Predicted growth response to pre-commercial thinning of *Eucalyptus obliqua* in southern Tasmania

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Abstract

A 16-year-old wet Eucalyptus obliqua / E. regnans *stand in Hays Road near Southport, Tasmania, was thinned to waste in 1999 using stem injection of glyphosate. An experimental trial was established to investigate growth response to pre-commercial thinning (PCT) of 0, 50% and 75% basal area (BA; m^2/ha) removals. Although slightly lower in site quality, the stand is similar to another stand thinned at age 16 years in 1983, 2.5 km away at Lovetts Road. Growth measurements taken over ten years following thinning at Lovetts Road were used to predict growth responses at Hays Road over the same period. Individual tree annual diameter increment advantage predicted for PCT was 0.93 cm and 1.4 cm for the 50% and 75% BA removal treatments respectively. Both PCT treatments produced growth responses which maintained stand BA increment. The unthinned and 50% BA removal stands were predicted to meet the basal area and pulpwood volume criteria set by Forestry Tasmania for commercial thinning ten years after PCT, at age 26 years. Approximately 160 m^3/ha of pulpwood could be removed from both types of stand at that time; the thinnings from the 50% BA removal stand would have an average tree diameter of 4.2 cm larger and an average pulpwood volume per tree of 0.14 m^3 greater than those from the unthinned stand. Retained trees were 4.7 cm and 0.19 m^3 larger respectively. Although recoverable pulpwood volume and basal area were comparable, the number of trees carrying this wood was too high in the previously unthinned stand to meet the criteria for retained stems/ha at the time of commercial thinning. It is therefore unlikely that the previously unthinned stand would actually be commercially thinned at this time. PCT at the 50% BA removal level has thus brought the commercial thinning, and a subsequent final harvest, forward in time.*

PCT at the 75% BA removal level has caused the greatest increase in size of retained trees but did not produce sufficient wood to enable a commercial thinning ten years later. Economic considerations are not discussed here but would form a key part of any decision regarding thinning regimes.

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Introduction

The principle of enhancing growth on final crop trees by removing competing trees around them has long been established in commercial thinning (Abbott and Loneragan 1983; Incoll and Webb 1970). The most common management objective of such a thinning is to maintain stand growth increments similar to those the stand would have achieved in its unthinned state, while concentrating wood production onto larger stems. Commercial thinning also serves to produce merchantable pulpwood earlier than the final harvest and to improve the sawlog: pulpwood ratio (Smith *et al.* 1997).

In recent years, early spacing of trees in areas of dense young eucalypt regrowth, dubbed 'pre-commercial thinning' (PCT), has been employed with similar objectives. PCT aims to prepare the stand for a subsequent commercial thinning and to

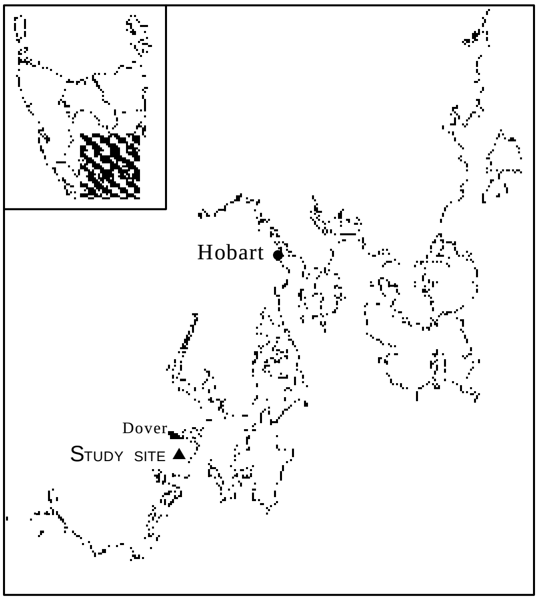

Figure 1. Location of the study site.

bring this harvest forward in time. This can be achieved by increased individual tree size, altered species composition, and reduced stocking which improves access for the commercial thinning (Connell and Raison 1996).

Following the signing of the Regional Forest Agreement in 1997, Forestry Tasmania (FT) set targets of 1000 ha/year for PCT of regrowth forest. The expectation is that these stands are likely to be suitable for commercial thinning within ten years of PCT (Forestry Tasmania 1998). Three research trials addressing growth response to PCT and fertiliser were established by FT in 1998 and 1999. Hays Road is one trial in the series and is the subject of this paper. These trials incorporated 0, 50% and 75% basal area (BA; m^2/ha) removal treatments. The 50% BA removal treatment is the standard FT operational prescription. The trials were designed to evaluate this prescription and to explore the effects of heavier thinning (75% BA removal) on stand and individual tree growth. Long-term results from these trials will not be available for many years. However, growth predictions which can help to evaluate the potential utility of PCT are needed as soon as possible.

This study used measured growth responses to thinning in a stand at Lovetts Road thinned in 1983 to predict growth responses in a nearby stand in Hays Road subjected to PCT in 1999. Both stands were even-aged eucalypt regrowth and were 16 years old when treated. Two levels of thinning intensity, approximating 50% and 75% BA removal, were evaluated. Unthinned control plots were established and maintained in both trials. The period of interest was the ten years following PCT. Predicted stand basal area, volume, and individual tree size at the end of this period (stand age 26 years) in PCT and unthinned stands were compared to the set of criteria used by FT when evaluating the suitability of stands for commercial thinning. These comparisons indicated the extent to which PCT can enhance the efficiency and profitability of later commercial thinning operations in lowland wet eucalypt forest.

Methods

Site descriptions

The two trials are located 2.5 km apart and are approximately 8 km south of Dover in southern Tasmania (Figure 1). The area receives about 1000 mm of rainfall per year. The forests have dense, wet sclerophyll understoreys, with soils derived from dolerite parent material. Site characteristics are given in Table 1.

Lovetts Road

This trial consists of ten plots, with two plots each in areas thinned to 500, 350, 250 and 150 stems/ha, and two plots left unthinned (Goodwin 1989). Thinned trees were felled to waste using chainsaws. The unthinned, 500 and 250 stems/ha treatments were used for the study reported here. They correspond to 0, 59% and 74% BA removal respectively.

Hays Road

This trial consists of 18 plots in three blocks. Each block contains two plots each which

Table 1. Site characteristics of the two study sites. (E. reg = Eucalyptus regnans, *E. obl* = E. obliqua, *E. glob* = E. globulus)

	Lovetts Road	Hays Road
Age at thinning (years)	16	16
Year of thinning	1983	1999
Method of thinning	chainsaw	stem injection
Aspect	south	north
Altitude (m asl)	320	240
Predominant species	*E. reg, E. obl, E. glob*	*E. obl, E. reg*
Site index[1]	44	40
Oldgrowth height potential[2]	E1	E2

[1] Mean height at age 50 years of the tallest 30 trees / ha.
[2] E1 represents a mature height potential of 55–76 m, and E2, 41–55 m.

Table 2. Stand characteristics at the two study sites before and after thinning. (Basal areas are m²/ha, DBHs are cm.)

	Lovetts Road retained stems / ha		Hays Road % total BA removal	
	500	250	50%	75%
Prior to thinning				
BA	33.6		24.8	
stems / ha	1700		1400	
DBH range	10.0–30.8		10.0–32.4	
After thinning				
% BA reduction	59	74	44[1]	67[1]
BA	13.8	8.8	14.2	8.3
stems / ha	484	291	550	288
mean DBH	18.4	18.3	17.8	18.9

[1] The prescribed BA removal levels, 50% and 75%, refer to the entire stand; the figures in the table refer to BA in stems greater than 10 cm DBH.

have been treated to remove 0, 50% and 75% of total BA. The BA reductions correspond to approximately 530 and 290 retained stems / ha respectively. On the unthinned plots, those trees which would have been retained under a 50% BA removal regime were identified. PCT was carried out using stem injection of glyphosate.

Thinning treatments

Basal area retention is expressed as the BA (m² / ha) present in the thinning treatments compared to that present in the unthinned controls at a given site (per cent). The 500 stems / ha retention treatment at Lovetts Road and the 50% BA removal treatment at Hays Road were used to evaluate the FT operational prescription (Table 2). The 250 stems / ha treatment at Lovetts Road and the 75% BA removal treatment at Hays Road were used to examine the effect of heavier thinning on stand and tree growth (Table 2). All stand characteristics reported refer to that portion of the stand consisting of stems greater than 10 cm in diameter over bark (DBH; cm), as this is considered to be the competing portion of the stand for this age group (Forestry Tasmania 1998). That portion of the stand greater than 17 cm DBH has also been considered separately for the age 26 years data because this is the portion of the stand considered 'merchantable' in terms of pulpwood, using current commercial thinning criteria.

Mortality

Tree mortality at Hays Road by age 26 years was simulated by using its measured incidence at Lovetts Road by treatment and diameter class between the ages of 16 and 26 years. Trees to be removed from the Hays Road dataset were chosen randomly within diameter classes before calculating the growth of remaining trees. For the unthinned stand, these were 12% of trees 10–15 cm DBH and 2% of trees 15–20 cm DBH. Some losses due to windthrow were recorded at Lovetts Road in the 500 and 250 stems/ha stands. These were felt to be due largely to site-specific factors; that is, the south-facing location close to the Southern Ocean and the physical removal of trees by chainsaw thinning, as opposed to the gradual loss of standing injected trees which can be expected at Hays Road. Therefore, windthrow was excluded as a source of mortality at Hays Road.

Diameter increment following thinning

Diameter growth following PCT was predicted separately for each treatment at Hays Road from measurements taken at Lovetts Road. Within each treatment, diameters at thinning at age 16 years of individual trees at Lovetts Road were plotted against their diameters at 2, 5, 10 and 15 years after thinning. Annual diameter increment began to decline with time ten years after thinning. Therefore, and because the period of interest for this study was the ten-year period after PCT, only the data for ages 16 and 26 years were used. Diameter at age 16 years was plotted against diameter at age 26 years for each treatment, and a separate simple linear regression fitted to each data set. These equations were applied to the diameters at thinning at Hays Road to predict individual tree size ten years after PCT.

Basal area

Individual tree BA was calculated using the diameters at age 16 years and the predicted diameters at age 26 years at Hays Road. This was converted to stand BA (m^2/ha) for the PCT and unthinned stands. Initial stand differences were investigated by growing on the nominated retained trees within the unthinned stand using the equations derived for the PCT stands, and comparing them to the results for the PCT stands themselves.

Height

Individual tree diameter (DBH) was plotted against total tree height (h; m) at Lovetts Road at age 16 and 26 years. The height-diameter relationships for all treatments were found to be virtually identical at age 16 years (immediately after treatment), so the datasets were pooled and a simple linear regression of height on the logarithm of initial diameter fitted to the combined dataset ($h = 8.7132 \ln(DBH) - 5.480$). This equation was used to estimate tree height for a small number of trees for which heights had been measured at Hays Road at age 16 years. The estimated heights approximated the measured heights extremely well, so the equation from Lovetts Road was used to estimate all tree heights at Hays Road at age 16 years. At age 26 years, the height-diameter relationship had differentiated among treatments at Lovetts Road, and therefore separate equations were derived. These treatment-specific equations were applied to the predicted diameters for Hays Road at age 26 years to estimate total tree height.

Volume

Volumes were calculated from measured or derived heights and diameters for individual trees at age 16 and 26 years at Hays Road using the VOLS97 program (Goodwin 1998). The first commercial thinning, especially in young stands, is generally considered a pulpwood removal. Therefore, pulpwood specifications were used in the program: a minimum DBH of 17 cm, a stump height of

0.3 m and a small-end diameter of 10 cm under bark. These individual tree volumes (m^3) were then converted to stand volumes (m^3/ha) for each treatment.

Simulated commercial thinning

Predicted stand characteristics at age 26 years of the areas which had and had not been subjected to PCT at age 16 years were compared to the FT criteria by which stands are assessed for their suitability for commercial thinning. Current FT policy and practice require a stand structure which enables the following: a minimum retained BA of 16 m^2/ha following a BA reduction of approximately 50%; at least 75 m^3 of merchantable wood available for removal; a maximum retention of 250 stems/ha; average retained tree size of at least 0.2 m^3; and 80% of retained trees containing at least a 3 m length of potential sawlog (Forestry Tasmania 1998). All these criteria refer to that component of the stand greater than 17 cm DBH only, as this is considered to be the minimum merchantable size for pulpwood.

If a treatment's predicted stand characteristics met these criteria, the stand was subjected to a simulated first commercial thinning. All trees which had been graded at age 16 years as pulp or short potential sawlog were removed first. In the unthinned stand, all trees which had not been nominated as retainers at age 16 years were removed next. A random number generator was then used to identify trees for removal until 16 m^2/ha retained BA was reached in each stand.

Results

Tree diameter

Predicted mean DBH at age 26 years for trees in the 50% BA removal stand was 4.0 cm greater than for the nominated retainers in the unthinned stand, and 9.3 cm greater than for all trees in the unthinned stand (Table 3a). Mean DBH at age 26 years for trees in the 75% BA removal stand was 8.8 cm greater than for the nominated retainers in the unthinned stand and 14.1 cm greater than for all trees in the unthinned stand. This represents an approximate doubling and tripling of diameter increment over ten years in the two treated stands respectively, compared to the unthinned stand. Virtually all trees in both PCT stands were of potentially merchantable size for pulpwood (Table 3b).

Stand basal area

At age 26 years, the unthinned stand had the greatest predicted basal area (Figure 2). However, the basal area increments of the two thinned stands were greater than those of the unthinned stand. Stand basal area of notional retainers in the unthinned stand was comparable (21.6 m^2/ha) to that of the 50% BA removal treatment when grown on using the equations derived for the latter. The exclusion of stems less than 17 cm DBH reduced the unthinned stand's BA by 7.3 m^2/ha to 35.8 m^2/ha at age 26 years, thus reducing its merchantable BA to a level equivalent to that of the 50% BA removal stand (36.9 m^2/ha). The 75% BA removal stand was not carrying sufficient wood at age 26 years to allow a 50% BA reduction to 16 m^2/ha in a simulated commercial thinning.

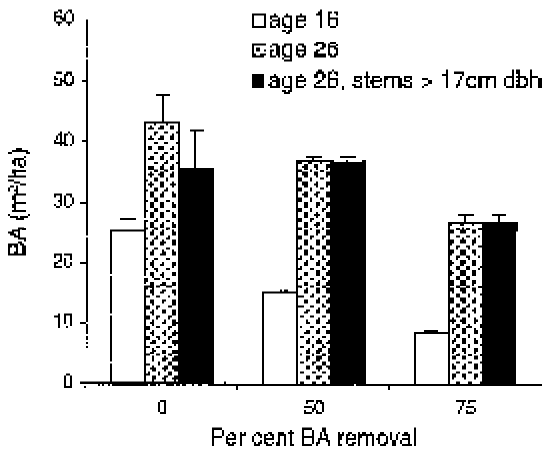

Figure 2. Stand basal area for an unthinned stand and two thinning treatments at age 16 years (actual measurements) and age 26 years (predicted values).

Table 3. Hays Road. (a) Diameter before PCT (age 16 years) and predicted values ten years after PCT (age 26 years), by treatment. Figures are treatment means with standard errors in brackets (n = 3). (b) Extractable pulpwood volume estimated using VOLS97 (Goodwin 1998).

(a) Diameter

Age (years)	DBH (cm) 16	DBH (cm) 26	Increment (cm)
Unthinned	15.3 (0.71)	19.8 (1.3)	4.5
Retainers in unthinned	18.3 (0.76)	25.1 (1. 8)	6.8
50% BA removal	18.5 (0.28)	29.1 (0.5)	10.6
75% BA removal	18.8 (0.85)	33.9 (1.4)	15.1

(b) Extractable pulpwood volume

Age (years)	Pulpwood volume (m^3/ha) 16	Pulpwood volume (m^3/ha) 26	Pulpwood volume (m^3/tree) 16	Pulpwood volume (m^3/tree) 26
Unthinned	74.9 (20.1)	286 (60)	0.2 (0.01)	0.42 (0.01)
Retainers in unthinned	60.6 (13.2)	219 (26)	0.19 (0.02)	0.46 (0.08)
50% BA removal	62.5 (2.16)	294 (3)	0.18 (0.01)	0.56 (0.03)
75% BA removal	36.8 (5.17)	211 (16)	0.17 (0.01)	0.73 (0.07)

Volume

At age 26 years, predicted pulpwood volumes in the unthinned and 50% BA removal stands were comparable (286 vs 294 m^3/ha, respectively) and both carried more merchantable wood than the 75% BA removal stand (211 m^3/ha) (Table 3b). Merchantable trees in the 50% and 75% BA removal stands were on average 0.14 m^3 and 0.31 m^3 larger, respectively, than those in the unthinned stand.

Simulated commercial thinning

The predicted stand characteristic of the unthinned and 50% BA removal stands met the FT suitability criteria for commercial thinning. Following the simulated commercial thinning at age 26 years, the retained trees in the 50% BA removal stand were on average 4.7 cm larger in DBH and contained 0.19 m^3 more pulpwood than retained trees in the previously unthinned stand (Table 4). The trees extracted at the time of commercial thinning from this previously unthinned stand were greater in number and 25% smaller in size than those from the 50% BA removal stand, although virtually the same volume of pulpwood was removed (158 vs 164 m^3/ha respectively) (Table 4).

Discussion

Predicted responses to PCT indicated increases in individual tree growth and maintenance of stand growth rate at Hays Road. Enhanced growth of retained trees due to early thinning has been reported previously in *Eucalyptus sieberi* (Hescock 1995; Kerruish *et al.* 1993), *E. regnans* (Incoll and Webb 1970; West 1991) and *E. obliqua* (Brown 1996).

Most prescriptions designed for commercial-age thinning aim to remove 50% of the stand's total basal area (CNR Victoria 1992; Forestry Tasmania 1998), a level which should both increase individual tree growth and maintain overall wood production

Table 4. Stand characteristics at Hays Road following a simulated commercial thinning at age 26 years. Figures are treatment means, with standard errors in brackets (n = 3). Data refer to that component of the stand greater than 17 cm DBH only.

	stems/ha	DBHob (cm)	BA (m^2/ha)	Pulpwood volume (m^3/ha)	Pulpwood volume (mean; m^3)	Mean tree volume (m^3)
Retained after commercial thinning						
non-PCT	285 (21)	26.2 (1.2)	16.1 (1.7)	129 (20)	0.45 (0.07)	
50% BA PCT	204 (7)	30.9 (1.1)	16.1 (1.6)	130 (16)	0.64 (0.06)	
Removed in commercial thinning						
non-PCT	393 (104)	24.0 (1.3)	19.8 (6.7)	158 (58)		0.39 (0.07)
50% BA PCT	318 (35)	28.2 (0.3)	20.8 (2.2)	164 (18)		0.52 (0.02)

(Incoll and Webb 1970). Critical basal area (CBA) has been defined as the (retained) basal area for which gross BA increment following thinning (i.e. excluding attrition) is 95% of maximum (Assmann 1961). Maximum BA increment is derived from that of the unthinned stand. CBA is approximately 56% BA removal for the component of the stand greater than 10 cm DBH in eucalypt regrowth stands in Tasmania (Goodwin 1990). This was the case at Lovetts Road after thinning at age 16 years, where the 500 stems/ha stand (59% BA removal) was able to maintain virtually the same BA increment as the unthinned stand over the ten years following thinning (unpublished data).

At Hays Road, the 50% removal of total BA at age 16 years resulted in a 44% BA reduction of the component of the stand greater than 10 cm DBH. Similar reductions have occurred in many stands of similar ages treated with PCT operationally using this prescription. The estimated BA increment at Hays Road in the ten years following PCT was slightly greater in the 50% BA removal stand than in the unthinned stand. This result may be attributable to either the assumptions regarding mortality (attrition in the unthinned stand only), or to the use of equations based on growth of individual trees at Lovetts Road which has a slightly higher site quality and had a slightly heavier BA removal. However, it would appear that a BA removal of 44% at age 16 (lighter than CBA) has reduced competition for resources sufficiently to produce a thinning response.

Goodwin (1990) posited that the strong response of young stands to thinning might be short-lived, necessitating a second thinning. However, given that a commercial thinning is generally planned to follow PCT as soon as practicable, it should be possible to maintain stand growth increment by repeated thinnings. PCT enables earlier recovery of pulpwood and compounds the growth advantages attributable to competition removal.

Webb and Incoll (1969) reported that gross BA increment in *E. regnans* stands younger than 30 years varied widely in response to thinning, and that in some cases thinning more heavily than 50% BA removal was possible without compromising overall wood production. At Hays Road, 75% BA removal produced approximately the same amount of wood in the ten years following PCT as either no thinning or 50% BA removal. No overall loss in stand productivity was observed. This treatment also resulted in the greatest growth on individual trees. However, by age 26 years, the stand was not carrying sufficient BA to be suitable for a commercial thinning. Thus, although this treatment maintains stand BA increment, it does not allow a commercial thinning to be brought forward. An alternative strategy following 75% BA removal would be to forfeit the income from an interim pulpwood crop and leave the stand to grow on until it reaches sawlog proportions.

PCT's greatest value lies in its long-term effect of preparing a stand for commercial thinning. During a commercial thinning in *E. sieberi* stands in Victoria 22 years after an early spacing, commercial thinning costs had been reduced by about 20%, pulpwood yield increased by 30%, and the size of retainers increased by 60% in comparison to an unthinned adjacent area (Raison *et al.* 1995). At Hays Road, the size of trees retained after the simulated commercial thinning was greater in the stand which had been subjected to PCT than in the previously unthinned stand, as was the size of trees removed. The lack of increase in pulpwood yields over those from the unthinned stand at this site is most likely due to the shorter amount of time between thinnings (ten years). The pulpwood in a stand which has been subjected to PCT is distributed on fewer stems and is growing in a forest that will have improved access and thus reduced extraction costs and operational damage. In addition, both mill-door value and wood quality have been shown to increase with increased tree diameter (Roberts and McCormack 1991; Smith *et al.* 1997; Waugh and Rozsa 1991).

The potential utility of PCT can be evaluated in terms of its effectiveness as a stand preparation tool for subsequent commercial thinning. When notionally thinned to a retained BA of 16 m^2/ha at age 26 years, the PCT stand met all the FT criteria for stand suitability for commercial thinning. The previously unthinned stand met all the criteria except the maximum allowable retained stems/ha requirement of 250; 286 trees were needed to carry the 16 m^2/ha BA. Therefore, although recoverable pulpwood volumes from the two stands are comparable, it is unlikely that the unthinned stand would actually be commercially thinned until the target for less than 250 retained stems/ha could be met on trees of sufficient size to carry the requisite BA. One effect of PCT at the 50% BA removal level has thus been to bring the age of commercial thinning, and the revenues produced, forward. The flow-on effect of being able to commercially thin earlier is that final harvest will also be brought forward.

The scheduling of thinning is an economic decision depending upon a number of factors, including cost of PCT, net economic benefit of subsequent commercial thinnings, and length of rotation.

Conclusions

The operational prescription for the removal of 50% of total BA developed for broadscale PCT achieved the objectives of enhancing the growth of crop trees, maintaining stand BA increment, and enabling a commercial thinning within ten years of PCT when growth estimates from Lovetts Road were applied to the Hays Road experiment. Ongoing monitoring of this and the two other PCT experiments is needed to verify these results. Furthermore, it should be noted that both sites used in this study are of quite high quality; results cannot necessarily be extrapolated to poorer quality sites. Results from the two intensities of PCT applied at Hays Road indicate that a higher level of BA removal would probably not compromise overall stand growth rates relative to unthinned areas but may defer the timing of subsequent commercial thinning.

A variety of wood production goals could be addressed by varying the intensity of BA removal during PCT. Intensities closer to 50% BA removal could provide an early pulpwood crop and a later crop of sawlogs, whereas intensities closer to 75% BA removal could possibly provide a medium-term crop of small sawlogs and large pulp trees, and/or a later crop of large sawlogs.

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