

Long-term response of *Eucalyptus regnans* F.Muell. to commercial thinning in a regrowth eucalypt forest in Tasmania

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Summary

A 24-y-old stand of *Eucalyptus regnans* (F.Muell.) in the Plenty Valley, Tasmania was thinned to residual basal areas of about 14, 21 and 28 m² ha⁻¹, representing basal area reductions of 65%, 50% and 33% (heavy, moderate, and light thinnings). Unthinned control plots were also established. Mean stand basal area in the light thinning plots was equivalent to that of the unthinned plots within about 20 y of thinning, and in the moderate thinning plots within about 30 y. At age 55 y, 31 y after thinning, stand basal area in the heavy thinning plots was about 8 m² ha⁻¹ (about 17%) less than in the unthinned plots. Increment advantages over the controls of 0.59, 0.47 and 0.44 m² ha⁻¹ y⁻¹ were related to moderate, heavy, and light thinning respectively. Although there were no significant differences ($P \leq 0.05$) among treatments, mean diameter for the largest 150 stems ha⁻¹ increased with heavier thinning. Mean net merchantable volume increments and sawlog volumes in all three thinned treatments exceeded those in the unthinned plots, and sawlog volume relative to total volume increased consistently with increased thinning intensity. The moderate thinning plots experienced negligible mortality, produced comparable basal area and more merchantable volume than the unthinned plots, and resulted in increased individual tree sizes and total sawlog volume. This was the only treatment which provided improvement for all these parameters over the 'do nothing' (unthinned) option.

Keywords: native forests; silviculture; thinning; stand density; increment; log size; mortality; *Eucalyptus regnans*; Tasmania

Introduction

In recent decades, the silviculture practised in regrowth eucalypt forests in Tasmania has become increasingly focused on the recovery of high-value products using shortened rotations, with expectations that thinning could reduce rotation length from 90 to 65 y (Whiteley 1999). Thinning at both pre-commercial and commercial stages has been employed to improve the structure and growth rate of native eucalypt stands by concentrating wood production onto larger stems which potentially contain sawlog material. These strategies are designed to prepare the stand for an eventual clearfell, and therefore specifically aim to maintain sufficient canopy cover to discourage regeneration, and sufficient

standing wood to enable a clearfell harvest about 40 y after a single commercial thinning. Productivity of a stand can be gauged as mean annual increment (MAI), with the age of peak MAI considered the age of peak productivity. When the MAI of a stand has begun to decline, silvicultural intervention such as thinning may be appropriate to boost stand productivity (Smith *et al.* 1997).

The inherently long-term nature of stand-growth studies means that although numerous workers have reported positive growth responses of eucalypts to thinning (Goodwin 1990; Kerruish and Rawlins 1991; Stoneman *et al.* 1996; Brown 1997; Connell *et al.* 1997; LaSala 2000), few studies have been able to follow long-term responses to thinning until stands approach rotation age (Connell *et al.* 2004). This paper documents an experiment established in 1968 in the Plenty Valley, Tasmania (GDA94 E490060 N5258350) near the site where the Chestermans Sawmill once stood. Australian Newsprint Mills, as it was then known, established the plots in a dense stand of 1946 fire-generated regrowth to determine the effect of thinning on volume production. The company's 1968/1969 Annual Report noted

Measurements to date indicate that most of the trees under 8" (20 cm) DBH have ceased active growth and are in the process of dying out through suppression. The bulk of the thinning yield will be of this suppressed class.

In this study, a 24-y-old stand of *Eucalyptus regnans* (F.Muell.) was thinned to three different thinning intensities in 1970, and unthinned control plots were also established. This paper quantifies the long-term growth responses to thinning at the Chestermans site, and relates them to those observed in similar stands elsewhere.

Methods

Study site

The experiment was established on an orange-red clay soil on dolerite parent material at 475 m asl. The forest consisted of a dense young *E. regnans* stand with small amounts of wattle (*Acacia dealbata*). The understorey was open and dominated by *Pteridium esculentum* (bracken fern). The site quality is high, with dominant trees averaging 45 m in height at age 50 y.

Experimental design

Transects were used to quantify the structure of the stand in 1968, and formal measurement plots established and measured in 1970 both before and after thinning. The experiment consists of eight plots, two for each thinning treatment (heavy, moderate and light) and two plots which were left unthinned. The records do not say how treatments were assigned to plots, but presumably the allocation was at random: no bias or systematic pattern is apparent. Each square plot measures 31.3 m × 31.3 m (0.098 ha), these dimensions having been converted from the original measured in the imperial system. The plots are surrounded by buffers of unthinned forest 8–35 m wide. The *A. dealbata* comprised only 3% of the original volume of the stand, and was almost entirely removed in the thinning.

Stand basal area was calculated for each plot at the start of the experiment using all *E. regnans* and *A. dealbata* stems >10 cm in diameter over bark at 1.3 m above ground level ('diameter' hereafter). The thinning treatments aimed to retain residual stand basal areas (BA) of 14, 21 and 28 m² ha⁻¹ from an initial mean stand BA across treatments of 38.6 m² ha⁻¹.

Measurement

At the start of the experiment, diameters of all trees (as defined above) were measured just before thinning, and records made of which trees had been retained. Subsequent measurements were taken at 2, 4, 13, 18, 23, 26 and 31 y after thinning, corresponding to 26, 28, 37, 42, 47, 50 and 55 y of age; no new trees which would have represented ingrowth (Curtin 1970) were included. Heights were measured for a selection of trees across the range of diameters at each measurement.

A one-way analysis of variance (ANOVA) detected no significant differences ($P \leq 0.05$) in stand BA among treatments at establishment. BA increments (BAINC) from the time of thinning were analysed without the introduction of a covariate or any other adjustment. Net BA, which incorporates losses due to mortality (Goodwin 1990), was used in all cases.

Eucalypt crop trees were ranked just after thinning into four groups within each treatment: the largest 100 stems per hectare (sph), then trees ranked 101–150, 151–200 and 201–250 on the basis of decreasing diameter. (The 201–250 group was omitted for the heavy treatment due to insufficient numbers of trees.) A one-way ANOVA detected no significant differences ($P \leq 0.05$) among treatments in mean diameter for each of these ranked groups at establishment. Mean diameters across the experiment

were 32.2, 27.3, 25.6 and 17.5 cm for trees ranked 1–100, 101–150, 151–200 and 201–250 respectively. This ranking procedure was repeated at each measurement, with a small number of trees moving between rank groups each time.

Volume calculation

Merchantable volumes were calculated for each tree using taper models and volume equations developed by Forestry Tasmania (A. Goodwin, Forestry Tasmania, *pers. comm.* c. 2002). A stump height of 0.3 m, a top diameter under bark of 10 cm and measured heights from within each treatment were used. These volumes were then summed for each plot and averaged by treatment. Stand volumes before and after thinning were used to calculate thinning yield. This same method was used at each re-measurement to calculate total stand merchantable volume. Net stand volume increment was calculated as the difference in merchantable volumes between 1970 and 2001. Gross volume increment was calculated as the difference between merchantable volume in 1970 and the maximum volume standing at any time during the experiment, regardless of any mortality which had occurred by 2001. Heights above the stump for different products were assessed by eye in the field at age 55 y, and were used to calculate standing pulpwood and sawlog volumes. Mean diameter, merchantable volume, and sawlog volume were calculated for each ranked group of crop trees for each treatment at age 55 y.

Results

Stand characteristics for each treatment before and after thinning are given in Table 1. Actual retained BAs of 14.1, 18.6, and 26.7 m² ha⁻¹ were achieved in the heavy, moderate and light treatments respectively, representing corresponding reductions in BA of 65%, 50% and 33%.

Initial stand volumes and thinning yields are presented in Table 2, basal area increments in Table 3, and gross volume in Table 4.

Stand basal area increments

There were no significant differences among treatments ($P = 0.11$) for net BAINC over the 31-y study period (Table 3). BAINCs in five out of six of the thinned plots ranged from about 20 to 29 m² ha⁻¹, whereas the two unthinned plots had BAINCs which, although quite different to each other, had a mean of 6.8 m² ha⁻¹. The low stand BAINC (14.7 m² ha⁻¹) for Plot 1 (light treatment) is partly a result of unauthorised tree-cutting which occurred late in the experiment.

Table 1. Mean diameter (cm), number of stems per hectare (sph), basal area (BA; m² ha⁻¹) by treatment just before and just after thinning at age 24 y. (Standard error of the mean is given in brackets; $n = 2$ in all cases.)

Treatment	Pre-thinning			After thinning		
	Diameter	sph	BA	Diameter	sph	BA
Heavy	20.1 (0.62)	1168 (66)	40.7 (0.05)	29.2 (0.27)	204 (0.0)	14.1 (0.35)
Moderate	20.0 (0.28)	1097 (127)	37.4 (2.95)	26.4 (0.62)	357 (20.4)	18.6 (0.56)
Light	19.6 (0.69)	1224 (112)	40.2 (0.46)	24.5 (1.38)	556 (56.1)	26.7 (0.35)
Unthinned	19.0 (1.13)	1188 (97)	36.2 (2.83)	19.0 (1.13)	1188 (97)	36.2 (2.83)

Table 2. Mean merchantable volume by treatment just before and just after thinning at age 24 y, and thinning yields ($\text{m}^3 \text{ha}^{-1}$). (Standard error of the mean is given in brackets; $n = 2$ in all cases.)

Treatment	Merchantable volume ($\text{m}^3 \text{ha}^{-1}$)		
	Prior to thinning	After thinning	Thinning yield
Heavy	313 (0)	130 (0.74)	183
Moderate	286 (22)	178 (0.06)	108
Light	302 (7)	235 (6.48)	67
Unthinned	279 (26.3)	279 (26.3)	0

Table 3. Stand basal area by plot, before and after thinning and at age 55 y, and net basal area increment (BAINC) for the 31-y experimental period

Treatment	Plot	Stand basal area ($\text{m}^2 \text{ha}^{-1}$)			
		1970		2001	BAINC 1970–2001
		Pre-thinning	After thinning		
Heavy	4	40.6	14.3	36.5	22.2
	7	40.7	13.8	34.5	20.7
	Mean	40.7	14.1	35.5	21.5
Moderate	2	34.4	18.2	39.7	21.5
	8	40.3	19.0	47.8	28.8
	Mean	37.4	18.6	43.7	25.1
Light	1	40.7	26.9	41.6	14.7
	5	39.8	26.4	52.7	26.3
	Mean	40.2	26.7	47.2	20.5
Unthinned	3 ^a	38.2	38.2	40.9	2.7
	6	34.2	34.2	45.2	11.0
	Mean	36.2	36.2	43.0	6.8

^aThe reason for the poor growth of Plot 3 is not apparent, but may be associated with soil compaction caused by logging operations. The plot is adjacent to an old logging road, which is on a low ridge. Plot 6, about 50 m away, is at a slightly lower altitude.

Table 4. Mean standing merchantable volume by treatment in 1970 and 2001, and gross and net increments in merchantable volume between these years. (Standard error of the mean is given in brackets; $n = 2$ in all cases.)

Treatment	1970 Standing merchantable volume ($\text{m}^3 \text{ha}^{-1}$)	Increment in merchantable volume 1970–2001		2001 Standing merchantable volume ($\text{m}^3 \text{ha}^{-1}$)	Total production ^a of merchantable volume over 31 y ($\text{m}^3 \text{ha}^{-1}$)
		Gross ($\text{m}^3 \text{ha}^{-1}$)	Net ($\text{m}^3 \text{ha}^{-1}$)		
Heavy	130 (0.74)	311 (18.0)	295 (10.5)	425 (11.4)	608
Moderate	178 (0.06)	374 (36.5)	368 (40.5)	546 (40.0)	654
Light	235 (6.48)	361 (61.0)	320 (83.0)	555 (89.5)	622
Unthinned	279 (26.3)	312 (8.0)	210 (40.5)	489 (14.5)	489

^a1970 thinning yield (Table 2) plus 2001 standing merchantable volume

The lack of significant differences among treatments for BAINC, and for other parameters reported below, may reflect the minimal replication in the experimental design together with damage sustained by Plot 1 and the large difference between the growth of the two unthinned plots, rather than the absence of any genuine response to treatment.

Increases in net stand BA over time for each treatment are shown in Figure 1. The three thinned treatments displayed similar

patterns of growth over time, with their most rapid growth starting at the time of thinning and continuing for about 13 y and contributing about $1 \text{ m}^2 \text{ha}^{-1} \text{y}^{-1}$ of BA. In contrast, the rate of increase in BA in the unthinned plots was much less, and fell below that of the other treatments markedly within 4 y following thinning. Light thinning plots had stand BA levels equivalent to the unthinned plots about 15 y after thinning ($\approx 40 \text{ m}^2 \text{ha}^{-1}$), as did moderate thinning plots after about 30 y ($\approx 43 \text{ m}^2 \text{ha}^{-1}$). Heavy

thinning plots had a similar stand BA increment (BAINC) to light thinning plots over the life of the experiment, but still carried about 8 m² ha⁻¹ (≈17%) less BA than the unthinned plots at age 55 y. Absolute BAINCs for this period were 25.1, 21.5, 20.5 and 6.8 m² ha⁻¹ for moderate, heavy and light thinnings and unthinned plots respectively, and notably do not decrease directly with thinning intensity. The increments in the thinned treatments represent corresponding advantages over the unthinned plots of 0.59, 0.47, and 0.44 m² ha⁻¹ y⁻¹, for treatments in above order.

Merchantable volume increments

Increases in net merchantable volume over time for each treatment are shown in Figure 2. As for BA, the most rapid increases in volume in the thinned treatments occurred in the first 13 y after thinning, with the rate of volume production in the thinned treatments markedly increasing over that of the unthinned plots within about 4 y. After 26 y, the moderate and light thinning treatments had exceeded the unthinned plots in standing merchantable volume by about 60 m³ ha⁻¹.

Gross stand merchantable volume increments following thinning were similar across treatments, ranging from 311 m³ ha⁻¹ in the heavy thinning and unthinned plots to about 370 m³ ha⁻¹ in the moderate and light thinning plots (Table 4). Net increments in merchantable volume were more disparate, with far less of the unthinned plots' gross volume increment surviving until age 55 y than in the three thinned treatments (67% vs 89–98%). Standing merchantable volume in 2001 was greatest in the light (555 m³ ha⁻¹) and moderate (546 m³ ha⁻¹) thinning treatments.

Standing sawlog volumes and the proportion of stand merchantable volume composed of sawlog increased with heavier thinning intensity, with trees in all three thinned treatments containing about 50–100 m³ ha⁻¹ more sawlog than those in the unthinned plots 31 y after thinning (Table 5). The ratio of sawlog volume to total volume increased consistently with heavier thinning, with 25% more volume being sawlog in the heavy treatment than in the unthinned.

Growth of ranked groups of crop trees

Mean diameter at age 55 y for the largest 150 crop trees was larger in each successively heavier thinning treatment (Fig. 3), although there were no significant differences among treatments for ranking group ($P = 0.162$ for ranked group 1–100 and $P = 0.724$ for ranked group 101–150). Mean diameters for crop trees ranked 151–200 in the moderate and light thinning treatments were larger by about 5 cm than those for the same ranked group in the heavy thinning treatment, and mean diameter for crop trees ranked 201–250 in the light treatment were larger by about 2 cm than those for the same ranked group in the moderate treatment.

Similar patterns among treatments were observed for mean merchantable volume per tree in trees ranked 151–200 ($P = 0.597$) and 201–250 (Fig. 4), and for mean sawlog volume per tree (not shown) for trees ranked 151–200 ($P = 0.599$). Mean individual merchantable tree volumes for trees ranked 1–100 increased with heavier thinning ($P = 0.231$), and for trees ranked 101–150 all three thinned treatments held similar, non-significant volume advantages over the unthinned plots (≈0.3 m³ ha⁻¹).

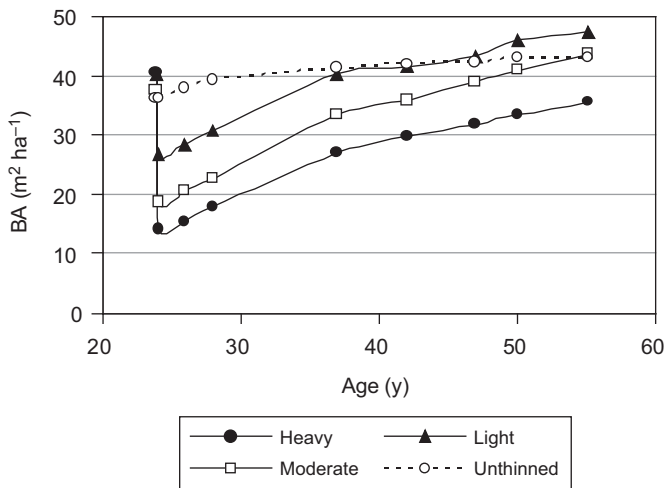


Figure 1. Mean stand basal area (BA) for treatments over time

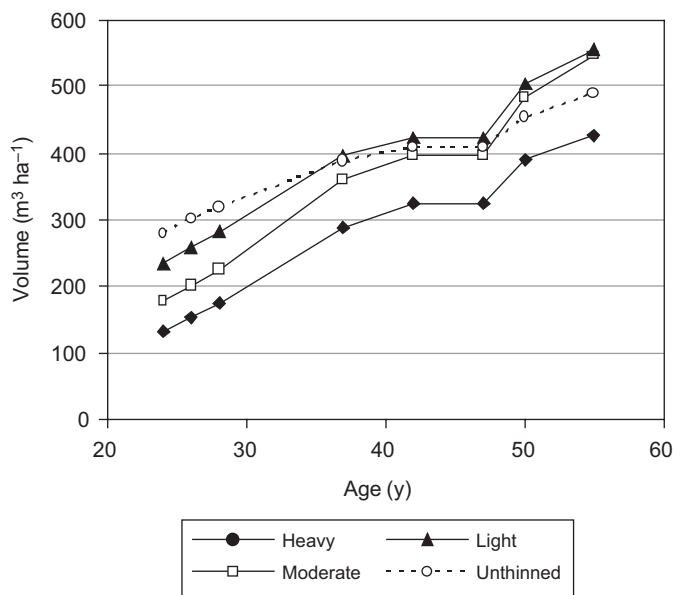


Figure 2. Mean merchantable volume for treatments over time

Table 5. Mean standing sawlog volume and fraction of volume composed of sawlog in 2001 (age 55 y), by treatment. (Standard error of the mean is given in brackets; $n = 2$ in all cases.)

Treatment	Standing sawlog volume (m ³ ha ⁻¹)	Fraction of volume composed of sawlog (%)
Heavy	240 (45.8)	56
Moderate	225 (26.3)	45
Light	197 (24.0)	37
Unthinned	147 (0.6)	31

Mortality

Loss of standing trees due to mortality was negligible in the heavy and moderate thinning treatments. About 20% of stems were lost in the light thinning treatment and about 60% in the unthinned treatment over the 31 y. This loss of trees in the unthinned plots was most rapid in the first 15 or so years following thinning, but did continue steadily in the second half of the experiment (Fig. 5).

Discussion

Increase in growth rates

Increased growth rates in the thinned plots, as measured by larger BAINCs, volume production and MAIs, demonstrate a release from competition. In contrast, growth in the unthinned plots was relatively static throughout the experimental period, and these plots continued to experience tree mortality through suppression. These observations indicate that the stand was fully utilising the site resources at the time of thinning. Stand basal area increment was not reduced by thinning even in the first years after treatment, a result also reported by Connell *et al.* (1997).

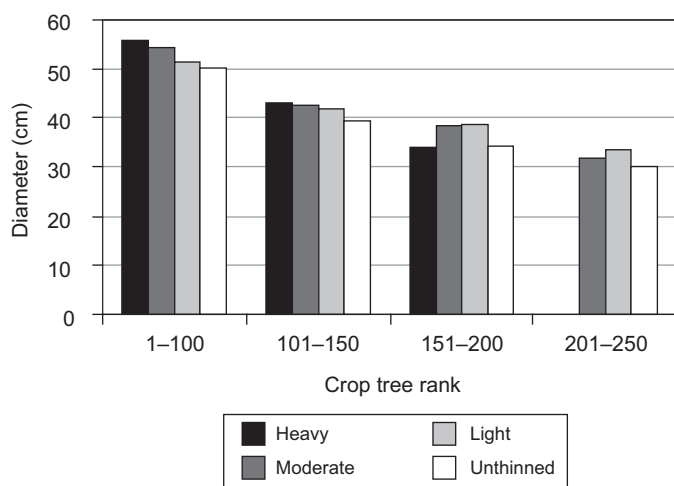


Figure 3. Mean diameter (dbh) for individual trees within ranked groups, shown as treatment means at age 55 y

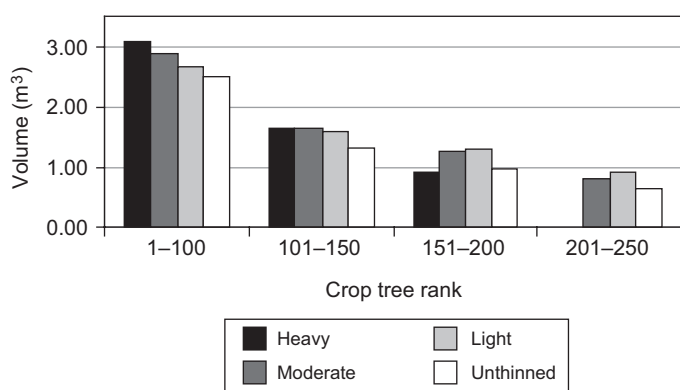


Figure 4. Mean merchantable volume for individual trees within ranked groups, shown as treatment means at age 55 y

The advantage conferred by thinning was most apparent in the largest 150 sph. Larger trees seem to have benefited more from heavy thinning, whereas smaller trees have benefited more from lighter thinnings. It would appear that any thinning-induced acceleration of dominance in crown-shy *E. regnans* (Florence 1996) is allocated first to the largest trees, with trees ranked 151 and larger responding similarly when competing with released dominants in the heavy thinning treatment or with all other trees in the unthinned treatment (Figs 3 and 4). Horne and Robinson (1990) reported a similar result, in which the largest 50 sph *E. delegatensis* R.T.Bak. trees displayed a positive response to thinning, while trees ranked 101–150 in thinned stands were significantly smaller than their counterparts in unthinned plots.

Comparisons with other regrowth stands

Although unthinned plots at Chestermans carried basal areas for age at the lower end of the range observed by Wang and Hamilton (2003) on ten plots of *E. regnans* in Victoria, the trends observed here are not dissimilar to those seen in other stands of young, wet sclerophyll regrowth. Thinned plots in even-aged stands of young *E. regnans* in the Florentine Valley, Tasmania (La Sala, unpublished Forestry Tasmania data) and near Toolangi, Victoria (Webb and Grose 1962) produced BAINC advantages over their respective controls similar to those observed at Chestermans (0.4–1.2 m² ha⁻¹ y⁻¹, depending on treatment). The results of this study should therefore be relevant in planning thinning operations for other wet sclerophyll sites and in evaluating current prescriptive practice.

Commercial thinning as practised by Forestry Tasmania targets stands between the ages of 25 and 40 y with a minimum BA of 32 m² ha⁻¹ (Forestry Tasmania 2001). A 50% BA reduction is prescribed, thinning to a residual BA of no less than 16 m² ha⁻¹ to be carried on 180–220 sph (Forestry Tasmania 2001). In Victoria, stands aged 20–40 y carrying at least 30 m² ha⁻¹ BA are targeted, to be thinned using a 50% BA reduction to no less than 17 m² ha⁻¹ (Department of Natural Resources and Environment 1997). At Chestermans, pre-thinning BA and tree

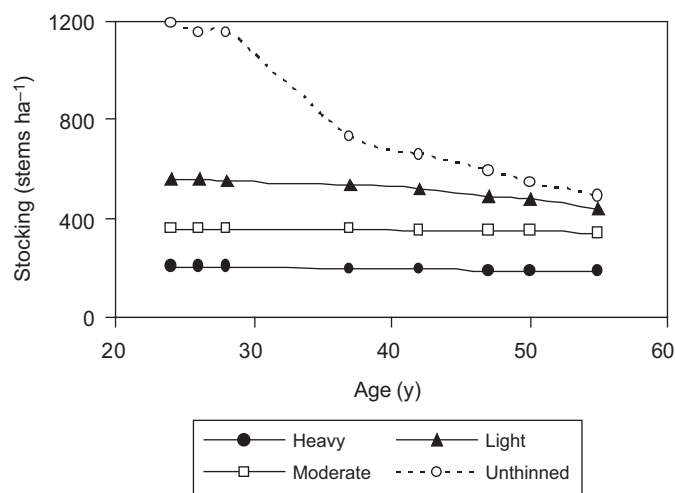


Figure 5. Stacking indicating stand mortality, shown as treatment means over time

density were considerably higher than those generally found in Tasmania at age 24 y, leading to stem retention rates in the heavy thinning treatment (204 sph) falling in the density range usually associated with a 50% BA reduction.

A minimum removable volume of 70 t ha⁻¹ (66 m³ ha⁻¹) of thinnings is also stipulated by Forestry Tasmania (2001), although operational practice suggests 100 t ha⁻¹ is a more reasonable figure for commercial viability. Typical thinning yields in the ash forests of East Gippsland¹ are about 150 t ha⁻¹. Recovered pulpwood volumes at Chestermans ranged from about 70 to 180 m³ ha⁻¹ depending on treatment (Table 2), with those from the light thinning (67 m³ ha⁻¹) falling below the commercial threshold.

The heavy thinning has resulted in the largest individual tree sizes and standing sawlog volumes, but these plots still carry the least merchantable wood 31 y after treatment. It is unlikely that this treatment will carry sufficient standing wood to be equivalent in volume to the unthinned treatment within 10 y (Fig. 2), 65 y being the nominal age for a final rotation in high quality, thinned stands (Whiteley 1999).

The light thinning has led to mortality (≈20%) through suppression since the time of treatment, representing wood which has been lost to recovery in much the same way as in an unthinned stand. The light thinning plots do carry more standing wood than the unthinned plots and a similar amount to the moderate plots, but still have small individual tree sizes and large numbers of pieces to be handled at harvest. This light thinning would have entailed similar planning and operational expenses yet yielded a smaller interim return without resulting in a substantially improved stand at rotation age.

Conclusions

The moderate thinning (50% BA reduction) plots experienced negligible mortality, produced comparable basal area and more merchantable volume than the unthinned plots, and resulted in increased individual tree sizes and total sawlog volume. Moderate thinning is the only treatment which provided improvement for all parameters over the 'do nothing' (unthinned) option.

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