Alternative Management Policies For Mountain Ash (Eucalyptus Regnans F.Muell) In Victoria.

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Introduction

The management of forests has become a complex and sensitive issue in recent times. Actions of conservation movements throughout Australia and the rest of the world, fuelled by environmental effects has forced various governments to re evaluate their objectives of managing forest. Major issues that have to be considered apart from the value of timber include environmental effects including greenhouse effect and other values of a standing forest such as recreation, conservation of natural flora and fauna and value of non wood products such as wild honey. However, with the exception of wild honey the other products are not sold and prices for them are not determined in the market. Hence the values of these services are subjectively estimated. Therefore, any reasonably reliable economic analysis of forest management must be based solely on the value of timber in the forest. Once the value of the timber to the society is estimated, it will give an indication of the minimum value that the other competing activities must generate in order to convince the policy makers to reshape the objectives of forest management. In economic terms this will give the opportunity cost to society of using a forest to obtain products other than timber. As such, the current study is limited to the analysis of timber production activities in mountain ash forests in Victotria.

Current management policies for public forests in Victoria emphasises the importance of economic viability in providing forest and nonforest products for the current and future generations. Environmental sensitivity also has been taken into account in outlining management plans. In terms of economic viability, the commercial management of forestry

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production and utilization activities expect to generate a 4 per cent return on funds invested. The policy emphasises the objective of maintaining a sawlog oriented forestry rather than a pulpwood oriented one. To achieve this and various environmental objectives, the minimum rotation periods for native hardwood forests have been set at 80 to 150 years, depending on the forest type.

Because of the high potential damage to the remaining trees and resulting loss, thinning of mountain ash stands in State Forests has been suspended since early seventies. However, research has been initiated with the collaboration of CSIRO to investigate the methods of reducing the damage and loss due to thinning. Limited scale thinning not exceeding 20 per cent of the basal area is carried out in these experiments. The research is still been carried out and no conclusive results available yet.

The economics of Mountain Ash has been analysed previously by Webb (1969) and Campbell (1974). Campbell has examined the effect of one thinning while none of them has considered the effect of the damage caused to the remaining trees. Current study obtains the optimal economic rotation periods for Mountain Ash stands and analyses the implications on a long rotation policy. The effect of thinning is examined to evaluate the economics of thinning loss due to butt damage. A simulation technique is used in the study for economic analysis utilizing an existing growth model for Mountain Ash (Incoll 1983).

Timber production in Victoria.

The timber industry makes a significant contribution to the economy of Victoria. The employment created is 6500 in the primary stage and 21,000 in further processing. The contribution to the manufacturing industry is about 8 per cent. The direct and indirect employment created by industry is about 42,000(DCFL 1986). The importance of this is highlighted by the fact that the majority of these jobs are created in the rural communities whose economic activities are based mainly on the production of primary products.

The timber industry in victoria is not self sufficient. Of the state's softwood consumption 55 per cent is imported from other states and overseas. Victoria exports sawn hardwood, pulp and paper, hardboard and particleboard mainly to New South Wales, the Australian Capital Territory and Queensland. A small volume of specialty timber is sold overseas (DCFL 1986 page 23)

Ash type forests which include mountain ash, alpine ash and shining gum represent the highly productive forests in victoria. There were 624,000 hectares of ash type forests in 1980 and this represents about 92 per cent of the highly productive forests in Victoria(Ferguson 1985). This gives an indication of the importance of ash type forest management to the timber industry in Victoria. Some of this land is not available for timber production. Some areas come under national parks and the catchments of the Melbourne Metropolitan Board of Works, whose objectives are to create an environment to obtain other forest values such as recreation, conservation of native flora and fauna and to harvest water. Even within the zones where timber harvesting is recommended by the Land Conservation Council[1], some areas are excluded to protect environmental or other values such as water, flora and fauna and historical and recreational sites. Some areas ar not suitable for logging activities due to topographical reasons. This restricts the total area allowed for timber harvesting to about 209,000 hectares or to 45 per cent of the area available for wood production. In addition to these public forests, there were 5920 hectares of ash type forests under private ownership in 1980.

Mountain ash timber has a high demand in furniture and construction industries. High quality logs are used to produce veneer boards. In addition the paper industry has recently increased its demand for hardwood pulp to produce high quality paper used in photocopiers and similar uses. There has been a shift in products in the paper industry from low quality paper used to produce supermarket paper bags to high quality paper. Mountain ash is one of the highly demanded hardwood pulp and some paper manufacturers have established their own mountain ash plantations to secure a guaranteed supply of hardwood pulp.

Silvicultural Characteristics of Mountain Ash

Mountain Ash is one of the tallest hardwood trees in the world and it naturally grows only in the mountains of Victoria and Tasmania. In Victoria about 625,000 ha of Ash type forests are located in high rainfall mount... ...gion of Central and Eastern Highlands, the Otway Ranges and South Gippsland Ranges. These forests occupy the upper reaches of the principal catchments of most major streams and they are nearly always even-aged[2], following severe wildfire or timber harvesting activity. In their natural state mountain ash forests continuously change. Age, fire, wind, snow, insects and fungi all have an effect on the stand growth and structure. Severe fire can destroy an older, open forest replacing it with dense regrowth. In the absence of a regenerative fire mountain ash would disappear from a site in about 500 years.

Mountain ash is a fast growing species and is well suited for plantations. Well stocked stands may attain a mean annual increment of 300 cu/ft/ac and more than 20,000 cu/ft/ac have been harvested from native stands (Buttler 1970 as cited by Campbell 1974). Because of their intolerant nature, successful regeneration of ash type eucalypts depends amongst other things, on the removal of competing vegetation to form a suitable seedbed for germination and early seedling growth (Campbell 1974). This has important implications for timber harvesting activities, as it requires that large areas of mature trees must be removed quickly if successful regeneration is to be obtained. The usual procedure in state forests is to

[1] The Land Conservation Council makes recommendations to the government of Victoria on zoning and use of public land.

[2] An even-aged forest is a stand consisting of trees of the same age

clearfell and regenerate either by planting or by areal seeding (Campbell 1974). Mountain ash forests cannot be satisfactorily re-established after timber harvesting activities unless natural requirements for regeneration are met. There must be a sufficient area clear felled to ensure that the site receives adequate sunlight, and a hot fire to remove all forest litter and expose the mineral soil in order to prepare a receptive seed bed for sowing. Alternatively, the site could be mechanically prepared for planting of seedlings.

The Ash type eucalypts are silvically well suited to thinning provided that the thinning operation is carefully controlled to avoid stem damage and the development of epicormic shoots. The trees remaining after thinning respond well to release and their gross volume production per acre is very close to that of an unthinned stand as long as the thinning intensity is not excessive (Campbell 1974). Basal area production is lost only where the stand is reduced to the extent that it cannot utilize the available space, or the stand is at an age that it cannot respond to the treatment due to loss of vigor. Thinning in Mountain Ash does not have a significant effect on the diameter growth of the retained trees until about 40 per cent of the basal area is removed (Webb 1966).

The actual decision on whether a stand should be thinned depends on economic factors, the location of the stand, roading, topography, ground condition and the size and quality of stems available for removal. Mountain ash is extremely susceptible to stem damage and unless the topography and ground conditions are suitable and operation is carefully carried out the losses from stem damage may negate any benefits from thinning (Campbell 1974).

Economic models of forest management.

The problems involved in the management of a forest are both biological and economic. From the economic point of view the forest is one form of growing capital. The fundamental economic problem is how much capital should be invested for what duration. This is known as the rotation problem in forestry[3]. The timber volume in a stand of forest changes over time. The dynamics of forest growth involves growth of height and diameter of individual trees, and mortality and basal area growth of the whole stand over the years. The rate of growth is not constant over time. Young trees grow at a faster rate than the mature trees. In an even-aged stand the rate of growth of volume at early ages may be slow because of high mortality of trees. Once the stand has stabilised, the rate of growth can be maintained at a high rate. However, as the stand grows older rate of growth declines. At some age there could be a stagnation in growth, and thereafter, due to decaying of old trees, the rate of growth could become negative.

The economic problem in forestry is to determine the optimum rotation period. The solution to this problem has in principle been known since Martin Faustmann's work in

[3]Rotation period is the time between planting and cutting a forest stand.

1849. However, Samuelson (1976) points out that many economists attempted to solve this problem incorrectly. Foresters prefer to look at the forest management problem from a purely biological point of view, disregarding the financial aspects. This may be acceptable if land and other inputs are costless and the effect of time is unimportant.

A variety of economic models used in forest management analysis. These include present net worth, financial maturity, the soil expectation value, the internal rate of return and the forest rent. In the optimum rotation period analysis, the output of a timber stand is expressed as a function of time, holding other inputs constant. Other basic assumptions include, perfect knowledge, constant relative prices over time and a perfect capital market.

Soil Expectation Value

The soil expectation value is attributed to Martin Faustmann an eighteenth century German economist. This gives the capitalized value of the infinitely long series of expected periodic income. As opposed to the single rotation optimization under present net worth analysis, the soil expectation value model optimizes the continuous rotation problem. The solution to the continuous rotation problem maximizes;

$$V_t = [Pf(t)e^{-rt} - C][1 + e^{-rt} + (e^{-rt})^2 + ...]$$

$$= [Pf(t)e^{-rt} - C][1 - e^{-rt})^{-1}]$$

This formula is based on the assumption that all rotation periods are of equal length. The logic underlying this is that in an infinite planning horizon under stationary conditions, once first rotation period is chosen, the second period, becomes the initial period for the rest of time horizon.

By differentiating the above equation with respect to t, the condition for the optimum rotation period is derived;

$$Pf'(T) = rPf(T) + rV(T)$$

Pf'(T) is the increase in the net value of the standing forest over a year, rPf(T) is the interest that can be earned if the net revenue from cutting the forest stand is invested. rV(T) is the opportunity cost of the investment tied up in the site, where V(T) represent the present value of the stream of future revenues, (commonly known as the site value).

The above equation describes the Faustmann-Pressler-Ohlin theorem, which says that "a forest stand shall be harvested when the rate of change of its value with respect to time is equal to the interest on value of stand plus interest on the value of the forest land" (Johansson and Lofgren 1985, page 80). The optimal rotation period is a function of the parameters

P,C and r. The following comparative static relationships have been derived by Johansson et. al.

$$\frac{dT}{dP} < 0$$

$$\frac{dT}{dC} > 0$$

$$\frac{dT}{dr} < 0$$

An increase in the price of timber increases the value of forest land which in turn increases the interest cost of lengthening the rotation period. To compensate for this interest cost, the forest manager must shorten the rotation period in order to obtain a higher rate of value growth.

An increase in the planting costs decreases the value of the forest land and decreases the interest cost on the value of land. As a result, the rotation period lengthens and the value growth of the forest declines.

An increase in the rate of interest leads to shortening of the rotation period in order to raise the rate of value growth of the stand. This will make the higher returns on invested returns from the cuttings and the interest on the value of land equal to the rate of value growth of the stand.

The Methodologies used in the Economic Analysis of Forestry Management.

Modern economic analyses of forestry management attempt to maximize the present value of net returns over an infinite number of rotation cycle following the Faustmann model. The methodologies that have been employed vary from the simulation approach (Campbell 1974) to highly complex dynamic programming (DP) models (Haight et. al. 1985). The other methodology that is becoming popular in economic analysis of forest management is optimal control theory (Cawrse et. al. 1984).

The simulation approach is simple to model and the optimal rotation period and returns can be easily obtained for operations without thinning, by complete enumeration. The complete enumeration has been a time consuming and expensive exercise until recently. However, modern computing facilities have made the task easier. The advantage of this method is that the optimal solutions can be found for any complex forest growth model with any number of descriptive variables. However, this methodology is inferior to others like dp because of having to use complete enumeration and because of the inability to incorporate a multitude of thinning decisions simultaneously with the rotation period analysis as in DP.

Dynamic programming techniques are currently widely used in the economic analysis of forest management. The advantage of DP is that it can obtain solutions simultaneously for optimal thinning levels and times as well as for the optimal rotation period. DP models become very complex as the number of state variables is increased and this is known as the 'curse of dimensionality'. Because of this dimensionality problem, direct adoption of very complex forest growth models with many variables into a DP framework is difficult. In such instances it may be necessary to sacrifice certain and sometimes important silvicultural characteristics that explain the complete growth process of a forest stand. Although dp allows practical consideration of a large number of alternative decisions such as many thinning intensities and ages, the specification of stocking density and time have to be restricted to discrete intervals (Brodie et. al. 1978).

The simulation model used in the current study simulates the growth of the forest on individual tree basis using an array of tree diameters. Adopting this model into DP requires a large number of states to accommodate many possible diameter distributions. This would make obtaining a numerical solution very difficult if at all possible. Hence the current study uses the simulation approach.

The Methodology and Model

The current study uses a simulation approach with complete enumeration to obtain the optimal rotation period and returns for unthinned stands. The thinning problem is examined by using carefully chosen thinning rates and intervals following the recommendations of Webb(1966). The economic model used is the soil expectation model with an infinite time horizon as described by the Faustmann Equation.

The objective of the current study is to estimate the optimal rotation periods for Mountain Ash stands in Victoria. The objective function is:

$$Max; NPR = [\sum_{i=1}^{n} P_i V_i(T) - C_1 e^{rT} - \sum_{t=1}^{T} C_{2t} e^{r(T-t)}] / [e^{rt} - 1]$$

Where;

NPR = net present value from rotations to infinity

P_i = Price of timber net of harvesting cost per cubic meter of grade i

T = Terminal or rotation age

t = age of the stand at any stage of growth

$V_i(T)$ = Volume of timber harvested at rotation age T (of grade i)

C_1 = Cost of establishment of the stand

C_{2t} = Annual cost of maintaining the stand at age t

The volume of merchantable timber harvested at each age is estimated by simulating the growth of the stand[4]. The model estimates the basal area at age 15 as a function of the number of trees in the stand and the site index (SI) (Site index is the Median Dominant Height of the stand at age 20, and it represent the productivity of the site. Mean dominant height is the average height of the 50 largest trees per hectare.) Mortality is simulated as a function of age and the number of trees in the stand from planting age till clearfelling. At age 15 the trees are distributed among diameter classes using the binomial distribution. This diameter class distribution is then converted into an array of tree diameters to simulate the growth of the stand on individual tree basis. Annual basal area growth of the stands over 15 years of age is simulated as a function of age, standing basal area and the site index. The basal area growth is then distributed among the trees on the basis of the diameter at breast height over bark of each tree. The median dominant height of the stand is estimated as a function of age and the site index. The dead trees are removed from the array of tree diameters according to the mortality rate applicable at each age.

The simulation model allows for thinning from below, if required, where 70 per cent of the trees removed are from those of the smallest diameter and the rest is from every third remaining trees except for the 75 largest remaining trees per hectare.

The trees felled at thinnings or at clearfelling are grouped into diameter classes. Then the height of the representative tree in each class is estimated as a function of median dominant height and the diameter of the tree. The volume of timber is then estimated under five product categories. These volumes are then multiplied by the number of trees in each class and summed up to estimate the total volume thinned or clearfelled.

Royalty Rates

Royalty rates charged by the DCFL are based on a formula developed to account for the distance of the site from the intended market and the price of the timber in that market. The state is divided into various zones and the rates are charged on a uniform quality basis. Currently there are 3000 royalty rates charged by DCFL for timber in the forests under its control.

To determine the royalty rates for Mountain Ash, the timber output is categorized into 6 groups on the basis of diameter size and defects in the wood. A representative set of royalty rates for Mountain Ash along with the diameter specifications and the maximum defect allowed in logs to fall into specific categories are given in the following table. Defect timber is charged at 80 per cent of the pulpwood rate.

At a given site the royalty is charged on the basis of product categories. The product category is determined by the diameter size and the quality of timber. The length a saw log

[4]The simulation method used here is similar to the STANDSIM model of the Department of Conservation Forestry and Land. The biological equations therein are also used in this model. A version of this model is described in Campbell et. al 1979.

Table 1 Royalty Rates

Product Category	Minimum Diameter cm	Maximum Defect Allowance per cent	Royalty Rate \$ per m^3
Veneer Logs	-	0	59.00
Saw Logs Quality A	50	2	50.00
Saw Logs Quality B	35	5	27.00
Saw Logs Quality C	30	20	22.00
Saw Logs Quality D	25	30	7.83
Pulp Wood	-	-	6.91
Defect Material	-	-	5.53

Source: Commerce Division, Department of Conservation Forest and Land. These are the royalty rates charged near Noojee in 1988 and they represent an average of the rates charged for Mountain Ash through out Victoria.

is cut is 2.7 meters. This length is identified as a section. To qualify to be a grade A saw log a section should be more than 50cm in diameter and should not contain more than 2 per cent defects by volume. For B, C, and D quality saw logs the minimum diameter sizes are 35, 30 and 25 cm and the maximum defect allowances are 5, 10 and 20 per cent respectively. As the stand matures, the diameter size of the trees increase. Hence the proportion of potential large diameter size log volume is expected to increase. In gross volume terms this actually happens. However, as the stand matures the defects in trees increase. Defects occur mainly due to two reasons. One is the internal defects created by the termite attacks from the bottom of the trees and the defects created by the fungal attacks at the openings caused by broken branches. This results in a complete loss of timber subjected to these attacks. The other type of defect is that created by knots in the bole caused by branches. The number of trees in a stand decreases due to mortality as a stand matures. This create an environment for the remaining trees to develop epicormic shoots and branches, thereby creating knots in the bole. In this case the timber is not lost, however the market value of such timber is low. Hence, the proportion of high quality timber does not increase with age as one would expect.

This created a practical problem in modelling volumes of timber under each category. The task has been especially difficult because of the difficulty in obtaining an estimate of the timber that has produced in forests under each category. The new royalty system has been introduced only in 1988, therefore, the information on average quantity of timber produced under each category is not available across the ages. Hence, an estimate was made about the possible proportions of each product category as given in Table 2.

The current analysis depends on these volume proportions which cannot be guaranteed to

Table 2: Estimated Proportions of Volume Under Each Product Category

Product Category	Proportion of Total Volume
A	2.5%
B	10%
C	25%
D	12.5%
Pulpwood	50%

These estimates are made on the basis of information obtained from the Department of Conservation Forest and Land.

be accurate. Hence, the results were simulated by changing these proportions. The changes were done in two ways. One is by increasing the proportions by a constant for all ages and the other is by changing the proportions on the basis of the age. That is the proportion of high quality logs was increased as the age increases keeping the pulpwood volume at a minimum of 50 per cent of the total.

The logging cost is borne by the buyers. The royalty rates given are net of logging cost. However, the DCFL spends money on preparing and maintaining roads. Where the access roads are not available the loggers prepare the roads. In such cases, the rates presented in Table 1 are reduced by $1.50 per cubic meter. Therefore, to arrive at a royalty rate net of roading cost, all the rates were reduced by $1.50 in the current analysis.

Regeneration cost

Regeneration cost includes the cost of land preparation, seed collection, nursery cost where applicable, seeding or planting, fertilizer where applicable and protection. Land preparation cost depends on the method used to prepare the land. Widely used methods are burning and mechanical preparation. Usually, both methods must be used in combination to prepare a site.

Planting is also done using two methods. One is to raise the seedlings in a nursery and plant them by hand in the field. The other is to sow the seeds in the field. When the seedlings are planted, fertilizer is applied to each plant. When the plants are young they have to be protected from animals. The cost of each activity is given in Table 3.

Except for the cost of animal control and land preparation the other costs vary with the planting density. On the basis of cost presented in Table 3 and assuming that land preparation requires both methods in equal proportion the costs used in the current analysis

Table 3: Regeneration Cost

Item	$ /ha
Land preparation	
Burning	60.00
Mechanical preparation	400.00
Regeneration by planting (1400 plants per hectare)	
Seed collection	80.00
Nursery cost	300.00
Planting	350.00
Fertilizer	40.00
Animal control	100.00
	870.00
Direct sowing	
Seed collection	190.00
Sowing	50.00
Animal control	100.00
	340.00

Source: Plantation Division, DCFL

Table 4: Regeneration Cost for 1000 Plants

Item	$ /ha
Planting cost	
Seed collection	57.00
Nursery cost	214.00
Planting	250.00
Fertilizer	29.00
	5[illegible].00
Direct Sowing	
Seed collection	136.00
Sowing	36.00
	172.00
Land preparation cost per hectare	
Burning .5	30.00
Mechanical preparation .5	200.00
	230.00
Animal control	100.00

are shown in Table 5.

Analysis of Results

The results of the numerical analysis are given in the following tables. The analysis is applicable for a stand regenerated with 1400 plants. This is the common stand size in DCFL plantations of mountain ash. The returns give the soil expectation value per hectare in each case.

Effect of the Rate of Discount

Table 6 gives the optimal rotation period and soil expectation value for an unthinned stand at various rates of discount ranging from 2 to 6 per cent. Also it gives the results under both planting and sowing. Rotation period under planting, where the regeneration cost is almost twice as much as under sowing, is relatively insensitive to the rate of discount. Rotation periods under the sowing regime shows greater sensitivity at the higher discount rates. The soil expectation values are higher under sowing as compared to those under planting. Under planting it becomes unprofitable to operate at discount rates at and above 5 per cent because of the high regeneration cost. However, as expected, the optimal rotation

Table 5: Total Cost of Planting or Sowing for Various Densities

Plant Density	Total Cost of of Planting $/ha.	Total Cost Sowing $/ha.
1000	880.00	502.00
1200	990.00	536.00
1400	1100.00	570.00
1600	1210.00	605.00
1800	1320.00	640.00
2000	1430.00	674.00

Table 6: Effect of Changes in Rate of Discount

Number	Rate of Discount	Planting		Sowing	
		Rotation Age	SE Value $/ha	Rotation Age	SE Value $/ha
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	[illegible]	28	39

period shortens as the rate of discount rises under both situations.

Effect of the Planting Density

Table 7 shows the rotation period and soil expectation value for stands of various planting densities. Except for the case under 2 per cent rate of discount the highest returns are given by the smallest stand, indicating that it is economical to have smaller stands. One reason for this is that the regeneration cost varies with the planting density, making it cheaper to establish smaller stands. The other reason is that the trees in smaller young stands grow at a faster rate than in large stands. The optimal rotation periods are lower for the smallest stand at high cost of regeneration under planting. This situation varies however, under lower cost of sowing. At rates of discount of less than 5 per cent it is still the lowest, reflecting the higher rates of value growth at lower ages in smaller stands. However, at rates above 5 per cent it becomes the longest rotation period among the group studied.

However, these results may not reflect the true economic situation on an optimal planting density. The smaller stands leave too much space for trees to branch. This results in more branches in trees and make the wood inferior due to knots. In addition broken branches make the trees more vulnerable to fungal attacks and increase the defects in the wood. To reflect the true situation it is necessary to account for the defects created by these factors. This information is unavailable and therefore, a sensitivity analysis applying various rates of defects may be helpful. This analysis is not undertaken in the current study, but has been planned for the future.

Price of Timber

The sensitivity of the rotation period to the timber price was examined by increasing and decreasing the prices of all category of wood by 10 per cent. The results are given in table 8. The rotation period is insensitive to the changes in prices except in the case of 6 per cent rate of discount under planting where, an increase in price has reduced the rotation period. The reasons for the lack of response in other cases is unclear. It could be due to the influence of factors such as the value growth of the stand specific to this species and the relatively high cost of regeneration. On the other hand it may be due to smaller changes in prices used in the sensitivity analysis.

Cost of Regeneration and Maintenance

Table 9 shows the results of the analysis of the sensitivity of rotation period to the cost. The costs were changed by 10 per cent both ways. The results show that the rotation period is not sensitive at all for changes in annual maintenance cost. Also, in the case of regeneration

Table 7: Effect of Changes in Planting Density

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
1000	.02	30	5498	30	6342
1000	.03	30	2478	30	3122
1000	.04	30	1049	30	1596
1000	.05	30	251	29	747
1000	.06	29	-227	29	236
1200	.02	32	5470	32	6437
1200	.03	32	2353	32	3095
1200	.04	32	888	32	1523
1200	.05	31	79	31	661
1200	.06	31	-400	28	158
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
1600	.02	36	4785	36	5972
1600	.03	36	1754	36	2678
1600	.04	36	353	36	1153
1600	.05	33	-338	30	377
1600	.06	30	-797	27	-59
1800	.02	38	4358	38	5643
1800	.03	38	1414	38	2429
1800	.04	37	79	34	987
1800	.05	34	-606	31	249
1800	.06	31	-989	25	-156
2000	.02	39	3835	39	5240
2000	.03	39	1054	38	2161
2000	.04	38	-204	34	795
2000	.05	34	-839	33	101
2000	.06	33	-1192	23	-260

Table 8: Effect of Changes in Price

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
			Normal Price		
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
			Price Increase by 10%		
1400	.02	34	6113	34	7195
1400	.03	34	2599	34	3435
1400	.04	34	857	34	1676
1400	.05	33	55	31	731
1400	.06	29	-452	28	202
			Price Decrease by 10%		
1400	.02	34	4132	34	5213
1400	.03	34	1500	34	2336
1400	.04	34	275	34	995
1400	.05	34	-392	31	275
1400	.06	31	-770	28	-124

Table 9: Effect of Changes in Cost

Number	Rate of Discount	Planting		Sowing	
		Rotation Age	SE Value $/ha	Rotation age	SE Value $/ha
		Normal Cost			
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
		Increase in Maintenance Cost by 10%			
1400	.02	34	4867	34	5949
1400	.03	34	1878	34	2714
1400	.04	34	486	34	1206
1400	.05	34	-274	34	398
1400	.06	31	-538	28	-50
		Decrease in Maintenance Cost by 10%			
1400	.02	34	5377	34	6459
1400	.03	34	2221	34	3057
1400	.04	34	746	34	1466
1400	.05	34	-64	31	608
1400	.06	31	-523	28	127
		Increase in Regeneration Cost by 10%			
1400	.02	34	4898	34	6088
1400	.03	34	1876	34	2795
1400	.04	34	467	34	1258
1400	.05	34	-304	31	430
1400	.06	31	-743	28	-32
		Decrease in Regeneration Cost by 10%			
1400	.02	34	5347	34	6320
1400	.03	34	2223	34	2975
1400	.04	34	765	34	1413
1400	.05	33	-32	31	576
1400	.06	29	-479	28	110

cost, the rotation period has shortened only at the rates of discount above 4 per cent, under higher cost of planting.

The sensitivity of rotation period to the changes in relative prices seems to depend on the rate of discount and the magnitude of the relative price change. At the lower rates, the rotation period is not sensitive as the present value of gross returns are higher. However, at higher rates it seems the rotation period is sensitive to the changes in relative prices. A large difference in cost can be observed between planting and sowing. At higher rates of discount sowing gives a lower rotation period whereas, at lower rates there is no difference between them. This indicates that the sensitivity to relative prices depends on the magnitude of the changes in relative prices and the rate of discount.

Product Category

The sensitivity of results to increases in quantity of timber in the sawlog grades A and B with a corresponding decrease in grades C and D, holding pulpwood quantity at 50 per cent, was examined and the results are given in table 10.

A 10 per cent increase in the proportion of grades A and B does not seem to have any effect on the rotation period. A 100 per cent increase has increased the rotation period except in the case of 6 per cent rate of discount under sowing.

The rotation period and returns were estimated without applying the limits on the higher grades on the basis of quality. The output was estimated on the basis of diameter size for all grades and 20 per cent of output was deducted from all grades to account for defects. Under this the rotation period has greatly increased at rates of discount less than 5 per cent under sowing and at rates less than 6 per cent under planting. This observation shows that the analysis of economically optimal rotation periods is highly sensitive to the product categorization. This is one of the limitations of the current analysis. The analysis in this section also, gives a clue to a new pricing policy to make longer rotation periods economical. A more size specific grading system with higher prices for high quality logs would justify higher optimum rotation periods.

Thinning

The effect of thinning on rotation period and soil expectation value is analysed at thinning rates varying from 10 to 40 per cent. An initial thinning was simulated at age 20 and a second thinning was simulated at age 30. Table 11 shows the effect of a single thinning at age 20. The results show that in all cases thinning has increased the returns and except for the case of 40 per cent thinning, the optimum rotation period has also increased. This indicates that it is beneficial to thin stands at rates between zero and 40 per cent. The thinning at higher intensities are not beneficial. This may be because of the relatively fewer number of trees

Table 10: Effect of Changes in the Product Proportions

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
		Normal Proportions			
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
		Increase in Proportions by 10%			
1400	.02	34	3443	34	6229
1400	.03	34	2063	34	2889
1400	.04	34	624	34	1334
1400	.05	34	-167	31	509
1400	.06	31	-607	28	38
		Increase in Proportions by 100%			
1400	.02	36	556[illegible]	36	6608
1400	.03	36	2233	36	3043
1400	.04	36	688	34	1392
1400	.05	34	-131	36	523
1400	.06	32	-606	28	28
		Product Specified by Diameter Size Only			
1400	.02	53	6166	53	6982
1400	.03	48	2036	48	2735
1400	.04	41	372	41	1035
1400	.05	36	-391	31	267
1400	.06	31	-776	28	-128

Table 11: Effect of Thinning

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
		No Thinning			
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
		Thinning at 10% at Age 20			
1400	.02	40	6737	40	7706
1400	.03	38	2804	38	3589
1400	.04	37	1027	35	1720
1400	.05	35	93	33	754
1400	.06	31	-426	30	209
		Thinning at 20% at Age 20			
1400	.02	41	6516	41	7470
1400	.03	34	2683	34	3519
1400	.04	34	1055	33	1783
1400	.05	33	168	33	830
1400	.06	32	-365	30	268
		Thinning at 30% at Age 20			
1400	.02	40	5916	39	6887
1400	.03	35	2463	30	3335
1400	.04	30	1008	30	1774
1400	.05	30	192	30	881
1400	.06	30	-312	30	330
		Thinning at 40% at Age 20			
1400	.02	38	5367	38	6369
1400	.03	38	2220	28	3039
1400	.04	28	828	28	1623
1400	.05	28	104	28	815
1400	.06	28	-348	28	311

left after thinning.

The results with a second thinning at age 30 are given in the tables 12 and 13. They show that the benefits of two thinnings are lower than that of a single thinning. Although the optimal rotation period increases when thinned at 10 per cent in both thinnings at 2 per cent rate of discount, the rotation period shortens in all cases at rates of discount higher than 2 per cent. Although the returns are higher than with no thinning the returns under two thinnings are lower than under single thinning in all cases. This may also have caused by the small plant density of the stand.

The effect of damage due to thinning is analysed for one case of single thinning and a case of multiple thinning. The results are given in table 14. It shows that if the loss of volume in the unremoved trees could be limited to less than 10 per cent it is still profitable to thin the stands. This indicates that if the cost of a new thinning method to restrict butt damage to less than 10% of the remaining trees, is less than the total benefit of thinning, then it is worth using that technique rather than not to thin at all.

Long rotation Periods

The effect of a longer rotation period on soil expectation value is shown in table 15. It shows that as opposed to the optimal thinning periods, an eighty year rotation period results in less returns or higher losses to the society from timber values. To justify such a long rotation period, the other forest products and activities should generate returns to infinity which gives the present values shown in the table.

Conclusions

This study has shown that the economic rotation period is much lower than the minimum suggested for native hardwood forests under the current pricing arrangements. If it is necessary to maintain hardwood forests for longer periods for reasons other than the timber value of the stand, then it is necessary to justify them on economic terms.

Thinning of mountain ash stands seems to be economical if the losses due to butt damage could be maintained at a rate lower than 10 per cent of the potential final volume of output.

The limitations of the study includes that it does not account for forest values other than the value of timber. Another limitation is that the problem of correctly specifying the volume of output in each category of product.

Table 12: Effect of Multiple Thinning (1)

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
		No Thinning			
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
		Thinning at 10% at Age 20 and 30			
1400	.02	42	6394	42	7332
1400	.03	34	2653	34	3489
1400	.04	34	1021	34	1741
1400	.05	34	1021	34	775
1400	.06	34	-421	31	206
		Thinning at 10% at Age 20 and 20% at Age 30			
1400	.02	40	5914	40	6883
1400	.03	32	2418	32	3285
1400	.04	32	917	32	1658
1400	.05	32	81	32	751
1400	.06	32	-428	31	206
		Thinning at 10% at Age 20 and 30% at Age 30			
1400	.02	40	5371	40	6340
1400	.03	40	2133	29	3025
1400	.04	29	768	29	1548

Table 13: Effect of Multiple Thinning (2)

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
		Thinning at 20% at Age 20 and 10% at Age 30			
1400	.02	41	5910	41	6864
1400	.03	32	2433	31	3312
1400	.04	31	956	31	1710
1400	.05	31	131	31	811
1400	.06	31	-374	31	260
		Thinning at 20% at Age 20 and 20% at Age 30			
1400	.02	39	5447	39	6432
1400	.03	39	2199	29	3099
1400	.04	29	832	29	1612
		Thinning at 30% at Age 20 and 10% at Age 30			
1400	.02	38	5510	38	6513
1400	.03	29	2313	29	3234
		Thinning at 40% at Age 20 and 10% at Age 30			
1400	.02	37	4913	29	5991

Table 14: Effect of Losses Due To Thinning

Number	Rate of Discount	Planting Rotation Age	Planting SE Value $/ha	Sowing Rotation age	Sowing SE Value $/ha
		No Thinning			
1400	.02	34	5122	34	6204
1400	.03	34	2049	34	2885
1400	.04	34	616	34	1336
1400	.05	34	-169	31	503
1400	.06	31	-611	28	39
		Thinning at 10% at Age 20 With a 10% Loss			
1400	.02	40	5608	40	6576
1400	.03	38	2189	38	2974
1400	.04	37	651	37	1343
1400	.05	35	-155	35	502
1400	.06	31	-604	31	31
		Thinning at 10% at Age 20 and 30 With a 10% Loss			
1400	.02	42	5305	42	6243
1400	.03	34	2042	34	2878
1400	.04	34	640	34	1360
1400	.05	34	-132	34	522
1400	.06	34	-595	31	29

Table 15: Effect of Long Rotation Periods

Number	Rate of Discount	Planting			Sowing		
		Rotation Age	SE Value $/ha	80 Year SE Value $/ha.	Rotation age	SE Value $/ha $/ha	80 year SE Value
1400	.02	34	5122	448	34	6204	1115
1400	.03	34	2049	-1169	34	2885	-584
1400	.04	34	616	-1680	34	1336	-1126
1400	.05	34	-169	-1823	31	503	-1282
1400	.06	31	-611	-1832	28	39	-1297

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