The East Gippsland Silvicultural Systems Project.
III: Site occupancy, species composition and growth to 12 years

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Summary

A major silvicultural experiment was established in lowland forest in East Gippsland in 1989 and 1990 to evaluate alternative silvicultural systems. A range of harvesting and site preparation treatments was applied in a replicated design over two seasons. Harvesting treatments were based on a series of gap sizes (0, 0.03, 0.25 and 1-ha gaps, 4 and 10-ha clearfells) and retained overwood (clearfell and 7, 22, 35 and 100% retained basal area). Results of site preparation by slash-burn and by mechanical disturbance are compared. A primary criterion for evaluation of these treatments was the success of eucalypt regeneration, including site occupancy, species composition and early growth.

Regrowth density, species, diameter and height were measured at ages 4, 5, 6 and 10 y after site preparation using small, dispersed plots. All harvesting treatments had a satisfactory level of site occupancy, but the level of site occupancy was lowest in the 10-ha clearfell at age 10 y. All harvesting treatments showed a significant shift in species mix of regrowth in favour of *Eucalyptus sieberi*, but this shift was less pronounced in the 7% retained overwood and clearfell treatments. Thus, the more intensive harvesting treatments stand out as being superior from the point of view of maintaining species composition. Rates of diameter and height growth in the regenerating stands were reduced by increasing levels of retained overwood and decreasing gap size.

Regrowth basal area and volume were measured in large plots 12 y after site preparation. It was found that the initially-lower levels of site occupancy in the 10-ha clearfell may increase the rate of merchantable volume production in the long term. Regrowth basal area and volume growth increased with increasing gap size and decreasing retained overwood. Inclusion of the growth of retained overwood increased the ranking of the 35% overwood over the 22% retained overwood treatment.

The differences between site preparation by slash-burn and mechanical disturbance were marginal. Although regrowth densities varied significantly at age 10 y in favour of mechanically-disturbed treatments, this did not translate into higher basal area or volume per hectare in these coupes. The initial competitive growth advantage of the slash-burnt treatments appears not to have been sustained.

Keywords: silvicultural systems; clearcutting; shelterwood system; regeneration; seed sources; survival; stocking density; growth; site preparation; fire; *Eucalyptus*; Victoria

Introduction

The Silvicultural Systems Project aimed to test the hypothesis that a better balance between economic and environmental concerns could be achieved in Victorian native forests by silvicultural systems other than clearfelling (Squire 1990). The Cabbage Tree Creek Silvicultural Systems Project is one of two experiments established to compare clearfelling with a number of partial harvesting regimes. A primary objective was to determine whether eucalypts would successfully regenerate and develop to replace the portion of mature forest removed by partial harvesting. An objective comparison can be based on appropriate indicators of sustainability, in this case, site occupancy (e.g. regrowth density), species composition and stand growth (height, diameter, basal area and volume) (Lutze *et al.* 2004). This paper compares the success of eucalypt regeneration on this basis to 12 y following a range of harvesting and site preparation treatments. Some silvicultural systems aim to provide a balance between the development of regeneration and the growth of more mature trees retained through the system. Thus a secondary objective was to compare the stand growth to 12 y on all harvesting and site preparation treatments.

Methods

The site, experimental design and treatments are presented in detail by Squire *et al.* (2006); a brief description follows.

Site description

The Cabbage Tree site is located in Cabbage Tree Block, Orbost District, East Gippsland Forest Management Area, Victoria. The average rainfall is about 1100 mm y^{-1} and altitude is 70–200 m asl. The main vegetation community is ‘Lowland Forest’ (four subcommunities dominated by *Eucalyptus sieberi*, *E. globoidea*, *E. baxteri* or *E. consideniana*) with minor occurrence of 'Damp Forest' (dominated by *E. obliqua* in association with *E. botryoides*, *E. globoidea* and *E. cypellocarpa*). *Eucalyptus croajingalensis* and *E. muelleriana* are also present on the site. The mature forest varied in height from 24 to 47 m and stand basal area from 10 to 80 m^2 ha^{-1} before treatment.

Experimental design

The Silvicultural Systems Project compared the effects of four classical silvicultural systems: clearfell, seedtree, shelterwood and group selection (Government of Victoria 1986; Squire 1990). These systems differ from one another in the size of the unit area harvested, referred to here as gap size; and in the proportion of trees retained within the harvested area, termed here the level of retained overwood. They also differ in the arrangement of successive harvests in time and space, and as such are often divided into those resulting in even-aged and uneven-aged stands. In this context, the SSP experiment at Cabbage Tree Creek trialled nine harvesting treatments (Table 1), as distinct from silvicultural systems; their arrangement in time and space was not examined. These harvesting treatments represent points along continua of increasing gap size and decreasing overwood retention (Squire *et al*. 2006).

In conjunction with the nine harvesting treatments, two site preparation treatments were also evaluated. About half of the coupes receiving each harvesting treatment were site-prepared by slash burning, and half by mechanical disturbance. Site preparation was carried out to ensure that eucalypt regeneration was not too limited by adverse seedbed conditions.

Harvesting treatments

Unharvested forest represents the starting point for both continua, that is a 0-ha gap and 100% retained overwood treatments. The group selection system is represented by gaps of three sizes: 0.03 ha, 0.25 ha and 1 ha. All gaps were naturally seeded by edge trees. The 0.03-ha gaps were created by the removal of a single dominant or co-dominant tree and usually, one or two adjacent suppressed trees. The 0.25-ha gap has a width of about one tree height. The 1-ha gap represents a gap width of about two tree heights, the greatest width expected to be effectively seeded by edge trees (Squire *et al.* 1991).

The shelterwood system is represented by two levels of retained overwood: 35% and 22% of basal area. The seedtree system is represented by the nominal retained overwood level of 7% of basal area. Retained overwood and seed trees were carefully selected on the basis of spacing, seed crops, species mix and form.

The clearfell system is represented by two coupe sizes: 4 ha and 10 ha. Both are too large to be effectively seeded by surrounding edge trees, hence both were artificially (aerially) seeded. The 10-ha clearfell was included to represent the end point for both continua; a 10-ha gap where the edge effect is no longer significant, and 0% retained overwood. By comparison, the edge effect was expected to influence a significant proportion of the 4-ha coupes.

Aerial seeding of the clearfell coupes was at a sowing rate of 50 000 viable seeds ha^{-1}, derived from a target regrowth density of 3000 stems ha^{-1} at age 2 y and an expected seedling percentage of 6%. This sowing rate is one-third the standard of 150 000 viable seeds ha^{-1} (Fagg 2001). The seed used was collected from the study area during harvesting and was applied as a mixture with a species composition that matched the presence of the five main species in the forest prior to harvesting: 35% *E. sieberi*, 24% *E. globoidea*, 24% *E. baxteri*, 13% *E. consideniana* and 4% *E. botryoides*.

All of the above treatments were replicated in space and most over two successive years (Table 2). Replication between treatments was unbalanced as a result of resource constraints, notably the limited size of the study area and the varying requirements of the component studies being undertaken. Replication between years was also unbalanced, with about one-third of the coupes regenerated in 1989 and the remainder in 1990. As far as possible, coupes were located randomly in the study area. The main exception was that some 0.03-ha gaps and some 22% and 35% retained overwood coupes were aggregated to meet design requirements for studies of harvesting safety and productivity.

Sampling design

Four years after regeneration, the original system of 2-m^2 germination and survival study plots was replaced by a series of 2-m radius (12.54 m^2) plots to monitor the development of the regenerating stands (Lutze 1998a). These plots were established

Table 1. Harvesting treatments in the Silvicultural Systems Project at Cabbage Tree Creek in East Gippland, Victoria

Harvesting treatment	Silvicultural system	Coupe size	Retained overwood (%)	Retained basal area (m^2)	Seed source
0.03-ha gap	Group selection	20-m diameter	0	0	Natural
0.25-ha gap	Group selection	50 m × 50 m	0	0	Natural
1-ha gap	Group selection	100 m × 100 m	0	0	Natural
4-ha clearfell	Clearfell	200 m × 200 m	0	0	Air seeded
10-ha clearfell	Clearfell	10 ha	0	0	Air seeded
7% overwood*	Seedtree	5 ha	10	3	Natural
22% overwood*	Shelterwood	2 ha	30	8	Natural
35% overwood*	Shelterwood	2 and 4 ha	50	13	Natural
Unharvested forest	Control	30 × 30 m	100	35	Natural

*The nominal fraction of basal area retained in these treatments was 10%, 30% and 50% respectively (Squire *et al.* 2006)

Table 2. Replication of harvesting and site preparation treatments by regeneration year, and sampling design for the study of eucalypt regeneration, density and growth in the Silvicultural Systems Project at Cabbage Tree Creek in East Gippsland, Victoria

Harvesting treatment	Replicates (coupes) per treatment					Sampling (no. plots)		
	Site preparation treatment y^{-1}				Total			
	Burnt		Disturbed					
	1989	1990	1989	1990		2-m radius plots per coupe	20 m × 20 m plots per treatment*	No. retained tree plots per treatment
0.03-ha gap	3	8	3	8	22	2	nil	nil
0.25-ha gap	3	5	3	5	16	6	4B, 4D	2B 1D
1-ha gap	3	4	3	4	14	8	nil	1B 1D
4-ha clearfell	2	2	2	2	8	16	6B, 7D, 2BE, 4DE	1D
10-ha clearfell	2	2	—	—	4	20	4B	2B
7% overwood	2	2	2	2	8	8	6B, 4D	2B, 2D
22% overwood	2	3	2	3	10	6	4B, 4D	2B, 2D
35% overwood	—	2	2	2	6	6	6D	2D
Unharvested forest	—	2	2	2	6	2	2B, 4D	1D 1N

*B = burnt coupes, D = disturbed coupes, E = 5 m × 50 m rectangular plot on each edge of coupe, N = no site preparation

in every coupe (Table 2). The new plots were assessed at ages 4, 5, 6 and 10 y after site preparation. As establishment of new seedlings was still occurring in some treatments, plots were thoroughly searched, and newly-observed eucalypts tagged and recorded, during each assessment. At ages 4, 5 and 6 y all regrowth was assessed for species, height and location, while only those > 1.6 m tall were measured for diameter at breast height over bark (dbhob). When regrowth was of coppice origin, this fact was also noted. At age 10 y the following were measured: dbhob of all regrowth > 1.6 m tall; dominance class of all stems; and the total height of the largest-diameter stems in each plot.

The 2-m radius plots were expanded concentrically at age 10 y to 15-m radius, because of some concern about the small area and number of dominant trees sampled by the plots with 2-m radius. For similar reasons the basal area of the regrowth was measured by the sweep of a factor 1 basal area wedge from the centre of each 2-m radius plot. Dbhob, dominance class and the height of the five largest-diameter eucalypts in each expanded plot were measured.

In order to keep pace with stand development, particularly the concentration of growth on and interaction between fewer, more widely spaced trees, larger fixed-area growth plots (20 m × 20 m) were established at age 10–12 y in all treatments with the exception of the 0.03-ha and 1-ha gap treatments (Table 2). Generally only one large plot was established in each of a number of randomly-selected coupes covering most treatments, the plot being located around a randomly-selected 2-m radius plot. At establishment, all regrowth stems > 1.3 m tall were assessed for species, dbhob and dominance class, and the height of the three largest-diameter trees and of 10 trees across the diameter range was measured. In the 4-ha clearfell treatment, edge plots 5 m wide extending 50 m from each edge into the coupe (i.e. 4 × 0.025-ha plots) were also established. The same measurements were made as in the 20 m × 20 m plots, except that the height of the largest-diameter tree was measured in 5-m subplots (25 m^2) sampled along the length of the plot.

Growth data on retained trees were collected from 20 plots, each about 40 m × 40 m (0.16 ha) in size, established immediately after harvesting of the 1989 replication. These plots sampled the unharvested edges of gaps and clearfells and the retained trees across the retained overwood treatments. The same measurements were made as in the 20 m × 20 m plots at about 2-y intervals from 1989 to 1999.

Data analysis

The following stand parameters were calculated:

Regrowth density at each age of assessment: density was calculated as the number of eucalypt regrowth stems per plot, converted to a per-hectare value.

Average regrowth diameter was calculated as the mean of the dbhob of all eucalypt regrowth stems > 1.6 m tall.

Maximum regrowth height and *maximum regrowth diameter*: the means of the height and diameter of the largest-diameter tree per plot provided a measure of the height and diameter of the 800 largest regrowth stems ha^{-1}.

Mean dominant height of regrowth and *mean dominant diameter of regrowth*: the five largest-diameter regrowth stems per 15-m radius plot provided a measure of the mean of the height and diameter of the 70 largest regrowth trees ha^{-1}. Some plots were excluded from analysis because they overlapped following expansion of the plot radii from 2 m to 15 m.

Regrowth basal area: the mean of the basal area sweeps of regrowth from the centres of the 2-m radius plot at age 10 y was calculated. At age 12 y the basal area was based on the 20 m × 20 m plots.

Basal area growth of overwood was calculated as the cumulative increase in basal area of overwood from repeated measurement of retained-tree plots in the period 1989–1999 (including trees that had died over the period). Individual-tree basal area increments were calculated, then summed for each plot, converted to a per-hectare value and to the same periodic basis (12 y) as was used for the regrowth data by multiplying by 1.2. Basal area growth of overwood net of mortality was also calculated by subtracting the basal area of dead trees at the time of mortality from the cumulative basal area increment.

Regrowth volume was calculated from the 20 m × 20 m plot data at age 12 y. Stem volume is a function of tree diameter, height and taper. As then-existing volume and taper functions were inaccurate for 12-y-old trees, total over-bark stem volume was approximated as:

$$\text{regrowth volume} = \frac{\text{regrowth basal area} \times \text{ regrowth height}}{3}.$$

This equation was applied to the trees measured for height. The regression relationship between basal area and volume was calculated for each plot and used to estimate volume for trees that had been measured for dbhob only. Individual-tree volumes were summed for each plot and converted to a per-hectare value.

Volume growth of overwood was calculated from the individual-tree volume increments over the period 1989–1999 in the same way that basal area growth of overwood was calculated. The same procedure was used for individual-tree volume estimation as used in the regrowth plots, except the regression relationship between basal area and volume was based on the Standsim single-tree volume table for *E. sieberi* (Incoll 1974). Volume growth of overwood net of mortality was also calculated by subtracting the volume of dead trees at the time of mortality from the cumulative volume increment.

Stand basal area and volume growth over 12 y was calculated as the growth in basal area and volume of regrowth plus the growth in basal area and volume of the overwood for each treatment. For the gap treatments, the growth of the overwood in edge plots in excess of that of overwood in the unharvested control (i.e. with no edge effect) was attributed to the gaps. Thus the growth of the gap treatments was increased by an amount equal to the basal area or volume growth per hectare of the pooled edge plots minus the basal area or volume growth per hectare of the unharvested plots. It was assumed that the area of edge affected by the gap increased linearly with gap size, so that per-hectare growth of overwood due to the gap did not vary over the range of gap sizes.

The following information on species composition and stand growth was summarised:

- *Species composition of retained basal area:* percentage of total retained basal area contributed by each species in retained-overwood coupes
- *Species composition of seed supply from retained overwood:* percentage of total assessed seed crops contributed by each species in retained-overwood coupes. The seed crop assessment procedure is described by Squire *et al.* (2006).
- *Species composition of regrowth basal area at age 10 y:* percentage of total basal area of regrowth contributed by each species in all coupes
- *Species composition of regrowth at age 10 y:* percentage of the regrowth density contributed by each species in all coupes
- *Species composition of the dominant regrowth at age 10 y:* percentage of the 70 largest regrowth trees per hectare contributed by each species in all coupes
- *Dbhob by species at age 10:* calculated as the mean of the dbhob of all regrowth > 1.6 m tall in each species
- *Height by species at age 10 y:* calculated from the height of measured seedlings and height estimated for the remaining trees that had been measured for dbhob only. A regression relating the dbhob to the height of all trees across plots was used to estimate the height of trees that had been measured for dbhob only.

The Restricted Estimation of Maximum Likelihood (REML) model was the most efficient tool for analysis because of the highly unbalanced and multi-level nature of the experimental design. REML (Genstat 5 Committee 1993) is ideal for analysis of multi-level data that is a mix of fixed (harvesting and site preparation treatments, and regeneration year) and random (coupe and plot) factors. It empirically finds the appropriate weighting of the coupe and plot data and is not compromised by the non-orthogonal design. The statistical model examines the isolated and interactive effects of harvesting and site preparation treatments and regeneration year. The model can also include covariates, such as measures of coupe site quality, as fixed or random effects. The dependent variates were regrowth density, average regrowth diameter, maximum regrowth height, maximum regrowth diameter, mean dominant height, mean dominant diameter, basal area, volume and species composition by different measures (i.e. retained basal area, seed supply from retained overwood, regrowth basal area, regrowth density, dominant regrowth).

Additional analyses for species composition and growth included:

- *Variation with measure of species composition:* a REML model was fitted for each species, which included the species proportion as the response variable and harvesting, site preparation, year of regeneration and source of species composition estimate (i.e. retained basal area, seed supply from retained overwood, regrowth basal area, regrowth density, dominant regrowth) as fixed factors.
- *Variation in dbhob and height with species:* species was added as a factor to the model examining the isolated and interactive effects of harvesting and site preparation treatments and regeneration year on regrowth dbhob and height.

All non-proportional data sets were transformed to the natural log scale to redress skewed distributions. Similarly, proportions were transformed by the arcsine transformation for analysis (Zar 1984). Analysis results are shown as the transformation in graphs to correctly represent 95% confidence intervals. Back-transformed means can be found in the related tables.

Results and discussion

Regrowth density

The initially-high regrowth density produced in the less-intensively-harvested treatments decreased dramatically between ages 4 to 10 y (Fig. 1), continuing the trend reported at age 3 y (Faunt *et al.* 2006). Density in the 0.03-ha gap at age 10 y was

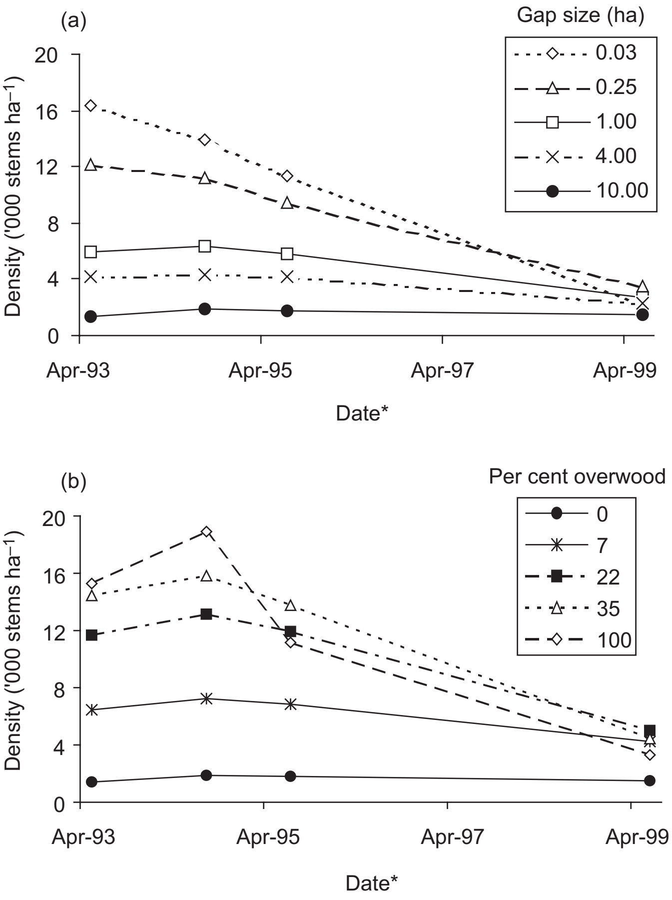

Figure 1. Regrowth density 4–10 y after site preparation in (a) the gap continuum and (b) the overwood continuum. Plotted lines show variation in harvesting treatment over time. Legend shows (a) gap size in hectares, and (b) percentage of overwood basal area retained at establishment. *Date applies to 1989 replication.

2300 stems ha^{-1}, an 86% decrease on stand density at age 4 y (Table 3). This contrasts with the 10-ha clearfell treatment where stocking remained relatively constant from age 4 y at 1500 stems ha^{-1}.

At age 10 y, the pattern in regrowth density varied significantly with the year of regeneration (Fig. 2, $P < 0.05$). Coupes regenerated in 1989 still followed the pattern established at the regeneration stage, with greater regrowth density in the smaller gaps — or as the level of retained overwood was increased. This can be attributed to the influence of level of seed supply on initial density (Fig. 2a), that is, the greater the retained overwood, or the smaller the gap, the greater the seedfall and hence germination on receptive seedbeds (Faunt *et al.* 2006). However, in coupes regenerated in 1990, regrowth densities in the smallest gaps and under the highest levels of retained overwood had decreased so much by age 10 y that they were the lowest recorded in any of the treatments (Fig. 2b). The reason for the difference between the years is unknown. However, a broad convergence of densities across the treatments was to be expected as the initial influence of seedfall was redressed by mortality. High mortality was expected because of the greater competition from mature trees in treatments with more retained overwood, or smaller gap size. Additionally, greater inter-seedling competition in the denser stands would increase mortality over time, in contrast to the stability of the stocking in the low-density 10-ha clearfell coupes.

The two regeneration years were replicates in time rather than formal treatments, hence the interaction can be dropped from the model to determine the overall effect of the harvesting and site preparation treatments. When combined, the overall pattern of regrowth density across harvesting treatments matched that of the 1990 coupes (Table 3). The combined year results supported the anticipated very poor survival from year 3 in the less-intensively-harvested treatments (Faunt *et al.* 2006).

Eucalypt seedling survival under overwood competition, beyond the initial establishment stage, has also been studied in *E. regnans* forest. Ashton and Willis (1982) reported that in unharvested

Table 3. Stand parameters of eucalypt regeneration at age 10 y in the Silvicultural Systems Project at Cabbage Tree Creek in East Gippsland, Victoria

Harvesting treatment	Seedling density (no. ha^{-1})	Dbhob (cm)			Seedling height (m)		Basal area (m^2 ha^{-1})
		Mean[a]	Max[b]	Doms[c]	Max[b]	Doms[c]	
Gaps (ha)							
0.03	2300	1.3	1.8	3.4	1.6	5.4	0.2
0.25	3600	2.0	3.3	8.4	4.8	9.4	1.7
1.00	2700	2.8	4.2	11.8	5.6	11.3	3.6
4.00	2300	4.4	7.7	15.9	7.6	13.5	7.0
10.00	1500	4.8	6.8	16.7	7.4	13.5	7.8
Overwood (%)							
0	1500	4.8	6.8	16.7	7.4	13.5	7.8
7	4200	3.5	6.1	17.5	7.0	14.4	9.0
22	5000	2.8	5.2	12.7	6.7	11.9	5.1
35	4400	2.1	3.8	10.7	5.5	10.8	2.6
100	3300	1.7	3.9	4.4	1.4	5.5	1.3

[a] Mean = mean of all regrowth >1.60 m tall
[b] Max = mean of largest-diameter tree per 2-m radius plot
[c] Doms = mean of five largest-diameter trees per 15-m radius plot

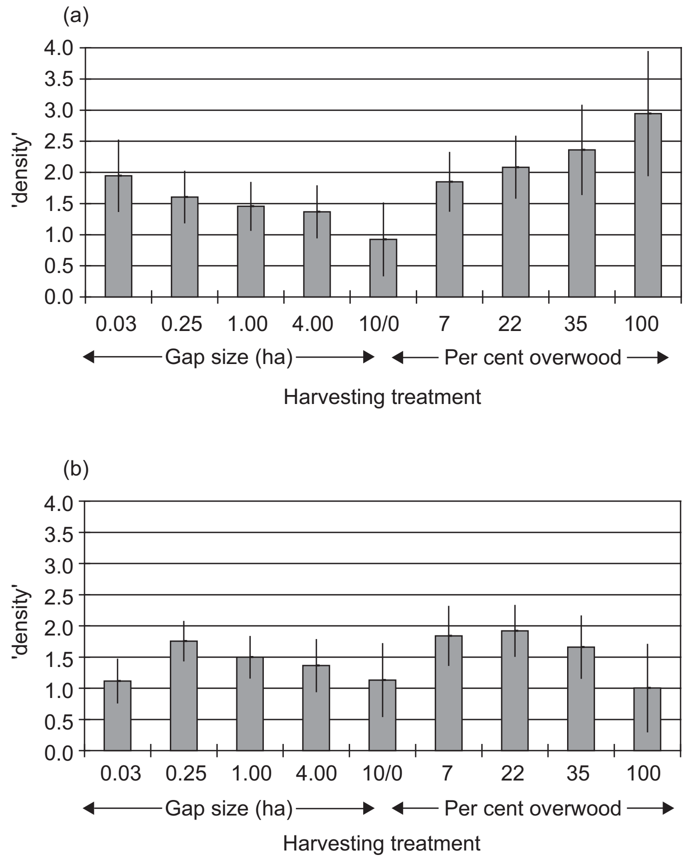

Figure 2. Regrowth density for each harvesting treatment at 10 y after site preparation in (a) coupes regenerated in 1989, and (b) coupes regenerated in 1990, where 'density' = ln((total stems ha^{-1} × 0.001) + 1))

stands on disturbed soil, *E. regnans* seedlings stagnated and were replaced by understorey species by 10 y, but on areas disturbed by a surface fire, regeneration persisted and grew to heights of 10–20 m after 30–40 y. In the replication of the SSP experiment in *E. regnans* forest (Squire 1990), van der Meer (unpublished data, Centre for Forest Tree Technology, Department Natural Resources and Environment, 1998) reported that sapling density at 8 y after site preparation varied from 350 to 9400 seedlings ha^{-1}, with 95–2338 dominants and codominants ha^{-1} and with density increasing with gap size. The comparison of density in these studies indicates a greater tolerance of overwood competition in the lowland forest compared to the *E. regnans* forest, which is consistent with their greater tolerance of inter-seedling competition (Florence 1996).

Regrowth density also varied significantly ($P < 0.05$) with site preparation treatment. At age 10 y, mechanically-disturbed treatments supported on average 800 more regrowth stems ha^{-1} than treatments site-prepared by slash-burn. At establishment, the influence of site preparation on density was confounded by the year of regeneration, that is, mechanically-disturbed treatments produced higher regrowth densities than those slash-burnt in 1989, and vice versa in 1990 (Faunt *et al.* 2006). The consistency of the year 10 result, which is significant from age 5 y, suggests that the method of site preparation is directly influencing rates of survival. That is, regrowth survival is greater in mechanically-disturbed treatments.

In contrast, Fagg (1987) reported that while seedling density was initially much higher on mechanically-disturbed seedbeds, subsequent survival was poorer, and seedling densities of sown *E. sieberi* and *E. globoidea* were similar on cultivated and burnt seedbeds at 7 y after sowing. He suggested that, among other things, greater competition between seedlings as a result of higher initial densities may have been responsible for the difference in survival between seedbeds. In the absence of a large difference in initial density at the Cabbage Tree site, the greater survival in mechanically-disturbed treatments may be due to better survival of small seedlings, possibly due to less competitive understorey. The main source of understorey competition throughout the period 4–12 y is likely to be woody plants, particularly acacias, which were more abundant and vigorous in the burnt treatments. There was a greater cover of acacias at 2.5 y in operational plots, and the basal area of acacias was greater in the 20 m × 20 m plots at 12 y in the burnt compared to the disturbed treatments (M. Lutze, unpublished data). Fagg (1987) also showed that the growth of acacias was greater on burnt than on disturbed seedbeds.

Diameter growth

The ranking of harvesting treatments for the *average regrowth diameter* remained relatively constant as the average diameter increased steadily between ages 4 and 10 y (Fig. 3). Average

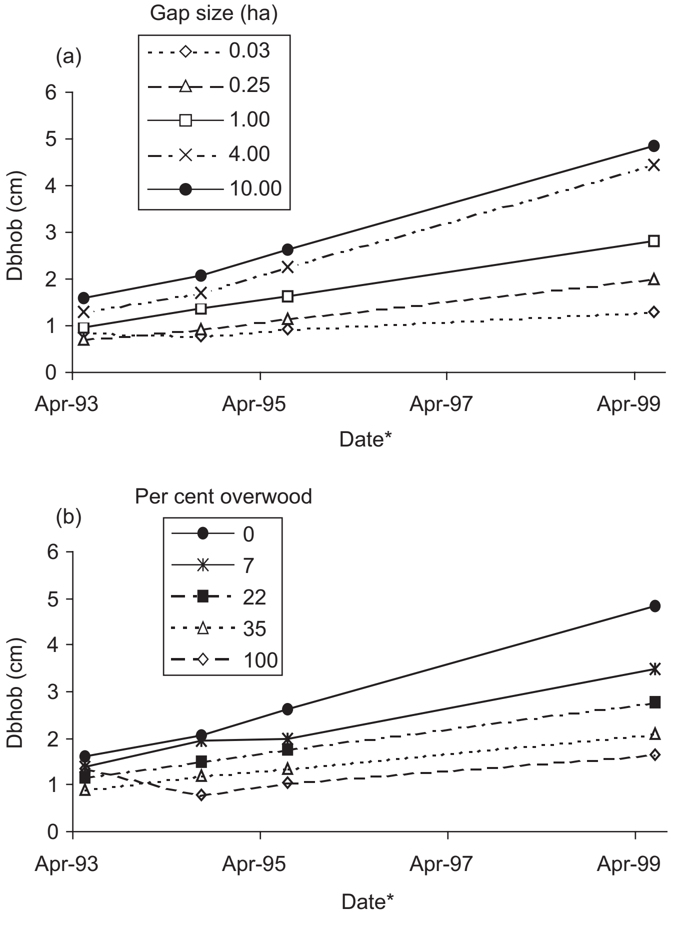

Figure 3. Average regrowth dbhob 4–10 y after site preparation in (a) the gap continuum and (b) the overwood continuum. Plotted lines show variation in harvesting treatment over time. Legend shows (a) gap size in hectares, and (b) percentage basal area of overwood retained at establishment. *Date applies to 1989 replication.

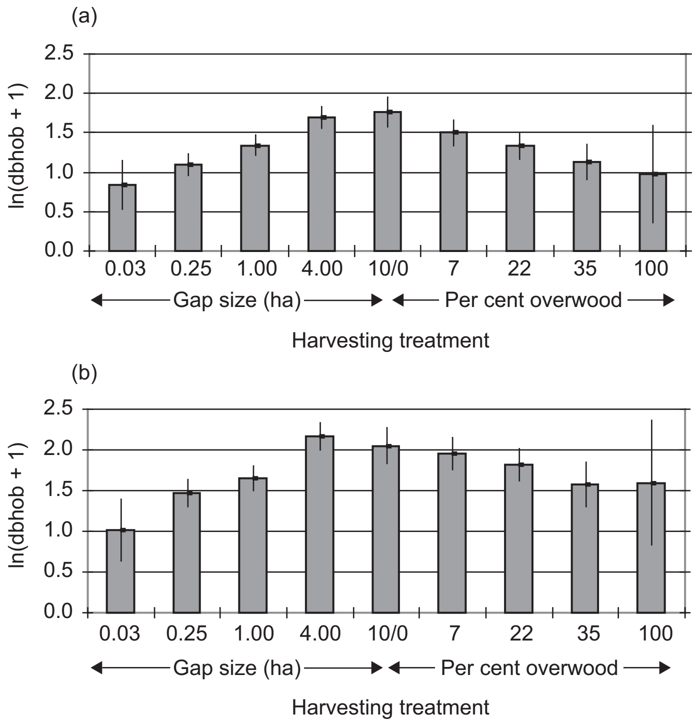

Figure 4. (a) Average and (b) maximum dbhob in each harvesting treatment 10 y after site preparation. Please refer to Table 3 for untransformed values.

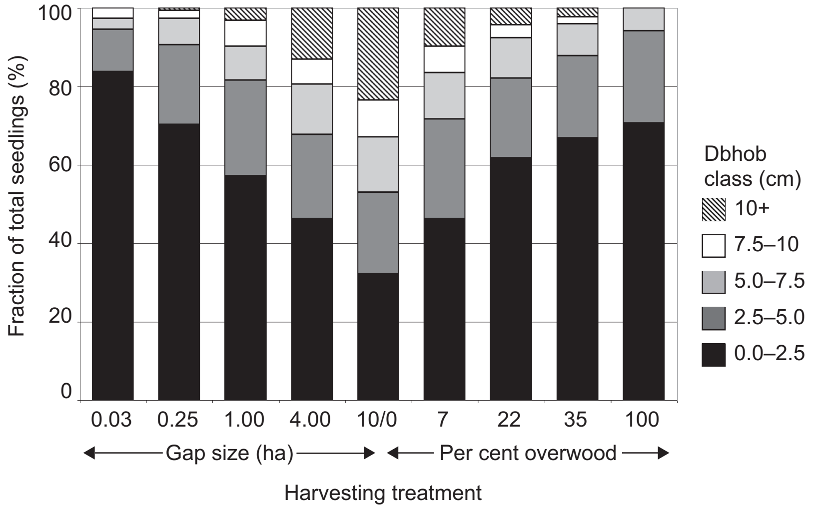

Figure 5. Proportion of total stems by 2.5-cm diameter classes in harvesting treatments at 10 y after site preparation.

diameter at age 10 y (Fig. 4a, Table 3) increased as gap size increased and the level of retained overwood decreased ($P < 0.05$), that is, as competition from retained mature trees was reduced. The most-intensively-harvested treatment, the 10-ha clearfell, produced regrowth with the largest diameters, on average 4.8 cm dbhob. This contrasted with 1.3 cm in the 0.03-ha gap treatment (Table 3).

The result for average diameter of regrowth was supported by the diameter distributions of the regenerating stands. The frequency of regrowth within 2.5-cm-dbhob size classes (Fig. 5) shows a strong, consistent pattern, that is, a greater proportion of larger regrowth in the more-intensively-harvested treatments. That is, as gap size increased or the level of retained overwood decreased, the regenerating stands contained a greater proportion of larger regrowth as a result of reduced competition from mature trees.

The ranking of harvesting treatment for *maximum regrowth diameter* differed slightly from that of average regrowth diameter in that the 4-ha clearfell had overtaken the 10-ha clearfell treatment (Table 3 and Fig. 4(b)). This difference is not significant but amounts to an additional centimetre of diameter growth in the 4-ha clearfell (Table 3). This result is contrary to the generally consistent pattern of greater growth in the more-intensive harvesting treatments. It is possibly an artifact of sampling: the 10-ha clearfell had only four replicates, at most half the number in most other treatments (Table 2), so it was more sensitive to site factors. The deliberately-created lower density of regrowth in the 10-ha clearfell also produced a larger proportion of plots with no measured trees than the 4-ha clearfell (30% vs 20%), and hence a further-reduced sample. The mean dominant diameter was similar in the 10-ha and 4-ha clearfells, and in the 7% retained overwood (Table 3). This supports the notion that the greater maximum regrowth diameter in the 4-ha clearfell was an artifact of sampling.

At the opposite end of the continuum, the 100%-retained-overwood treatment also produced somewhat counter-intuitive results. Though variable, the unharvested treatment produced some large regrowth with an average maximum regrowth diameter of 3.9 cm at 10 y. Thus, some regrowth in the unharvested forest was developing as vigorously as that where competition from retained mature trees had been more than halved, as in the 35%-retained-overwood treatment. The large difference in confidence intervals between the two treatments (Fig. 4b) indicates that a 3.9 cm dbhob regrowth stem was a much less reliable outcome in the 100% than in the 35%-retained-overwood treatment. The mean dominant diameter declined significantly with increasing overwood density ($P < 0.001$), there being a 6 cm difference in dbhob between the 35% and 100%-retained-overwood treatments. The difference between mean dominant and maximum regrowth diameter was much smaller for the 100%-retained-overwood treatment than for others, which suggests that the maximum regrowth diameter result for the 100% retained overwood may also have been an artifact of sampling.

The effect of site preparation on average regrowth diameter was significant to age 6 y ($P < 0.05$), with regrowth in slash-burnt treatments a marginal 0.2–0.3 cm larger than that in mechanically-disturbed treatments. By age 10 y, this difference was no longer significant. This pattern was repeated in the maximum regrowth diameter, which was a significant 0.5–0.6 cm greater in slash-burnt than disturbed treatments to age 6 y, but by age 10 y the difference of 0.1 cm was not significant. In contrast, the mean dominant diameter was significantly greater in slash-burnt than in mechanically-disturbed treatments at age 10 y ($P < 0.05$), but the difference of 2 cm was small.

Height

The response of maximum regrowth height to harvesting treatment at age 10 y varied with regeneration year (Fig. 6, $P < 0.05$). Coupes regenerated in 1990 showed the anticipated pattern of greater height growth with reduced competition from mature retained trees. In the 1990 coupes, maximum regrowth height was only 0.8 and 0.4 m respectively in treatments with the most overwood, that is, the 0.03-ha gap and the 100%-retained-overwood treatments. In contrast, maximum regrowth height in the same treatments in the 1989 coupes was 3.7 m and 4.6 m. The reason for this difference is not clear, but there were at least double the number of replicates (coupes) in these treatments in the second year (Table 2); the six 0.03-ha gaps established in 1989 was increased to 16 in 1990, and the 100%-retained-overwood was increased from two to four coupes. Hence the 1990 results might be considered a more reliable estimate due to greater replication. However, only one or two regrowth plants were required to regenerate a 0.03-ha gap, and the two 2-m-radius plots sampling these coupes may have missed seedling(s) with this potential.

When the regeneration years are combined, the pattern for maximum regrowth height is similar to that reported for maximum regrowth diameter, that is, regrowth in the 4-ha clearfell had overtaken that in the 10-ha clearfell between the ages 6 and 10 y. However, the advantage was marginal and not significant. At age 10 y the maximum regrowth heights were 7.6 m in the 4-ha clearfell (Table 3), closely followed by 7.4, 7.0 and 6.7 m respectively in the 10-ha clearfell, and 7% and 22% retained overwoods. As for the mean dominant diameter, the mean dominant height decreased with increasing overwood and decreasing gap size ($P < 0.001$), although it was similar in the 10-ha and 4-ha clearfell and 7% retained overwood (Fig. 7 and Table 3). Hence levels of competition from retained mature trees, either as retained overwood or gap edge, do not appear to influence height growth of the dominant regrowth to a significant degree in retained overwood up to 22%, and gap size down to 4 ha.

As was found for the maximum regrowth diameter, the effect of site preparation on maximum regrowth height was significant to age 6 y ($P < 0.05$), when regrowth was 0.3–0.4 m taller in slash-burnt than disturbed treatments. By age10 y, however, this ranking had reversed to an insignificant height advantage of 0.2 m in treatments prepared by mechanical disturbance. The mean dominant height was not significantly different at age 10 y ($P > 0.05$), the height being 1.4 m greater in slash-burnt treatments. The results suggest that the dominant trees may retain an ongoing height advantage in slash-burnt treatments, but the early height advantage is not maintained by the larger population of regrowth. This result supports the assertion that initial substantially-superior growth rates in fire-prepared seedbeds are not sustained in the longer term (Lockett 1998; Lutze and Featherston 1999).

Basal area

At age 10 y, the response in regrowth basal area to harvesting treatment (Fig. 8, Table 3, $P < 0.001$) was more a function of regrowth size than regrowth density. Thus basal area of the regenerating stand increased as the level of competing basal area in mature retained or edge trees declined. An exception to this

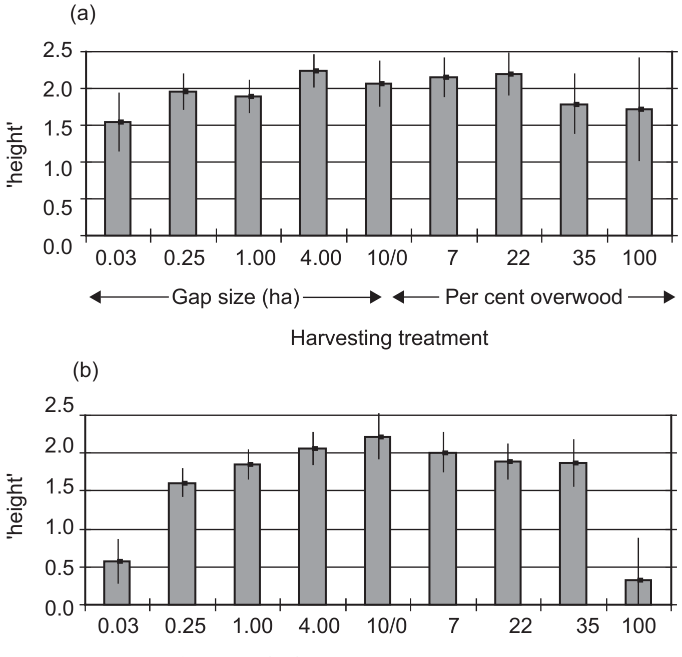

Figure 6. Maximum regrowth 'height' in each harvesting treatment at 10 y after site preparation in (a) coupes regenerated in 1989, and (b) coupes regenerated in 1990, where 'height' = ln(height (m) + 1)

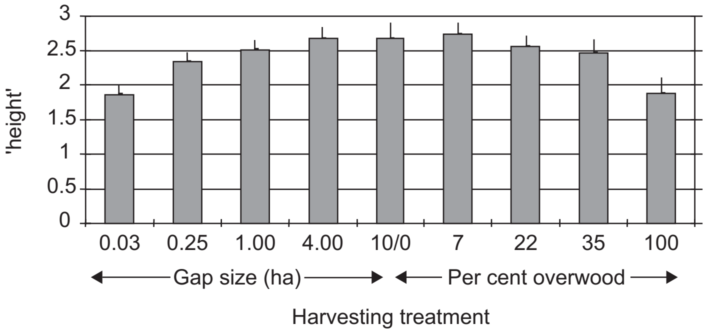

Figure 7. Mean dominant 'height' for each harvesting treatment 10 y after site preparation, where 'height' = ln(height (m) + 1)

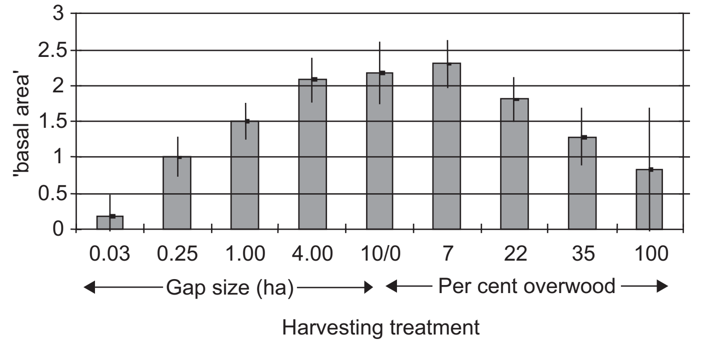

Figure 8. Regrowth 'basal area' for each harvesting treatment at 10 y after site preparation, where 'basal area' = ln(basal area (m^2 ha^{-1}) + 1)

was the 10-ha clearfell, where regrowth density in the regenerating stand was artificially low, as manipulated by the air seeding regime (Squire *et al.* 2006). Hence although the size of the 10-ha clearfell regrowth was close to that in the 7% retained overwood, the lower density resulted in a total basal area about 1 m^2 ha^{-1} less (Table 3). This indicates that the clearfell treatment had lower site occupancy until age 10 y. The 4-ha clearfell had a lower basal area than either the 10-ha clearfell or 7% retained overwood, which might be explained by the suppression of growth by edge trees.

Inclusion of the coupe pre-harvesting basal area, height or volume as a covariate did not change the significance or ranking of harvesting treatment effects and the covariate term was not significant. Thus, although there were significant differences between treatments in the pre-harvesting stand characteristics, and this may indicate differences in inherent site productivity, they were not great enough to significantly affect development of the regrowth. When regrowth originating from coppice is excluded from the calculation of basal area, the change in harvesting treatment means was marginal and their ranking remained unchanged.

Basal area at age 10 y varied with site preparation treatment ($P < 0.05$), basal area being marginally greater (by 1 m^2) in slash-burnt areas. This further demonstrates that basal area at age 10 y is a function of regrowth size rather than density, given that site preparation by mechanical disturbance significantly increased density but decreased basal area compared to slash burning.

Volume

The pattern of response in regrowth volume varies with regeneration year (Fig. 9, $P < 0.001$). The regrowth volume within the 10-ha clearfell was significantly greater than within the 22% and 35%-retained-overwood treatments in 1990, but not in 1989. The relatively poor growth of the 10-ha clearfell in 1989 could be not be attributed to differences in site occupancy, as seedling density was similar between years. Perhaps nutrient availability was less in the 1989 replication, because the intensity of the slash burns was much lower in that year (Raison *et al.* 1993; Squire *et al.* 2006). Where regeneration years are combined, regrowth volume increased as levels of competing mature retained or edge trees were reduced along the overwood and gap size continua. In contrast to basal area at age 10 y, the 10-ha clearfell was carrying similar basal area and volume as the 7% retained overwood at age 12 y (Table 4).

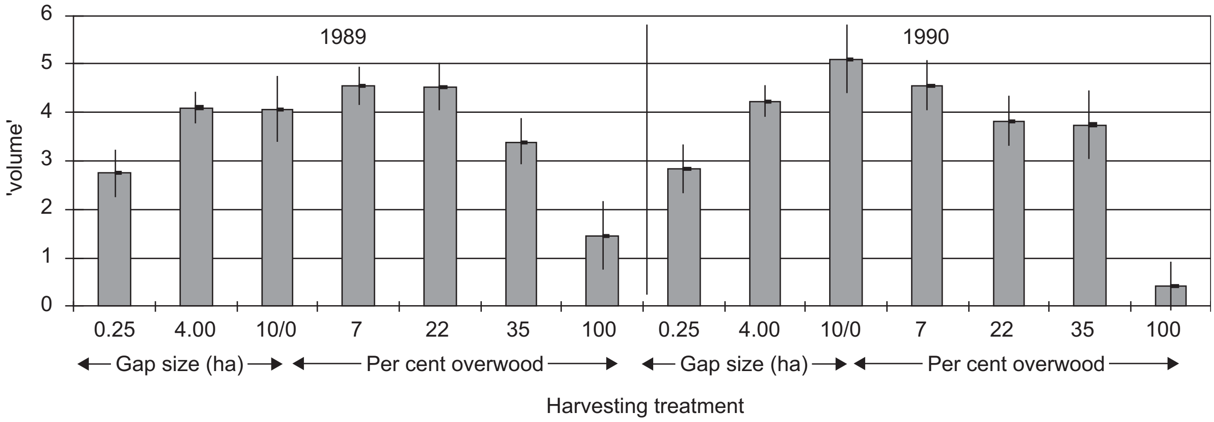

Figure 9. Regrowth 'volume' for each harvesting treatment by year of regeneration at 12 y after site preparation, where 'volume' = ln(volume (m^3 ha^{-1}) + 1)

Table 4. Basal area and volume growth (total for the 12-y period) following harvesting treatments at the Silvicultural Systems Project at Cabbage Tree Creek in East Gippsland, Victoria

Harvesting treatment	Basal area (m^2 ha^{-1})			Volume (m^3 ha^{-1})		
	Regrowth	Overwood*	Total	Regrowth	Overwood*	Total
Gaps (ha)						
0.03	No data	—		No data	—	—
0.25	4	2	6	16	22	38
1.00	No data	—	—	No data	—	—
4.00	12	2	14	65	22	87
10.00	19	2	21	98	22	120
Overwood (%)						
0	19	2	21	98	0	98
7	17	0.3	17	96	4	100
22	13	1.0	14	65	10	75
35	8	3.9	12	36	42	78
100	0	4.9	5	3	52	55

*Overwood basal area and volume growth to year 12 = measured growth to year 10 × 1.2

Although seedling densities varied significantly with site preparation at age 10 y in favour of mechanically-disturbed treatments, this did not translate into higher volume per hectare at age 12 y. This supports the earlier suggestion that the greater densities in mechanically-disturbed treatments may be due to better survival of small seedlings, particularly those < 1.3 m tall, which make no contribution to volume. This would explain why the average regrowth diameter was also similar between mechanically-disturbed and slash-burnt treatments.

Other studies in eucalypt forests have shown the long-term suppressive effects of scattered retained old trees (e.g. Incoll 1979; Rotherham 1983; Bi and Jurskis 1996; Bauhus *et al.* 2000) and gap edges (Bowman and Kirkpatrick 1986) on diameter, height, basal area and volume increment of regrowth. Generally these studies have been retrospective, assuming that the regrowth is even-aged and the distance effect has not been altered by subsequent disturbance. However, within the limitations of the retrospective approach, there is a consistent pattern in that the development of regrowth increases with increasing distance from retained trees over a large range of regrowth age. The suppressive effect at the stand level is generally quantified by adding the effects of individual retained trees, for an integrated measure of stand productivity, such as volume (e.g. Incoll 1979; Rotheram 1983; Bassett and White 2001). This study, however, has empirically established the relationship between overwood either as scattered trees or as a continuous edge on a range of stand regrowth parameters to age 12 y.

In previous studies, estimates of loss of volume due to the presence of 5 habitat trees ha^{-1}, each of 100 cm diameter, were 39% (after Incoll 1979) and 16% (after Rotheram 1983). The results to year 12 at the Cabbage Tree site are not consistent with these previous estimates, because regrowth volume in the 7%-retained-overwood treatment, which carried about five retained trees ha^{-1} each of 86 cm diameter, was similar to the clearfell treatments. This lack of suppressive effect is probably due to lower site occupancy in the 10-ha clearfell and the effect of edge trees in the 4-ha clearfell treatments up until year 12 y, as previously discussed.

Evaluation of site occupancy by regeneration

In Victoria's native forests, the sapling survey may be used to determine whether an area has been successfully regenerated 4–10 y after harvesting. Quadrats of 3.57 m radius (40 m^2) are surveyed at intervals of 30 m on parallel transects 80 m apart. The results are evaluated against the site occupancy standard that 65% of quadrats be stocked (Dignan and Fagg 1997). This stocking standard is equivalent to a regrowth density of about 1000 stems ha^{-1} for the aggregated regrowth distributions at the trial site. According to this standard, all the harvesting treatments have acceptable site occupancy at age 10 y. However, the measure for even-aged stands includes an acceptability criterion requiring that regrowth be of an acceptable size (3–15 m) and not suppressed (Dignan and Fagg 1997). An analysis of dominance class at age 10 y indicates there were < 1000 unsuppressed trees in the 10-ha clearfell, and thus it does not meet the acceptability criteria. In uneven-aged stands, saplings are acceptable if they are capable of developing into productive trees on release from overwood competition. In the 0.03-ha and 0.25-ha gaps, and the 100%-retained-overwood treatment there were < 1000 unsuppressed regrowth ha^{-1} at age 10 y, but the capacity of regrowth of any dominance class to respond to release is largely unknown for the lowland forest.

The site occupancy standard for even-aged regrowth is based on the relationship between regrowth density early in the rotation and timber yield and quality over the full rotation. It depends on the principle that both basal area and volume growth are sensitive to the spatial distribution and quantity of regrowth, and that if the standard is not met timber production will be compromised (Lutze *et al.* 2004). The SSP experimental design is such that regrowth density and overwood growth suppression are confounded for most treatments. However, both the 10-ha clearfell and 7%-retained-overwood treatments are practically free of overwood competition, but the density in the 10-ha clearfell was substantially lower. The lower density has resulted in lower basal area and volume, which clearly indicates a lower level of site occupancy up to age 10 y. The site occupancy outcome is due to the low establishment density that was deliberately created in these treatments when the operational prescription for air seeding rates was reduced by two-thirds (Squire *et al.* 2006).

The advantage of low initial seedling density is that the stand may produce larger-diameter logs over a given rotation; a longer rotation may be avoided only by costly non-commercial early thinning in the denser stands (Raison *et al.* 1995). The disadvantage of low initial seedling density is that these stands may take longer to fully occupy the site, as is the case here. By age 12 y, the 10-ha clearfell had reached levels of basal area and volume similar to that of the 7% retained overwood. The Standsim model for *E. sieberi*-dominated stands (Incoll 1974) predicts that merchantable volume growth over a rotation increases with decreasing initial density to levels below the density of the 10-ha clearfells. However, a model developed for a similar forest type, the dry eucalypt forest of eastern Tasmania, predicted that merchantable volume would be greater in the stands established with higher initial density (Lockett and Goodwin 1999). Further monitoring is required to determine the long-term effect of the lower initial density of the clearfell treatments.

The influence of low initial density and site occupancy on timber quality also needs to be evaluated. A number of studies have shown that eucalypts planted at low density produce large branches and have an increased incidence of internal defect from poor branch shedding (Incoll and Mc Kimm 1985; Marks *et al.* 1986). However, studies of the effect of density on branching and defect in natural regrowth are confined to retrospective studies in *E. diversicolor* forest of Western Australia (Bradshaw and Gorddard 1991) and wet lowland forest of Tasmania (Wardlaw *et al.* 1997). Thus further monitoring of stand development is required to determine the stem and wood quality outcomes of different initial densities created through the more intensive harvesting treatments.

The comparison of density, volume and basal area in the 4-ha clearfell with 7% retained overwood suggests that portions of the 4-ha clearfell also had lower site occupancy. The trends in survival indicate that the 0.03-ha-gap and 100%-retained-overwood treatments may eventually reach a point of low site occupancy, although growth performance alone may be enough to preclude them from further consideration.

Species composition

The species composition of regrowth at 4, 6 and 10 y did not vary significantly with site preparation treatment. As previously reported (Lutze 1998b), the percentage of *E. sieberi* at age 4 y increased significantly with increasing retained overwood, and the percentage of *E. baxteri* and *E. globoidea* decreased significantly with increasing retained overwood. The same trend occurred at age 6 and 10 y in these species, but the effect was no longer significant. The species composition did not vary significantly with gap size. A similar result was obtained with the species composition of regrowth basal area at age 10 y. The percentage of *E. sieberi* increased significantly with increasing retained overwood (Fig. 10, $P < 0.05$); *E. sieberi* contributed 44% and 41% of total basal area in the 10-ha clearfell and 7%-retained-overwood treatments respectively, but increased to > 90% in the 35% and 100%-overwood treatments. There was a corresponding significant decrease in the percentage of *E. globoidea* ($P < 0.05$) with increasing percentage of retained overwood.

It was previously suggested that the trend in species composition with retained overwood may be due to variation in the species composition of seed supply. Significant positive correlation between the species composition of seed supply and species composition of regrowth in retained overwood coupes indicates that seed supply has some influence on species composition of regrowth. However, neither the species composition of retained basal area nor estimated species composition of seed supply from retained overwood shows a similar trend with harvesting treatment. The variation in species composition of regrowth, and lack of similar variation in the species composition of overwood, suggest that factors additional to the relative seed supply by species have influenced the relative abundance of species. Another interpretation is that the seed supply estimates were poor due to various factors, and that *E. sieberi* provided a much greater proportion of seed than estimated (Lutze 1998b).

The difference in species composition between treatments may have been the combination of seed supply and competition effects. Where *E. sieberi* dominated the seed supply, such as in the gaps and higher retained overwood treatments, it quickly dominated the site through rapid growth, then suppressed and eventually killed most individuals of other species. Where there was a more balanced species distribution of seed, such as in the seed tree treatment, or a deficit in total seed supply, such as in the 10-ha clearfell treatment, competition from *E. sieberi* was not as great and individuals of other species survived and grew reasonably quickly.

Eucalyptus sieberi contributed a greater proportion of regrowth basal area (56%) than regrowth stocking (51%), indicating that its basal area averaged over all the treatments was greater than that of other species (Fig. 11, $P < 0.001$). The faster basal area growth of *E. sieberi* is correlated with its greater average dbhob at age 10 y in most harvesting treatments, but there was a significant species × harvesting treatment interaction ($P < 0.05$). Notably, *E. baxteri* had greater dbhob in the treatments with greatest overwood retention (0.03-ha gap and 100% overwood) and in the 7% retained overwood ($P < 0.001$), and *E. globoidea* had greater dbhob in the 1.00 and 0.03-ha gaps. The greater diameter of *E. baxteri* and *E. globoidea* under high levels of retained overwood is indicative of their greater tolerance of competition than is found in *E. sieberi*. Amongst the five most common species, *E. sieberi* had the greatest and *E. globoidea* had the least height growth to age 10 y over all treatments. The growth differences were reflected in the species composition of the dominant regrowth at age 10 y, that is, species composition of the 70 largest-diameter trees ha^{-1}, in which the percentages of *E. sieberi* (63%) and *E. globoidea* (6%) varied greatly from the percentages in the retained seed supply and regrowth density (Fig. 11).

In Victoria, the standard used to evaluate the objective of maintaining species composition is that, for a coupe to be successfully regenerated after harvesting, there be at least 10 acceptable stems of all eucalypt species present before harvesting (Dignan and Fagg 1997). This was proposed as an interim standard to be subject to research and review. It only loosely

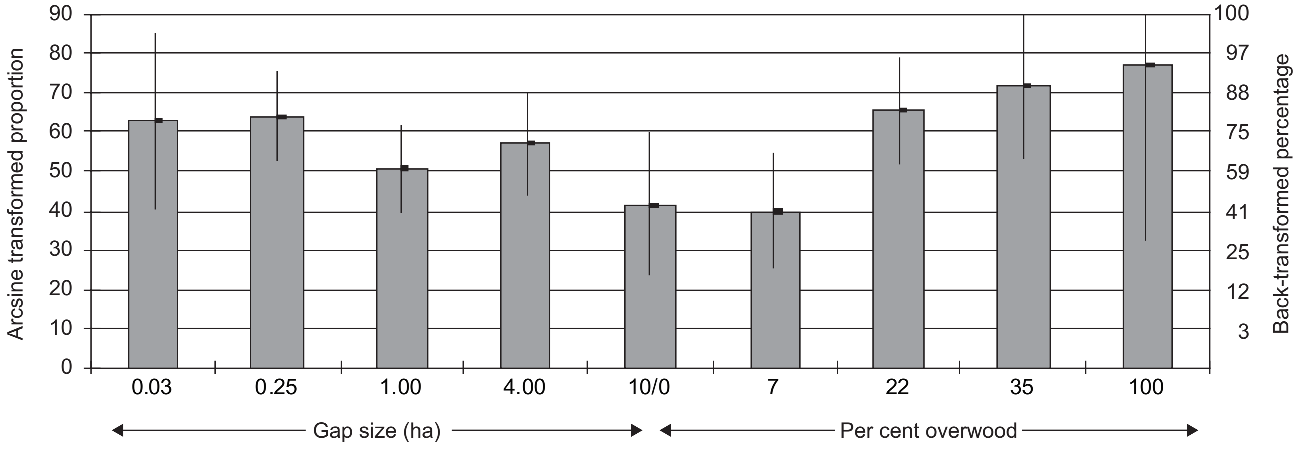

Figure 10. Proportion of regrowth basal area attributable to *E. sieberi* at age 10 y for each harvesting treatment

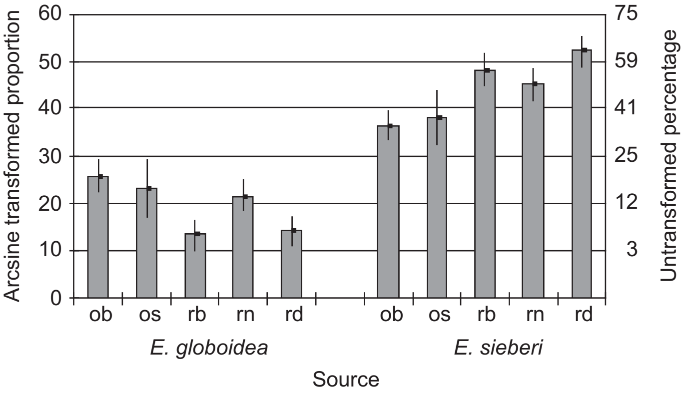

Figure 11. Proportion of overwood basal area (ob), overwood seed supply (os), regrowth basal area (rb), regrowth density (rn), and regrowth density of dominants (rd) at age 10 y for *E. globoidea* and *E. sieberi*

reflects the organisation's policy — to approximate the composition and spatial distribution of species present on the coupe prior to harvesting, except where past management practices have led to altered species composition (DNRE 1996). An intuitive interpretation of the general policy might translate into either of the following specific objectives:

- to establish regeneration where regrowth density by species is the same as that by species prior to harvesting, or
- to establish regeneration where the area occupied by each species is the same as that occupied by each species prior to harvesting.

The latter objective is more consistent with the concept of site occupancy because it considers the spatial distribution as well as number of each species. In the absence of stocking data (i.e. frequency of stocked plots), basal area is probably a better indicator than density because it gives a greater weighting to dispersion of species.

In order to achieve the species composition objective, a careful assessment of seed crops was carried out in the retained overwood treatments to ensure that the species mix of the seed supply matched species composition by basal area of the pre-harvesting stand. The assessment was carried out in a more rigorous manner for the 7%-retained-overwood treatment, and the result was a closer match to the original species composition of the five main species: 35% *E. sieberi*, 24% *E. globoidea*, 24% *E. baxteri*, 13% *E. consideniana* and 4% *E. botryoides* by basal area. This was the composition of the sowing mix applied in the clearfell treatments, which also achieved a good match between the species composition of regrowth basal area and the original forest. All other treatments resulted in significant shifts in species composition, as indicated by the greater representation of *E. sieberi* and lesser representation of *E. globoidea* in regrowth at 10 y than in the original stand; the percentage of *E. sieberi* was 38% by seed supply, 35% by overwood basal area and 56% by basal area of regrowth; the percentage of *E. globoidea* was 16% by seed supply 19% by overwood basal area and 5% by basal area of regrowth (Fig. 11, $P < 0.001$).

Thus the species composition at age 10 y was a closer match to the original forest in the clearfell and 7%-retained-overwood treatments than in the gap treatments, and these treatments stand out as being better at meeting the objective of the species composition indicator. The marginal change in the proportion of eucalypt species in intensively-harvested treatments is consistent with the findings of retrospective studies in lowland forest. There were marginal changes in the frequency of eucalypt species in quadrats dominated by regrowth as compared to those dominated by mature forest (Loyn *et al.* 1980; Griffiths and Muir 1991; Mueck and Peacock 1992). Those studies, however, did not include areas of low-intensity harvesting, which performed so poorly in terms of the species composition measure of regeneration success at the Cabbage Tree site.

The effect of harvesting on eucalypt species composition has been studied in other mixed-species forest types in south-eastern Australia with similar environmental attributes, including the *E. obliqua*/peppermint (various eucalypt species) / gum (various eucalypt species) forests of central Victoria and eastern Tasmania (Kellas *et al.* 1988; Elliott *et al.* 1991). In contrast to the dominance shown by the common ash-type eucalypt (i.e. *E. sieberi*) in lowland forest of East Gippsland, *E. obliqua* has not dominated regrowth in these forests. Florence (1996) suggests that the poorer lignotuberous quality of *E. obliqua* may have contributed to the lower representation of the species in the regrowth compared to the mature forest in central Victoria. The combination of low-intensity harvesting and mild slash burns may have released the lignotuberous peppermints which would suppress any new *E. obliqua* seedlings. The experiment at the Cabbage Tree site has produced 'large wave seedling regeneration' (Florence 1996), as virtually all advance growth was destroyed by the sequence of harvesting disturbance followed by intensive site preparation. Thus the non-lignotuberous property of *E. sieberi*, in contrast to most species of the dry sclerophyll forest (Florence 1996), has not disadvantaged the occurrence of *E. sieberi*. The more vigorous *E. sieberi* seedlings have tended to dominate, particularly where propagules of other species have been less plentiful, such as in the less-intensively-harvested treatments.

Purdie and Slatyer (1976) found that changes in site floristics of dry sclerophyll communities persist until the next disturbance. These disturbances may be frequent in the gaps that are created in an uneven-aged system, through subsequent harvesting and fire disturbances up until the gap reaches maturity. Provided there is sufficient survival of the less dominant but more persistent species through the initial stages of gap establishment, the species composition could swing back to one less dominated by *E. sieberi*. The greater tolerance of competition and stronger lignotuberous properties of the associated eucalypt species in the lowland forest should enhance their ability to survive and respond to frequent disturbance. There is a deficiency of information about the factors that affect the long-term species composition of the lowland forests of East Gippsland.

Overwood growth

Basal area growth of the overwood increased as levels of mature retained overwood increased (Table 4, $P < 0.05$). For the gap treatments the growth of the overwood in edge plots in excess of that of overwood in the unharvested control (i.e. with no edge effect) was attributed to the gaps. The response of trees on the edges of gaps did not vary much over the gap size range of

0.25–10 ha, hence all plots surrounding gaps were pooled for analysis. For the 12-y period since harvesting, edge trees had a small but not significant basal area growth advantage of 2.0 $m^2 ha^{-1}$ over unharvested forest (6.9 $m^2 ha^{-1}$ vs 4.9 $m^2 ha^{-1}$, $P > 0.05$). The 35% retained overwood stands had marginally less basal area growth (3.9 $m^2 ha^{-1}$) than the unharvested forest (4.9 $m^2 ha^{-1}$), indicating that basal area increment of individual trees had increased by a factor of about two in the 12-y period since harvesting. In contrast, the 7% and 22%-retained-overwood stands had significantly less basal area growth (0.3 $m^2 ha^{-1}$ and 1.0 $m^2 ha^{-1}$ respectively, $P < 0.05$). In these two treatments, basal area growth is a smaller proportion of the unharvested basal area growth than the proportion of basal area retained, which indicates that individual tree growth was slightly reduced in the 12-y period since harvesting. The volume growth shows a similar trend. Edge trees had a 22 $m^3 ha^{-1}$ advantage over unharvested forest (74 vs 52 $m^3 ha^{-1}$); the 35% retained overwood (42 $m^3 ha^{-1}$) and unharvested forest were similar; and the 7% retained overwood had a significantly lower increment of 4 $m^3 ha^{-1}$ in the 12-y period since harvesting ($P < 0.05$, Table 4).

Mortality of overwood occurred in the edge, 7% and 22%-retained-overwood plots. Mortality had its greatest effect on the estimate of growth on the edge of gaps, basal area and volume growth being reduced by 0.7 $m^2 ha^{-1}$ and 7 $m^3 ha^{-1}$ respectively in the 12-y period since harvesting. The inclusion of mortality did not change the significance or ranking of the effects of different harvesting treatments.

Stand growth

Currently there are no standards of regeneration success relating to growth, other than the acceptability criteria included in site occupancy (Dignan and Fagg 1997). From a silvicultural system point of view, growth should be evaluated on a sufficiently broad time and spatial scale to quantify the interaction between management units over time. In the case of group selection systems, the stand is harvested through a number of periodic harvests, the proportion of the stand that is harvested at each period being dependent on the length of the felling cycle (e.g. 15 y) and the length of the rotation, where rotation is the time taken for an age cohort to reach maturity (e.g. 90 y). Stand growth is the result of a complex interaction between the different age cohorts. In the case of shelterwood systems, two age cohorts are created by the first or regeneration harvest, which interact until the removal of the remaining older cohort by the shelterwood harvest. This coupe-level experiment involves a single harvesting cycle or regeneration harvest, and thus does not allow a comprehensive evaluation of the growth dynamics of the system. However, the experiment does allow quantification of the effect of the harvesting regime on the growth within the treated stand and on adjacent retained vegetation, which provides some indication of the growth outcomes of the associated silvicultural system.

In the 0% and 7%-retained-overwood treatments the growth is largely confined to that of the regrowth. Although the 10-ha clearfell / 0% retained overwood may not meet the criteria for site occupancy of even-aged regrowth stands, the diameter growth in them was the greatest of all the harvesting treatments. As discussed with respect to site occupancy, the greater diameter growth may prove to outweigh the effect of the low seedling density. This was reflected in the regrowth basal area increment to 12 y of the 10-ha clearfell / 0% retained overwood, which was the greatest of all treatments.

The stand volume growth to 12 y varied with the level of retained overwood and gap size (Table 4). The stand response was similar to the regrowth response in the gap continuum, growth increasing with gap size. In the retained overwood continuum, however, the stand growth within the 35%-retained-overwood treatment exceeded that within the 22%-retained-overwood treatment, because of the accelerated growth of the retained overwood. Stand growth within the 7%-retained-overwood treatment exceeded that within the 35%-retained-overwood treatment, because the accelerated growth of the overwood in the latter was not sufficient to balance the greater growth of the regrowth in the former.

The harvesting treatments, however, are only the first stage of the silvicultural systems they represent. In the group selection system, regeneration within gaps would in time be released from competition from surrounding edge trees as further gaps were harvested. Similarly, competition from retained overwood would be removed in time where the stands are treated as true shelterwoods. The growth rates of the treated stands might then increase were the regrowth to respond to release from competition. There is a deficiency of information about the ability of regrowth to respond to release in the lowland forests of East Gippsland.

Conclusions

Harvesting (gap and retained overwood continua) and site preparation treatments were evaluated at age 10–12 y in terms of the sustainability indicators of regeneration success (site occupancy, species composition and early growth). Following is a summary of the major findings:

Site occupancy and species composition

At age 10 y at the Cabbage Tree site all treatments had a satisfactory level of site occupancy — even the unharvested and clearfell treatments. However, the level of site occupancy was lower in the clearfell treatment, as indicated by lower regrowth density, a larger number of unstocked plots and lower basal area increment of regrowth compared to that of the 7% retained overwood treatment. Comparison of regrowth and overall volume growth over 12 y indicated that the initially-lower levels may be beneficial for timber production, although timber quality may be compromised.

The differences between site preparation treatments based on slash burning and mechanical disturbance are marginal, particularly in terms of site occupancy. Although regrowth density varied significantly at age 10 y in favour of mechanically-disturbed treatments, this did not translate into higher basal area or volume per hectare in these coupes. This suggests that the greater density in mechanically-disturbed treatments may be due to better survival of suppressed regrowth, possibly due to a less competitive understorey.

All treatments showed a significant shift in species mix of regrowth in favour of *E. sieberi*, but this shift was less pronounced in the 7% retained overwood and clearfell treatments. Thus, the more intensive harvesting treatments have a greater capacity to meet the objective of maintaining the pre-harvesting species composition.

In summary, on the basis of regeneration success indicators — site occupancy and species composition — the best regeneration was achieved in the 7% retained overwood followed by the 4-ha and 10-ha clearfell treatments. However, thus far, all harvesting and site preparation treatments trialled are acceptable in terms of eucalypt regeneration. Caution should be applied in attributing these short-term treatment effects to whole silvicultural system effects.

Growth

The results to age 10 y at the Cabbage Tree site suggest that all treatments — even the unharvested treatment — have individuals that are growing and will continue to do so. According to the current acceptability criteria for regeneration, the 10-ha clearfell treatment has insufficient trees that are not suppressed. This negative effect, however, may be outweighed by the superior diameter growth of regrowth in this treatment. This study has empirically established the relationship between overwood, either as scattered trees or as a continuous edge, on a range of stand regrowth parameters to age 12 y. Rates of diameter and height growth in the regenerating stands were reduced by increasing levels of retained overwood and decreasing gap size. It follows that the time eucalypt regrowth will take to replace the harvested mature stand, that is, the rotation length, may be greater in the less-intensive harvesting systems. However, the potential growth response to release is not well understood, and further study of this aspect of stand dynamics is planned. Total stand growth reflected the trends of the regrowth — basal area and volume growth increasing with increasing gap size and decreasing retained overwood. Inclusion of the retained overwood growth, however, increased the ranking of the 35% retained overwood to a position above that of the 22%-retained-overwood treatment.

The initial competitive growth advantage of the slash-burnt treatments appears not to have been sustained. It remains to be seen how much of a size advantage will be maintained by the dominant trees in the slash-burnt treatments throughout the rotation.

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