radiata* plantations in N.S.W. (including the simulation and evaluation program RADVAL) and also discusses some of the factors included in analysis. Applying RADVAL to the situations faced by the Forestry Commission of New South Wales indicates that relatively severe thinning regimes are financially preferable to those incorporating light and frequent thinnings, and that financially optimal rotations over a wide range of forest

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conditions are in excess of 45-50 years. These findings, particularly the one favouring extended rotations, are contrary to much of the current thinking on plantation management in Australasia.

Some discussion follows on why this is so. Consideration being given, first, to the importance of correctly specifying costs, returns and discounting interest rates when evaluating the economics of silviculture. Consideration is also given to the effects on the economics of silviculture of price: size gradients, the differential values per unit volume of logs of different sizes.

Some comments are made on other less critical factors, and the relevance of all this analysis and consideration is viewed in the light of the situation facing the Forestry Commission of New South Wales.

ANALYTICAL PROCEDURES AND DISCUSSION

Methods of Analysis

To compare proposed silvicultural regimes in *P. radiata* plantations it is necessary to have statistics describing the probable outcomes of these regimes. It is not practicable to field test these silvicultural regimes and compare measurements so that an alternative method is required. One way of providing statistics of the outcomes is to construct a simulation model from factual data and use this model to predict the outcomes.

A yield table is one such model, although a simple one, and more complex models are incorporated in computer simulation programs. Simulation models may be stand or tree based and stochastic or deterministic. The type of simulation process used is unimportant provided that it is sensitive enough to accurately distinguish between alternative silvicultural options. The model that has been developed in the Forestry Commission of New South Wales, code named RADVAL, is a stand predictor based on deterministic functions. RADVAL is made up of a number of basic processes, each of which consists of one or more regression equations which have been developed from least squares analyses of factual data.

Program RADVAL, as with other stand simulation programs, treats one stand in isolation and by specifying a silvicultural regime, the program will process a set of statistics describing the stand, to produce statistics of the outcomes from this simulation. The input statistics are composed of biological and economic data and are as follows:—

(a) age, predominant height and stand table
(b) prices of the various products including log haul allowance
(c) costs of producing the yield.

Some costs are automatically calculated such as felling and snigging allowance. To obtain information to compare silvicultural regimes it is only necessary to specify those costs associated with the variable factors of silviculture. For a forest owner having only one age class and having borrowed capital to establish this plantation at a fixed interest rate, the costs of establishment with the interest charges must be included in the analysis to determine the best financial rotation for the forest owner. For situations where there are many stands the overall cash flow may be all that is important and this may be independent of establishment costs of the plantations.

The user of the program, as well as specifying a silvicultural regime, must specify further important parameters. The interest rate on borrowed capital or opportunity cost of capital and an estimate of the rate of price change of the forest products and costs associated with their production. A further parameter which sets the minimum allowable volume to be removed from an operation, requires specification.

After accepting input, both of stand statistics and values of various parameters, the program predicts the outcomes of treating the stand by this particular silvicultural regime. This simulation is divided into a number of distinct processes. These are activated for each specified felling operation in the silvicultural regime chosen and the following statistics are generated:—

(i) Biological growth of the stand
  — Height
  — Basal area
  — Proportions of basal area growth to diameter classes
  — Trees removed in thinning
  — Volumes obtained at time of the felling operation, both of total stand and trees thinned.

(ii) Monetary returns to the plantation owner
  — Revenue from pulp and sawlog sales.

(iii) Profitability
  — Present net worth of the rotation if the stand is clearfelled at that felling.

There are two methods of searching for optimal silvicultural regimes once the basic processes of growth and valuation have been described in mathematical terms. The first one is to utilise a computer program such as RADVAL and perform a series of simulations by treating a stand by a variety of silvicultural options. The best option can be selected by observation. The danger in this approach is that only a finite number of options can be compared and the best one may not be included in the analysis. The advantage is that only those options which are feasible are considered and the relative benefits of one option over another option are known.

The second approach is to construct a dynamic programming model which uses the simulation processes as a component. This model, which would be somewhat larger than a simulation model, would automatically find the optimal financial regime from all possible options. Feasibility constraints would need to be built into the model. Dynamic programming models have been developed which find optimal silvicultural regimes, including the clearfelling age (Schreuder, 1971).

The choice of method depends on the forest owner and his particular problem. As will be discussed below, optimal financial rotations are not as important as the overall yield scheduling problem for plantation owners such as the Forestry Commission of New South Wales and to analyse these problems it is of more use to have a simulator such as RADVAL than a dynamic programming model.

Optimal Regimes in N.S.W. — Current Thoughts

There are two distinct situations in New South Wales plantations, excluding consideration of site, where optimal silviculture is influenced by market constraints. The first is the "normal" situation where the plantation area is large and there is a market for pulpwood. The Tumut and Bathurst groups of plantations currently of 50 000 and 40 000 ha respectively, are in this category. The second situation is where there is no feasible market for pulp either now or in the forseeable future, and logs harvested from the plantation are sold to sawmills.

The optimal thinning regimes applying to these situations are:

Thinning		Normal pulp market*	No pulp market
First:	Initial stocking at thinning	1483 stems/ha (600 s.p.a.)	740-938 stems/ha (300-400 s.p.a.)
	Age	13	18-20
	Residual basal area	14.9 m^2/ha (65 ft^2/ac)	22.9 m^2/ha (100 ft^2/ac)
Second:	Age	22-25	25-27
	Residual basal area	25.3 m^2/ha (110 ft^2/ac)	25.3 m^2/ha (110 ft^2/ac)
Third:	Age	30-32	32-34
	Residual basal area	27.6 m^2/ha (120 ft^2/ac)	27.6 m^2/ha (120 ft^2/ac)
Fourth:	Age	37-40	39-41
	Residual basal area	27.6 m^2/ha (120 ft^2/ac)	27.6 m^2/ha (120 ft^2/ac)

* Regime 1 in Tables 1 and 2.

For both situations it is preferred that clearfelling be postponed as long as possible and should be no earlier than age 45. Even if clearfelling is held off until age 50 or older it is not desirable to perform a fifth thinning. The performance of stands at ages in excess of 55 years is not well known in New South Wales and although it is preferable to postpone clearfelling as long as possible it is not recommended that clearfelling be postponed to ages in excess of 60 years on poor sites in New South Wales. The figures quoted are specific to good sites where mean increment of merchantable volume is in the range 14-20 m^3/ha/year. For poorer sites the first thinning is delayed and thinning intervals are wider and clearfelling is sooner.

The situation where there is no pulp market requires a low initial stocking and this can be achieved by either a non-commercial thinning at ages 4-6 or by wider espacement at planting. The latter option is less desirable and should only occur where there are labour problems. The first production thinning in this instance is all sold as small sawlogs.

The normal situation having a pulp market shows a regime which is somewhat different from that previously used in New South Wales. Earlier thinking as expressed by Gentle *et al.* (1962) and Lugton (1968) favoured frequent thinnings at four to five year intervals while maintaining basal areas as close to the optimum at that age as possible. Comprehensive analysis by Forrest (1971; 1973), using data from research plots as well as the original version of the *P. radiata* simulator, showed that it was desirable from a financial point of view to thin more heavily and less frequently. Forrest (1971) also established that there is a wide band of density, expressed as standing basal area per hectare, where increment loss is minimal. He favoured a thinning regime which reduced the number of trees so that density was below the production optimum for a portion of the rotation.

The optimal thinning regime shown above is adapted from that favoured by Forrest (1971; 1973) and is substantiated by recent analyses using the simulation program RADVAL which has 1974 versions of growth equations. The relationship of this thinning regime with the density bands and optimal levels at different ages prepared by Forrest (1971) are shown on Fig. 1.

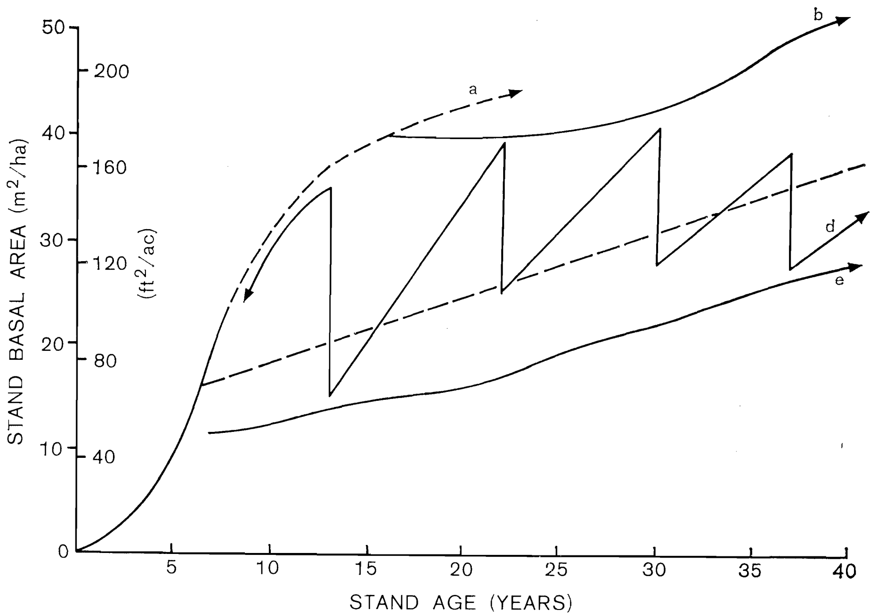

FIG. 1—Stand basal area development.
a. Basal area (b.a.) development in unthinned stands
b. Maximum b.a. for 90% maximum increment (Forrest, 1971).
c. Basal area for maximum increment (Forrest, 1971) (straight line).
d. Regime 1 (Tumut)
e. Minimum b.a. for 90% maximum increment (Forrest, 1971)

Critical Factors in the Economic Analysis

The optimal silvicultural regimes presented in the previous section are in conflict with much of the current thinking on *P. radiata* silviculture in Australasia (e.g. Fenton and Sutton, 1968) particularly insofar as they indicate rotations in excess of 45-50 years. There are two major reasons for this, both of which are critical factors in evaluating the economics of alternative silvicultural regimes. The first is the set of assumptions that have been adopted for translating future forest operations to the decision-making present and the second is the differential values adopted for logs of different sizes.

As discussed in a previous paper by the present junior author (Watt, 1971) estimating the profitability of silvicultural operations is partly a simple arithmetic process based on the well known discounting formula $V_0 = V_n (1 + p)^{-n}$ and very much a difficult exercise in properly defining what is meant by costs, returns and the price of time. If these are not properly defined, mathematical juggling, no matter how sophisticated it may be, will produce nothing of value and may be highly misleading.

The price of time is given by the discounting interest rate used to convert future costs and returns to their present values. In its current planning, the Forestry Commission of New South Wales uses an interest rate of 10% p.a. Coincidentally this approximates the rate of interest presently charged by the New South Wales Treasury on the funds loaned to the Commission for silvicultural and other investments.

If this discounting interest rate of 10% was used for evaluating thinning regimes with costs and returns expressed in present day prices it would falsely indicate that optimal silvicultural regimes would terminate with final fellings some 25 to 30 years after planting. This error would arise because of the basic inconsistency of using an interest rate incorporating a factor to allow for changes in the value of money over time for discounting future costs and returns not so adjusted for inflation.

The program RADVAL avoids this inconsistency by requiring, as input parameters, estimates of the rates of price change for the inputs and outputs of silvicultural investments. In its current planning, the Forestry Commission of New South Wales bases these estimates on the extrapolation of past trends.

Unfortunately, the Commission's costs for establishing and maintaining plantations over a long period are not available. Limited data indicate that the Commission's costs have changed at much the same rate as the Index of Prices Paid by Farmers for Goods and Services, as published by the Australian Bureau of Agricultural Economics. This Index ,in turn, has shown high correlation over a long period with the more familiar Consumer Price Index, as published by the Australian Bureau of Statistics.

This index showed a fairly stable increase of 2 to 4% p.a. for most of the post-World War II period up to 1970. Since 1970 it has expanded wildly, with rates of increase as high as 16% p.a. There is a variety of opinion on the expected behaviour of consumer prices in the future, but an average long term rate of change of 6% p.a. has been decided upon for analyses in the Forestry Commission of New South Wales.

The discounting interest rate and the rate of input price increase can be combined to yield the effective or real rate of discount. If a cost item to be incurred in n years' time costs $\$V$ today it would cost $\$V(1.06)^n$ at the time expenditure actually occurred, and its discounted value would be $\$V(1.06)^n\ (1.10)^{-n}$. It can easily be shown that $(1.06)^n\ (1.10)^{-n}$ is equal to $(1.0377)^n$, or that the real rate of discount for future costs expressed in today's prices is 3.77%.

If it was assumed that stumpage prices will increase at the same rate as input prices, 6% p.a., the effective discount rate for incomes would also be 3.77%. Clearly, if analysis proceeded in terms of present prices and with a real discount rate of 3.77% it would be expected that optimal silvicultural regimes would be directed towards longer rotations than indicated by analyses in terms of present prices incorrectly discounted with an inflation-weighted discount rate of 10%.

In present planning by the Forestry Commission of New South Wales it is not assumed that product prices will change at the same rate as input prices. In the United Kingdom, real prices for wood products rose at an average annual rate of 2% over the first half of the century (Johnston *et al.,* 1967) and in the United States since 1800, the wholesale price of timber has risen at a real rate of 1.7% p.a. (Hair and Ulrich, 1972).

The Australian situation is not as well documented. However Wilson (1964) presented data indicating that Australian sawnwood prices rose at an average annual real rate of 2.5% over the 17 years 1945/46 to 1962/63, and between 1966/67 and 1973/74 the Australian Bureau of Statistics Wholesale Price Index for Timber, Board and Joinery used in House Building rose by 2.1% annually, in real terms. There is little doubt that continuing scarcities of wood will result in a continuation of these trends. Indeed, the United States Forest Service has predicted a yearly addition of 1.5% to the real price of timber if long-term equilibrium between supply and demand is to be achieved (U.S.D.A., 1973).

It seems reasonable to assume that the considerable scope for productivity increases in harvesting and processing plantation-grown wood will enable stumpages to increase at a slightly higher rate than the prices for the converted product. Consequently the Forestry Commission of New South Wales has adopted in its analyses a real rate of stumpage price increase of 2% p.a., or a rate of increase in market prices of 8% p.a.

In combination with the market discount rate of 10%, this produces an effective discount rate for future incomes of 1.85%.

It is not difficult to appreciate that this will indicate that rotations should be extended even further than if incomes were discounted at an effective rate of 3.77%.

The critical nature of this concept of effective discount rate is indicated by the "sensitivity" of changing the rate of price change of standing timber, as demonstrated by Fig. 2. Here the other two rates are fixed and the rate of price change of standing timber is varied from zero percent to 8% p.a. One standard thinning regime was used for this analysis and all other inputs were essentially similar.

The site chosen for analysis (Buccleach S.F.) is one of the better ones in N.S.W. with an M.A.I. at age 40 of approximately 18 m^3/ha. Rotation length was not extended past 60 years as there is no knowledge of the longevity of *P. radiata* plantations past this age in New South Wales.

At a rate of 8% it is shown that the financial rotation exceeds 60 years, although in reality it is expected that the onset of mortality would cause a rapid decline in present net worth at or around age 60. If the rate of price change of standing timber is proven to be no more than that of general prices, then a rotation age of approximately 45 years is preferable for the situation analysed. At lower rates of price increase the rotation age recedes further.

Assuming that the relationship between the rate of increase of general prices and the cost of capital is correct, it is imperative that plantation owners raise the price of standing timber at least in keeping with general prices to remain profitable. However, with large government plantation owners such as the Forestry Commission of New South Wales there are conflicting institutional factors and broader issues are sometimes more important than the microeconomic motive of maximising profit. Prices charged for standing timber may therefore not always indicate true value.

A second critical factor affecting the profitability of silviculture, and hence optimal silvicultural regimes, is the so-called price : size gradient. As discussed in some detail by Humphreys (1971) logging costs fall appreciably with increasing log size, and log values for sawn output increase with size due to increases in the unit value of sawn output (because of increasing proportions of higher grades), increases in sawn yield, and decreases in sawing costs.

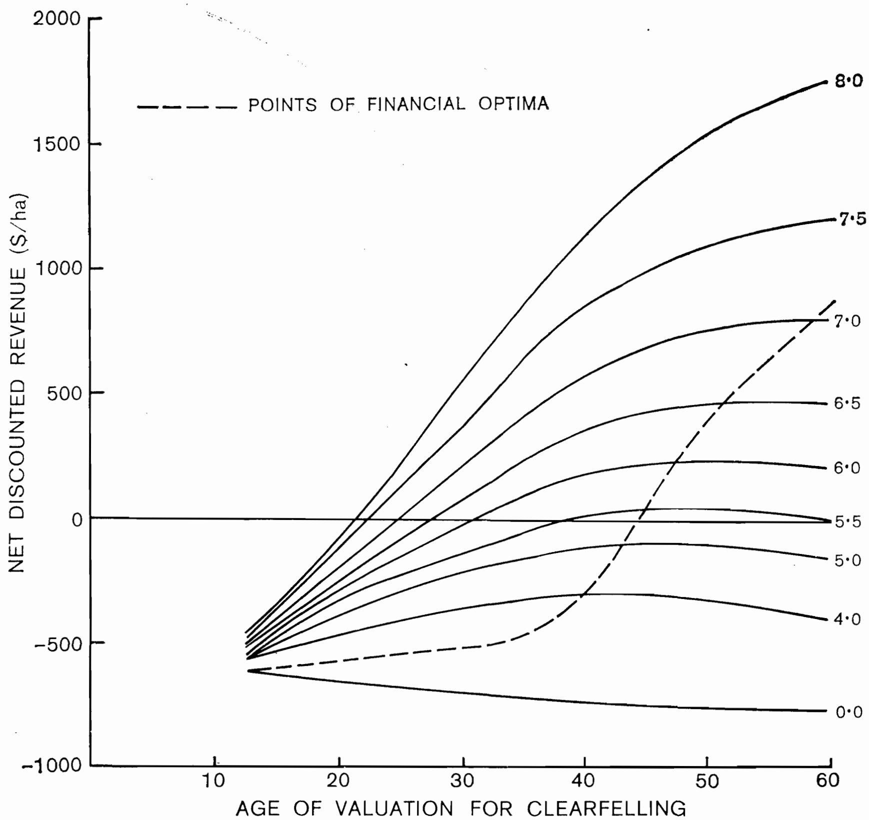

FIG. 2—Effect of price change of standing timber (% p.a.) on net discounted revenue for the rotation, predicted by plantation simulation program RADVAL, Buccleuch S.F. Borrowing rate (discount rate) at 10% p.a. and rate of increase of plantation costs (general inflation rate) at 6% p.a.

The program RADVAL incorporates a simulator of the *P. radiata* marketing system currently in use in New South Wales. This system, which sells standing timber on an essentially residual stumpage basis, incorporates logging and milling allowances, both of which decline with increasing log size.

The net effect of these declining allowances on stand values is shown in Fig. 3. This shows the average price obtained from the stand managed by Regime 1 of Tables 1 and 2, if clearfelled at ages varying from 22 years to 60 years.

Clearly, the price : size gradient adopted in New South Wales is relatively steep. This encourages the retention of standing timber for long rotations and directs optimum silviculture towards concentrating stand growth on a relatively small number of final crop trees per unit area. In combination with the lower effective discount rates (than elsewhere in Australasia) adopted in New South Wales it provides much of the explanation for the comparatively conservative optimal regime outlined in the preceding section.

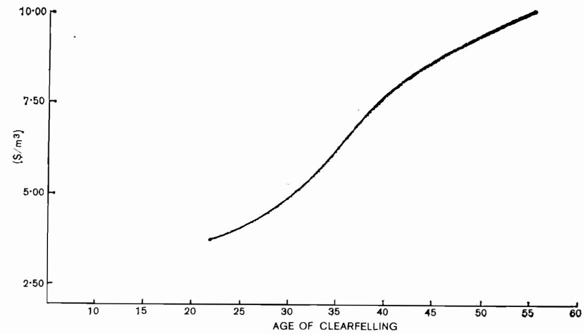

FIG. 3—Average price for standing timber (total crop) by age from simulation of Tumut plantations using program RADVAL.

TABLE 1—Mensurational comparison of two silvicultural regimes using program RADVAL (for a Tumut plantation; 1413 trees/ha at age 13)

	Silvicultural Regime 1				Silvicultural Regime 2			
Age (yrs)	B.A. Removed (m^2)	B.A. Remaining (m^2)	Mean d.b.h.o.b. Removed (cm)	No. of Trees Remaining	B.A. Removed (m^2)	B.A. Remaining (m^2)	Mean d.b.h.o.b. Removed (cm)	No. of Trees Remaining
13	19.7	15.0	15.8	504	15.4	19.3	15.5	658
18					11.3	23.3	24.1	417
22	14.1	25.0	28.9	299				
23					10.1	25.2	30.5	280
28					7.5	27.4	36.3	209
30	13.2	27.5	38.7	191				
32					6.4	27.7	41.9	164
36					5.9	27.7	47.2	131
37	10.5	27.7	46.7	132				
40	31.6	0	54.2	0	33.0	0	56.1	0

Economic and Environmental Considerations

There are many factors in the management of plantations which have been abstracted from and omitted in past analyses. One of the reasons has been the extreme difficulty in quantifying a large number of factors as well as the general difficulty of comparing silvicultural regimes.

Using simulation models such as the one incorporated in program RADVAL it is now possible to consider a larger number of interrelated factors. One important factor in the consideration of thinning plantations is the economies of scale of operations. Biological motivations are toward frequent thinnings of low intensity whereas operational motivations are toward few, but heavy, thinnings. Environmental motivation in most instances will be towards few thinnings with long intervals between them.

To resolve this problem, it is necessary to test a range of silvicultural regimes incorporating the real costs of the plantation operation. A simple example is given in Tables 1 and 2 where two silvicultural regimes are compared. The plantation is an

TABLE 2—Financial comparison of two silvicultural regimes using program RADVAL for a Tumut plantation

	Silvicultural Regime 1				Silvicultural Regime 2			
Age	Merchantable Volume (m^3/ha)	Total Revenue ($/ha)	Costs ($/ha)	Discounted to 1975 ($/ha)	Merchantable Volume (m^3/ha)	Total Revenue ($/ha)	Costs ($/ha)	Discounted to 1975 ($/ha)
-2 (1975)			—235.63	—235.63			—235.63	—235.63
0 (1977)			—164.30	—152.56			—164.30	—152.56
3			—44.38	—36.87			—44.38	—36.87
8			—207.89	—143.54			—207.89	—143.54
12			—10.50	—6.25			—10.50	—6.25
13			—52.51	—30.12			—37.07	—21.28
13	79.99	170.50		+129.36	60.51	128.49		+97.88
18							—29.65	—14.13
18					76.76	237.22		+164.59
22			—52.51	—21.60				
22	111.83	343.47		+221.18				
23							—37.07	—14.68
23					82.91	266.87		+169.21
28							—37.07	—12.21
28					66.46	264.40		+152.86
30			—42.01	—12.85				
30	122.85	546.09		+303.14				
32							—37.07	—10.53
32					60.11	303.93		+163.48
36							—37.07	—9.07
36					55.05	345.94		+172.60
37			—42.01	—9.91				
37	98.62	625.16		+306.01				
40			—197.68	—41.71			—210.04	—44.33
40	307.01	2377.10		+1100.26	321.84	2564.90		+1187.34
Annual			—9.88	—187.94			—9.88	—187.94
Total	720.30	4062.32		+1180.97	723.64	4111.75		+1218.94
Per annum	18.01				18.09			
Per cent					+.46	+1.2		+3.2

average one from Tumut District and standard costs of establishment and early tending of the plantation have been included. Interest and inflation rates are the same in both cases and are of the following magnitudes:

Cost of capital 10% p.a.
Rate of price change of revenues 8% p.a.
Rate of price change of costs 6% p.a.

The plantation is due to be planted in 1977 and establishment operations are taking place from 1975 to 1977. Silvicultural regime 1 is the same one used to produce the results in Figs. 1, 2 and 3. Silvicultural regime 2, is a similar one insofar that first thinning is at the same age and clearfelling is at the same age with approximately the same number of trees, however, this regime has five intermediate thinnings compared to three in the first regime. The biological comparisons are given in Table 1 and the financial comparison in Table 2.

When data was specified for program RADVAL to perform these two simulations no allowances were made for economies of scale or environmental costs. There is a control variable in RADVAL which after setting will make decisions on thinning, namely whether to perform the thinning once the predicted thinning volume is known. For these runs this variable was not set so that the simulated thinning takes place regardless of the volume yield. Also logging costs and administrative costs have been deducted in an approximate flat rate per unit volume basis.

Silvicultural regime 2 produces marginally more volume and approximately $38 per hectare more in present net worth than silvicultural regime 1 (Table 2). In reality, however, the logging contractors would require special allowances to perform a first (or intermediate) thinning for such a small volume per hectare. Additionally marketing supervision would be expected to be related more to area logged than volume removed, such that it would be cheaper to supervise the harvest of volume V from the single area A than the same volume V obtained as $.6V$ per unit area from the larger total area $1.7A$.

It is difficult to quantify the environmental costs of harvesting operations, involving as they do a complex of effects on erosion, water quality and aesthetic values. Generally, however, from experience in New South Wales plantations it is believed that environment costs are related to thinning intensity in the manner shown in Fig. 4. Clearly, the shape of this curve indicates that relatively heavy, infrequent thinnings are preferable to frequent light ones, and that it is preferable to concentrate operations to obtain a specified volume rather than to spread them over a wider area with lighter thinning intensity.

In a constant returns to scale situation the choice is clear and silvicultural regime 2 would be preferred whenever the forest owner was able to make a choice. However, when the economies of scale are considered as well as the soil disturbance problem, the apparent advantage of $38 per hectare is easily removed and preference is for silvicultural regime 1. On logging supervision alone a saving of two operations is expected to reduce the net discounted revenue in real terms by at least $20 per hectare. Logging costs, although currently based on unit volumes, would show in real terms a much greater difference between the two regimes, after discounting to present net worth. The risk of catchment damage, although difficult to quantify, can be valued in

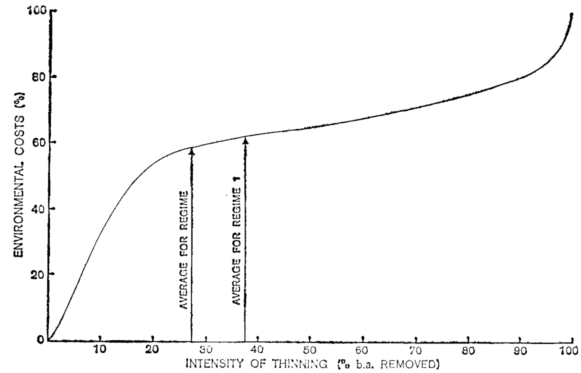

FIG. 4—Environmental costs, as percentage of that experienced in clearfelling, for varying thinning intensities.

terms of a simple choice here and it is the experience of the Forestry Commission of New South Wales that more road repairs and catchment problems would occur in silvicultural regime 2.

There are other factors to consider when comparing silvicultural regimes. One is the risk of wind and snow damage, which is greater in silvicultural regime 1. Another is the risk of disease and insect damage which although a minor problem in Australia to date, could well be higher in the more drastic treatments of silvicultural regime 1. Once the choices have been narrowed down to a small number of silvicultural options by consideration of the larger issues it is then possible to consider these factors mentioned above and make judgments in terms of past experience if quantitative data are not available.

Relevance of Silvicultural Optima

There are a number of constraints to thinning practice in *P. radiata* plantations which are being discussed in other sections of this conference. Some of these constraints are real and some are artificial. Our distinction between them is that real constraints cannot be changed except with large, uneconomic amounts of investment whereas artificial constraints can be changed by an amount of investment which warrants consideration.

Biological constraints are usually real ones whereas operational, technological, market and resource constraints are often artificial and need to be analysed in conjunction with the silvicultural options. These artificial constraints, which are better described as considerations, need to be analysed in larger models than the simple approach using a simulation program such as RADVAL.

Hence owners of each plantation or group of plantations need to make decisions regarding silviculture of the plantations for a particular situation, and this may be altogether different from that of another plantation owner. For the Forestry Commission of New South Wales it is not possible to find one financially optimal silvicultural regime. One major reason for this is that the forest resource both planted and natural is large and the areas of individual age classes are quite different. The planting distribution in New South Wales is usually a small area of old plantation planted prior to the Second World War, and following a period when there were no plantings, increasing areas in each age class up to the early 1970s and then a slight tapering off in areas planted each year.

Treatment of each unit of the plantation by the same silvicultural regime will result in erratic wood flows, greatest in years of harvesting those age classes with the largest areas.

It may be possible to sell the wood that is harvested in these erratic wood flows. However, it is certain that the prices obtained will not be as high as those obtained from a less erratic flow. Market considerations do become real constraints at a certain level of periodic variation in wood flows. The situation confronting the Forestry Commission of New South Wales is that potential wood flows are increasing at a rapid rate whilst the potential markets are tied to the establishment of wood-using plants. Export of logs, while possible, is not economic because of distance of major plantation zones from ports. This means that all other considerations aside it is necessary to provide a wood flow from the plantation which has a regular or stepwise increase until a levelling off of periodic wood requirement is reached.

As well as these market and resource constraints there are operational constraints in some New South Wales plantations. There are a number of areas that were planted with pine and which have slopes in excess of 15 degrees. It is certainly possible to thin these areas at appropriate times. However, the added costs and environmental risks mitigate against thinning and the options open for these areas have been restricted to clearfelling.

As a result of this combination of resource and market constraints, with some further problems of steepness, it is evident that the application of one optimal strategy to the plantation areas will not be feasible and some alternative approach is needed. It is clear that some stands will need to be treated in a manner which is sub-optimal, compared to a situation where the plantation is a normal forest and markets are stable. The goal of the plantation manager becomes one of minimising the loss of sub-optimally treating certain components of the plantation. This can also be thought of as maximising the net discounted revenue from the complete plantation zone.

The task of the analyst is to devise a number of strategies or silvicultural regimes which when applied to the individual plantation units provide satisfactory wood flows at an aggregate level. Wood flow in this sense includes pulpwood, small sawlogs and large sawlogs, each having a different market constraint.

A computer system code named RADHOP has been developed in New South Wales to solve these problems and it is based on simulation using RADVAL followed by linear programming to allocate silvicultural regimes to forest units. This system is similar in many ways to MASH which is for yield regulation planning of the Mountain Ash resources managed by the Victorian Forest Commission (Gibson *et al.,* 1974). However, RADHOP is designed to accommodate a variety of silvicultural regimes in which thinnings is an integral part. This system while operational has not been described by publication and a report is forthcoming.

The initial selection of silvicultural regimes which can be applied to individual stands is made so that there is adequate flexibility in the model. Two distinct types of regimes are often selected where one aims at producing large quantities of pulpwood as early as possible, while the other aims at producing as much large sawlog material in the future. Analysis by linear programming will indicate the most profitable allocation of these regimes to the individual forest and units.

It is conceivable that planning models which are much larger than RADHOP, and which may even use RADHOP as a component, will be developed in the future and the variable of major interest to planners will be silviculture. The technology is available to develop these larger models. However, acceptability by forest managers and other people affected is a limiting factor.

Despite all these local realities there is some benefit in knowing the financially optimal silvicultural regime for a stable market and a regular plantation resource. One benefit is that future plantings and replantings can be planned so that the ultimate plantation composition is as close as possible to that where harvesting can proceed in the financially optimal manner. This planning of future plantings includes so many other considerations that desire to convert the plantation resource to a normal forest is relevant in broad terms only. As explained earlier, problems of deciding on the ideal regime cannot be divorced from these considerations. It is also possible that the optimal silvicultural regime may change in a locally stable situation, as world demand for wood products changes.

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