GROWTH RESPONSE OF *EUCALYPTUS REGNANS* DOMINANT TREES TO THINNING IN NEW ZEALAND

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ABSTRACT

Quarter-sawing helps to reduce drying degrade in *Eucalyptus regnans* F. Muell., and large sawlogs with a minimum small-end diameter of 40 cm are recommended in order to use this technique. The growth rate of dominants will determine the time taken to grow trees capable of producing these large logs.

A trial with initial stockings of 2500, 1111, and 625 stems/ha, thinned between ages 5 and 11.8 years, with two unthinned treatments, was analysed at age 19 years to determine the effect of stocking on growth of dominant trees. Stocking was not the main influence although diameter of dominant trees tended to be greater in treatments with lower initial and final stockings.

Keywords: growth; thinning; dominant trees; *Eucalyptus regnans*.

INTRODUCTION

In the early 1970s *Eucalyptus regnans* was planted for pulpwood production (Hayward 1987) and was also recommended by the New Zealand Forest Service for planting for high-quality solidwood uses (Purey-Cust 1979; New Zealand Forest Service 1981; James 1988). There were very few stands of *E. regnans* and none were managed, and so any advice on silviculture was speculative. Drying degrade was recognised as a problem but it was minimised by quarter-sawing (Bunn 1971). A final stocking of 100 stems/ha was recommended to concentrate growth on selected stems, with trees harvested at 75 cm diameter at breast height (dbh) (Forest Research Institute 1976). Trees of this size were considered necessary in order to produce sawlogs with a small-end diameter of 40 cm that are suitable for quarter-sawing (Haslett 1988), and they are likely to be dominants in a stand at time of harvesting.

Growth response of dominants has been reported for a 7-year-old *E. regnans* stand in Kinleith Forest, New Zealand with one component comprising plots unthinned or thinned to 350 stems/ha (Messina 1992). The dominants, identified as the largest 100 stems/ha on the basis of their diameter (mean top diameter 100, MTD_{100}), grew significantly more in the 2 years and 5 months after thinning.

Borough *et al.* (1978) reported the size of dominant trees 8 years after thinning of a 3-year-old *E. regnans* regrowth stand in Victoria. Mean dbh of the largest 74 stems/ha was 31.5 cm in the 616 stems/ha plot, 26.9 cm in the 1235 stems/ha, and 22.4 cm in the unthinned control. Another unreplicated trial, with thinning treatments applied to a 10 year-old *E. regnans* regrowth stand in Tasmania, showed a growth response by dominant trees which was most pronounced in the plot thinned the most. At age 20 years mean dbh of the dominants (trees over 13 cm dbh at age 10) was 34 cm in the 250 stems/ha plot, 26.5 cm in 440 stems/ha, and 24 cm in the control (Goodwin 1990).

The objective of this study was to analyse the impact of thinning on the growth of plantation-grown dominant trees over a longer period of time. The rate of growth of the dominants will determine the time required to produce trees of the recommended size (75 cm dbh) for sawlog production.

Data were obtained from a trial planted in Kaingaroa Forest which had been regularly assessed from age 4 to age 19 years. The trial had been established to provide information on growth and yield for a range of thinning and pruning regimes at time of harvesting. In the initial proposal most treatments were planned to result in a final crop of 100 stems/ha but this prescription was later modified to provide a range of final-crop stockings so that the data collected would be useful for developing growth models.

METHOD

Trial Establishment

The trial was planted in 1978 in the central North Island, near Murupara, in Cpt 1209 and 1210 of Kaingaroa Forest. The altitude of the site was 210 m, the annual rainfall 1323 mm, and the soil was classified as a yellow-brown pumice. Seedlings were raised as bare-rooted stock from seed collected in a natural stand at Franklin, Tasmania, Australia. Nitrogen fertiliser (60 g urea) was applied to each tree shortly after planting. Weeds were controlled by chemical application before planting, and later by hand-releasing of bracken fern (*Pteridium esculentum* (Forst.f.) Cockayne) and scrub species on several occasions (A.E.Hay pers. comm.).

The trial design was unorthodox. It was divided into three replicates of 3 ha each. Within each replicate, 1-ha sub-blocks were planted at 2-, 3-, and 4-m^2 spacings corresponding to 2500, 1111, and 625 stems/ha respectively (Table 1). Each 1-ha sub-block was divided into four treatment plots and, commencing at age 4 years, thinning and pruning treatments were applied. There were 11 different treatments (33 plots in total). The treatment destined to be thinned to 50 stems/ha occupied two adjacent plots (0.5 ha) to provide sufficient trees for analysis after final thinning.

Treatments

The thinning and pruning treatments were designed to provide a range of intermediate and final stockings combined with either no pruning or pruning in two or three lifts. Intermediate stockings were 2500, 1500, 400, and 100 stems/ha at age 8 years. Final stockings ranged from unthinned 2500 stems/ha (stocking after mortality was 911 stems/ha at age 19 years) to 400, 300, 100, and 50 stems/ha. Trees were selected to remain after thinning on the basis of spacing, size, straightness, and freedom from stem defects, such as sweep, forks, etc. (Forest Research Institute 1987).

TABLE 1–Trial design and treatment schedule for the 11 treatments in the *E. regnans* regime trial

Initial stocking (stems/ha)	Treatment	Age thinned (years)				Age pruned (years)		
		5	8	11.8	18	4	5	8
		Stocking (stems/ha)				Prescribed pruning height (m)*		
2500	**T1**							
	T2	1500		700	300			
	T3	1200		400				
	T5	800	400			2.4	4.5	6.0
1111	**T4**							
	T6	650	325			2.4	4.5	6.0
	T7	500	250			2.4	4.5	6.0
	T8	400	100			4.5	6.0	
625	**T9**	275	200			4.5	6.0	
	T10	125				4.5	6.0	
	T11	200	100	50		4.5	6.0	

* Trees were pruned to the lesser of either the prescribed height or half of tree height. In treatments T8, T9, T10, and T11 any trees pruned to less than 6 m at age 5 years were pruned to 6 m at age 8 years.

Data Collection and Initial Processing

Measurement plots of 0.09 ha within each 0.25-ha treatment plot (0.24 ha and 0.5 ha respectively for T11) were delineated at age 4 years and annual assessments undertaken until age 16 years, and then at age 19 years. Diameters of all trees were measured on each occasion. Total tree height and green crown height of all trees were measured at age 4 years. Thereafter, a sample of trees was selected for measurement of heights for deriving a regression equation relating total height to dbh (Ellis & Hayes 1997). Thirty trees per plot were measured until age 11 years and thereafter 12 trees (where stocking permitted). Stem quality of all stems was assessed at age 11 years by recording defects such as forking, sweep, crooked stem, or leaning stem.

The tree data for each treatment plot were processed using the Permanent Sample Plot System (Dunlop 1995) to calculate stocking, basal area, live standing volume, thinned volume, and a height/diameter regression equation. The volume function used was derived from data collected in *E. regnans* plantations in Kinleith Forest, central North Island (Hayward 1987). Height of green crown up to age 7 was affected by pruning; however, it was not included in the analysis due to confounding with stocking level, which also affects green crown height.

To investigate any differences in growth of dominants and co-dominants between treatments, four classes of dominant and co-dominant trees were defined as the 50, 100, 150, and 200 largest diameter trees/ha, regardless of form or spacing (MTD_{50}, MTD_{100}, MTD_{150}, and MTD_{200}). Mean diameter and the height at age 19 years corresponding to that diameter were calculated for each treatment plot using the method described by Dunlop (1995).

Large, poorly formed trees were felled in the thinned treatments but in unthinned treatments (T1 and T4) some forked trees of poor form were amongst the dominants. Therefore, the selection criteria varied between treatments. To assess the impact of including poor-form trees in T1 and T4, the equivalent of 100 trees/ha were selected based on large diameter, good form (tree quality at age 11 years), and spacing. The mean diameter of the trees selected was calculated for ages 11 and 19 years.

Current annual increment (CAI) of MTD_{100} at ages 7, 10, 15, and 19 years was also calculated in order to determine the impact of thinning on growth rate. The first three intervals were shortly after thinning treatments (ages 5, 8, and 11.8 years) when response to thinning may have been apparent.

Statistical Analysis

Four separate analyses using the following variables were undertaken:

(1) **Stand values:** Stand height, basal area, live standing volume, and total volume production (sum of total live standing volume at age 19 years and total volume of thinnings).

(2) **Size of dominants:** MTD_{50}, MTD_{100}, MTD_{150}, and MTD_{200}.

(3) **Effect of tree selection:** Analysis of MTD_{100} at age 19 years was repeated using selected trees for T1 and T4.

(4) **Rate of growth of dominants:** Current annual increment (CAI) of MTD_{100} at ages 7, 10, 15, and 19 years.

All analyses were undertaken assuming the 11 treatments were randomly located in each block. Therefore a two-way analysis of variance (ANOVA), testing for block and experimental treatment effects, was performed for each variable using the following model:

$$Y_{ij} = \mu + b_i + t_j$$

where Y_{ij} is the mean of the variable for the plot located in the i^{th} block receiving the j^{th} treatment, μ is the mean over all blocks and treatments, and b and t refer to block and treatment. Means tests for differences between individual treatments (adjusted for block effects) were also undertaken. All analyses were carried out using PROC GLM (SAS Institute Inc. 1994).

RESULTS

Stand Values

Treatment did not affect MTH_{100} but there were significant differences for the other stand variables (Table 2). Treatment 2 was thinned at age 18 years and had a very low basal area and volume compared with treatments of similar stocking. For all other treatments, basal area was dependent on stocking, with the unthinned treatments (T1 and T4) being significantly higher in basal area than the other treatments. Basal area in those treatments thinned to less than 200 stems/ha was significantly less than in those thinned to a higher stocking. Mean volume for each treatment followed a similar pattern but there was more differentiation of treatments. Total volume production was also significantly lower in the treatments thinned to less than 200 stems/ha.

Size of Dominants

The mean diameters for each dominance class at age 19 years are shown in Table 3. Average diameter of dominant and co-dominant trees varied only slightly despite the wide

TABLE 2–Stand values per hectare for the 11 treatments in the *E. regnans* regime trial at age 19 years

Treatment	Stand values at age 19 years				Thinning yield	
	Stocking* (stems/ha)	MTH† (m)	Basal area (m^2/ha)	Live standing volume (m^3/ha)	Number of thinnings	Total volume production (m^3/ha)
T1	911	35.9 a	38.0 a	448.6 a		448.6 a
T2‡	304	34.0 a	19.9 d	241.1 de	3	361.5 bc
T3	374	34.7 a	26.6 c	326.2 c	2	426.8 ab
T4	556	36.0 a	33.7 b	417.6 ab		417.6 abc
T5	370	34.1 a	25.8 c	305.9 cd	2	355.4 bc
T6	304	36.0 a	28.1 c	359.7 bc	2	397.0 abc
T7	256	36.2 a	24.4 c	316.3 c	2	351.4 c
T8	100	33.7 a	14.4 e	186.6 ef	2	246.1 d
T9	204	36.0 a	24.8 c	327.7 c	2	345.0 c
T10	107	33.1 a	15.9 de	202.5 ef	1	221.6 d
T11	51	n/a	12.1 e	160.6 f	3	224.9 d

* Live stocking after mortality or thinning.
† Height corresponding to the 100 largest diameter stems/ha (MTD_{100}).
‡ Thinned at age 18 years
Means followed by the same letter are not significantly different at $p \geq 0.05$

TABLE 3–Mean diameter at age 19 years for dominance classes 50, 100, 150, and 200 stems/ha for all 11 treatments.

Stocking (stems/ha*)		MTD_{50} (cm)		MTD_{100} (cm)		MTD_{150} (cm)		MTD_{200} (cm)	
T1	911	**T2**	39.2	**T2**	35.6	**T2**	33.5	**T2**	31.9
T2	304†	**T5**	42.5	**T5**	39.4	**T5**	37.0	**T5**	35.3
T3	374	**T1**	42.8	**T1**	39.4	**T3**	37.4	**T3**	35.5
T4	556	**T3**	43.3	**T3**	39.5	**T1**	37.5	**T1**	35.8
T5	370	**T4**	45.5	**T4**	40.7	**T4**	37.9	**T4**	35.8
T6	304	**T7**	46.6	**T8**	42.6	**T7**	40.1	**T7**	37.6
T7	256	**T8**	47.9	**T7**	42.6	**T6**	41.6	**T6**	39.0
T8	100	**T6**	48.0	**T6**	44.3	**T9**	43.0	**T9**	39.6
T9	204	**T9**	49.4	**T10**	44.6				
T10	107	**T10**	51.8	**T9**	45.9				
T11	51	**T11**	54.5						

* Stocking at age 19 years
† Thinned at age 18 years
Means that are not significantly different ($p \geq 0.05$ level) are followed by a common line.

range of stocking and thinning treatments. However, for each dominance class, larger diameters were associated with the treatments with lower stockings.

Selected Trees in Unthinned Plots

The mean diameter of the selected trees in the unthinned treatments, T1 and T4 (based on their form at age 11 years), was less than that of the MTD_{100} at ages 11 and 19 years (Table 4). The difference was greatest for T4 which was significantly different to the MTD_{100} in other treatments (Table 5). However, the mean diameter of the selected trees in T1 was not statistically different to the other treatments planted at 1111 stems/ha but all thinned (T2, T3, or T5).

Height

The heights of the 50 (MTD_{50}) to 200 (MTD_{200}) largest diameter stems/ha did not differ significantly with stocking, and means varied by less than 2 m (Table 6).

TABLE 4–Mean diameter of best 100 stems/ha selected at age 11 and mean diameter of corresponding trees at age 19 years.

Treatment	Age 11		Age 19	
	MTD_{100} (cm)	Selected trees mean dbh (cm)	MTD_{100} (cm)	Selected trees mean dbh (cm)
T1	27.1	25.2	39.4	36.9
T4	30.0	25.9	40.7	31.9

TABLE 5–MTD_{100} in thinned treatments and diameter of selected trees in unthinned treatments at age 19 years.

Treatment	Criteria	Mean dbh (cm)
4	Selected 100	31.9
2	MTD_{100}	35.7
1	Selected 100	36.9
5	MTD_{100}	39.6
3	MTD_{100}	39.6
8	MTD_{100}	42.7
7	MTD_{100}	42.8
6	MTD_{100}	44.5
10	MTD_{100}	44.7
9	MTD_{100}	46.1

Means that are not significantly different ($p \geq 0.05$ level) are followed by a common line.

TABLE 6–Mean top height by category at age 19 years.

Category	Mean MTH (m)
MTD_{50}	36.0
MTD_{100}	35.0
MTD_{150}	34.6
MTD_{200}	34.2

Growth of MTD_{100}

Differences between mean diameter increment of the MTD_{100} (CAI) for all treatments at age 7 were significant ($p=0.0001$). Trees in treatments T9 and T10, which were established at 625 stems/ha and thinned to the lowest stocking, grew faster than those in the other treatments but they were not significantly different from each other (Table 7). As the other treatment established at 625 stems/ha, T11, was thinned to 50 stems/ha at age 11 years it was not included in the analysis. There was also no significant difference within the other two groups of treatments established at the same stocking (2500 stems/ha and 1111 stems/ha) despite there being an unthinned control and different thinning treatments in each group.

The effect of treatment was also significantly different (p=0.0013) for CAI of MTD_{100} at age 10 years but the rate of growth was not related to stocking. Significant differences between treatments for CAI were not found at age 15 or 19 years.

TABLE 7–Current annual increment of diameter of MTD_{100} trees at ages 7, 10, 15, and 19 years for all 10 treatments.

CAI of MTD_{100} (cm)							
Trt	Age 7	Trt	Age 10	Trt	Age 15	Trt	Age 19
10	3.1	**9**	3.0	**10**	2.1	**6**	1.5
9	3.0	**6**	2.9	**8**	2.0	**9**	1.5
8	2.4	**8**	2.7	**7**	2.0	**7**	1.5
4	2.4	**5**	2.6	**5**	1.9	**1**	1.4
7	2.2	**10**	2.5	**6**	1.8	**10**	1.4
3	2.0	**7**	2.4	**9**	1.8	**8**	1.4
6	2.0	**4**	2.2	**3**	1.7	**5**	1.4
1	1.9	**1**	2.1	**4**	1.6	**3**	1.4
2	1.9	**3**	1.9	**1**	1.5	**4**	1.2
5	1.8	**2**	1.8	**2**	1.3	**2**	n/a*

* Thinned during the period
Means that are not significantly different (p≥0.05 level) are followed by a common line.

DISCUSSION

Trial Design

The trial was not specifically designed to study growth response of dominants. Trees in plots thinned to lower stockings were pruned more severely than those in plots thinned to higher stockings. Trees in T4 and T6–8 (all 1111 stems/ha initially) were treated to three different levels of pruning at 4 years — unpruned, and pruned to either 2.5 or 4.5 m tree height. Only the 4.5-m pruning reduced growth (6% reduction in volume after 1 year) (Deadman & Calderon 1988). The long-term impact of pruning on growth could not be measured because the treatments were thinned to different stockings, but very little green crown was removed in subsequent pruning lifts and so a long-term effect on growth was unlikely.

Selection of Trees

Trees that comprised the dominant component of each plot could have been affected by treatment because only trees of reasonable form remained in the thinned treatments. An attempt was made to standardise across treatments by selecting trees in the unthinned plots based on form as assessed at age 11 years and spacing. The results indicated that dominant trees may include grossly malformed trees because the mean diameter was smaller in the unthinned treatment (T4) when these were excluded.

Stand Volume Production

Thinning to less than 200 stems/ha significantly reduced live standing volume and total volume production at age 19 years. Thinning to higher stockings resulted in little loss of stand volume. Harvesting thinnings for pulpwood is likely to be uneconomic and some damage to remaining trees would be inevitable, resulting in volume loss of high-quality wood. Production of pulpwood with the harvesting of sawlogs may be possible but would depend on harvesting and transport costs and the price for pulpwood at the time of harvesting.

Size and Growth of Dominants

At age 19 years, diameter but not height of dominant trees tended to be greater in treatments with lower initial and final stockings than in treatments with higher initial and final stockings. However, many of the treatments were not significantly different despite a range of initial stocking and thinning treatments. This indicates that stocking is not the main influence on growth of dominant trees.

The significantly larger CAIs of MTD_{100} that occurred in lowest stocked plots (T9 and T10) after thinning at age 5 years suggest that thinning to a very low stocking at an early age will give the greatest response. However, the lower initial stocking (625 stems/ha) could have influenced growth rate as well. By age 19 years the rate of growth (ranging from 1.2 to 1.5 cm/year) was not significantly different for any of the treatments. If this growth rate continues, then it will not be possible to harvest trees of 75 cm at this site until they are about 40 years old.

Reasons for Lack of Response after Age 7 Years

The lack of growth response to thinning in dominants after age 7 years may have been caused by root competition from other vegetation or by poor tree health. Competition may have been provided by the understorey of bracken fern and shrub species which grew more vigorously in lower stocked plots (Goodwin 1990). Alternatively, the development of the understorey may have been caused by poor crown health, leading to increased light penetrating the canopy. Leaf spot fungi such as *Aulographina eucalypti* (Cooke and Massee) von Arx and Müller, *Mycosphaerella cryptica* (Cooke) Hansford, and *M. nubilosa* (Cooke) Hansford were observed infecting the crowns in the trial. This caused leader dieback when the trees were young, but damage was less obvious in subsequent years. Leaf spot fungi are associated with poor health and death of *E. regnans* in the central North Island (M.Dick pers. comm.). Sites where high rainfall occurs during periods of warm temperature are conducive to growth of leaf spot fungi (Hay *et al.* in prep.). At the trial site the mean rainfall in the summer quarter was 320 mm (New Zealand Meteorological Service 1983), slightly higher than the maximum of 302 mm (mean 226 mm) in the climatic domain found by Lindenmayer *et al.* (1996).

CONCLUSION

Results from this study indicated that thinning increased size of dominants in an *E. regnans* trial at age 19 years and ensured that, through selection at the time of thinning, dominants were better formed trees. However, there was a range of responses, indicating that stocking was not the major factor limiting the growth of dominants. Further research is required in New Zealand to better understand the growth of dominant trees in eucalypt stands. This research should be undertaken before large eucalypt plantations are established for solid wood production.

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