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Growth and branching habit of *Eucalyptus nitens* at different spacing and the effect on final crop selection

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Abstract

An experiment to investigate the effects of initial spacing on the growth, branching habit and form of *Eucalyptus nitens* (Deane et Maiden) was established on a highly productive site at Upper Castra in northern Tasmania, Australia, in 1992. The experiment covered stockings ranging from 500 to 1667 stems ha⁻¹ (SPH). At age 5 years there was competition within the stand and significant impacts of stocking on tree growth. The degree of competition varied with stocking, indicated by green crown height which varied significantly with stocking, ranging from nearly 5 m at 1500 SPH to 2.5 m at 500 SPH. Restriction of branch growth therefore occurred earlier at higher stockings, however, tree diameter growth was also restricted by higher stocking. The mean dominant height (MDH) of the stand was 15.15 m at age 5 years with no difference between stockings. Total stand volume was significantly related to stocking, higher stocking having higher volume. Forks and ramicorns were prevalent and 16% of all stems had forks and 44% had forks or ramicorns. Below 1000 SPH the mean largest branch in the first 6 m log length was over 35 mm. The number of branches larger than 35 mm increased rapidly at lower stockings. The trial was also evaluated for commercial thinning and selection of 300 final crop stems suitable for pruning and growing to produce sawlogs or veneer logs. At age 5 years only 37% of stems met the requirement for selection for final crop. If branch criteria for final crop selection were included, 1000 SPH produced barely sufficient numbers of select stems. The implications of stocking on stand management are discussed and initial stockings of 1000–1100 SPH are recommended for *E. nitens* plantations. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Spacing; Stocking; *Eucalyptus nitens*; Eucalypt plantations; Branching; Thinning selection; Early growth

1. Introduction

Initial stocking in eucalypt plantations has a major influence on options for future management. With

high costs of seedlings and planting it is important that only the number of seedlings required to achieve the management objectives be planted. Schonau (1974) working with *Eucalyptus grandis* (Hill), Maiden on a poor site (mean annual increment (MAI) 10.6 m³ ha⁻¹ at age 10 years) found that lower stock-

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ing (1200 SPH) produced less total growth than higher stocking (1700 SPH), although growth of larger stems (>12.5 cm DBHOB) was greater. Meskimen and Franklin (1978) found increased total volume growth with higher stocking up to 3363 SPH. Schonau (1984) and Schonau and Coetzee (1989) therefore, recommend high stocking and frequent thinning for production of highest volume from *E. grandis*.

Chances of infection with decay forming fungi in *E. nitens* through pruned branch stubs increases with increasing branch size (Wardlaw, 1995; Gerrand et al., 1997). Therefore, information on branch development on highly productive sites is needed for the development of pruning regimes.

For eucalypt plantations in Tasmania, grown for sawlogs and veneer logs, a pulpwood thinning will improve the financial return (Neilsen and Wilkinson, 1990). Initial spacing is critical to the overall management of the stand. Initial stocking must provide sufficient stems to fully occupy a site and enable high volume production for the pulpwood thinning. More importantly the number of trees planted must allow for selection of a required number of suitable final crop trees (Gerrand et al., 1997).

Correct spacing will give an optimum combination of average tree volume (piece size) and total volume to be harvested in a commercial thinning operation. Volume available for thinning must be sufficient for a commercial operation before the mean dominant height (MDH) of the stand exceeds 20 m and the stand has a high risk of wind damage after the thinning (Gerrand et al., 1997). At moderate stocking merchantable volume will decrease little compared to high stocking while piece size will increase and establishment costs decrease. Time taken to reach final crop size will also be reduced and this will have a substantial effect on economic returns. With low stocking merchantable volume will decrease, reducing financial viability. Determining optimum spacing is often difficult, depending on markets and biological factors (Shepherd et al., 1990).

An experiment at Upper Castra was established to investigate the effect of spacing on tree height and diameter, volume production, branching habits and stem form. The experiment was also used to investigate the diameter distribution of stands of *E. nitens* at different stocking and the effect of different stocking on final crop selection.

2. Methods

2.1. Experimental area

The experimental site was located approximately 15 km south of Ulverstone, in northern Tasmania. The area was in a temperate environment at an altitude of 310 m with a mean annual rainfall of 1250 mm. The soils were deep, well-drained krasnozems (USDA classification, Hapludox) characterised by reddish brown clay loam topsoils overlying reddish brown light clay subsoils (Grant et al., 1995). The 4 ha site originally carried high quality *E. obliqua* L'Herit., of mature top height 34–41 m, but had been cleared and used for agricultural cropping for many years. Consequently competition from woody weeds was minimal. The site has an SI of 33.5 m and the MAI achieved at age 5 years of 22 m³ ha⁻¹ (1000 SPH) was considered very good for the temperate climate (Beadle and Inions, 1990).

2.2. Experimental design

The experiment was a randomised complete block design with four replications of six stocking treatments ranging from 500 to 1667 SPH (Table 1). Two spacings at different rectangularity were included at the median stocking of 1000 SPH. There were a total of 24 plots. The plots were 30×30 m with a variable inner measured plot of approximately 25 trees.

2.3. Establishment

Prior to planting, the entire area was disc ploughed to remove herbaceous weeds and crop stubble. Weed

Table 1
Stocking (SPH) treatments, tree space, spacing and rectangularity for 30 × 30 m square plots of *E. nitens* in the Castra experiment

SPH planted	Tree space (m ²)	Spacing (row×tree)	Rectangularity
1667	6	3 × 2	1.5
1333	7.5	3 × 2.5	1.2
1010	9.9	3.3 × 3	1.1
1000	10	4 × 2.5	1.6
833	12	4 × 3	1.33
500	20	5 × 4	1.25

control consisted of pre-planting broadcast application of 91 ha^{-1} of amitrole and 201 ha^{-1} atrazine. Toorongo provenance *E. nitens* container growth stock, from Forestry Tasmania's Perth nursery, were planted in late winter, 1992. Survival was excellent but to ensure full stocking any failed trees were replaced for six months after planting. Extra seedlings heeled in on site and some additional stock from the nursery, of the same seed source, were used.

2.4. Measurement

The experiment was measured at age 5 years, following canopy closure. DBHOB of all trees on the measured plot, a sample of heights (5 per plot), so that volume could be estimated (Wilkinson and Neilsen, 1995), and MDH, based on the tallest 50 SPH evenly distributed over the area, were measured. Merchantable volume was calculated as volume $>10 \text{ cm}$ top diameter in stems of $>12 \text{ cm}$ DBHOB. Height to the base of the green crown (green crown height) was measured to demonstrate suppression of the lower crown. Forks and ramicorns (large high angle branches) were recorded. Two measures of branching were used, largest branch on the lower 6 m of stem and the number of branches $>35 \text{ mm}$ diameter on that section of the stem. Branch angle was also estimated in four classes. Stem form was scored for defects, sweep, kinks and lean. A system of scoring stem straightness on a scale of 1–4 was used for assessment of severity (Gerrand et al., 1997). Trees were assigned to canopy classes; dominant, co-dominant, sub-dominant (intermediate) and suppressed (overtopped), in relation to their crown position (Smith, 1962; Shepherd, 1986).

A final crop selection system was adopted. To qualify as final crop trees, trees had to have straight stems with no forks or ramicorns in the lower 6 m of stem. There should be no more than 10 cm deviation (sweep), over 6 m and no severe kinks. Trees should also be dominant or co-dominant in the stand so that they could maintain good growth and not suffer suppression by adjacent unpruned, non-select trees, before these are thinned. Additionally there should be no more than one branch $>35 \text{ mm}$ diameter. This latter criterion could be avoided by early pruning of potentially large branches.

2.5. Analysis

Correlation analysis, regression analysis and ANOVA were used for analysing the data. Treatment means were compared using LSD analysis. For stand analysis, trees were assigned to diameter classes and canopy classes. Growth of the stand was projected to age 7 years using an *E. nitens* growth model (Candy, 1997). Total and merchantable volume were estimated using the model and the stand distribution derived from the plot data. The plots were projected to reach MDH of 19.5 m at age 7 years and would require thinning at that stage to avoid possible wind damage (Gerrand et al., 1997). A DBHOB of $>12 \text{ cm}$ and a piece size of 0.2 m^3 was required for stems to be commercial at thinning (J. Simpson, personal communication).

3. Results

3.1. Green crown height

Green crown height varied significantly with stocking ranging from nearly 5 m at 1500 SPH to 4 m at 1000 SPH and 2.5 m at 500 SPH (Fig. 1). At mid and high stocking the stands were close to suppression and containment of branch growth over the lower log length (6 m) of the stem.

3.2. Growth

At age 5 years the MDH was 15.15 m with no difference between stockings. This was equivalent to a site index (SI), MDH at age 15 years, of 33.5 m (Candy, 1997). Stand volume at age 5 years was significantly related to stocking with higher stocking having higher volume, 1500 SPH having $140 \text{ m}^3 \text{ ha}^{-1}$, an MAI of $28 \text{ m}^3 \text{ ha}^{-1}$, 1000 SPH having $110 \text{ m}^3 \text{ ha}^{-1}$, an MAI of $22 \text{ m}^3 \text{ ha}^{-1}$, and 500 SPH having $70 \text{ m}^3 \text{ ha}^{-1}$, an MAI of $14 \text{ m}^3 \text{ ha}^{-1}$ (Fig. 2). Using an *E. nitens* growth model (Candy, 1997), the stand at 1000 SPH, unthinned, was projected to peak at $37 \text{ m}^3 \text{ ha}^{-1}$ MAI at age 16 years.

Tree volume growth across the site was uniform with less than 1% of the total SS variation between plots in block differences. Mean DBHOB was linearly related to stocking with higher stocking having lower

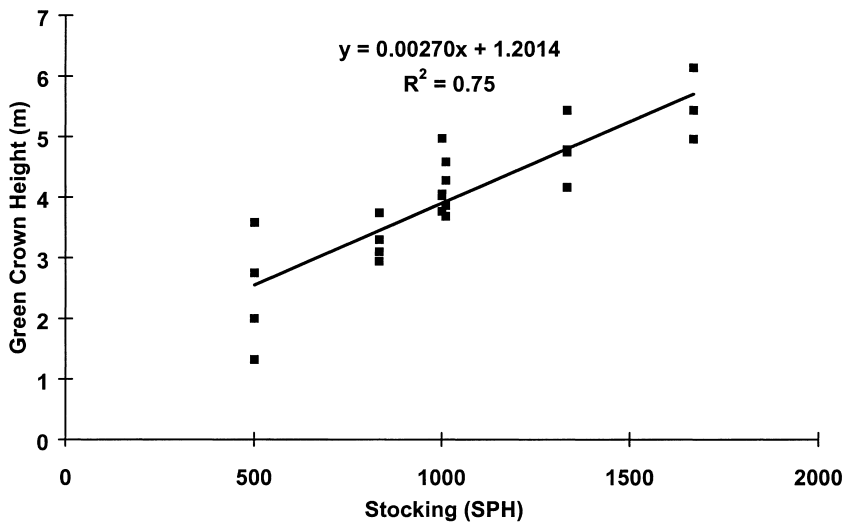


Fig. 1. Green crown height by stand stocking relationship, at age 5 years, for *E. nitens* plots planted at various stockings.

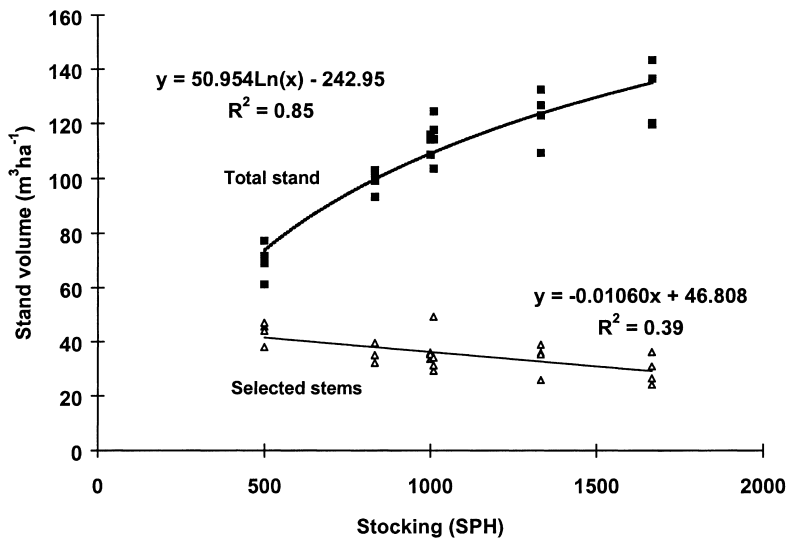


Fig. 2. Stand volume per hectare by stand stocking relationship of the whole stand and selected 300 SPH for 5 year old *E. nitens* plots.

mean DBHOB (Fig. 3). Mean DBHOB varied from 18 cm at 500 SPH to 16.5 cm at 1000 SPH and 14 cm at 1500 SPH. Stem volume varies similar to DBHOB with $0.14 \text{ m}^3 \text{ stem}^{-1}$, for the lowest stocking of 500 SPH, to $0.11 \text{ m}^3 \text{ stem}^{-1}$ at 1000 SPH and $0.09 \text{ m}^3 \text{ stem}^{-1}$ at 1500 SPH.

3.3. Branch size and habit

For all trees there was a relationship between largest branch and stem DBHOB. Largest branch was strongly correlated with stocking with higher stocking having smaller branches (Fig. 4). Mean largest branch

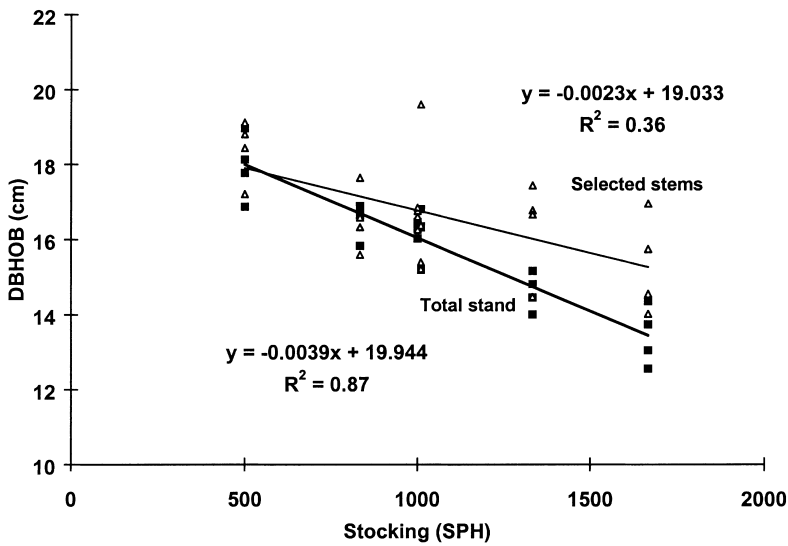


Fig. 3. Mean tree DBHOB by stand stocking relationship for the whole stand and the selected 300 SPH for 5 year old *E. nitens* plots.

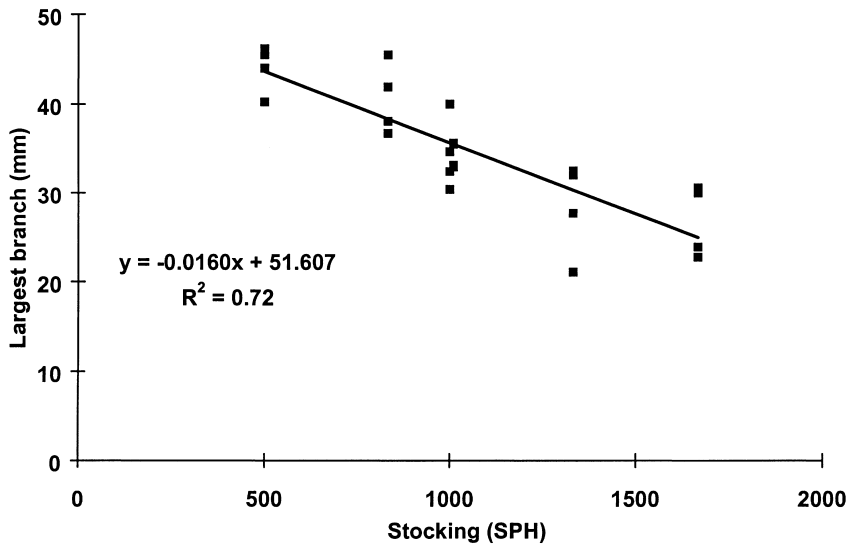


Fig. 4. Largest branch by stand stocking relationship, at age 5 years, for *E. nitens* plots planted at various stockings.

was 28 mm at 1500 SPH, 36 mm at 1000 SPH and at 500 SPH it increased to about 44 mm. The number of branches >35 mm diameter increased rapidly with lower stocking indicated by a significant second order regression (Fig. 5). Branch angle varied little with stocking.

There were no significant differences for branches between the plots at 3.3×3 and 4×2.5 m spacings, rectangularities of 1.1 and 1.6, respectively.

Forks and ramicorns were prevalent and 16% of all stems had forks and 44% had forks or ramicorns. There was a slight though insignificant trend of

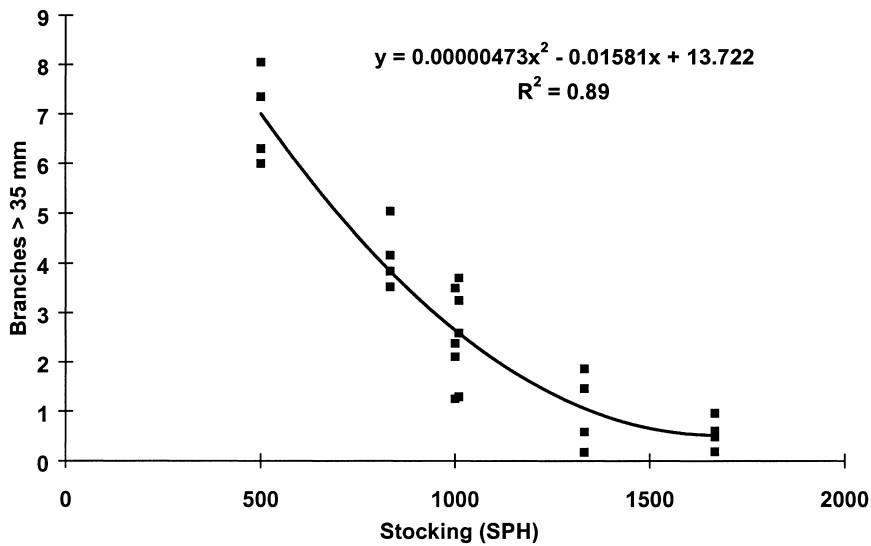


Fig. 5. Mean number of branches >35 mm diameter by stand stocking relationship, at age 5 years, for *E. nitens* plots planted at various stockings.

Table 2

Volume ($\text{m}^3 \text{ha}^{-1}$) at age 5 years, and projection of total, thinning and merchantable thinning volume at age 7 years, in plots of *E. nitens* at different stockings

SPH planted	Total volume age 5 years ($\text{m}^3 \text{ha}^{-1}$)	Projected total volume age 7 years ($\text{m}^3 \text{ha}^{-1}$)	Total thinning volume age 7 years ($\text{m}^3 \text{ha}^{-1}$)	Merchantable thinning volume age 7 years ($\text{m}^3 \text{ha}^{-1}$)
500	70	143	53	38
833	99	186	114	89
1000	114	204	138	105
1010	115	206	140	108
1333	123	218	164	121
1667	130	228	182	128

increasing number of ramiforms and forks with lower stocking. The correlation of forks plus ramiforms with largest branches was significant.

3.4. Stand volume of selected stems

Total volume produced by *E. nitens* was greater at higher stocking at age 5 years and was projected to maintain that advantage to time of thinning at age 7 years. The volume of selected stems decreased with increasing stocking while the wood available for thinning increased substantially (Fig. 2). At age 7 years a stocking of 1667 SPH was predicted to have

31% greater total volume than 1000 SPH. However, thinning volume for 1667 SPH would only yield $21 \text{ m}^3 \text{ha}^{-1}$ greater volume, than for 1000 SPH, accompanied by a $22 \text{ m}^3 \text{ha}^{-1}$ increase in non-merchantable wood volume (Table 2).

Volume at age 5 years in trees to be retained following thinning was $29 \text{ m}^3 \text{ha}^{-1}$ at 1667 SPH, $35 \text{ m}^3 \text{ha}^{-1}$ at 1000 and $43 \text{ m}^3 \text{ha}^{-1}$ at 500 SPH. DBHOB also reflected these differences with an average of 15.3 cm at 1667 SPH, 16.6 cm at 1000 SPH and 18.4 cm at 500 SPH (Fig. 3). Of the select trees severity of stem defects was significantly higher at 833 and 500 SPH (Table 3).

Table 3

Mean stand variables of select 300 SPH final crop sawlog stems at age 5 years for *E. nitens* plots established at different stockings

SPH planted	Total select volume (m ³ ha ⁻¹)	Tree volume (m ³)	DBHOB (cm)	Severity of form defect ^a	Largest branch (mm)	Number of branches >35 mm
500	43.6a	0.15a	18.4a	2.4a	42.5a	6.99a
833	35.4b	0.12b	16.5b	1.9b	38.1ab	4.25b
1000	35.2b	0.12b	16.6b	1.3c	31.5c	1.54cd
1010	36.0b	0.12b	16.6b	1.6bc	34.4bc	2.22c
1333	34.0bc	0.11bc	16.3bc	1.6bc	31.3c	1.05de
1667	29.4c	0.10c	15.3c	1.4c	28.7c	0.20e

Equivalent letters indicate non-significant differences between spacing treatments.

^aSeverity of form defect classes 1 or 2 are suitable for final crop sawlog trees. Severities classes 3 and 4 are unsuitable.

Table 4

Percentage of *E. nitens* in plots with forks and ramiforms, unacceptable straightness or >1 branch >35 mm diameter and unsuitable for selection as final crop sawlog stems at different stockings

SPH planted	Forks plus ramiforms (%)	Unacceptable stem straightness (%)	SPH prunable based on stem form only	Branches >1>35 mm (%)	SPH prunable including branch constraints
500	55a	62a	83a	18a	127a
833	53a	55ab	61b	82ab	242ab
1000	41ab	49bc	50b	258b	381bc
1010	50ab	47bc	47b	183ab	356b
1333	47ab	33c	27c	491c	593d
1667	37b	40c	18c	688c	798d

Equivalent letters indicate non-significant differences between spacing treatments.

3.5. Stems suitable for pruning and final crop selection

Percentage of trees with forks and forks plus ramiforms was significantly greater at lower stocking and as the form was significantly poorer there was a lower proportion of select or prunable stems (Table 4). With stockings of 500 and 833 SPH the number of select prunable trees was less than the required 300 SPH (Table 4). If branch criteria for final crop selection were included, 1000 SPH produced barely sufficient numbers of select stems. There were substantial significant differences between treatments for number of large branches, and therefore prunable stems, with lower stockings producing fewer suitable stems (Fig. 6 and Table 4). Branch size criteria had a larger effect on select stem proportion at lower stocking (Fig. 7).

The distribution by canopy class was similar across all stockings, averaging 24% dominant, 46% co-domi-

nant, 25% sub-dominant and 10% suppressed. At age 5 years around 90% or better stems at stockings of 1000 SPH or less were of merchantable size (>12 cm DBHOB) while for 1333 SPH, 82% and for 1667 SPH, 71% were of merchantable size. This meant that, compared to 1000 SPH, of 333 extra SPH planted for 1333 SPH only 200 were merchantable and of 667 extra planted for 1667 SPH only 300 were of merchantable size (Table 5).

Due to selection constraints on form and branching at 1000 SPH, between 50 and 60 of the 300 selected final crop stems fell into the sub-dominant and suppressed canopy categories. At higher stockings the number was less but even at 1667 SPH there were 30 sub-dominant trees selected (Table 5). At 500 SPH many trees outside of the selection criteria had to be retained to make up 300 SPH with 13 SPH of the selected stems forked, 68 of canopy classes 3 or 4 and 262 with >1 branch >35 mm diameter.

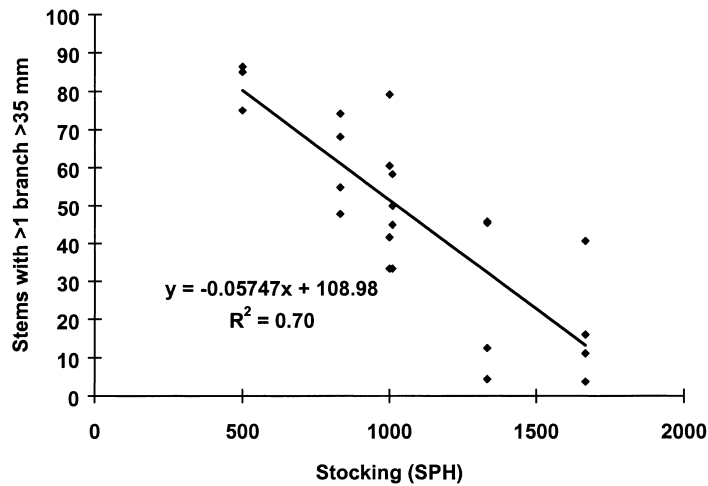


Fig. 6. Stems with >1 branch >35 mm diameter by stand stocking relationship for 5 year old *E. nitens* plots.

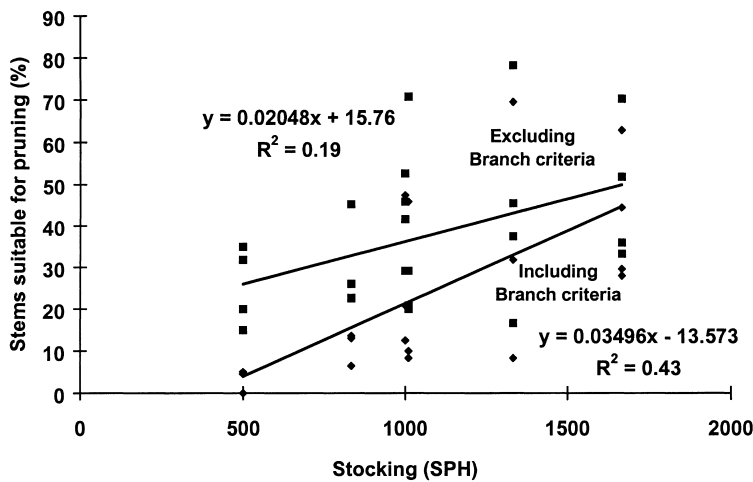


Fig. 7. Relationship of stems suitable for pruning, excluding and including branch criteria, by stand stocking for *E. nitens* plots.

4. Discussion

4.1. Stand growth and branch relationships with stocking

For *E. nitens* total volume production increased with increasing stocking while mean tree parameters, DBHOB and tree volume, were reduced. These results are similar to those of others investigating stocking in eucalypt plantations (Schonau, 1974; Meskimen and Franklin, 1978; Schonau, 1984; Schonau and Coetzee, 1989). Similar findings apply to studies in conifer

species (Wardle, 1967; Sutton, 1968). With the range of stockings in this experiment there was no difference in MDH. This has also been the case in some trials for various pine species where no difference in the height growth of dominants was detected (Ware and Stahelin, 1948; Bramble et al., 1949). The effect of stocking on MDH in other trials has varied with species, in some instances increasing with higher stocking and in others decreasing (Shepherd, 1986).

By the time of measurement at age 5 years there was competition within the stand at all stocking levels and significant impacts of stocking on individual tree

Table 5

Number of various canopy class stems in the whole stand and for the selected 300 SPH, and number of stems of merchantable size (>12 cm DBHOB), in *E. nitens* plots at various stockings at age 5 years

SPH planted or select	Dominant	Co-dominant	Sub-dominant	Suppressed	Merchantable (>12 cm DBH)
1667	401	633	401	232	1189
Select	105	165	30	0	71
1333	301	659	244	129	1089
Select	105	180	15	0	82
1010	209	505	209	88	889
Select	33	211	45	11	88
1000	240	460	240	60	970
Select	87	164	39	10	97
833	189	306	220	118	754
Select	71	134	63	32	91
500	91	244	122	43	482
Select	62	169	56	13	96

growth in the closer spaced stands. Competition increased with increased stocking, indicated by increasing height to base of the green crown. Control of branch growth therefore occurred earlier at higher stocking. Tree diameter growth was also restricted by increased competition at higher stockings, and therefore, branch size was strongly correlated with DBHOB. Consistency in the relationship, between branch diameter and DBHOB, for different canopy classes and different stockings indicated similar control of both by competition. Studies of branching in a number of species had demonstrated that branch size was closely related to DBHOB at the time of branch suppression and that branches were larger with lower stocking (Eversole, 1955; Sutton, 1970; James and Revell, 1978; Malimbwie et al., 1992). In both *Pinus radiata*, D. Don and Douglas fir, size of branches was larger on lower stockings, but there was also a large variation between sites with highly productive sites having much larger branches than poor sites for trees of the same DBHOB (Eversole, 1955; Sutton, 1970; James and Revell, 1978).

In this experiment, data on largest branch and number of branches >35 mm diameter were determined, as both size and number of large branches influenced potential wood quality, susceptibility to decay, suitability of trees for pruning and pruning costs. Branches larger than 35 mm were considered unacceptably large, if unpruned, as they would create large knots and seriously weaken the structural strength of timber. Mean largest branch increased

linearly with decreased stocking. More significantly the number of branches >35 mm increased exponentially at decreased stockings, seriously reducing the merchantability of the stand. Control of branching to less than 35 mm diameter, by stocking, required stockings of 1000 SPH or higher. This experiment had more double leaders than found in general populations of *E. nitens* (Pederick, 1979). The level indicated the high fertility of the site, with number of double leaders in plantations of *E. nitens* increased with increased nutrient supply (Neilsen, 1996). The trees also had a large number of ramicornis. These defects not only reduced the number of stems suitable for final crop selection but would lead to increased thinning costs and reduced thinning volume.

Decay entry in eucalypts was commonly associated with branches and in *E. regnans* F. Mueller decay and other defects were found to increase with branch diameter (Marks et al., 1986). In regrowth *E. delegatensis* R.T. Baker and *E. regnans* 88% of trees had decay, and branches accounted for more than half of the decay incidents (Wardlaw, 1996). Waugh and Li Yang (1994) noted decay associated with branch stubs of *E. regnans* in unpruned stands, but not with *E. nitens*. Infection of pruning wounds by fungal pathogens may be more serious than infection through branch stubs of unpruned stems. In *E. delegatensis* in New Zealand, pruning, mainly of dead branches, was associated with stem decay in about half of the trees assessed (Gadgil and Bawden, 1981). In another study, four years after pruning, 12 of 15 pruned

E. regnans had decay and decay severity was related to branch size (Glass et al., 1989). Branch diameter was important in both pruned and unpruned eucalypt stems but rates of infection were greater in pruned stems (Nicholas, 1992). It was concluded that branches should be removed before they reached 25 mm diameter to minimise the chance of decay infection. In *E. nitens* in Tasmania, larger branches substantially increase the chance of decay infection, the chance of decay breaking out of infected stubs and the extent of resulting decay in the stem (Wardlaw, 1995; Gerrand et al., 1997).

The long term effect and spread of decay in the stem of *E. nitens* were not known. Four years after pruning decay in *E. regnans* had spread longitudinally and towards the pith but not outwards (Glass et al., 1989). However, in older unpruned stands slow outward movement was observed (Marks et al., 1986). White and Kile (1991) also measured outward movement of decay following breaking down of barrier zones several years after decay entry via logging damage. Measures to minimise decay entry by controlling branch growth, with moderate stockings, have therefore been advocated. Maximum size of branches pruned have been defined in operational prescriptions by Forestry Tasmania (Neilsen et al., 1996).

4.2. Thinning

There are many aspects of stand dynamics that need to be considered in developing a regime for growing a forest crop. If a commercial thinning is to be undertaken, initial stocking needs to be selected carefully. Initial stocking affects the total volume growth, piece size, volume available for thinning and size and quality of the stand to be grown on to rotation age. An initial stocking of 1200 SPH, with progressive thinning to 100 SPH final stocking was recommended for eucalypts in New Zealand (Deadman and Hay, 1987). Such a regime would produce an excellent final crop but would be unlikely to yield commercial thinning volumes. The *E. nitens* spacing plots here would be nearly 20 m MDH at age 7 years and would require thinning (Gerrand et al., 1997). For commercial thinning, using currently available or projected technology, approximately 100 m³ ha⁻¹ (J. Simpson, personal communication) would be required and this can

only be obtained at age 7 years from 1000 SPH or more.

Higher stockings of 1333 and 1667 SPH would produce greater total volume than 1000 SPH but much smaller increases in merchantable thinning volume, a greater proportion of the extra wood produced in higher stocked stands being in small stems and tops of trees. More than half of the extra wood produced at 1667 SPH, compared to 1000 SPH, was not merchantable. Smaller piece size at higher stocking also affected economics which was so dependent on piece size that it determined whether a commercial thinning would be viable.

Beadle et al. (1994) indicated that about 34% of stems were of suitable form for pruning, out of 1430 SPH planted in various *E. nitens* stands in southern Tasmania. The percentage of prunable stems was less at higher altitude. Fertiliser treatment and site quality also affected numbers acceptable for selection as final crop trees with fewer suitable stems on more fertile sites (Neilsen, 1996). In trials in north-eastern and southern Tasmania it was relatively straightforward to select 300 suitable SPH for retention at age 3 years from *E. nitens* stands planted at 1000–1200 SPH. However, attempting to select 400 SPH did start to include stems of poorer form or vigour than was generally considered acceptable (Gerrand et al., 1997).

In this experiment an average of 37% of stems met the form requirement for selection. At stockings below 1000 SPH less than the required 300 SPH stems of suitable form were obtained. Plots planted at higher stocking afforded more scope for selecting final crop stems. At 1000 SPH about 300–450 SPH selected stems were within the criteria for form, while at 1667 SPH there were 800 SPH suitable. However, this extra selection came at a high cost of planting and restriction of the growth of the final crop trees.

Because of the risk of decay, branch criteria, size and angle, have been included as part of the selection criteria for pruning for final crop *E. nitens* stems (Wardlaw, 1995; Neilsen et al., 1996). If branch criteria were included the number of suitable retained stems at lower stocking were limited. Only marginal numbers of suitable stems were available in stands planted at around 1000 SPH. Form pruning has been proposed by Nicholas (1992), to reduce the dependence of final crop selection on branch size criteria. This would be done 1 or 2 years prior to normal

pruning and would remove branches which would otherwise grow beyond the branch size constraint at the time of normal pruning.

Most stands of *E. nitens* have shown substantial variability in growth and form. Even on this uniform site only 60–70% of stems were dominants or co-dominants. Only 25–40% of dominant and co-dominant stems in the stands were suitable for final crop selection based on the defined criteria. This resulted in a spread of canopy classes in the final selection. To obtain 300 suitable stems, retention of trees in canopy classes other than dominants and co-dominants was required. At 1667 SPH, 270 SPH selected stems were within the criteria for selection, with the remaining 30 in the sub-dominant class while at 1000 SPH between 50 and 60 stems were in the sub-dominant and suppressed classes. At less than 1000 SPH, stems of unsuitable form would need to be retained to achieve 300 SPH. As these trees add no value to the final crop, fewer than the desired final crop numbers would be retained in practice. For *E. regnans*, 50% of crown removal from trees 8 m tall, reduced volume growth (Glass et al., 1989). However, 50% crown removal from 9.5 and 7.5 m tall *E. nitens*, selected as co-dominants, had no effect on growth or stem taper (Pinkard and Beadle, 1997, 1998). The effects of retaining sub-dominants and suppressed stems in the stand and the effect of pruning these stems was not clear. Within the stands described here competition was evident from the change in stand structure of medium and high stockings. The trees at lower canopy classes in the stand were likely to fall further behind, even without pruning, and pruning would aggravate this (John Cunningham, personal communication). Currently a thinning of competing non-selected dominant and co-dominant trees adjacent to these selected trees from lower canopy classes should be undertaken at the time of pruning. However, if the lower rate of stem growth of these lower canopy class trees reflects genetic inferiority, rather than chance variation, these stems may not respond to this thinning and would continue to fall behind in growth. They would then contribute little to the final crop.

4.3. Management objectives

On the Tasmanian site around 1000 surviving SPH are required to meet the objective of branch diameter

control likely to be needed for the veneer/sawlog eucalypt plantation program. In this experiment care was taken to ensure fully stocked plots. In routine plantations survival of around 95% have generally been achieved, meaning planting 1050–1100 SPH to achieve the required final stocking of 1000 SPH. This was in line with most eucalypt plantations established for sawlog production in a number of countries which have generally been planted at initial stockings of around 1000–1100 SPH (Jenkin, 1990). Planting lower numbers was unlikely to achieve target final crop numbers with currently available genetic material and would not provide adequate branch control. Higher numbers were not required for final crop objectives, and could delay thinning by restricting growth on the trees to be thinned, and so piece size. Higher numbers would also stretch the limited available quality genetic material (Gerrand et al., 1997). However, to achieve management objectives high survival rates must be achieved and variability in growth minimised.

Commercial thinning during the life of the crop may be desirable from a silvicultural, as well as financial, point of view. With stocking retained to thinning age some control of branch size on the unpruned section of final crop trees may allow structural grade timber or core veneer to be cut from logs above a pruned butt log. As damage to eucalypts leads to decay in a significant proportion of wounds (White and Kile, 1991), consideration of commercial thinning must allow the development of systems which will minimise this damage, such as the use of out-row thinning, the removal of entire rows of trees at the time of thinning, to aid access. This may require removal of every fifth row in eucalypts and this would seriously reduce the selection intensity for final crop trees as allowances for out-rows would have to be taken into account.

It has been projected (Candy, 1997) that at current growth rates, a mean tree of 60 cm DBHOB, a size suitable for quarter sawn sawlog could be produced by age 24 years. Material suitable for rotary veneer would be produced in 12–16 years. These rotations may be short enough to head off substantial radial spread of decay in infected trees.

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