A comparison of four-year-old regeneration following six silvicultural treatments in a wet eucalypt forest in southern Tasmania

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Abstract

The Arve 031 Community Demonstration Forest was established as part of the Southern Forests Community Research Project during the period 1991–93. Its establishment was a response to community concerns regarding the effects of clearfelling and high intensity slash-burning on rainforest tree regeneration, and thus special species timber production, in southern wet forests. Six silvicultural treatments were trialled along two continuums: (1) increasing overwood retention, from clearfell to oldgrowth retention to shelterwood to single-tree selection; and (2) decreasing gap size, from clearfell to large gap (0.7 ha) to small gap (0.25 ha) to single-tree selection. Measurements were undertaken for this study during the period 1995–97. Regeneration of Eucalyptus regnans *and various rainforest tree species were compared between treatments.*

All treatments were stocked with eucalypt regeneration at age four years. However, seedling density and height decreased along the two treatment continuums and was largely attributed to the suppressive effects of increased retained overwood and edge effects. This is expected to impact on later timber volume yields. In contrast, the density of rainforest tree regeneration increased along the two treatment continuums, suggesting that non-clearfell and non-burn treatments could favor the production of special species timbers. Various biological factors that have contributed to this coupe-level result are discussed. Caution must be used when drawing such conclusions from short-term studies confined only to early growth stages.

This study reiterates the concept that different silvicultural treatments can be matched to specific forest management objectives: the very purpose of silviculture. However, the operational application of non-clearfell treatments to favour special species timber production at the landscape level may prove challenging in the light of such considerations as higher management costs, reduced harvesting productivity, lower eucalypt timber production, increased fire risk and greater spatial and temporal disturbance to the forest landscape.

Introduction

During the first half of this century, selective logging of the best quality eucalypt and rainforest species was used to harvest timber from the wet forests of southern Tasmania (Forestry Commission 1994; Cubit 1996). There was little knowledge of regeneration requirements, and regeneration depended instead on the sporadic occurrence of wildfires. Although wildfires occasionally

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resulted in good regeneration, lack of wildfires resulted in poorly stocked forest (Forestry Commission 1994). To overcome this problem, clearfelling with high intensity slash-burning was developed (Gilbert and Cunningham 1972) and is today the most frequently applied silvicultural system in wet eucalypt forest (Wilkinson 1992). In one operation, this system removes most trees on a coupe. A characteristic of wet forest which influences this choice of silvicultural system is dense understorey vegetation (Forestry Commission 1994). The clearfelled area is regenerated using a high intensity slash-burn to remove this dense understorey and create a seedbed receptive for the establishment of eucalypt seedlings. This technique has been demonstrated to fulfil the biological requirements for regeneration of eucalypts in wet forest (Gilbert and Cunningham 1972; Strachan and King 1992; King *et al.* 1993).

Some community groups are concerned about clearfelling and the use of high intensity slash-burning (Ferguson 1985; Kimmins 1992; Cubit 1996). For example, in the late 1980s, community members objected to several regeneration burning operations following clearfelling in southern wet forests, on the basis that slash-burning regenerated eucalypts at the expense of rainforest species (Allen 1992). A return to selective logging was called for, with a greater emphasis on the utilisation and regeneration of rainforest trees for special species timbers. This resulted in the Forests and Forest Industry Council appointing a Community Research Forester to address this and related issues by implementing the Southern Forests Community Research Forestry Project (Allen 1992).

One of the key terms of reference for that project was a commitment to establish a Community Demonstration Forest in which alternative silvicultural methods to clear-felling with high intensity slash-burning could be demonstrated. This included an evaluation of silvicultural options for the regeneration of the rainforest component following utilisation of special species timbers. Thus, the Arve 031 Community Demonstration Forest was established, with six harvesting treatments undertaken during the period 1991–93.

The comparison of treatments reported here follows their measurement in 1997. This study has the broad objectives of comparing regeneration success between eucalypt and rainforest tree species on each treatment, and considering their likely performance and timber production potential. Given the original project was not designed as a statistically rigorous study, the aim of the comparison is to identify trends in regeneration performance between treatments, and present them with support from other south-eastern Australian silvicultural studies. This information will also provide insight and guidance for implementing future, more rigorous silvicultural research in the wet eucalypt forests of southern Tasmania.

Methods

Study site

The Arve 031 Community Demonstration Forest has been established in 60 ha of wet eucalypt forest located in the Huon District in southern Tasmania, approximately 25 km west of Geeveston township on Arve Spur 3 (Figure 1). The site was chosen on the basis of ease of public access and its forest type, which, although variable, contained a rainforest understorey component. It is at an altitude of 120 m, with uniform deep red clay-loam soils derived from dolerite (Neyland 1992). Topography is undulating, with slopes up to 15°. Rainfall is approximately 1200 mm per annum.

The forest type is predominantly mixed forest (Gilbert 1959), having a rainforest understorey and eucalypt overstorey. Some areas of the study site did not contain rainforest species and are therefore classed as wet sclerophyll forest (Kirkpatrick *et al.*

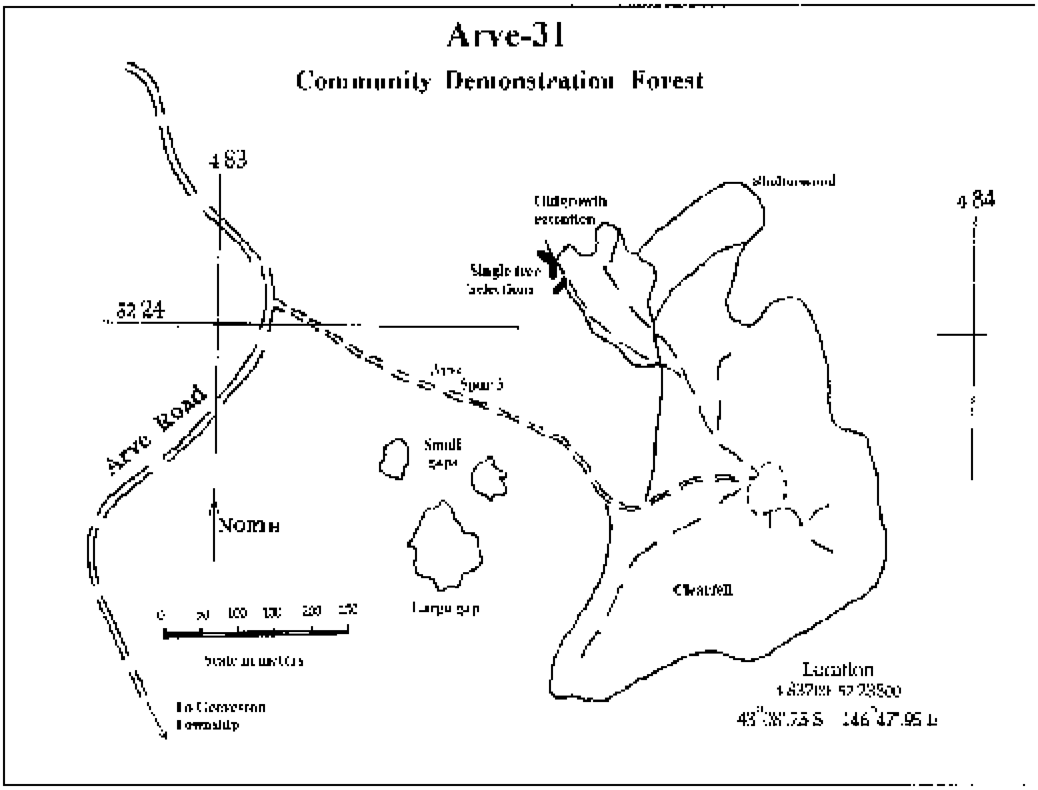

Figure 1. Locality map and treatment layout of the Arve 031 Community Demonstration Forest in the Southern Forests area, Huon District, Tasmania.

1988). *Eucalyptus regnans* (giant ash) is the dominant eucalypt, with occasional *E. obliqua* (brown-top stringybark). Tall stumps with shoe-holes, and fire scars on oldgrowth trees are evidence of past selective logging and a wildfire in 1934. As a result, forest structure is multi-aged, with 34- and 63-year-old eucalypt regrowth and scattered oldgrowth estimated to be 250+ years old. Neyland (1992) identified five specific vegetation communities, three of which contain rainforest species. Four of the most prominent vegetation communities have a sclerophyll component dominating their understorey. Species include *Pomaderris apetala*, *Acacia dealbata*, *A. verticillata*, *A. melanoxylon*, *Olearia argophylla* and *Phebalium squameum*. Scattered rainforest tree species are present, usually as saplings but occasionally as stands of mature individuals. These include *Nothofagus cunninghamii*, *Atherosperma moschatum* and *Phyllocladus aspleniifolius*. Together with *Acacia melanoxylon*, these represent the range of special species timbers available on the site. *Eucryphia lucida*, a nectar-producing species of high value to the honey industry, and *Dicksonia antarctica* (soft tree-fern) are two other rainforest species scattered throughout the study site.

Treatment establishment

Table 1 lists the six harvesting treatments and coupe sizes. Three to four selected oldgrowth individuals were retained per hectare as part of the oldgrowth retention system. Their selection was largely based on tree size and age, and their potential for fauna habitat. An even distribution of trees was retained on the shelterwood treatment to 16 m^2/ha. The objective of these trees is to provide shelter for eucalypt regeneration, and to reduce the short-term visual impacts of harvesting. Figure 1 shows the demonstration site and treatment layout.

Table 1. Harvesting treatments in the Arve 031 Demonstration Forest with site-preparation treatment, number of replications, the amount of retained basal area (BA), and coupe size of each. Survey plots refer to regeneration measurements. (HIB = high intensity burning; dist. = disturbed; LIB = locally intense burning of slash heaps; browsing stations monitor marsupial browsing.)

Harvesting treatment	Treatment code	Site preparation	No. of 'replicates'	Retained BA (m^2)	Coupe size (ha)	No. of browsing stations	No. of survey plots
Clearfell	CF	HIB	1	0	10.50	3	20
Oldgrowth retention	OGR	Soil dist. + LIB	1	3	2.00	1	20
Shelterwood	SW	Soil dist. + LIB	1	16	3.50	3	20
Large gap	LG	Soil dist. + LIB	1	–	0.70	1	20
Small gap	SG	Soil dist. + LIB	2	–	0.25	1	18
Single-tree selection	STS	Soil disturbed	3	–	0.09	0	–

Harvesting commenced on 6 May 1991 and concluded on 15 July 1992. It was undertaken by a contractor equipped with a D6 crawler tractor and two 25-tonne excavators. Details of harvesting costs, extracted yields of forest products, including special species timbers, and an assessment of harvesting safety are reported in Allen (1992).

Fire-line and seedbed preparations were carried out during March / April 1992 by a separate contractor using a 30-tonne excavator and D4 crawler tractor. Table 1 lists the type of seedbed preparation undertaken for each harvesting treatment. The clearfell treatment was treated with a broadcast, high intensity slash burn (HIB), conducted on 18 March 1993. This was followed by aerial sowing of *Eucalyptus regnans* seed at a rate of 1.25 kg / ha on 26 March. The number of viable seeds (vs) in the seedlot used was 255 000 vs / kg; thus, the coupe received approximately 318 700 vs / ha. The clearfell coupe was treated with 1080 poison to minimise the effects of browsing by marsupials.

All non-clearfell treatments were soil disturbed during or following harvesting. Harvesting residue was slash-heaped and burnt, resulting in small areas of locally intense burning (LIB) and widespread mechanical disturbance of soil. Burning of slash heaps occurred on 24 April 1992. No such seedbed preparation was undertaken for single-tree selections, except for the disturbance of soil which occurred during falling and extraction of the single trees. Natural seedfall was relied on for the supply of eucalypt seed to all non-clearfell treatments. Use of 1080 poisoning was not undertaken on these treatments.

In this paper, two treatment continuums away from clearfelling are referred to: one of decreasing gap size, from clearfell to large gap to small gap to single-tree selection; and one of increasing retained overwood, from clearfell to oldgrowth retention to shelterwood to single-tree selection. Note that the single-tree selections were approximations only, since the contractor selected oldgrowth individuals too near the influence of the oldgrowth retention boundary (Figure 1). Hence, the single-tree selections were immediately adjacent to larger boundary gaps resulting from the oldgrowth retention treatment.

Regeneration measurements

Following establishment, and prior to this study, a standard regeneration survey (Forestry Tasmania 1996) was undertaken on the clearfell coupe during May 1994. Results of that earlier survey indicated 96% of 16 m^2 plots were stocked with at least one *E. regnans* seedling. No formal regeneration measurements were undertaken on non-clearfell treatments. However, informal reconnaissance undertaken at the time confirmed that *E. regnans* regeneration was at least present on all these latter treatments.

In addition, following harvesting, a browsing trial was established on 13 July 1993 to assess the impact of browsing on eucalypt regeneration across treatments. Table 1 indicates the number of browsing stations established by treatment. Each was positioned on a flat, uniformly burnt seedbed. An exception to this occurred for the shelterwood treatment where one station were established on a soil-disturbed seedbed. At each station, a fenced and unfenced plot was established. Chicken-wire fences were erected to a height of 1.3 m and each plot was 12 m x 12 m. Both plots at each station were hand sown with *E. regnans* seed at four times the recommended sowing rate (Forestry Commission 1991). This was in addition to any seed that was aerially sown or that fell naturally.

Densities of *E. regnans* seedlings were measured on plots at browsing stations during May 1995 at age two years, using a two-metre wide swathe across each plot. An assessment of height was undertaken in 1996 at age three years, based on the tallest 15 *E. regnans* stems.

Broadscale regeneration was assessed during January 1997 at approximately age four years. Standard circular 4 m^2 plots were used (Forestry Tasmania 1996). Single-tree selections were an exception to this, since all regenerated stems could be measured. Most measurements were confined to an inner plot of radius 1.13 m (area 4 m^2). Concentric circular plots were also used of radius 2.26 m (area 16 m^2) and 10.3 m. Table 1 lists the number of plots measured for each treatment coupe. These plots were located at 20 m intervals along parallel transects. For the clearfell treatment, two transects were used at approximately 100 m apart. Transects on the smaller oldgrowth retention and shelterwood areas (Table 1) were located closer together. Plots in gaps were located at 10 m intervals along transects positioned between opposite edges and passing close to the gap centre. These were expected to measure any height gradients with increasing distance from edges.

The following assessments or measurements were undertaken on the 4 m^2 plots: seedbed type, presence or absence of at least one *E. regnans* seedling, the total number of *E. regnans* seedlings, the height of the tallest *E. regnans* seedling, the height and species of the tallest non-eucalypt species to assess levels of height competition, the density and species of rainforest tree regeneration, and other species present. *Eucalyptus obliqua* seedlings were rarely found. Because of the time which had elapsed since site preparation, seedbeds were classified only broadly as burnt, soil disturbed, or undisturbed.

If no *E. regnans* seedlings were present on a 4 m^2 plot, its concentric 16 m^2 plot was searched according to Forestry Tasmania (1996). A plot point was recorded as being stocked if a seedling was located within the 16 m^2 plot area.

The estimate of mean eucalypt height on 4 m^2 plots may not indicate the height potential of each treatment, due to the potential for competition by adjacent unmeasured trees (Bassett and White, in press). Therefore, the tallest *E. regnans* on each concentric 10.3 m radius plot was located, and its height and diameter (DBHob) recorded. These heights were used to calculate mean dominant height (MDH), representing the tallest 30 trees per hectare. MDH is a common measure used for eucalypt regrowth assessment since it is a more appropriate indicator of growth potential (site index) for the principal crop species (Husch *et al.* 1982; Lockett and Candy 1984; Forestry Commission 1994).

Data analysis

Seedbed types, MDH and density were charted, and obvious trends identified. Due to insufficient replication, no statistical

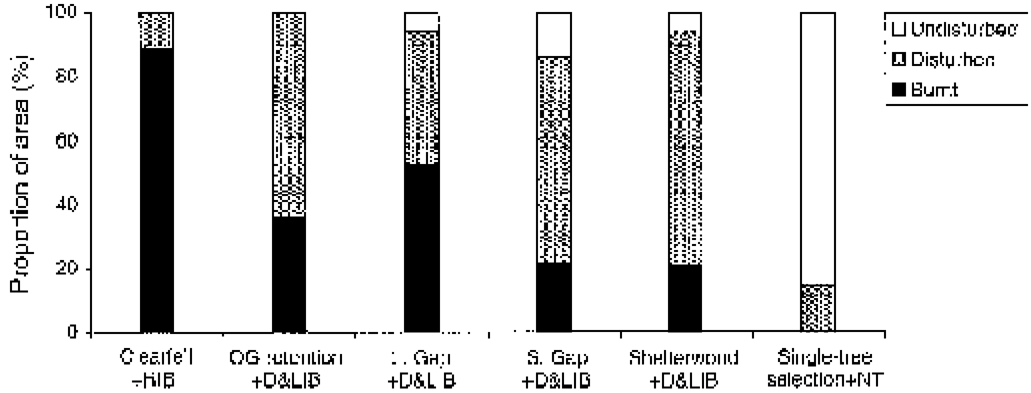

Figure 2. Proportion of seedbed type estimated from survey plots for each silvicultural treatment at the Arve 031 Community Demonstration Forest. Categories are undisturbed, soil disturbed, and burnt. (HIB = high intensity burn; D&LIB = soil disturbed with locally intense burning of slash heaps; NT = soil disturbed with no further treatment.)

comparisons were made. The range and coefficients of variation (CV), where CV is the standard deviation expressed as a percentage of the mean, were calculated for all height and density data to indicate levels of within-coupe (between-plot) variability.

For each single-tree selection, the area disturbed by the fallen tree and projected canopy space formerly occupied by that tree were mapped to calculate disturbed area. The location of any soil disturbance that had occurred as part of the harvesting operation was noted. The height of all *E. regnans* regeneration was measured and a mean calculated. Vegetative regrowth and release of understorey individuals were noted.

Results

Seedbed receptivity and early colonisation

Figure 2 shows broad seedbed classifications by proportion of coupe area for each silvicultural treatment. The regeneration burn on the clearfell coupe was of high fire intensity, and effectively reduced the heavy quantities of slash that remained following harvesting. The resulting ash seedbed was distributed uniformly across 89% of coupe area (Figure 2). In contrast, the non-clearfell treatments had the highest proportion of soil-disturbed seedbed, resulting from slash-heaping operations. Burning of these slash heaps only resulted in small, isolated areas of ash seedbed. Disturbed soil is suitable for germination of *E. regnans* seed (Fagg 1980; Strachan and King 1992), and when considered in addition to ash seedbeds, most non-clearfell treatments had sufficient area receptive for eucalypt seed germination (Figure 2). For example, the standard in Victoria requires a minimum 75% of potential seedbed area to be receptive (Squire *et al.* 1991). The exception to this occurred for single-tree selections, where only 15% of the entire area, including the projection of its opened canopy space (approximately 0.09 ha), was soil-disturbed by each fallen tree during log extraction.

All seedbed types were colonised at an early stage by a combination of herbs, ferns and a sedge, effectively reducing seedbed receptivity over time. However, treatments exhibited different levels of coloniser development and persistence. For example, a species of *Marchantia* (a liverwort) was widespread on burnt seedbeds in all treatments within a few months following slash-burning but, by age four years, it was uncommon in the clearfell coupe and remained widespread in gaps. In addition,

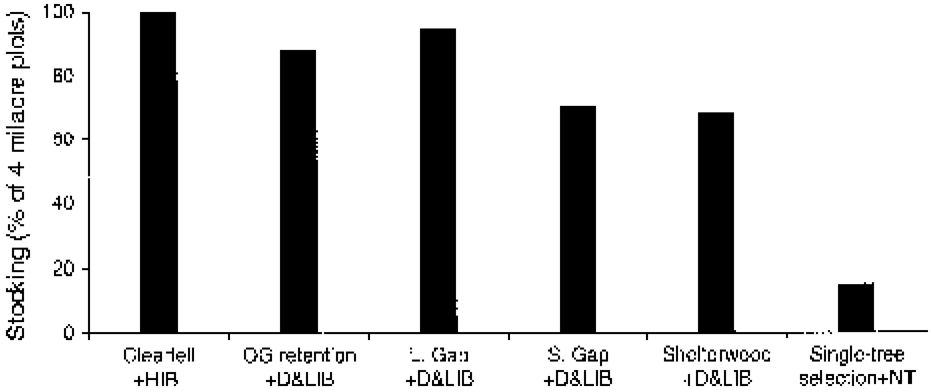

Figure 3. 16 m² (4 milacre) stocking of Eucalyptus regnans *regeneration by silvicultural treatment. The figure for single-tree selections is derived from actual stocked-area measurements. (HIB = high intensity burn; OG = oldgrowth; D&LIB = soil disturbed with locally intense burning of slash heaps; NT = soil disturbed with no further treatment.)*

Table 2. Seedling density of Eucalyptus regnans *and rainforest tree species by treatment, including plot range and coefficients of variation (CV) for* E. regnans, *at the Arve 031 Community Demonstration Forest.*

Harvesting treatment	*E. regnans* density (stems / ha)	Eucalypt density per 16 m² plot: range	Eucalypt density per 16 m² plot: CV	Rainforest tree density (stems / ha)
Clearfell	14 375	1–61	61%	94
Oldgrowth retention	4 262	0–15	68%	75
Shelterwood	2 337	0–11	108%	494
Large gap	4 375	0 –13	63%	625
Small gap	1 875	0–11	114%	306
Single-tree selection	916			

Histiopteris incisa (a ground fern) colonised all seedbeds following harvesting, with greater densities on non-clearfell treatments. By age four years, it had declined on most treatments but continued to occupy sites in single-tree selections, including undisturbed forest floor.

Gahnia grandis (a sedge) was observed in various densities, largely restricted to soil-disturbed sites. Areas that had experienced heavy soil disturbance and machinery movement during slash heaping, possibly indicating soil compaction, were most densely colonised by *G. grandis*. Thus, with the exception of single-tree selections, *G. grandis* was most prominent on non-clearfell treatments, and sparse on the hot slash-burnt clearfell and locally intensely burnt areas in other treatments. Plots heavily colonised by this species were often found to contain few or no *E. regnans* seedlings.

Eucalypt stocking and density

Figure 3 presents the proportion of 16 m² plots for each treatment stocked with at least one *E. regnans* seedling. Table 2 presents the density (stems / ha) of *E. regnans* seedlings, and the range and variation (CV) of density between plots for each silvicultural treatment. Density of rainforest tree species is also given in Table 2. The frequency distributions of stem heights and densities are presented in Figures 4 and 5 respectively.

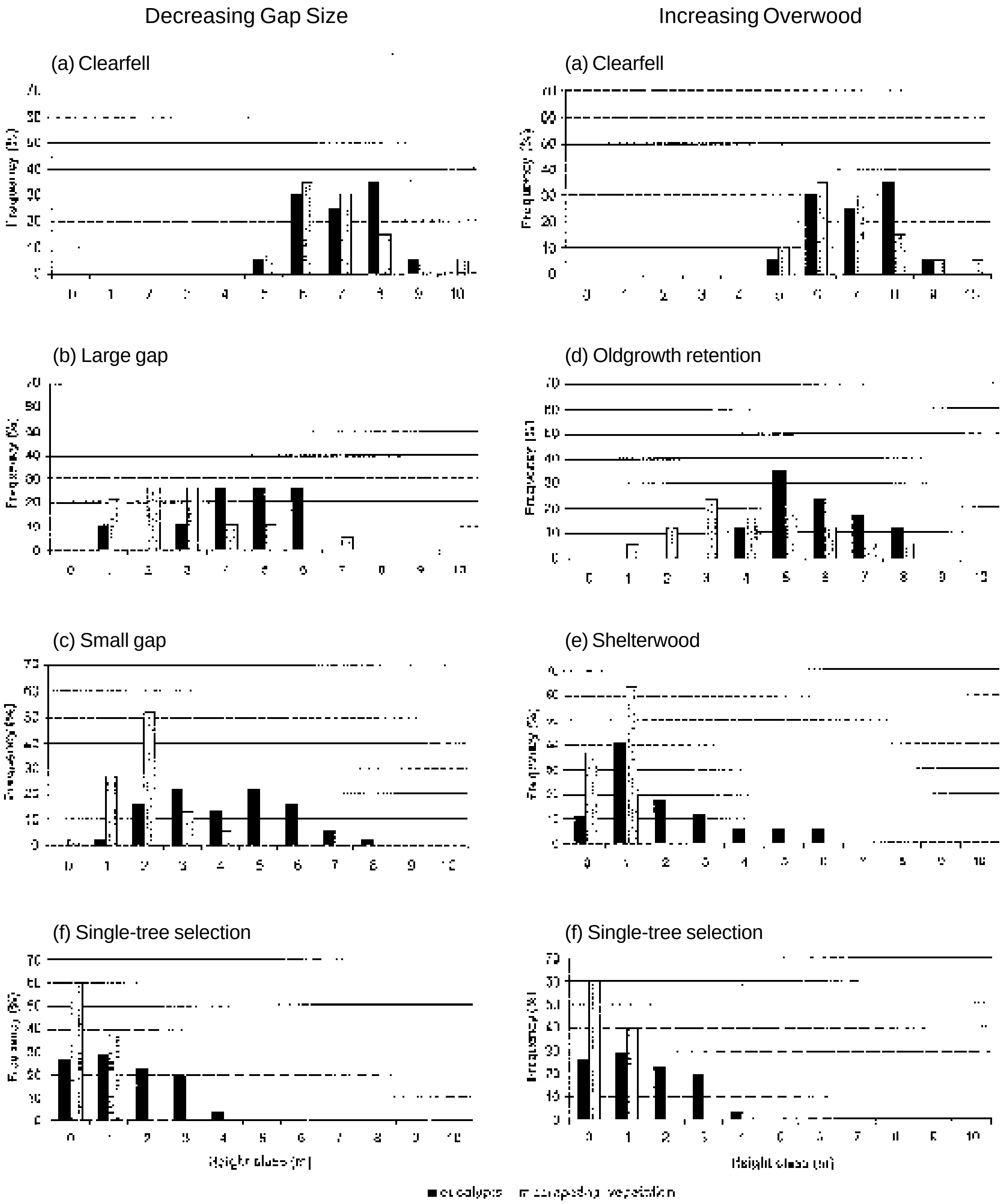

Figure 4. Frequency distribution of mean dominant heights (MDH) for Eucalyptus regnans *regeneration and mean heights (MH) for competing vegetation on treatments in the continuums of decreasing gap size (a-b-c-f) and increasing overwood (a-d-e-f) at the Arve 031 Community Demonstration Forest.*

Table 3. Height of Eucalyptus regnans *and the tallest competing understorey species, including proportional height (Prop. ht) of MDH trees in comparison to the clearfell, and mean stem diameter (DBHob) (Ø) of MDH trees. (CV = coefficient of variation; MDH = mean dominant height; MH = mean height; treatment codes as shown in Table 1)*

	E. regnans MDH					*E. regnans* MH			Understorey MH		
	MDH (m)	Range (m)	Prop. ht	CV	Mean Ø (cm)	MH (m)	Range (m)	CV	MH (m)	Range (m)	CV
CF	7.5	5.4–9.1	100%	13%	6.2	6.6	4.3–8.8	16%	7.2	5.1–9.9	17%
OGR	6.3	4.4–8.1	84%	19%	4.9	4.2	1.9–8.1	50%	4.5	1.1–7.0	40%
SW	2.4	0.6–6.8	32%	72%	1.5	0.6	0.2–1.4	70%	1.1	0.0–1.8	44%
LG	4.9	1.3–6.7	65%	31%	3.8	2.6	1.4–6.2	56%	3.3	1.1–7.0	45%
SG	4.6	1.0–8.2	61%	37%	2.9	2.5	0.1–5.2	71%	2.4	1.5–4.9	35%
STS	*3.6	3.0–4.2	48%		–	2.0	0.3–4.2	59%	–		

* 'MDH' for STS is mean height of all seedlings present, not MDH (mean of the 30 tallest trees / ha).

The eucalypt stocking levels of small gaps and the shelterwood treatment barely meet the accepted operational stocking standards (Figure 3; > 80% of area or 65% of 16 m^2 plots; Forest Practices Board 2000). However, at a density of approximately 2000 stems / ha (Table 2), these results could be regarded as adequate for *E. regnans,* provided stems are well distributed (Walters 1991). Table 2 indicates that density in small gaps and the shelterwood had high levels of between-plot variation at age four years, possibly suggesting poor distribution. However, stocking was considered adequate given the reasonably even distribution of plots stocked with at least one seedling.

The number of *E. regnans* stems per hectare decreased with increasing overwood and decreasing gap size (Table 2), which parallels the increasing proportion of plots with no seedlings along the same continuums (Figure 5).

For single-tree selections, the only area stocked with eucalypt regeneration was that area soil-disturbed during log extraction. This occurred at a mean rate of ten established seedlings per single-tree selection.

Eucalypt height and diameter growth

Table 3 presents the mean dominant height growth (MDH) of *E. regnans* at age four years by harvesting treatment, including the corresponding MDH range, proportional difference in dominant height growths by comparison with clearfell, CVs, and stem diameters. Frequency distribution of heights are shown in Figure 4. Figure 6 presents the mean height of *E. regnans* for fenced and unfenced browsing plots in the three treatments monitored. Shelterwood results have been split into seedbed type. An ashbed effect on height growth can be observed by comparing height of burnt versus disturbed (unburnt) shelterwood plots.

Clearfelling with high intensity slash-burning produced the tallest eucalypts with greatest diameter growth to age four years (Table 3). Growth was slower on non-clearfell treatments with increasing levels of retained overwood and decreasing gap size. There was also a shift of height distribution from essentially normal in the clearfell coupe to skewed (towards zero) along these continuums (Figure 4), indicating a suppression effect on growth. Although there was a trend of decreasing height along the gap-size continuum, no consistent height gradient within gaps could be detected at age four years. Figure 6 indicates that browsing has contributed to this effect, with *E. regnans* seedlings more severely browsed in non-clearfell treatments. This is shown by the greater disparity between fenced and unfenced *E. regnans* heights on burnt

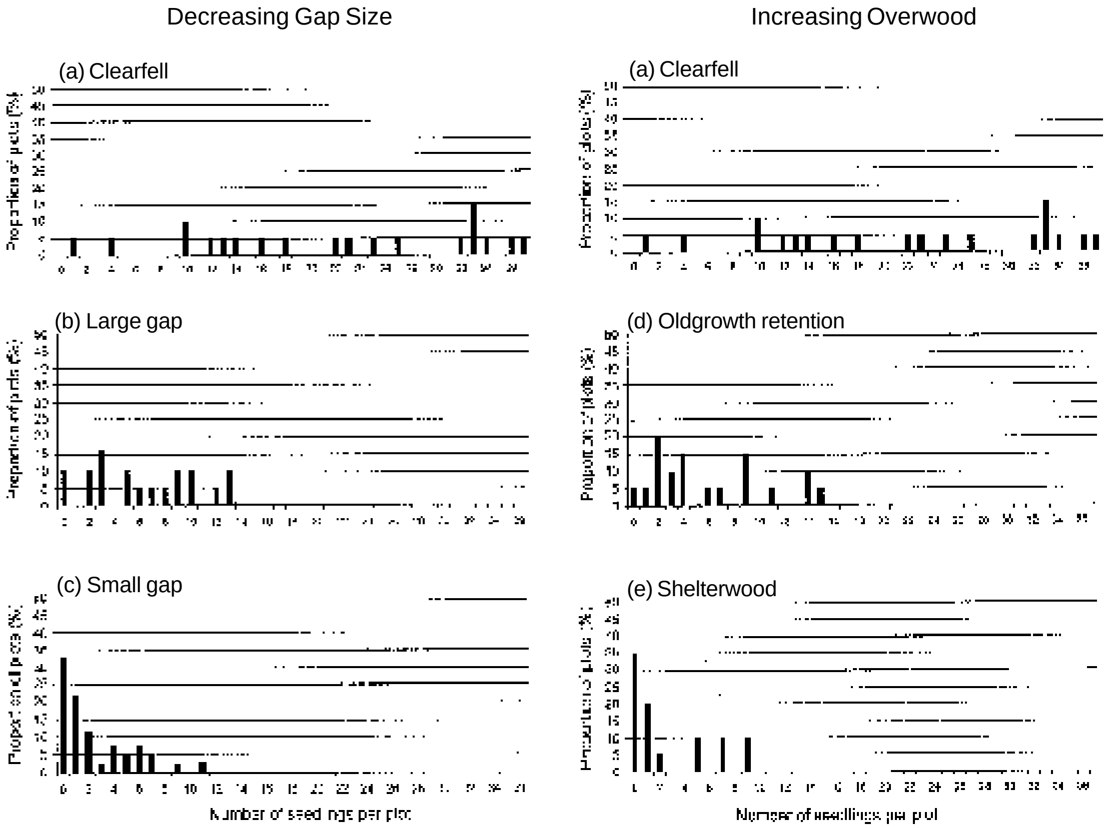

Figure 5. Frequency distribution of stem densities for Eucalyptus regnans *regeneration on treatments in the continuums of decreasing gap size (a-b-c) and increasing overwood retention (a-d-e) at the Arve 031 Community Demonstration Forest.*

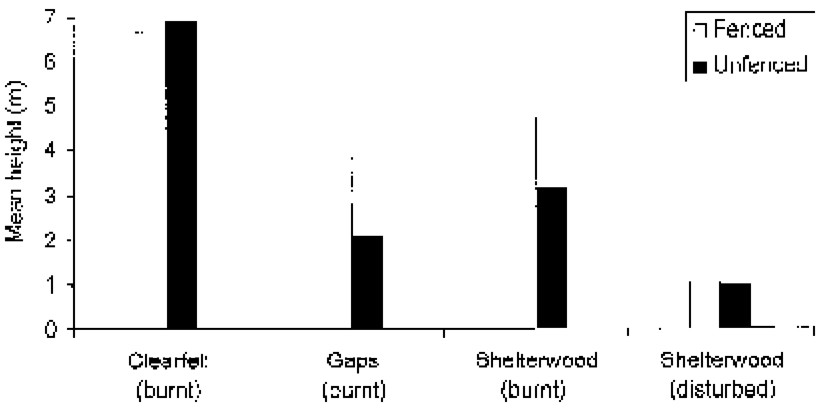

Figure 6. Mean height of Eucalyptus regnans *in fenced and unfenced burnt plots at age three years in three harvesting treatments at the Arve 031 Demonstration Forest.*

Table 4. Mean height range (m) by harvesting treatment for the tallest understorey species competing for height with Eucalyptus regnans *at the Arve 031 Community Demonstration Forest.*

Species	Clearfell	Oldgrowth retention	Shelterwood	Large gap	Small gap	Single-tree selection
Acacia dealbata	5.1–9.9	2.7–8.0		1.1–7.0	4.9	
Acacia verticillata			0.3–1.6			
Pomaderris apetala	*	0.2–4.1		1.4–3.7	1.7–3.4	1.1
Gahnia grandis		1.4–3.0	0.7–1.8		1.6–3.0	
Pteridium esculentum			1.1		1.5–2.5	
Histiopteris incisa					1.7	0.9
Anopterus glandulosus			0.5			
Anodopetalum biglandulosum			1.2			
Melaleuca squarrosa			1.8			

**P. apetala* was also present in high densities but at only 4–5 m height (i.e. subdominant to *Acacia dealbata*).

seedbeds in gaps and the shelterwood, and no doubt influenced by the differential use of 1080 poisoning.

Height competition from understorey species

Table 3 presents the mean height of the tallest understorey species (competing vegetation) recorded on 4 m^2 plots for each treatment, including its range and variation. A comparison of this with the MDH for eucalypts can be made here. Similarly, a comparison of their height class distributions is presented in Figure 4. A summary of the tallest competitive species by treatment at age four years is presented in Table 4.

Table 3 indicates that the tallest *E. regnans* seedlings on all treatments are maintaining a height advantage over understorey species. However, height competition between them is most severe on the clearfell, even though the tallest heights were recorded there. The clearfell is covered in a dense thicket of *Acacia dealbata*, *Pomaderris apetala* and *E. regnans* to a mean height of approximately 7 m. Although the occasional dominant individual of *E. regnans* emerges from this thicket (MDH trees), the mean height of the tallest understorey species is similar to that of the *E. regnans* population (Table 3). This intense competition is also evident in Figure 4a which shows the close similarity of height class distributions. The stem density of the understorey species was not measured, but observations indicate it to be greater than that estimated for *E. regnans*. *Acacia dealbata* was the principal competitive species, being clearly taller than *Pomaderris apetala* on all clearfell plots (Table 4).

There seems to be less competition from understorey species in gaps, shelterwood and oldgrowth retention treatments. Table 3 shows a greater margin between the MDH of *E. regnans* and the mean height of competing understorey vegetation on these treatments. Figure 4 represents this as increasing proportions of smaller height size-classes for competing vegetation, with *E. regnans* exclusively occupying taller height classes in shelterwood and small gap treatments. Observations also suggest that density of understorey species on these treatments is currently lower and more spatially variable than on the clearfell treatment, resulting in increased structural diversity. Furthermore, the number of competing understorey species most closely competing with *E. regnans* for height is greater on these treatments (Table 4).

Other species noted during surveys on all treatments at age four years included *Acacia melanoxylon*, *Monotoca glauca*, *Cenarrhenes nitida*, *Bauera rubioides*, *Blechnum wattsii*, *Polystichum proliferum* and *Dicksonia antarctica*.

Rainforest tree regeneration (special species timbers)

Rainforest tree species, in various proportions, occurred in three of the five communities prior to treatments (Neyland 1992), and were represented in the vicinity of all coupes. However, results from Table 2 indicate a sharp increase in rainforest regeneration along the continuums of decreasing gap size and increasing retained overwood. This parallels the reduction of ash seedbed area, increasing edge effect, and increase in the structural diversity of regrowth, indicating possible fire, seed supply and microsite effects.

The most frequent species represented in four-year-old regrowth at Arve 031 are *Nothofagus cunninghamii*, *Atherosperma moschatum* and *Eucryphia lucida*. *Nothofagus cunninghamii* was the only regrowth rainforest tree species observed in the clearfell. In both gap treatments, all three rainforest species were frequently found in dense groups of seedlings up to the six-leaf stage on disturbed seedbed, indicating significant seedfall events from parent trees in gap edges. Some had only recently appeared amongst other understorey species and in shaded conditions, indicating protracted recruitment since harvesting.

Seedlings of *Phyllocladus aspleniifolius* were observed in gap and shelterwood treatments. They were found as isolated seedlings with a density of approximately 180 stems/ha. Seedling height (4–5 cm), and the presence of leaves and phyllodes were consistent with regeneration within the last four years following harvesting. No parent trees were located nearby; thus, seed supply was likely to be soil-borne or dispersed by birds (Barker 1991; Hickey and Savva 1992). In contrast, *P. aspleniifolius* was not found in clearfell or oldgrowth retention treatments, although Neyland (1992) reported that *P. aspleniifolius* regrowth was scattered throughout the clearfell area prior to harvesting.

Discussion

Eucalypt regeneration

An important finding of this study is that all silvicultural treatments resulted in some established eucalypt regeneration at age four years following harvesting. However, for routine application in wet eucalypt forests, an important criterion of a silvicultural treatment used for wood production is that it will establish a highly productive eucalypt regrowth component (Forestry Commission 1993, 1994). Although all treatments were considered stocked here, stocking alone does not completely describe the success of eucalypt regeneration. Rather, this and other studies (e.g. Bassett and White, in press) indicate that use of non-clearfell treatments will have negative impacts on the productivity, and possibly ultimate success, of eucalypt regrowth. *Eucalyptus regnans* density, and height and diameter growth were greatest on the clearfell slash-burnt treatment which created an obstruction free, relatively uniform ashbed over a large proportion of the harvested area. In this environment, regeneration of *Acacia dealbata* and *Pomaderris apetala* has also been intense, competing vigorously with *E. regnans*, and likely contributing to fast growth rates. *Acacia dealbata* and *Pomaderris* species are known for their highly competitive early growth following fire in wet Tasmanian and Victorian forests (Cremer and Mount 1964; Cunningham and Cremer 1965; Ashton 1976, 1981; Mount 1979; Jordan *et al.* 1992; Ough and Ross 1992; Neyland and Brown 1994; Hickey 1994; Chesterfield 1996).

This contrasted with all other treatments, where *E. regnans* density, and height and diameter growth *decreased* with increasing overwood and decreasing gap size, a finding also consistent with results from other studies (Ashton 1976; Campbell and Bray 1987; Walters 1991; King *et al.* 1993; Dignan *et al.* 1998; K. Faunt, P. Geary, R. Cunningham and P. Gibbons, pers. comm.). The suppressive effects of retained overwood as single trees or edges are known to severely decrease eucalypt height growth and early survival per cent, with competition for site resources from them, such as for light, moisture and nutrients, impacting heavily on nearby eucalypt regrowth productivity (Bassett and White, in press; Breidahl and Hewett 1995). Other more subtle impacts are also known, such as allelopathy, increasing effectiveness of pathogens, lower light intensities, and the antagonistic nature of unburnt, damp soils to the survival of germinating *E. regnans* under canopy or small gap conditions (Ashton and Turner 1979; Ashton and Willis 1982; Ashton and Chinner 1999). In this study, suppressed *E. regnans* seedlings developed a spindly appearance, with more widely spaced leaf axils and larger, fewer leaves. Dignan *et al.* (1998) quantified this characteristic, measuring an increase in the height to diameter ratio and a reduction in the seedling vigor of suppressed *E. regnans* seedlings.

The broadly distributed ashbed conditions on the clearfell treatment in this study (Figure 2) may have also influenced height growth of eucalypt regeneration. Ashbed conditions have been demonstrated elsewhere to benefit early eucalypt height growth following first rotation slash-burning (Raison 1980; Lockett and Candy 1984; Walters 1991; Lockett 1998; Lutze and Featherston 1999). Figure 6 concurs with this, indicating shorter dominant heights on fenced, soil-disturbed plots compared with fenced, slash-burnt plots in the shelterwood treatment.

It is suspected that inconsistent seed supply between treatments also contributed to lower seedling densities along the two continuums. The clearfell was artificially sown with more than twice the recommended sowing rate for *E. regnans* in Tasmania (Forestry Commission 1991), resulting in 14 375 stems/ha at age four years (Table 2). No record could be found to explain why this was done. This highlights the need for an initial rigorous research plan to be developed and adhered to in future trials. By comparison, it is suspected that seedfall from retained trees and gap edges in non-clearfell treatments, while being adequate, was highly variable. Given the shelterwood treatment had a higher basal area (Table 1) and a larger number of retained crowns, it could be expected on average to supply a larger quantity of seed than the oldgrowth retention. A higher and more uniformly retained basal area usually indicates larger seed-crop potential (Bassett *et al.*, in press). However, seedling density was lower under shelterwood, possibly indicating smaller seed crops there. Furthermore, even though burning is known to induce seedfall (Bassett and Geary, in press), it is suspected that seedfall was not induced to fall by burning the isolated slash heaps in this study. Moderate to high intensity *broadcast* slash-burning is required to achieve larger quantities of induced seedfall from standing *E. regnans* trees (Cunningham 1960; Cremer 1965). It is therefore expected that seed supply to treatments other than clearfelling consisted largely of smaller and variable inputs of protracted natural seedfall.

Given the early colonisation and persistence of *Marchantia* and *Gahnia grandis* on seedbeds in gaps and the shelterwood treatment, seedbed receptivity is expected to have fallen rapidly there. The protracted natural seedfall of *E. regnans* in these treatments is likely to have coincided with a more developed successional stage of seedbed colonisation, rendering seedfall beyond 3–5 months less effective. The persistence of early colonisers in the non-clearfell treatments is likely to be due to the moister, more shaded conditions prevailing in them during periods of warm weather. Cremer and Mount (1964) found *Marchantia polymorpha* to be intolerant to summer exposure, possibly explaining the rapid decline of the species in the clearfell beyond age six months. Jarman and Fuhrer (1995) reported that *Marchantia* can persist below natural canopy gaps.

Another impact on seedling density may result from the increased browsing pressure in the gaps and shelterwood. Browsing is more severe close to forested edges (Clunie and Becker 1991; Di Stefano, in press), and such edge effects increase with decreasing gap size (Bradshaw 1992; Strachan and King 1992). Young *E. regnans* seedlings are known to be easily defoliated by browsers, which significantly impacts on seedling survival (Gilbert 1961; Cremer and Mount 1964). The fact that 1080 poison was used in the clearfell as browsing control but not in other treatments has undoubtedly masked the potential effects of browsing after clearfelling. Cremer (1969) confirmed that if *E. regnans* seedlings survive heavy browsing, their early height growth can be significantly retarded, the effect depending on browsing intensity and whether or not browsed seedlings lose occupancy of the site to unbrowsed competitors (Wilkinson and Neilsen 1995). Although browsing was controlled on only one of the treatments (clearfell), results from fenced plots (shown in Figure 6) provided a comparison of treatment effects on height growth in the absence of browsing. The height of eucalypts in soil-disturbed, fenced plots on the clearfell coupe tended to be 1–2 m higher than in similar fenced plots on gap and overwood treatments (Figure 6).

It is perhaps remarkable that gaps and single-tree selections were at least adequately stocked in this study, given the presence of intense browsing and factors already identified as limiting eucalypt density and growth under gap conditions. However, whether seedlings will survive in the long-term in the low light conditions typical of small gaps to ultimately dominate these sites is an issue (Ashton 1981). The effects of low light can be expected to intensify over time, given that *E. regnans* requires an increasing quantity of light with age (Ashton and Turner 1979). Over a life-time of studying *E. regnans* in central Victoria, Ashton and Chinner (1999) have never observed seedling regrowth to survive in similar gap niches beyond 10–11 years since disturbance.

Of interest here is the overriding implication of suppression of eucalypt regrowth height and stem diameter growth by retained overwood or edge trees. A reduction of eucalypt volume increment and sawlog yield is inevitable if non-clearfell treatments are applied in southern wet forest. This has been considered elsewhere to be a commercial loss (Dignan *et al.* 1998; Bassett and White, in press) and is a well-established implication (Opie 1969; Ashton and Turner 1979; Incoll 1979; Rotheram 1983; Kellas *et al.* 1987, 1996; Battaglia and Wilson 1990; Bradshaw 1992; Breidahl and Hewett 1995; Bi and Jurskis 1997).

Rainforest tree regeneration

Unlike *E. regnans*, the density of rainforest tree species *increased* along the continuums of increasing overwood and decreasing gap size, and in the absence of broadscale, high intensity slash-burning. Studies by Hickey and Savva (1992) and Jordan *et al.* (1992) support this. The former study also found that the density of rainforest tree species increases closer to seed sources. At Arve 031, rainforest trees retained in gap edges formed this source. Neyland and Hickey (1990) and Hickey *et al.* (1982) suggest that gap or shelterwood treatments with seed trees retained in coupe edges or as overwood, and with cool or no burning will encourage rainforest regeneration and provide the best production potential for special species timbers.

The different dynamics of vegetation recovery dictated by each silvicultural treatment may have influenced early recruitment of rainforest species. For example, development of the regenerating thicket of *Eucalyptus regnans, Acacia dealbata* and *Pomaderris apetala* on the clearfell was vigorous, uniform in structure and effectively resulted in the complete utilisation or intensive shading of microsites at an early stage. This has left few favourable sites available for establishment of rainforest tree species in the first four years on this treatment. Mount (1979) and Barker (1992) reported that germination of *Phyllocladus aspleniifolius* is usually slow, confirming its effective exclusion from regeneration opportunities that require fast germination in response to early colonisation. This is likely to be related to its requirement for relatively higher light conditions (Read 1985). The fact that a small quantity of *Nothofagus cunninghamii* was located under the wet sclerophyll thicket on the clearfell is indicative of its higher level of shade tolerance and competitive ability (Read 1985).

In contrast, recovery of understorey vegetation in gaps and the shelterwood was slower, had a more protracted emergence, and was more variable in species, succession, spatial arrangement and structure. This pattern of early succession in the absence of fire was also characterised by the failure of *Acacia dealbata* and *Pomaderris apetala* to develop a uniform sclerophyll thicket, enabling a greater variety of less vigorous species to develop. Lack of high intensity fire is known to affect understorey development in this way (Cunningham 1960; Cunningham and Cremer 1965; Cremer and Mount 1964; Ashton 1976, 1981). Consequently, competition within sclerophyll understorey regeneration was relatively light in non-clearfell treatments, and a more diverse mosaic of suitable microsites was likely to be available for the protracted regeneration of rainforest tree species in space and over time. Calais and Kirkpatrick (1983) noted the ability of continuous recruitment in rainforest species, and Neyland and Brown (1994) found rainforest tree species successfully establish amongst persisting *Histiopteris incisa*.

Seedlings of *Phyllocladus aspleniifolius* in this study were located in open spaces in regrowth on soil-disturbed seedbeds with a mixture of soil, litter and slash. Some were associated with an additional light moss cover. Barker (1992) found *P. aspleniifolius* to require similar microsites. The absence of this species on the clearfell at age four years, regardless of the fact that soil-stored seed was probably present (Neyland 1992), is likely to be related to the fast colonisation of the *A. dealbata* / *E. regnans* thicket creating very low light conditions at ground level.

These results indicate that silvicultural treatments other than clearfelling with high intensity slash-burning best suit the biological regeneration requirements of rainforest tree species. The most appropriate are likely to be gap selection and the shelterwood treatment, with site preparation using soil disturbance.

Operational application

One deficiency of small case studies such as this is that their results only relate to coupe-level information, and the absence of landscape-level management factors such as current operational costs make it difficult to draw meaningful conclusions (Burgess *et al.* 1997). Even though the regeneration of rainforest tree species is likely to be maximised with the exclusive application of certain non-clearfell treatments, it is difficult to imagine that their landscape-level application for special species timber production could be currently feasible. For example, consider the landscape-level and exclusive use of gaps to accommodate higher production of special species timbers. Constraints on this would include current harvesting technologies, the increase of the spatial and temporal disturbance to forests if current levels of eucalypt timber production are maintained relative to clearfelling (Burgess *et al.* 1997), increased fire risk, loss of eucalypt timber production potential if current levels are not maintained, and higher management costs, such as the increased density of roading required and the increasing dependence on machine disturbance for site preparation (King 1991).

Rather than adopting any single treatment, a simulated landscape-level silvicultural study undertaken by Burgess *et al.* (1997) following the Silviculture Systems Project in Victoria (Squire 1990) suggests that a complete range of silviculture treatments should be considered for use in a particular area, according to the relative priority of forest management objectives. These objectives could include eucalypt timber production, special species timber production, fauna conservation, flora conservation, and enhancing social amenity values. The results of this report support a scenario where clearfelling with high intensity slash-burning is used to fulfil eucalypt timber production requirements, while concurrently identifying appropriate areas and landscape scales where non-clearfell and non-slash-burn treatments are used to increase production of special species timbers. Undertaking a landscape study similar to Burgess *et al.* (1997) would assist with identifying acceptable economies of scale and the technology and silvicultural development required to apply the latter.

Further development

A further deficiency of small case studies such as this is the short period of measurement undertaken, usually focussing only on the period of seedling establishment. Of relevance to this study is the fact that longer term factors may also affect the post-harvest recruitment of rainforest tree species. For example, suitable microsites may develop as forest structure changes with age, even on the clearfell. Barker (1992) reported this may occur for *Phyllocladus aspleniifolius* as understorey structure changes and increases its diversity with age. Although *Acacia dealbata* and *Pomaderris* can persist for many decades (Ashton 1976), their density decreases rapidly in the first eight years (Cunningham and Cremer 1965). Within 10 years, the competition associated with the sclerophyll thicket typically reduces and results in clear emergence of the dominant conical crowns of *E. regnans* (Ashton 1976). Perhaps it could be beyond this time that a gradual recruitment of rainforest tree species which have seed that is soil stored or dispersed by birds will occur on the clearfell. Interestingly, Hickey (1994) found no significant difference in the mean frequency of *Phyllocladus aspleniifolius* between oldgrowth or 19–30-year-old regrowth mixed forests following first rotation clearfelling in Tasmania. Thus, longer term, more rigorous research is required before final conclusions are made on the most appropriate production treatments for special species timbers.

Conclusions

This study provides some insights into the silviculture of wet eucalypt forests in Tasmania, and addresses some of the key terms of reference for the Southern Forests Community Research Project (Allen 1992). Important findings are:

- All harvesting treatments at Arve 031 resulted in some established eucalypt regeneration at age four years.
- A major difference between clearfell and non-clearfell treatments is their effect on eucalypt density, and height and diameter growth, which all decreased along the continuums of increasing overwood and decreasing gap size. These trends are attributed to increased suppression from retained overwood or edge trees, seed supply, increased browsing pressure, decreased area of ashbed effect, and variation in the dynamics of understorey regeneration along these continuums. However, a valid comparison of treatments was hampered by differences in seed supply and browsing control between clearfell and non-clearfell treatments.
- Non-clearfell treatments favoured the early regeneration of rainforest tree species in this study. This is particularly true for gaps and shelterwood treatments, where the levels of burnt ashbed are less, sources of overhead seed are greatest, and the structural and spatial diversity of regrowth are greatest, the latter providing a greater number of suitable niches for the germination and establishment of rainforest tree species.

The results of this study suggest that silvicultural treatments other than clear-felling may have value in meeting specific management objectives where eucalypt timber production is not considered to be of primary importance. There is a need for longer term research to further investigate these findings. Such research will require more rigorous design and implementation of treatments.

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