Pre-commercial thinning of fenced *Eucalyptus obliqua* regeneration enhances growth of both *Acacia melanoxylon* and *Eucalyptus obliqua*

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Abstract

A thinning trial was established to investigate the effect of different levels of eucalypt overstorey removal on the growth and form of blackwood (Acacia melanoxylon) *in coupes that had been fenced at establishment to prevent browsing of this high-value timber species. Pre-commercial thinning (PCT) by stem injection was used to reduce eucalypt basal area by 0%, 50% and 75% (CON, PCT50, PCT75) in a young (9-year old) stand of* Eucalyptus obliqua *in north-western Tasmania. Monitoring was conducted over a 5-year period to determine the effects of PCT on overall stand productivity and on wood production in three distinct cohorts of the stand: the blackwoods, the potential eucalypt crop at final rotation age (250 stems/ha, largely trees containing a sawlog), and the potential eucalypt pulpwood crop at commercial thinning (CT) age (between 25 and 30 years).*

Over the 5 years following PCT, the mean annual diameter growth rate of blackwood was significantly greater in the PCT75 treatment (0.83 cm/yr), whereas there were no significant differences for this parameter between PCT50 (0.66 cm/yr) and CON (0.58 cm/yr). Mean annual diameter growth rates of the eucalypt potential sawlog crop trees in both thinned treatments (c. 1.2 cm/yr) were almost twice that of a similar sample of trees in CON (0.65 cm/yr), but were not significantly different from each other. Basal area increment in the cohort of eucalypt pulpwood trees destined for removal in a CT was greater in PCT50 (4.6 m²/ha) than in CON (3.1 m²/ha) over the five year period, although the difference was not significant.

Modelling of the stand to age 25 years showed that mean individual eucalypt tree pulpwood yields at a commercial thinning (CT) for pulpwood at that age would be too small to be commercial in the CON treatment (0.05 tonnes), marginal in the PCT50 treatment (0.21 tonnes), and adequate in the PCT75 treatment (0.27 tonnes). However, total pulpwood yields were only considered to be commercially viable (> 100 t/ha) where CT followed PCT50. When the PCT75 regime was re-run with a CT for pulpwood at age 28 years, individual tree and total removable volumes increased and were both considered commercially viable Since the focus of these fenced coupes is primarily to increase the production of high-quality blackwood and eucalypt sawlogs, these data support a recommendation for PCT75 at age 10-12 years with the possibility of CT at about 30 years, anticipating a rotation length of 65-70 years.

Introduction

Germination of blackwood (*Acacia melanoxylon*) from ground-stored seed is prolific after harvesting or disturbance where the original forest was well stocked with blackwood (Wilkinson and Jennings 1994). However, most of this regeneration is eaten by native mammal browsers. Since 1985, Forestry Tasmania has been fencing eucalypt regeneration coupes established after clearfelling blackwood-rich wet eucalypt forest, to increase blackwood survival (Jennings and Dawson 1998). More than 1200 hectares of this fenced-intensive blackwood (FIB) resource has now been established. There is great variability in tree densities across the FIB coupes, but some coupes have very high numbers of both blackwood and eucalypt saplings, and the eucalypts may require thinning for optimum blackwood growth. There is currently no silvicultural prescription available for early thinning in these stands that takes into consideration both the understorey blackwood and the overstorey eucalypt stems.

Pre-commercial thinning (PCT) is employed to concentrate wood production onto fewer, larger stems (Connell and Raison 1996; LaSala 2000). In Tasmania, stands considered suitable for PCT are typically eucalypt regrowth aged 10-25 years, in wet sclerophyll forests dominated by *Eucalyptus obliqua* and *E. regnans*. Glyphosate herbicide is injected directly into the unwanted stems, to achieve a retention rate of approximately 500 stems/ha. PCT is normally done in preparation for a commercial thinning (CT) planned for age 25-40 years, which would typically leave a final crop tree density of 180-220 stems/ha.

Jennings *et al.* (2003) showed that young blackwood saplings responded positively to increased light availability in a trial where light wells were manually cleared around target blackwood stems in a densely stocked FIB stand. However, these treatments were expensive and were not designed to be used on an operational basis. The current experiment was designed to evaluate the effect of two intensities of eucalypt PCT (a standard operational procedure) for the treatment of FIB areas. The objective of the study reported here was to develop a eucalypt PCT prescription that would improve the form and growth rates of blackwood, in addition to achieving the standard PCT objectives of enhancing growth of retained eucalypts, shortening the planned rotation, and increasing the sawlog:pulpwood ratio (Forestry Tasmania 2001).

Methods

Plant nomenclature throughout follows Buchanan (2005).

Study site

The area selected for the experiment is part of Togari 021A (TG021A), a 37 ha coupe regenerated and fenced in 1989. It is located in State forest on Riseborough Road, 16 km south-west of Smithton in north-western Tasmania (GDA: 327300 E, 5469100 N).

The site receives about 1200 mm of rainfall annually (data for Togari Station supplied in 2005 by Climate and Consultancy Section, Tasmania and Antarctica Regional Office, Bureau of Meteorology, Hobart) and is approximately 60 m above sea level. The coupe is on brown clay soils derived from Cambrian mudstone, with gently undulating topography. Before harvesting, the site carried sparse *Eucalyptus obliqua* forest 30-40 m tall with a blackwood sub-canopy 20-25 m tall and a wet sclerophyll understorey (*Pomaderris apetala, Nematolepis squamea, Acacia* spp.) 10-15 m tall.

The coupe was clearfelled in early 1988 and the harvesting residue burnt in February 1989, producing an excellent seedbed (R. Lucas pers. comm.). The coupe was aerially sown with *E. obliqua* seed and fenced with wire netting in April 1989. A regeneration survey in August 1990 indicated that the coupe was considered fully stocked with eucalypt seedlings by Forestry Tasmania standards at that time (Forestry Tasmania 1991). In addition, blackwood seedlings were common throughout the coupe, although not surveyed at this time. The coupe carried approximately 3000 live eucalypt stems/ha and 1000 live blackwood stems/ha (of all sizes) at age 9 years when PCT was first carried out, as estimated from temporary stem-tally plots (see below).

Experimental design, establishment and treatment

In April 1998 (stand age 9 years), a contiguous area on the eastern side of TG021A was divided into thirty-six 50 m x 50 m blocks each of 0.25 ha (Figure 1). Nine of these blocks were then discarded due to the presence of snig tracks, landings or gaps in the regeneration created during incomplete aerial sowing. Temporary circular survey plots of 0.01 ha were located in the centre of each of the remaining twenty-seven blocks, and tallies of eucalypts and blackwoods within 2-cm diameter classes taken to characterise the stand. Target stem retention rates of 800, 1100 (Cunningham and Peña 2000) or all eucalypt stems/ha were randomly assigned to nine blocks each. No blackwoods were to be thinned in any treatment.

Selection of trees for retention was done on the basis of form, size and spacing in December 1998, immediately followed by stem injection using glyphosate (Cunningham and Peña 2000) of all unwanted eucalypt stems ≥5 cm diameter at breast height (1.3 m) over bark (dbhob). Tree selection and injection were performed by independent contractors.

The temporary circular measurement plots in the twenty-seven 50 m x 50 m blocks were re-measured in May 1999 (stand age 10 years). Within these plots, basal area (BA; m^2/ha) was calculated for all measured eucalypts, both live and injected. Retained stem numbers varied widely and,

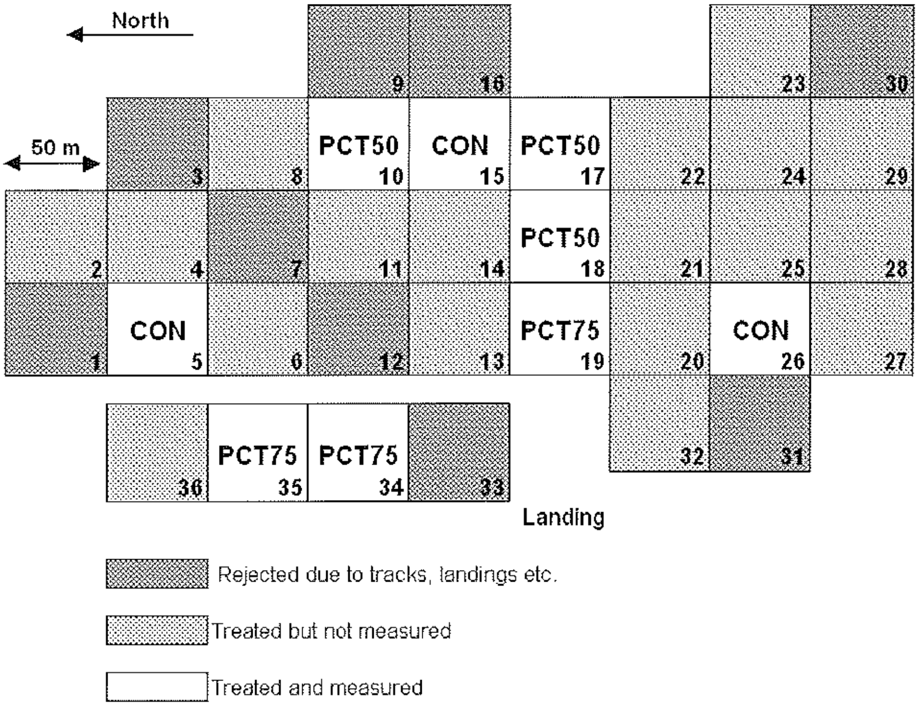

Figure 1. Trial map showing block layout. Each block was 50 m x 50 m (0.25 ha). Circular measurement plots of 0.02 ha were located in the centre of each treated and measured block.

Table 2. Regimes used in growth modelling. PCT and CT treatments were applied to the eucalypt component of the stand.

	PCT		CT	
Regime	% BA removal	Age (years)	% BA removal	Age (years)
CONI				
CT			50	25
PCT50	50	10		
PCT50CT	50	10	50	25
PCT75	75	10		
PCT75CT	75	10	50	25
PCT75CT$_{28}$	75	10	50	28

purpose of this was to determine the effect of eucalypt PCT on the amount of pulpwood available at CT, the average pulpwood volumes of individual trees, and the size of trees retained at CT for a later sawlog harvest. The growth model used is based on inventory and research plots throughout Tasmania, and is routinely used for resource estimates by Forestry Tasmania. This model takes into account factors such as stand age, site quality, and species characteristics when estimating future growth and yield. When thinning regimes are modelled, larger trees and trees of potential sawlog form are retained preferentially until user-defined conditions are met.

Tree measurements taken in May 1999 (stand age 10 years) for both live and injected eucalypts were combined to approximate the pre-thinning characteristics of the stand. These baseline data for the nine circular measurement plots in the trial were then used as a basis for modelling each of the three PCT treatments.

Growth of the stand was modelled to age of 25 or 28 years using six different regimes, some of which then incorporated a eucalypt CT at age 25 or 28 years which removed 50% of the standing BA (Table 2). Eucalypt stand BA, stems/ha and volume yields were predicted for the stand at commercial thinning age. Average tree volume was derived by dividing predicted merchantable yield/ha by the number of stems/ha, then converted to average tree yield of pulpwood in tonnes by multiplying by 1.053.

The growth model used the following criteria:

- Merchantable wood was calculated for the bole between a stump height of 0.3 m and a top diameter under-bark of 10 cm.
- Minimum log lengths were defined as 2.4 m for sawlog and 3.6 m for pulpwood.
- Minimum small-end diameter for sawlog was 30 cm under bark.
- All thinnings were regarded as pulpwood.

Results

Blackwood growth and mortality

Mean blackwood diameter at the start of the experiment was between 5.8 and 6.2 cm dbhob across the three treatments, and increased to between 8.9 and 10.0 cm dbhob over the 5-year period (Figure 2). There was no blackwood mortality during this period. Within each treatment, growth was fairly uniform in each successive year. PCT75 produced the largest blackwood mean annual growth rate for individual tree diameter (0.83 cm/yr over the

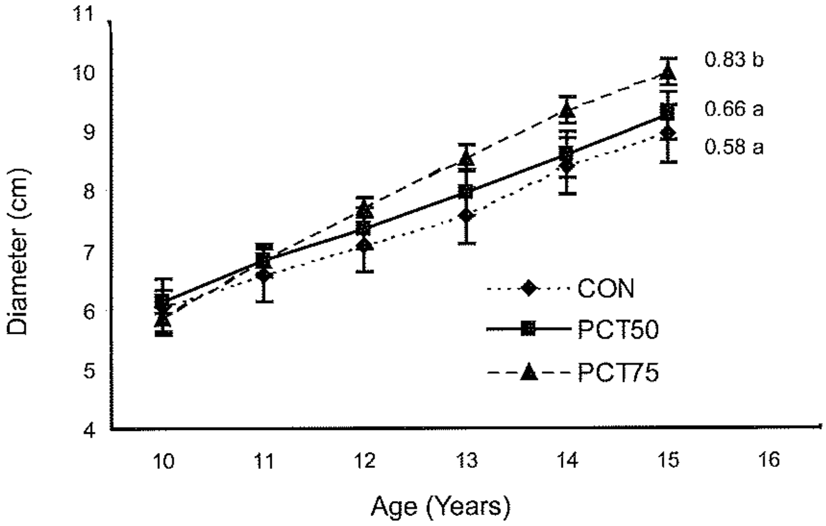

Figure 2. Mean blackwood diameter (dbhob) for the 5-year measurement period. Bars show standard errors of the plot means (n = 3). Mean annual increments over the 5-year period (cm/yr) are shown for each treatment. Values with the same letter are not significantly different.

5-year measurement period), which was significantly different from that of the other two treatments (F = 15.63; df = 2; P = 0.004). The mean annual diameter growth rates for blackwoods in PCT50 (0.66 cm/yr) and in CON (0.58 cm/yr) were not significantly different from each other.

The mean height of the lowest green branch, which determines the length of clear bole, for blackwood trees in all treatments increased from approximately 5 m at age

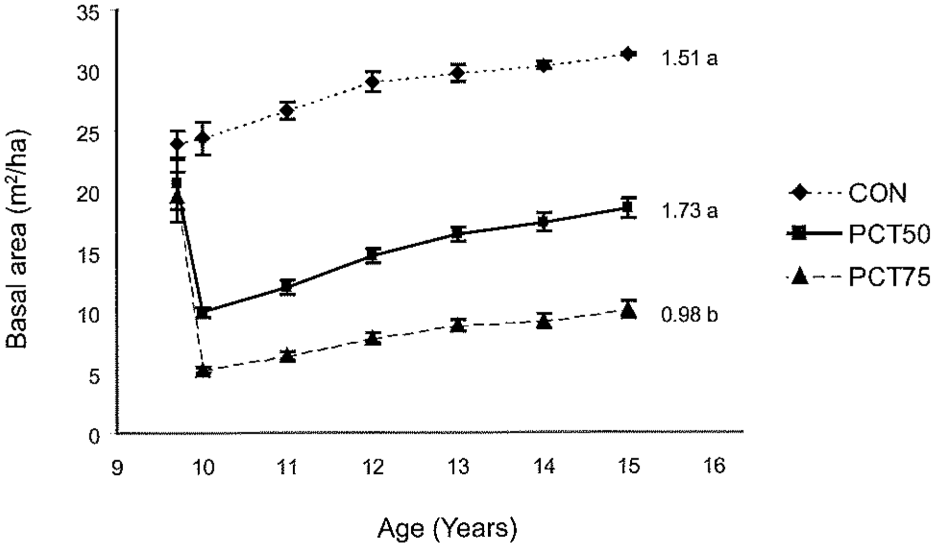

Figure 3. Mean eucalypt stand basal area per ha for all treatments over the 5-year measurement period. Bars show standard errors of the plot means (n = 3). Mean annual increments over the 5-year period (m²/ha/yr) are shown for each treatment. Values with the same letter are not significantly different.

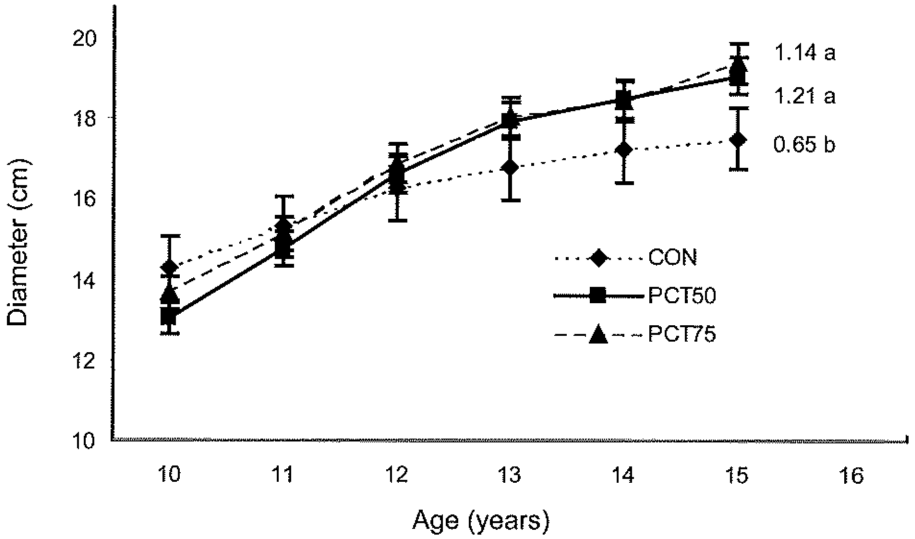

Figure 4. Mean eucalypt potential sawlog crop tree diameter (dbhob) for the 5-year measurement period. Bars show standard errors of the plot means (n = 3). Mean annual increments over the 5-year period (cm/yr) are shown for each treatment. Values with the same letter are not significantly different.

11 years to almost 6 m at age 14 years (data not shown). There were no significant differences in lowest green branch height among the treatments at either measurement.

Regime	Modelling Age		Stems/ha	BA (m^2/ha)	Merchantable yield (tonnes/ha)	Average tree yield (tonnes)
CON	25	standing	1840	48.0	217	0.12
CT only	25	retained	642	24.0	152	0.23
	25	removed	1198	24.0	65	0.05
PCT50	25	standing	809	35.2	238	0.29
PCT50CT	25	retained	324	17.6	135	0.41
	25	removed	485	17.6	104	0.21
PCT75	25	standing	491	28.2	196	0.40
PCT75CT	25	retained	175	14.1	111	0.63
	25	removed	316	14.1	85	0.27
PCT75	28	standing	474	32.4	249	0.54
PCT75 CT28	28	retained	171	16.2	137	0.80
	28	removed	303	16.2	112	0.37

Table 3. Eucalypt stand data modelled at age 25 or 28 years, and pulpwood yields following commercial thinning at those ages.

Eucalypt stand growth and mortality

Eucalypt mortality among the measured trees on each plot (apart from the injected trees) was nil for PCT75, 2% for PCT50 and 8% for CON during the measurement period. Those trees that died were predominantly suppressed trees. The changes in eucalypt stand basal area for all treatments over the 5-year measurement period are shown in Figure 3.

For the 5-year period following treatment, mean eucalypt stand BA increment in the PCT75 treatment was significantly lower than in either PCT50 or CON, which did not differ significantly from each other (F = 10.69, df = 2; P = 0.01).

Growth of eucalypt potential sawlog crop trees

Over the 5-year period, the mean annual diameter growth rates of the predicted eucalypt sawlog crop trees in both PCT50 (1.21 cm/yr) and PCT75 (1.14 cm/yr) treatments were significantly larger than those of the notional group of crop trees in the CON treatment (0.65 cm/yr), but were not significantly different from each other (F = 42.87; df = 2; P < 0.001) (Figure 4).

Growth of eucalypt pulpwood crop trees

Figure 5 shows the changes in mean stand BA over time for the predicted eucalypt pulpwood cohort. There was a steady increase in BA of both treatments, with that for the trees in the PCT50 treatment being greater than that for those in the CON treatment. However, the BA growth rates for the 5-year measurement period of the CON (0.62 m^2/ha/yr) and the PCT50 (0.92 m^2 /ha/yr) treatments were not significantly different (F = 0.29; df = 1; P = 0.63) when the initial mean BA measurement was used as a covariate in the ANOVA.

The group of eucalypts remaining on the PCT75 plots that were not identified as sawlog crop trees (generally about an additional 250 stems/ha) are not directly comparable with the eucalypt pulpwood cohort described above for the PCT50 and CON plots (600 stems/ha). However, they did show an increase in mean diameter of 5.2 cm over the measurement period (as compared with 3.7 cm for the eucalypt pulpwood cohort in PCT50 and 2.2 cm in CON). This indicates that these trees benefited considerably from the heavier BA removal in the PCT75 treatment.

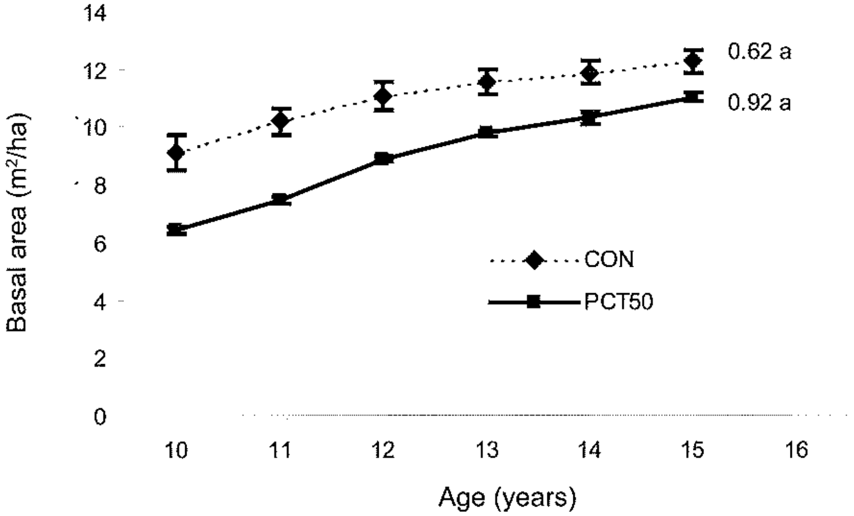

Figure 5. Mean basal area per ha for the eucalypt pulpwood crop trees over the 5-year measurement period. Bars show standard errors of the plot means (n = 3). Mean annual increments over the 5-year period (m^2/ha/yr) are shown for each treatment. Values with the same letter are not significantly different.

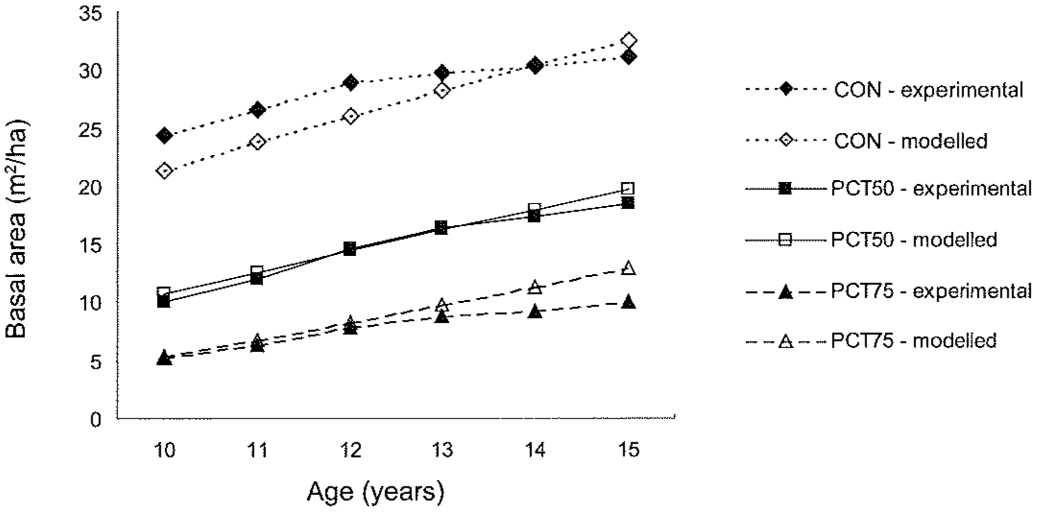

Figure 6. Experimental versus modelled stand basal area for each treatment.

Growth modelling results

Initial (pre-treatment) stand data from all nine of the experimental plots 9 years after establishment were used to model growth following each of the PCT treatments. The resultant model's characterisation of the stand at age 10-15 years compared with experimental results collected from the three plots actually measured for each treatment is shown in Figure 6. Modelled predictions of eucalypt stand BA in the three PCT treatments were compared to experimental results over the 5-year period following treatment. The two sets of results were consistent in the PCT50 treatment in all years and in the PCT75 treatment for the first three years, after which the modelled results exceeded those observed in the experiment. The two sets of results were more consistent in the CON treatment at the end of the 5-year period.

Pulpwood yields from a simulated CT at age 25 years were predicted to be 104 tonnes/ha when CT followed PCT50 (PCT50CT), 85 tonnes/ha when CT follows PCT75 (PCT75CT) and 65 tonnes/ha when CT was the only operation performed (CT) (Table 3). The PCT75CT regime was re-run with a CT at age 28 years (PCT75CT28) because at age 25 years the PCT75 plots were modelled as carrying a BA of 28.2 m^2/ha, which is below the Forestry Tasmania minimum standard BA of 32 m^2/ha for CT (Forestry Tasmania 2001). Thinning yields at age 28 years for the PCT75CT28 treatment were 112 tonnes/ha.

Modelled mean individual tree yields of pulpwood as predicted at age 25 years were 0.05 tonnes when CT was the only operation performed, 0.21 tonnes in the PCT50CT treatment, and 0.27 tonnes in the PCT75CT treatment, the latter increasing to 0.37 tonnes at 28 years (Table 3).

The number of retained stems following the modelled CT was 642 and 324 stems/ha in the regimes CT and PCT50CT respectively, and 175 and 171 stems/ha in the two iterations of the PCT75CT regime (Table 3).

Discussion

The impact of the PCT75 treatment on blackwood diameter growth rate was small (a 43% increase in growth rate over 5 years) but significant. Jennings *et al.* (2003) showed that increasing light availability to blackwood crowns increased tree diameter growth by up to 160% over a six year period. That study, located in another section of TG021A, involved removing all eucalypt competition from the stand, as well as removing understorey species in light wells of varying radius around each target blackwood. The eucalypt basal area reductions in the current PCT trial are much lighter, and only PCT75 resulted in any significant gain in blackwood diameter growth rate.

Jennings *et al.* (2003) also showed that high levels of light availability to blackwood crowns adversely affected their ability to shed branches and significantly reduced the height of the clear bole. The increase in light available to the understorey blackwoods in the current PCT experiment, in which the understorey species remained intact after the PCT operation, was insufficient to affect branch suppression (as measured by lowest green branch height) in either of the treatments. It therefore appears that it is not necessary to wait for the establishment of a clear blackwood bole to any particular height before a PCT operation can take place.

Swamp blackwood has been shown to increase diameter growth in response to thinning of blackwood at 40-50 years. When approximately 30% and 50% of live blackwood stems were removed from a 40-year-old swamp blackwood stand, Mesibov (1982) recorded mean annual diameter growth rates over the following two years of 0.4 cm/yr in unthinned plots, compared to 0.7 and 0.8 cm/yr for the retained trees in these two respective thinning treatments. When approximately 75% of the live blackwood stems were removed from a 45–55 year old stand, the mean diameter growth rate doubled from 0.45 cm/yr for trees in the unthinned plots to 0.9 cm/yr for retained trees in the thinned plots over two years (Mesibov 1981). The response of blackwood to thinning in the current experiment, presumably via increased light availability, is consistent with the increased blackwood growth resulting from the older swamp thinning.

The rotation length after thinning required for understorey blackwood to reach sawlog size is currently uncertain as no thinned stands have been grown to sufficient age. However, the combination of PCT and CT treatments of overstorey eucalypts may allow a relatively short rotation of about 70 years, by which time the best understorey blackwood trees should have reached millable size.

There is potential, however, for the blackwood crop to be unacceptably damaged during the eucalypt CT operation, because the eucalypts removed will be much larger than the understorey blackwoods retained. The *Pomaderris* layer below the blackwoods is also likely to be severely damaged during such an operation, and opening up the stand to this extent risks windthrow of the blackwoods. Another trial was established by Forestry Tasmania in 2002 with even heavier early thinning of the eucalypt overstorey, taking the eucalypt stocking down to 250 stems/ha at age 13 years. This one-off early thinning of the eucalypts should avoid the likely damage likely from a mid-rotation CT operation. Stands thinned using this prescription would not be scheduled for a CT, but rather allowed to grow on to a final rotation of 65-70 years.

Both thinned treatments (PCT50 and PCT75) in this experiment significantly increased diameter growth rates for the eucalypt potential sawlog trees that would be left after the subsequent CT. Interestingly, PCT75 imparted no more advantage to this cohort than did PCT50, indicating that the current operational PCT prescription of a 50% reduction of eucalypt BA is sufficient to release this component of the stand from competition. This is consistent with the results of La Sala (2006).

Productivity of the eucalypt component of these mixed eucalypt-blackwood stands, as quantified by mean annual BA increment, was not significantly affected by PCT50 but was decreased by PCT75, as found by LaSala (2006). This reflects the rapid increase in BA in the pulpwood cohort of the PCT50 plots, which was almost 50% faster than that in the CON treatment. The data thus indicate that the PCT50 treatment, which results in a retained density of approximately 500 stems/ ha, effectively releases both the interim pulpwood crop and the predicted final sawlog crop from competition. This is again consistent with the current Forestry Tasmania prescription for young eucalypt stands, which specifies the removal of no more than 50% of the original standing BA in a PCT operation, to a minimum of 16 m²/ha (Forestry Tasmania 2001).

Other prescriptions for thinning in eucalypt regrowth (Forestry Tasmania 2001) include a minimum removable volume of 70 tonnes/ha of pulpwood (although current operational experience suggests 100-120 tonnes/ha as a reasonable minimum for commercial viability), a minimum tree volume for thinnings of at least 0.2 m³, and damage rates on retained stems of <10%. These parameters generally result in a retention rate of 180-220 stems/ha and 16-20 m²/ha BA.

A density of 180 stems/ha corresponds to a between-tree spacing of approximately 8 m, which seems to be the minimum operating distance for machinery to keep damage levels within acceptable limits. The number of retained stems following a modelled CT was therefore impractically high in the regimes CT and PCT50CT (642 and 324 stems/ha respectively), but quite workable in both iterations of regime PCT75CT (175 and 171 stems/ha.

Pulpwood yields from a simulated CT at age 25 years can be considered just adequate when CT followed PCT50 (PCT50CT, 104 tonnes/ha), but insufficient when following PCT75 (PCT75CT, 85 tonnes/ ha) or when CT was the only operation performed (65 tonnes/ha). Thinning yields at age 28 years for the $PCT75CT_{28}$ treatment were 112 tonnes/ha, a small delay in harvest which may be offset financially by greater returns.

Modelled mean individual tree pulpwood yields at a commercial thinning (CT) at age 25 years were too small to be commercial in the CON treatment (0.05 tonnes), marginal in the PCT50CT treatment (0.21 tonnes), and adequate in PCT75CT (0.27 tonnes) (Table 3). Larger individual piece sizes increase the financial viability of removing pulpwood trees in a commercial thinning. The non-sawlog crop eucalypts retained in PCT75, although not directly comparable to the pulpwood cohort of the other treatments because of the smaller number of trees, also benefited considerably from heavy basal area reduction in terms of increased annual diameter increment.

The data presented here suggest that a 75% reduction in eucalypt basal area at an early (PCT) age (e.g. 10-15 years) in these mixed eucalypt-blackwood forests will significantly advantage both the final crop trees and the blackwoods. However, the modelling indicates that this will compromise overall eucalypt merchantable volume by almost 20% at age 25 years when compared to only 50% reduction in eucalypt basal area in the PCT operation. This loss of eucalypt productivity may be justified by the enhanced growth of the blackwood crop trees. The wider spacing of the eucalypts may also allow a subsequent CT, if scheduled, to be carried out with less damage to the blackwood understorey. Delaying the CT to age 28 years was also modelled and shown to allow merchantable volumes to be harvested from this regime commercially.

The following regime is therefore recommended for highly stocked (>1000 stems/ha) young eucalypt stands with high numbers (>500 stems/ha) of blackwoods where the management objectives include both enhancement of blackwood growth and commercial thinning of the eucalypt crop:

- PCT of 75% eucalypt basal area at age 10–15 years, followed by
- CT of 50% eucalypt basal area at age 30 years, and
- a final eucalypt crop tree stocking of no more than 200 stems/ha.

This preliminary prescription will be revised as growth models are developed and real costs become available for pre-commercial and commercial thinning in fenced-intensive blackwood stands. The current mortality rate of the blackwood saplings in the size class measured is extremely low, although some plots have a very high blackwood density (maximum of 1150 stems/ha). It is likely that coupes (or parts of coupes) that carry high blackwood densities would also require thinning of the blackwood to maintain good blackwood crown development and diameter growth rates.

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