Comparison of financial returns from sawlog regimes for *Eucalyptus nitens* plantations in Tasmania

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Summary

Thinning and pruning trials in E. nitens *plantations at three sites in Tasmania were used to evaluate a range of sawlog regimes for their financial return and log-product outputs. Trial plots were 'grown on' from the last measurement age, which ranged from 5.3 to 10.5 years, to each of six clearfall ages between 20 and 45 years in five-yearly intervals. Both stand- and single-tree growth models were used to 'grow on' individual trees measured on trial plots. Eight waste thinning regimes combining either pruning or no pruning with each of 100, 200, 300 and 400 stems/ha residual stocking were evaluated, along with two commercial thinning regimes with pruning and residual stocking of either 200 (CTP2) or 300 stems/ha (CTP3).*

Log assortments at clearfall were simulated using a taper model and log specifications. Stumpages by log small-end diameter class were then applied to pruned logs and sawlogs while a single pulpwood stumpage was used for thinning and clearfall pulpwood volumes. Costs were included for establishment, annual maintenance, land rent, and thinning/pruning where applicable. Internal rate of return (IRR) was calculated for each combination of site, regime and clearfall age. Sensitivity of IRR to assumed costs and stumpage was not investigated here but realistic values were used based on costs incurred in eucalypt plantation establishment and management, and international prices for softwood products experienced in recent years. Detailed results by site and clearfall age are given for the CTP2 regime, including IRR and log outputs of average mid-diameter, average and total log volumes, and total stumpage for each of pruned logs and sawlogs. For each of the 10 regimes combined with each clearfall age, a linear regression of IRR on site index was carried out using IRR and site index calculated for each plot over the three sites. From this regression, IRR was predicted for each clearfall age combined with values of site index in 1 m intervals between 20 and 32 m. The peak IRR over the six clearfall ages, and the clearfall age at this peak were then related to site index.

Results indicate that, given the assumptions used, the best regimes in terms of IRR are CTP2 and the pruned waste-thinning regime with 100 stems/ha residual stocking. There is a strong relationship between IRR and site index with moderately high to very high site quality (i.e. site indices above 28 m) giving good financial returns. Economically viable commercial thinning, with at least 100 m^3/ha of pulpwood recovered at thinning, can be achieved at lower site qualities with site index above 22 m. For the CTP2 regime, full recruitment of potential pruned logs did not occur until 10 to 15 years after the peak IRR at age 25 on a high quality site with site index 30 m.

Introduction

Tasmania has approximately 54 000 ha of *Eucalyptus nitens* plantations most of which have been established in the last 15 years by private companies for pulpwood production. Government-owned plantations are being viewed primarily for sawlog and veneer log production from pruned stands (Gerrand *et al.* 1997). The work described here was carried out to allow private and public forest growers to evaluate the commercial returns and volumes of different log products that could be obtained from sawlog regimes in plantations of *E. nitens*. Neilsen and Wilkinson (1990) and Gerrand *et al.* (1993) also investigated the economics of growing eucalypt plantations in Tasmania under sawlog regimes. Both papers use a relatively basic approach to prediction of log products at clearfall and resulting financial returns. Neilsen and Wilkinson (1990) make assumptions about mean annual increment (MAI) in total stem volume and the proportion of this volume in different log products but they do not grow on actual diameter distributions and predict log assortments at clearfall. Gerrand *et al.* (1993) carried out simulations of stand growth using STANDSIM (Coleman 1989), with the *E. regnans* growth models developed from growth data from even-aged native forests (Opie 1972; Campbell *et al.* 1979), and made some modifications to outputs to make the results more applicable to eucalypt plantations. They also determined log-product volumes simply by using an assumed value of average proportion of total stem volume for the different log products.

This paper brings together results from two other projects reported along with this work: (a) a series of thinning and pruning trials reported in Gerrand *et al.* (1997) which include evaluation of sawlog waste-thinning regimes in *E. nitens* plantations, and (b) growth and yield models for *E. nitens* plantations developed from permanent plot data in Tasmania and New Zealand, including the data from (a) and reported in Candy (1997). The work described here complements that of Gerrand *et al.* (1997) by combining the models in Candy (1997) with a tree taper model and log assortment algorithm to allow detailed analyses of expected log-product output and financial returns for each of three sites reported in Gerrand *et al.* (1997) for sawlog regimes. We compare a number of pruned and unpruned waste-thinning regimes as reported in Gerrand *et al.* (1997) and two pruned and commercial thinned regimes including the recommended sawlog regime in Gerrand *et al.* (1996). To generalise the financial results, we develop a relationship between peak internal rate of return (IRR) and site index for each regime. Peak IRR is the maximum of the IRRs calculated for the six clearfall ages used in simulations (i.e. ages 20, 25, 30, 35, 40, 45). To determine the relationship between peak IRR and site index for each of the 10 regimes combined with each clearfall age, a linear regression of IRR on site index was carried out using IRR and site index calculated for each plot over the three sites. From this regression, IRR was predicted for each clearfall age combined with values of site index in 1 m intervals between 20 and 32 m. The peak IRR over the six clearfall ages and the clearfall age at this peak were then related to site index.

Our approach differs from previous work (Neilsen and Wilkinson 1990; Gerrand *et al.* 1993) by (i) taking into account within-site variation in growth rates, (ii) starting simulations with actual tree diameter distributions, (iii) using individual-tree growth models and (iv) combining detailed log product assortments with stumpages by log small-end diameter class to produce total pruned log and sawlog stumpage (or revenue) for incorporation in financial analyses.

It is not possible to investigate in detail each of the very large number of possible silvicultural regimes that could be applied The best way for a forest grower to investigate potential regimes is to carry out simulations of the type described here with the specific inputs and outputs most applicable to that grower. Sensitivity of IRR to assumed costs and stumpage was not investigated here but realistic values were used based on costs incurred in eucalypt plantation establishment and management, and international prices for softwood products experienced in recent years[1]. Yang and Waugh (1996), in a study of sawn structural products recovered from samples of unpruned, plantation-grown *E. nitens* trees

Table 1. Regime descriptions and codes.

Regime code	Description	Outrows	Pruned (stems/ha)	Residual stocking (stems/ha)
WT1	waste thinning, unpruned	none	0	100
WT2	waste thinning, unpruned	none	0	200
WT3	waste thinning, unpruned	none	0	300
WT4	waste thinning, unpruned	none	0	400
WTP1	waste thinning, pruned	none	100	100
WTP2	waste thinning, pruned	none	200	200
WTP3	waste thinning, pruned	none	300	300
WTP4	waste thinning, pruned	none	400	400
CTP2	commercial thinning, pruned	1 in 3	300	200
CTP3	commercial thinning, pruned	1 in 3	450	300

aged 15, 24 and 29 concluded that sawlogs from these plantations produced useful structural products of similar quality to those from plantation-grown softwoods. The effect of silvicultural regime on sawlog quality is handled here in a simplistic fashion, whereby waste-thinning regimes and commercial-thinning regimes are assumed to produce high quality, knotty sawlogs in unpruned sections of the tree.

Data and methods

Study sites and regime trials

Sample plot data from regime trials were available for three study sites and these are described in Gerrand *et al.* (1996, 1997). Two of the regime trials consisted of randomised complete block experiments at the following sites: Goulds Country 1 (GC) and Hastings 19 (HA). A further trial at Creekton Road (CK) was included because of this site's high productivity compared to the other two sites. However, there were differences in the experimental design and treatments at CK compared to those at GC and HA.

The sample plots were 0.1 ha in size at GC and HA and 0.16 ha at CK. All trees were measured for diameter at breast height (DBH), pruned height (where applicable), and a sample of tree heights was measured, with the height of the tallest tree in each 0.02 ha section of the plot also recorded (i.e. mean dominant height tree or MDH tree). The average of the heights of the MDH trees gives plot MDH (Candy 1997).

The plantations were established in 1984 (GC), 1988 (HA) and 1989 (CK), with the latest measurement of the plots used as a starting point for growth model projections

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[1] International prices for export softwood sawlogs and pruned logs are generally quoted as a single price, 'free on board' per cubic metre with no variation with log diameter, but buyers of export logs usually specify strict ranges for minimum small-end diameter (SED), maximum large-end diameter, and mean SED of a consignment (Turland and Borough 1996). We have introduced a sliding scale with small-end diameter class to these international prices after conversion to stumpage. This is consistent with domestic sawlog sales practice and reflects the economic value of thinning to produce larger average log diameters. Also, we have used international export prices for eucalypt pulpwood rather than the usually lower price of export softwood pulpwood. We use stumpages exclusively so that only costs to the grower need be considered. In a study of this nature, absolute values of stumpage and resulting estimates of IRR can change dramatically as markets shift to exploit new products. If relative values of stumpage between pruned logs, sawlogs and pulp logs are maintained over time, then relative differences in IRR between different sawlog regimes and site qualities remain relevant. Absolute values of IRR should be interpreted in the context of future markets as is the case with any product with a long lead-time between initial investment and financial return.

at ages 10.5 (GC), 7.6 (HA) and 5.3 (CK) years. The regime trials at GC and HA consisted of four replicates of four waste thinning and pruning regimes where the single thinning was carried out at age three for HA and age six for GC at the same time as the pruned plots were pruned. Of the four replicates, two were randomly assigned the pruning treatment and two were left unpruned. Pruning was carried out in a single lift to 6.4 m at GC. At HA, pruning was done in two operations; to 2.3 m when MDH was around 7 m and to 6.4 m when MDH was 12 m. The residual stockings were 100, 200, 300 and 400 stems/ha and the final treatment was an unthinned control. Table 1 gives a summary of the regimes, with a regime code given for easy reference.

The mean stocking of the unthinned control plots (with standard deviation in brackets) was 829 stems/ha (sd=123) at GC and 1247 (sd=129) at HA. As the CK study was designed to compare the cost and quality of various methods of pruning (i.e. high versus low pruning and saws versus shears) no thinning was carried out (Gerrand *et al.* 1996). High pruning was to 6.4 m in two lifts, and eight plots were used with average stockings of 1260 stems/ha (sd=135).

Simulated thinning

Commercial thinning.—The recommended regime of Gerrand *et al.* (1996) given in their Table 6 involves planting 1000 stems/ha, pruning 300 stems/ha final-crop trees, and a commercial thinning at around age 10 to 12. This is not one of the regimes Gerrand *et al.* (1996) applied at the three sites. However, the unthinned plots at each site could potentially have a commercial thinning when they reach this age. To allow this type of regime to be examined here, simulated thinning was carried out at age 12 on the unthinned and pruned plots at each of the three sites. Two thinning regimes, CTP2 and CTP3 (see Table 1) were applied: the CTP2 regime retained 200 stems/ha after the single commercial thinning, while CTP3 retained 300 stems/ha. In each case, thinning was simulated by (a) taking one in three rows as an outrow and (b) thin the residual stand after row thinning by allocating the highest probability of retention to pruned stems with the largest DBHs. To allow a sufficient number of pruned stems to be retained because each third row was an outrow, it was assumed that for CTP2, 300 stems/ha were pruned in three lifts at ages three, four and five, while for CTP3, 450 stems/ha were pruned at these ages.

The plots were 'grown-on' from the last measurement to the thinning age using the models given by Candy (1997). The algorithm used to thin the plots first removed row thinnings by randomly selecting trees at the appropriate rate and then removed the trees in order of smallest to largest in DBH, with the largest pruned stems given highest probability for retention. Selection of the trees for thinning by size class used a thinning algorithm developed for *P. radiata* plantations by Candy (1989). This thinning algorithm was modified to allow selection based on an individual tree's DBH rather than its DBH class as in Candy (1989). The volume of thinned trees was calculated using a taper model for *E. nitens*, with a small-end diameter limit of 8 cm and minimum log length of 3.6 m. In Gerrand *et al.* (1997), a selective waste thinning of trees competing with final-crop trees to a residual stocking of 750 stems/ha with first pruning at age three or four is recommended. This treatment was not included here because the growth models of Candy (1997) do not explicitly include effects due to competition and the effect on final crop tree growth of this 'release' thinning cannot be simulated.

Waste thinning.—For the GC and HA sites, waste thinning was carried out as a treatment. To allow a comparison of the waste thinning regimes at these two sites with the high quality CK site, simulation of waste thinning of the CK plots was carried out for each of the four residual stockings of 400, 300, 200 and 100, with retention of pruned stems. The simulated thinning was carried out at age five without row thinning and with step (b) of the thinning algorithm described above used to

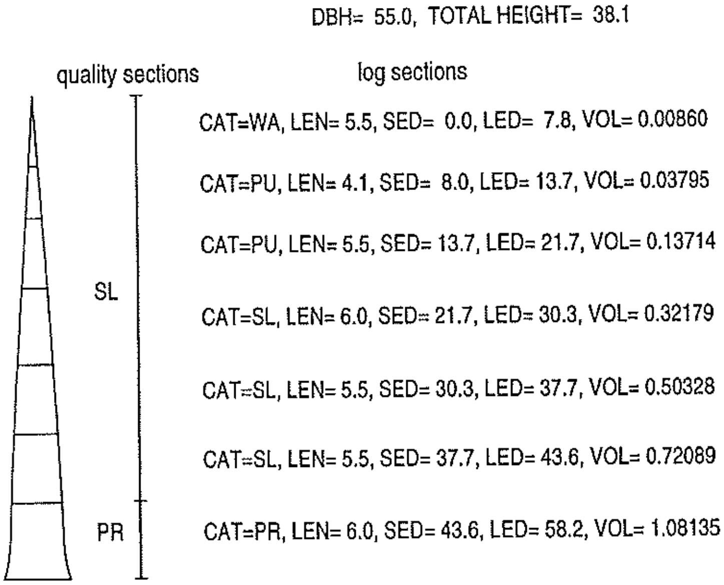
Table 2. Log specifications (SED = small-end diameter).

Product	Minimum SED (cm)	Minimum length (m)	Maximum length (m)	Preferred length (m)
Pruned	40	5.5	6.5	6.0
Short pruned	40	2.4	5.5	5.5
Sawlog	20	4.8	6.0	5.5
Short sawlog	30	2.4	6.0	5.5
Pulp	8	3.6	6.0	5.5

remove trees. To increase replication, the pruned and unpruned waste-thinning regimes were applied to the unthinned plots at the GC and HA sites, using simulated thinning as carried out for the CK plots.

Projected log assortment at clearfall

The models described by Candy (1997) were used to grow on the plots to clearfall ages of 20, 25, 30, 35, 40 and 45 years. Stand and single-tree growth models were used to grow on individual tree DBH, and tree pruned height was retained to allow log assortment routines to take into account variation in actual pruned height. The site index of each plot was calculated, where site index is defined as the MDH at age 15 (Candy 1997). A log assortment program was then used to predict the volume of logs by pruned log, sawlog and pulpwood product classes using a taper model (Candy 1997) and log specifications. The log specifications are given in Table 2 in terms of minimum small-end diameter (SED) under bark, minimum and maximum length, and preferred length. Preferred length logs are cut unless this results in more than a specified



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DBH= 55.0, TOTAL HEIGHT= 38.1
CAT=WA, LEN= 5.5, SED=  0.0, LED=  7.8, VOL= 0.00860
CAT=PU, LEN= 4.1, SED=  8.0, LED= 13.7, VOL= 0.03795
CAT=PU, LEN= 5.5, SED= 13.7, LED= 21.7, VOL= 0.13714
CAT=SL, LEN= 6.0, SED= 21.7, LED= 30.3, VOL= 0.32179
CAT=SL, LEN= 5.5, SED= 30.3, LED= 37.7, VOL= 0.50328
CAT=SL, LEN= 5.5, SED= 37.7, LED= 43.6, VOL= 0.72089
CAT=PR, LEN= 6.0, SED= 43.6, LED= 58.2, VOL= 1.08135
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Figure 1. Example log assortment for a single tree with 6 m pruned height and log categories (CAT) of PR = pruned, SL = sawlog, PU = pulp, WA = waste, LEN = length, SED = small-end diameter, LED = large-end diameter, VOL = volume. (Diameters and volume are under bark values.)

Table 3. Land cost for a range of site indices.

Site index	20	24	28	32
Land cost ($/ha)	1200	1400	1600	1800

Table 4. Stumpages for sawlogs and pruned logs by small-end diameter (SED) class.

SED class (cm)	20–25	25–30	30–35	35–40	40–45	45–50	> 50
Pruned ($\$/m^3$)	-	-	-	-	150	160	170
Sawlog ($\$/m^3$)	45	50	60	70	80	90	100

length of pruned log or sawlog being wasted. In this case the log assortment algorithm will cut shorter lengths of this product, if possible, to minimise wastage. For these simulations, the maximum allowable length of wastage was set at 0.5 m for each of pruned logs and sawlogs. Figure 1 gives an example log assortment for a tree with a DBH of 55 cm and height of 38.1 m.

Costs, stumpages and interest rates

For the financial analyses, pruning was assumed to be carried out in lifts of 2.4, 4.8 and 6.4 m at ages three, four and five respectively. The cost of pruning was set at $1.00 per pruned tree for the first lift and $1.60 for second and third lifts. For waste thinning, the cost of thinning was set at $350, $300, $250 and $200/ha for residual stockings of 100, 200, 300 and 400 stems/ha respectively. We use an annual 6% interest on capital value as land rent, with capital value increasing with site quality. The effect of the annual land rent and annual stand management and maintenance cost on cash flow are treated simply by discounting these costs back to establishment year and considering them along with establishment as a fixed, 'once-off' cost. The internal rate of return (IRR), which is the interest rate for discounted cash flows which gives a zero Net Present Value (Clutter *et al.* 1983), was calculated for each combination of clearfall age, regime, and replicate plot. The IRR was calculated for cash flows at establishment, stand treatment (i.e. thinning and/or pruning) and clearfall using a general nonlinear optimisation algorithm in GENSTAT (Genstat 5 Committee 1993). The establishment cost was set at $1600/ha, with an annual maintenance cost of $54/ha/yr treated in the same way as land rent. Table 3 gives land costs for a range of site indices. Table 4 gives the sawlog and pruned log stumpages by log small-end diameter under bark class used in the calculation of IRRs. Pulpwood from both thinning and clearfall was assumed to have a stumpage of $\$45/m^3$. Values of cost of land (LC) assume a slope less than 10% and distance from the mill of 100 km. The relationship between LC and site index is a best guess in the absence of any data.

Data analyses

For the CTP2 regime, results are given separately for each of the three sites for each of the six clearfall ages between 20 and 45 years. The results include IRR, total volume, pruned log volume, total pruned log stumpage, sawlog volume, total sawlog stumpage, average pruned log mid-diameter and log volume, mean tree DBH, mean number of pruned logs, total volume, and mean annual increment (MAI) for total volume where total volume includes the thinning volume. The total stumpages for pruned logs and sawlogs are simply the sum of all the individual log stumpages. Standard

Table 5. Summary data for sites.

Site	Goulds Country (GC) mean (min,max)	Hastings (HA) mean (min,max)	Creekton Rd (CK) mean (min,max)
Site Index (m)	23.1 (20.5, 25.1)	21.6 (16.0, 26.3)	29.9 (26.5, 34.5)
Thin to 200 stems/ha volume (m^3/ha)	62.1 (49.0, 72.0)	69.8 (62.9, 88.3)	198.5 (178.2, 238.3)
Thin to 300 stems/ha volume (m^3/ha)	50.6 (39.7, 58.8)	59.5 (50.7, 78.9)	175.9 (155.8, 214.1)

errors of the above variables were calculated as the square root of the sum of between-plot within-site and within-plot error variances for each clearfall age divided by the square root of the number of replicate plots for the site (i.e. two plots each at CG and HA and eight plots at CK).

For all regimes, the relationship between peak IRR (i.e. maximum IRR over the range of clearfall ages) and site index is given. To determine this relationship, the IRR was calculated for each plot at each site and each clearfall age (CFAGE) with corresponding site index obtained from the measured MDH of the plot (Candy 1997). The IRR was then used as the response variable in a mixed linear (regression) model fitted using GENSTAT with fixed effect model given in GENSTAT notation by

'CFAGE*REGIME+CFAGE*REGIME.(SITEINDEX)'

and random effect of 'PLOTS.SITE'.

Predictions from the regression model of IRR for each regime and clearfall age for a grid of site index classes in 1 m intervals between 20 m and 32 m were then obtained and sorted within regime and site index class to give peak IRR. The predicted clearfall age of this peak IRR was also obtained.

Results

Table 5 gives mean, minimum and maximum site index at each site and mean, minimum and maximum thinning volume for the simulated commercial thinning regimes, CTP2 and CTP3.

The mean stocking of the unthinned plots at GC was only 839 stems/ha. This explains why the thinning volume was lower than HA despite the higher mean site index at GC. Regressions of thinning volume for the CTP2 regime, V2, and the CTP3 regime, V3, on site index were calculated excluding the data from the GC site due to its low stocking. These regressions were therefore based on 10 plots (two from HA and eight from CK) and are given below, first for CPT2 by

$$V2 = -162.2 + 11.969 \text{ (Site Index)}$$

($R^2 = 0.94$),

and for CPT3 by

$$V3 = -158.4 + 11.102 \text{ (Site Index)}$$

($R^2 = 0.95$).

The regressions of thinning volume were used to predict the minimum site index required to achieve a thinning volume of 100 m^3/ha. This specific volume is considered the minimum required for a commercial thinning. The minimum site indices were 21.9 m for CTP2 and 23.4 m for CTP3.

Figure 2 gives plot mean IRR for the CTP2 regime for each site and clearfall age using (a) the standard pulpwood stumpage of \$45/m^3,

Table 6. Wald statistics for terms in the regression model of IRR (internal rate of return).

Regression term	Wald statistic (chi square)	Degrees of freedom	Probability
REGIME	1060.8	9	< 0.001
CFAGE	186.3	5	< 0.001
REGIME.CFAGE	249.3	45	< 0.001
SITEINDEX	531.8	1	< 0.001
REGIME.(SITEINDEX)	627.3	9	< 0.001
CFAGE.(SITEINDEX)	842.2	5	< 0.001
REGIME.CFAGE.(SITEINDEX)	107.8	45	< 0.001

and (b) a \$35/m^3 pulpwood stumpage. Figure 3 gives mean total pruned volume and stumpage, Figure 4 gives mean of average pruned log mid-diameter and log volume, Figure 5 gives mean total sawlog volume and stumpage, Figure 6 gives mean of plot average DBH and mean number of pruned logs, and Figure 7 gives mean total volume (including thinning volumes) and mean MAI for each site for the CTP2 regime.

The IRRs for all regimes applied to the full set of 48 plots were regressed against site index, with a separate relationship for each combination of regime and clearfall age. It was found that all factor combinations were required in this model since all terms were significant. This is shown in Table 6 which gives Wald statistics for each factor combination. The inclusion of all terms in the regression produced unrealistic predictions in a few cases due to the lack of balance in the data. These were successfully 'smoothed' by dropping the third order interaction 'REGIME.CFAGE.(SITEINDEX)' from the regression, which was then used to form predictions for site indices ranging from 20 to 32 in 1 m intervals for each regime and clearfall age. The use of site index as a linear term in the model was adequate as demonstrated in Figure 8 for (a) all regression residuals and (b) plot average residuals represented by random plot effects estimated using the linear mixed model.

Figure 9 shows IRRs predicted from the regression model versus clearall age for (a) unpruned and (b) pruned regimes for a site index of 30 m corresponding to the mean CK site index. Figures 10 and 11 show (a) peak IRR and (b) clearfall age at peak IRR versus site index relationships for unpruned and pruned regimes respectively.

Discussion

As expected, there is a strong positive relationship between peak IRR and site index so that reasonable to good financial returns are only achieved on sites with moderately high to very high site quality (i.e. site indices above 28 m) (Figures 10 and 11). Given assumed costs and stumpages, the best regime in terms of IRR for site indices above 26 m is the commercially thinned regime with 200 stems/ha residual stocking (CTP2). At site indices below 26 m, the pruned waste-thinning regime with 100 stems/ha residual stocking (WTP1) is the best regime, but IRRs in this lower range of site index are marginal in terms of financial viability. The general trend of clearfall age at peak IRR decreasing with site index was expected and, on high sites above 28 m site index, rotation length is generally less than 35 years.

The IRR for the CTP2 and CPT3 regimes falls off quickly as site index drops compared to

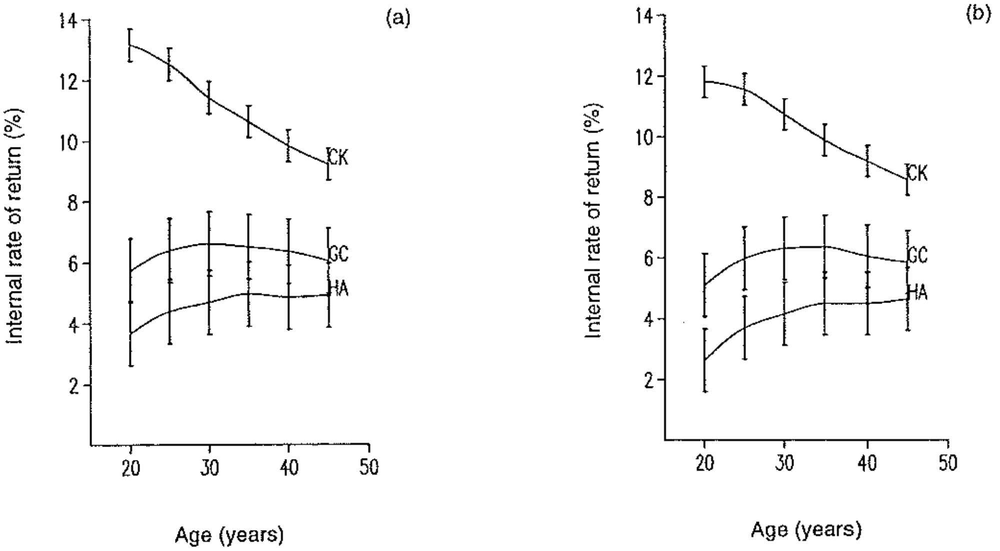

Figure 2. Mean internal rate of return for each site with standard error bars shown for pulpwood stumpage of (a) \$45/m^3 and (b) \$35/m^3.

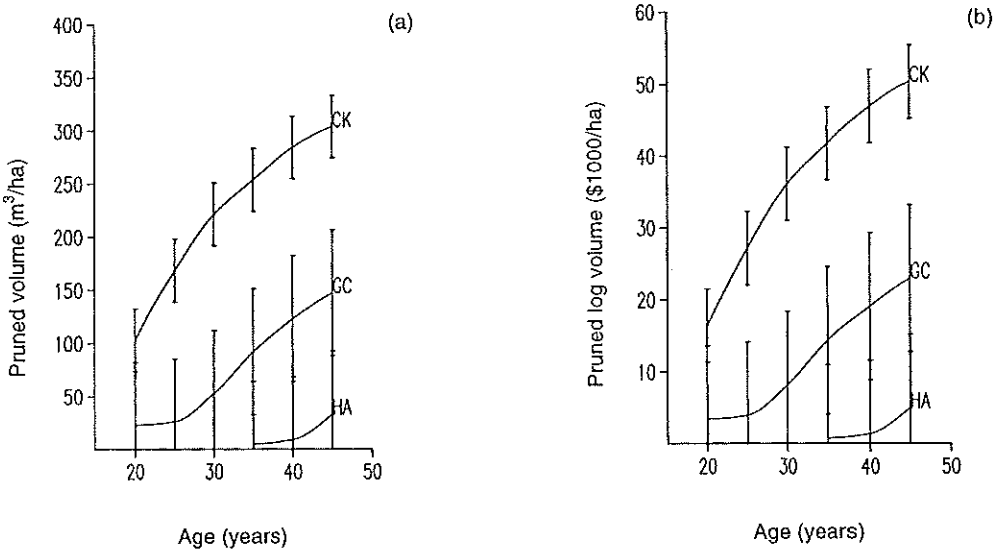

Figure 3. Pruned log output at clearfall age showing (a) total pruned log volume and (b) total stumpage of pruned logs.

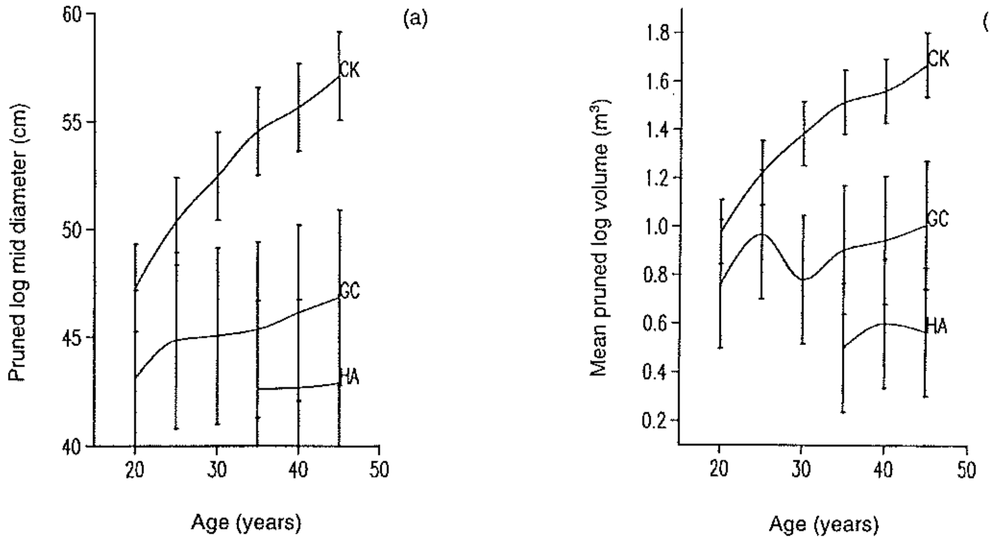

Figure 4. Pruned log output at clearfall age showing (a) average log mid diameter and (b) average log volume (under bark values).

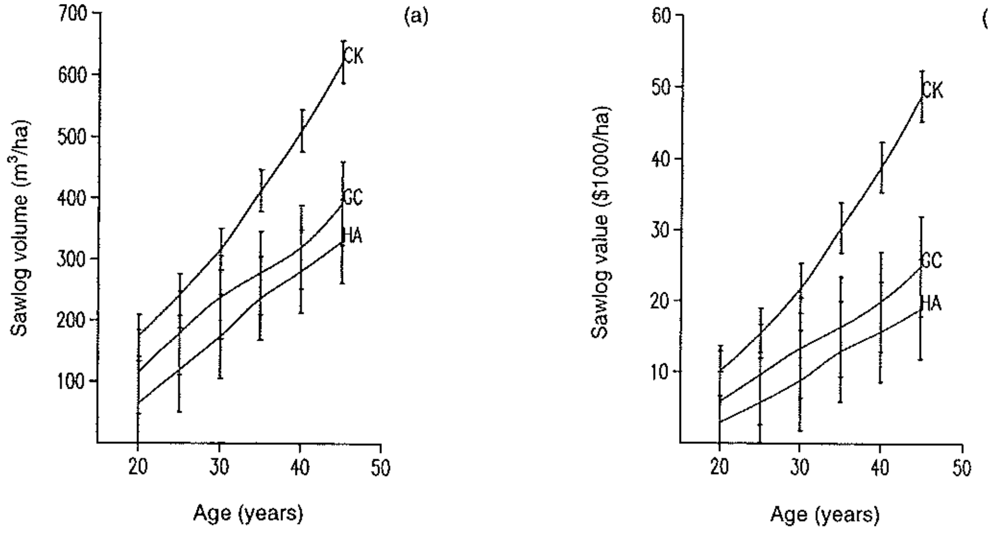

Figure 5. Sawlog output at clearfall age showing (a) total sawlog volume and (b) total stumpage of sawlogs.

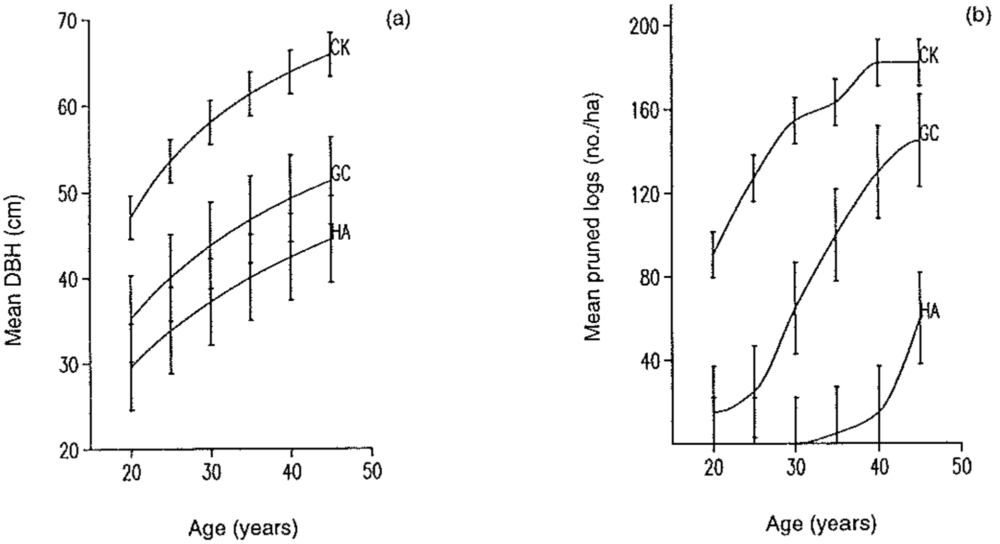

Figure 6. Average tree size effect on recruitment of pruned logs showing (a) mean DBH and (b) mean number of pruned logs (including short logs).

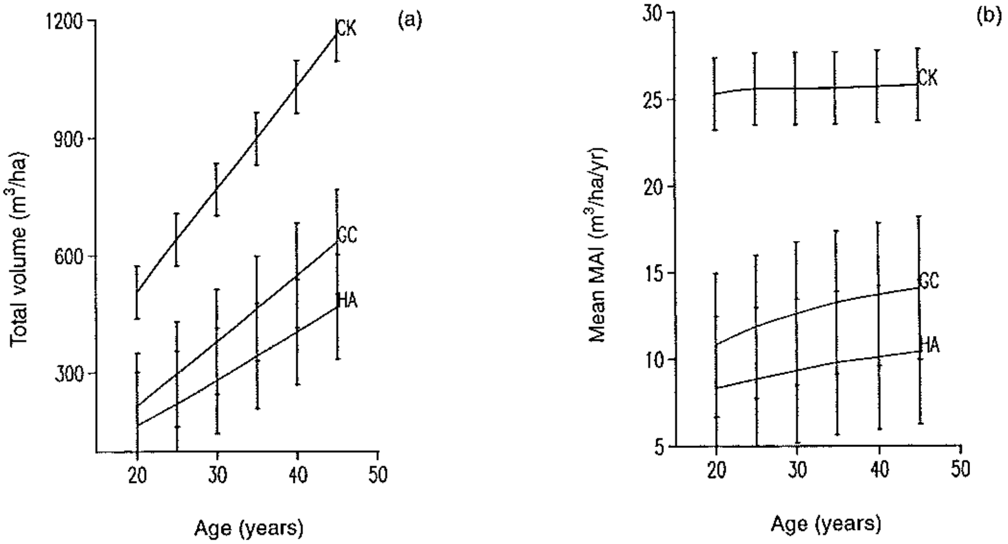

Figure 7. Volume growth, including thinning volume, showing (a) total volume and (b) mean annual increment (MAI).

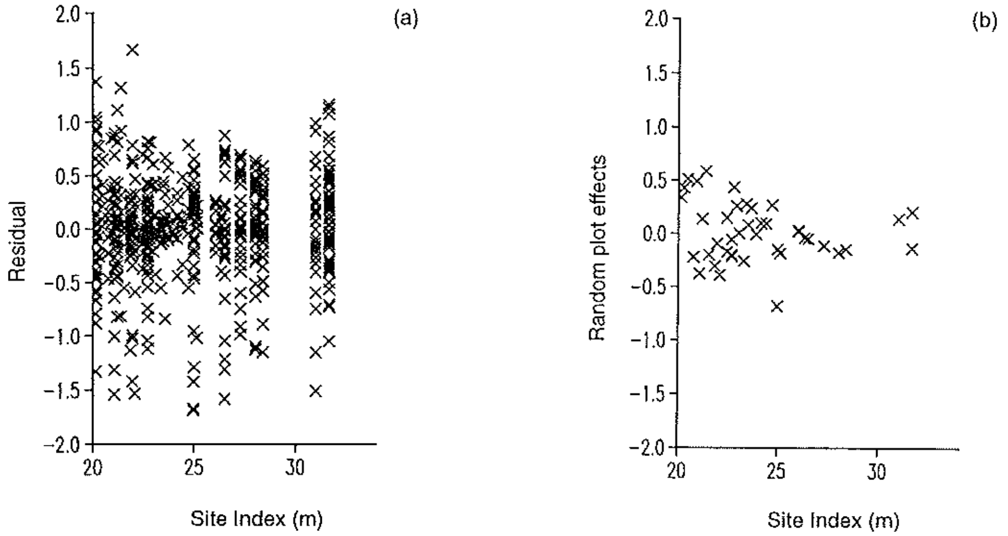

Figure 8. Regression model (a) residuals and (b) random plot effects.

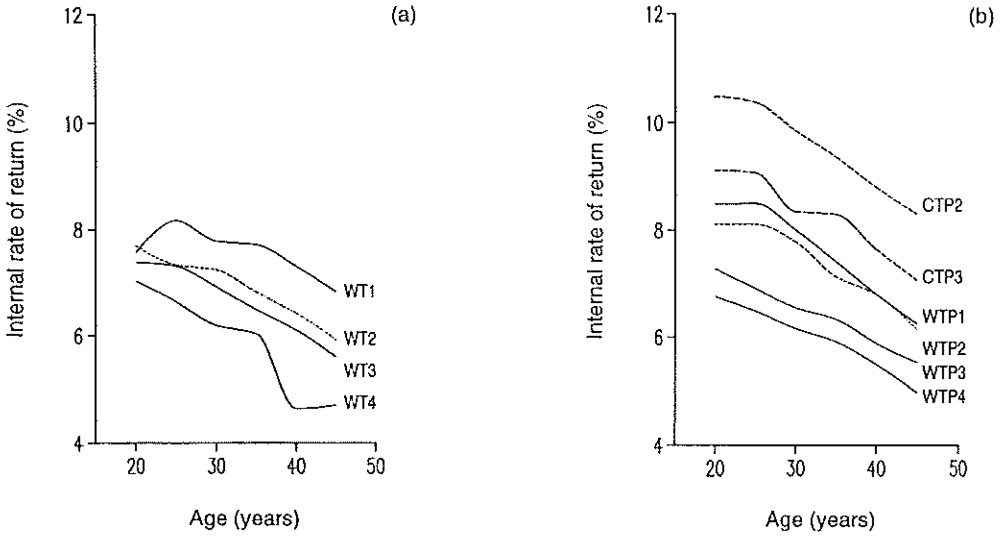

Figure 9. Predicted internal rate of return for (a) unpruned and (b) pruned regimes for site index 30 m. (Regime codes are given in Table 1.)

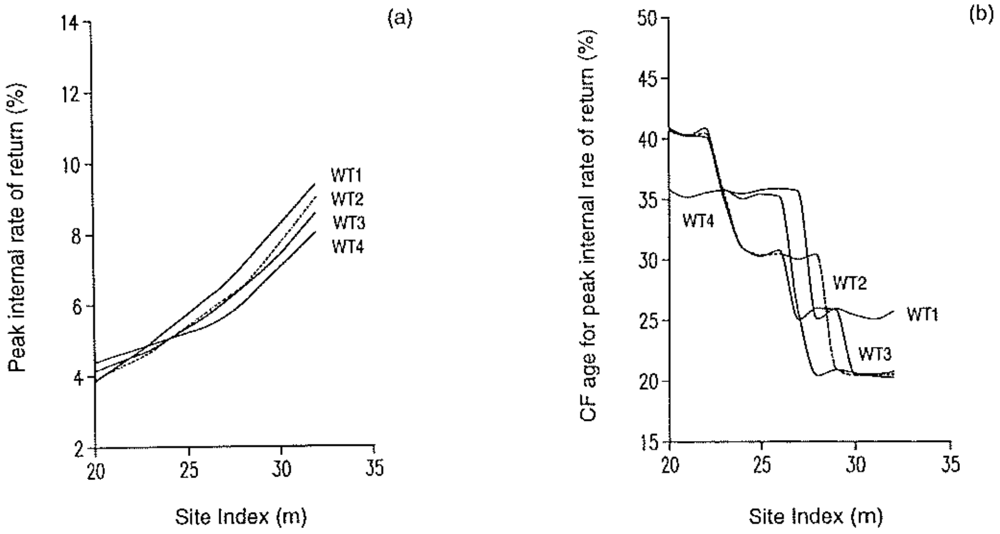

Figure 10. Unpruned regimes showing (a) peak IRR and (b) clearfall age at peak IRR. (Ages are jittered to avoid overlap.)

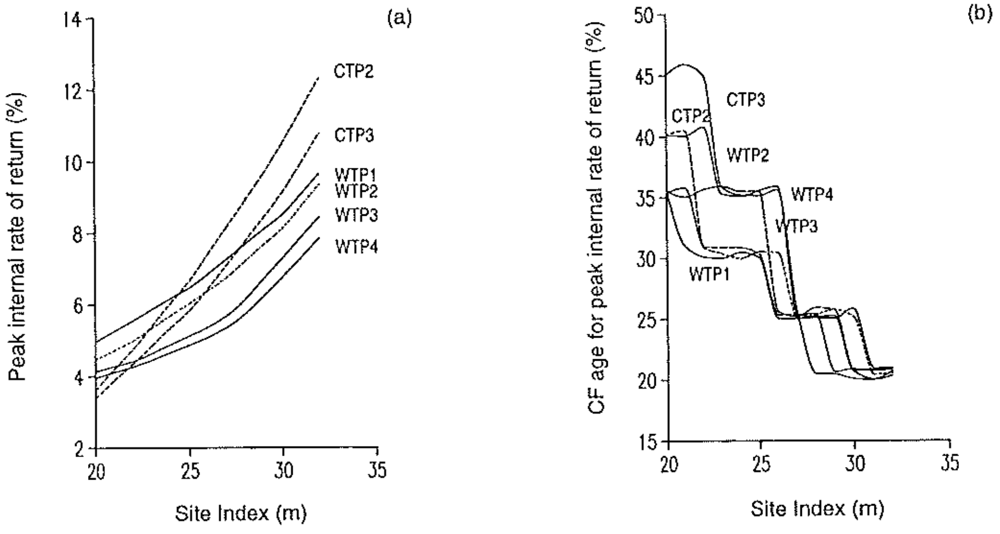

Figure 11. Pruned regimes showing (a) peak IRR and (b) clearfall age at peak IRR. (Ages are jittered to avoid overlap.)

WT1 and WTP1. This reflects the difficulty of recruiting sufficiently large pruned logs to meet minimum log specifications at lower site qualities given the high stocking up to commercial thinning. For the CTP2 regime, full recruitment of potential pruned logs did not occur until 10 to 15 years after the peak IRR at age 25 at the high quality site with site index 30 (Figures 2 and 6). Also, for the lower quality sites of GC and HA, recruitment of pruned logs was still well below the full potential of 200 stems/ha by age 45 (Figure 6). This problem of small 'final crop' tree size probably explains the poorer performance of the CTP3 regime where 300 stems/ha final-crop trees are competing rather than 200 stems/ha. The use of a release waste thinning at first pruning as given in Gerrand *et al.* (1996) would improve this situation by removing trees competing with final-crop trees. On high quality sites, this may not be necessary or economic due to the reduced thinning volume and possible heavier branching on final-crop trees caused by the release waste thinning. The only encouraging result for lower site qualities is that economically viable commercial thinning, with at least 100 m^3/ha of pulpwood recovered at thinning, can be achieved at lower site qualities with site index above 22 m.

The IRRs achieved are a complex function of the relative value of pruned log to sawlog stumpages as a function of log SED, the relative value of pulpwood stumpage, the cost of pruning and thinning, and the growth rates and log assortments at clearfall. The results for IRR here are highly specific to the assumed values of stumpage and cost. For example, the superiority of the pruned regimes reflects the much higher value of pruned log stumpages compared to those for sawlogs. The results are more general for growth rates, DBH distributions at clearfall, and regime since we have included trial plot data from a range of sites and regimes and developed relationships between peak IRR and site index. The growth model projections are subject to prediction error which, for individual plots, may be high due to the long projection interval. The longest projection interval used here is almost 40 years (i.e. from age 5.3 at CK to clearfall age of 45). For a 20-year projection period from age 10 to 30 for an individual unthinned plot with site index 30 m, Candy (1997) obtained a percentage error of 38% for stand basal area. However, when predictions are averaged over a sample of plots, the error for the mean of the individual plot predictions would be substantially less. Also, here we are mostly concerned with relative differences in IRR between regimes and the relationship of peak IRR with site index. Percentage prediction errors should apply almost equally across regimes so that, despite differences in replication between the GC, HA sites compared to the CK site, the relative ranking of regimes should be reasonably insensitive to any bias in growth model projections.

For a given site quality, the relative ranking of regimes in terms of IRR will depend largely on the effect of regime on product assortments obtained at clearfall, the pulpwood volume at thinning for the commercially thinned regimes, and the stumpages these products attract. Differences in treatment costs between regimes are also important but these should remain relatively stable along with establishment costs, apart from increases due to inflation. Future stumpages are more difficult to predict due to the volatility of international supply and demand and rapid changes in wood processing technology and product development.

The other financial input that we consider to be highly variable is the market value of land and thus land rent and its relationship with site index. The higher cost of high quality land will offset to a degree the effect on IRR of increased growth rate on higher quality sites so the assumed relationship of capital value and site index used here may not discount the higher sites sufficiently for some regions. The market value of land will depend on competing interests for the particular piece of land which we cannot take fully into account but we have used realistic values relevant for northern Tasmania where agriculture and forestry compete strongly for land. Despite the difficulty in assigning capital value to different site qualities, we believe the strong relationship between peak IRR and site index is fairly robust to the range of capital land values likely to be encountered on different site qualities. For a given site quality, land rent will affect the financial return from each regime almost equally (i.e. calculation of the IRR is a solution of a nonlinear equation) and, since the emphasis here is on the relative ranking of regimes in terms of IRR rather than absolute values of IRR, the uncertainty in land value is less important than other costs and stumpages.

For young plantations that are at the stage where a forest manager has a number of options available in terms of thinning and pruning, forest inventory can be used to determine site index. The work described here, or similar simulations with regimes, costs, and stumpages appropriate to the particular grower, can then be used to determine the optimum regime. The growth models described by Candy (1997) can be applied to inventory plots to give expected wood flows by log product type and expected cash flows. This study has shown how these simulations can be carried out for a selection of regimes.

Where land is being evaluated for plantation establishment or existing stands are too young for inventory to be reliable (i.e. less than three years), the site index will be unknown. To overcome this difficulty, process-based growth models can be used to estimate site productivity in the landscape using data captured on geographic information systems (GIS), including altitude, aspect, latitude and derived climatic variables using systems such as ANUCLIM (McMahon *et al.* 1995). The site productivity measure derived from the GIS/ process model can be used to predict site index using a calibration data set. Research work to do this is currently being carried out co-operatively with the Cooperative Research Centre for Sustainable Production Forestry. Further, using a GIS, simulations to determine the financial return of sawlog regimes similar to those carried out here could take into account distance to mill (Gerrand *et al.* 1993) and slope class which we assumed were fixed.

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