The evaluation of different seedbed preparation techniques for the regeneration of dry lowland forests in Tasmania after partial logging

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Summary

During the 1970s and early 1980s the clearfell burn and sow silvicultural system was seen as the best means of replacing the previously degraded stands in dry lowland forest in Tasmania with a vigorous regrowth forest. During the 1980s a number of problems were experienced in obtaining adequate regeneration on some of these dry forest coupes. In 1991 and 1992 a series of experimental trials was established in order to determine the most satisfactory method of seedbed preparation that would ensure adequate regeneration in an area considered as 'typical' of the dry lowland forest of the east coast of Tasmania. A variety of seedbed preparation techniques was used in association with a seedtree partial logging system. These included pre- or post- harvest burning, pre- or post- harvest cultivation, and normal logging disturbance. The results indicate that pre-harvest cultivation is the most effective treatment as measured by the fraction of plots stocked and density of seedlings. The cost of pre-harvest cultivation compared favourably with that of both the post-harvest cultivation and the pre- or post-harvest burning treatments.

Introduction

Dry sclerophyll communities of mixed species of eucalypts form the dominant lowland forest type of northern and eastern Tasmania (Forestry Commission 1991a). The forest estate (>15 m tall) totals more than 1.1 million hectares, of which 53% is in private ownership. Many stands have been subject to grazing, associated burning, localised ringbarking as an adjunct to the agricultural enterprises, and the selective harvesting of mill-logs and firewood for local use; consequently they have been degraded from a timber quality perspective. Following the introduction in the 1970s of wood-chip exports, and the expansion of the pulp-wood industry in eastern Tasmania, Felton and Cunningham (1971) recommended the adoption of the clear-fell and slash burn silvicultural system as the best means of replacing these 'degraded' forests. Although Felton and Cunningham (1971) and Lockett and Rich (1977) both recognised the potential value of advance growth[1] they favoured the promotion of new seedlings, while advance growth that was not lost in the fire would supplement the stocking arising from sowing.

By the 1980s it had become apparent that this system was not always a reliable method for obtaining adequate regeneration in the dry open forest. Initial concerns focused on the environmental impacts and later on the problem of achieving stocking standards. Bowman and Jackson (1980) discussed the possible adverse effects of slash burning on dry forest, including escape of fire, loss of nutrients and structural changes to soils. They considered that a reappraisal of the procedure was required, together with research on silvicultural systems that utilised mechanical disturbance rather than fire.

Keenan (1986) and Orr and Todd (1992) highlighted the potential for regeneration to fail in highland and lowland dry forests, respectively, and both recommended the use and expansion of partial logging systems. They considered that the retention of a forest canopy had a number of beneficial effects including moderation of the severity of frost and the provision of a continuing source of seed.

During the 1990s the forest-industry had generally adopted the use of partial logging systems. In these systems, the basal area is reduced to between 8 and 15 m^2 ha^{-1}, depending upon the condition of the stand and the local environmental conditions. Care is taken to retain existing advance growth. Seedbed-preparation under partial logging systems relies upon disturbance associated with the logging operation, or where necessary on additional techniques such as slash burning or mechanical disturbance.

The use of mechanical disturbance to form a receptive seedbed has been the subject of a number of studies (Grose 1960, Minore et al. 1977, Walters 1991, King and Cook 1992, and Lutze 1998), and since the mid-1990s, post-harvest scarification and hand seeding has become routine silvicultural practice on approximately 25% of dry forest coupes in Tasmania.

Low intensity slash burning is also routinely used. The use of low intensity slash burns in dry forests has a number of potential advantages over the use of high intensity burn. The technique allows the retention of advance growth, and it may also reduce the loss of organic matter and other nutrients from these comparatively infertile soils.

Despite these changes in silvicultural practice in dry forests, the degree of regeneration success was unclear. In 1990, CSIRO Forestry and Forest Products and Boral Timber Tasmania commenced research on a variety of both pre- and post-harvest seedbed preparation techniques to determine their effectiveness

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[1] Advance Growth: regeneration established before a current logging operation, sufficiently developed to survive independent of environmental extremes, but not yet merchantable size (Forestry Commision 1990).

in securing adequate regeneration. This paper reports the result of that work.

Methods

Site

The study site was located near Nugent (42°41’ S 147°45’ E, 350 m AMSL) on the East Coast of Tasmania. The annual rainfall of between 700 to 750 mm is typical of dry forest, which in Tasmania generally occurs in areas with an annual rainfall below 900 mm/yr. A discrete flat-topped hill of 250 ha was surveyed: aspect, gradient, basal area of each tree species, tallest tree species, dominant ground cover, abundance of advance growth, and texture of the surface-soil were recorded at 472 sample points. Full results of this survey have been reported previously (Pennington and Ellis 1995).

A history of grazing and frequent fires had produced a mixed-age, fire-damaged forest with few trees less than canopy height. The forest consisted of mainly mature stands of *Eucalyptus obliqua, E. tenuiramis, E. pulchella, E. globulus, E. amygdalina, E. ovata and E. viminalis*. These were grouped into 9 forest types on the basis of similarity of dominant and principal codominant species and topographical position (Table 1). The ground cover varied with dominant eucalypt species. Grass was dominant beneath *E. pulchella; Lepidosperma sp., Gahina sp.* and *Acacia verticillata beneath E. ovata* and the moist *E. obliqua;* and *Leptospermum sp., Cyathodes* and *Epacris sp.* beneath *E. tenuiramis* and *E. amygdalina*. However there was considerable small-scale variation in understorey reflecting topographic effects.

Table 1. Aggregation of stands by dominant species* and major division of the landscape.

Forest types	Species						
	Gl %	Ob %	Pu %	Te %	Am %	Vim %	Ov %
	UPLAND SITES						
E. obliqua	*7.7*	79.8	2.9	4.8	0.0	0.5	4.3
E. tenuiramis	*5.2*	24.8	5.2	56.6	0.0	1.7	6.3
E. pulchella	*22.7*	3.3	53.1	0.5	9.0	0.0	11.4
E. amygdalina	*22.0*	9.9	15.2	0.0	47.6	3.7	1.6
E. globulus	*42.3*	6.3	36.0	8.0	6.8	0.0	0.6
	WETLAND SITES						
E. ovata	2.6	30.8	9.2	3.6	8.7	0.0	45.1
	STEEP SOUTHERN SLOPES (RINGBARKED) **						
E. obliqua	17.9	59.1	0.0	0.0	0.7	21.8	0.4
E. globulus	44.0	33.8	0.0	0.0	0.0	22.2	0.0
E. viminalis	25.9	36.6	0.0	0.0	0.0	37.4	0.0

* A dominant species contributes >30% of the basal area of a stand.

** Not included in study.

Seedbed preparation techniques were applied to the four upland forest types dominated by *E. obliqua, E. tenuiramis, E. pulchella, and E. amygdalina*. Structure of the stands on the steep southern slopes differed from those on the rest of the area. These consisted of regrowth that developed following ringbarking and were not included in experimental operations.

The duplex soils were derived from Jurassic dolerite. They are relatively shallow and vary in depth over bedrock from 20 cm to 100 cm, rarely to 120 cm. However the bedrock is fractured so that the rooting-depth may exceed soildepth. All profiles contained a large proportion of stones and cobbles that substantially reduced the volume of soil available for roots, and probably impaired treegrowth. On convex and level topography the differential removal of fine material had concentrated rock at the surface and reduced the water-holding capacity of the upper 20 cm or so of the profile. The amount of water available between field capacity and nominal wilting point was relatively low in all soils (8%-26% of the soil’s oven dry weight). On level sites, and in depressions, perched water tables in winter restricted depth of rooting, whilst the low water-holding capacity exacerbated summer drought. Samples were taken from three stands of each of the four forest types from the surface 0-10 cm (A1 horizon), 10-20 cm (leached A2), and from between 40-60 cm as representative of the clay B horizon. Their analysis for total and exchangeable elements indicated a generally low level of fertility (Table 2).

Table 2. Chemical analyses of soil

Depth (cm)	pH	Organic Carbon	Total					Exchangeable		
			N	Ca	Mg	K	P	Ca	Mg	K
			(%)					Millieqivalent %		
0-10	5.8	3.41	0.16	0.42	0.20	0.96	0.014	5.87	4.30	0.32
10-20	5.8	1.13	0.04	0.25	0.23	0.83	0.010	2.80	1.97	0.20
40-60	5.4		0.03	0.41	0.36	0.70	0.007	7.53	10.08	0.20

Mean of 3 samples per 4 species type.

Silvicultural system and seedbed preparation treatments

The structure and condition of the stands dictated the silvicultural system of clearfelling with retention of seed trees. Seed trees, with preference given to those of good form, were selected from each dominant species present in the stand. Harvesting commenced in January of each year and continued during the summer. The operation conformed as closely as possible to normal practice, subject to the small individual areas being cut. The degraded state of the forest was confirmed by the low yield of mill-logs. In 1992 only 100 m^3 (~110 t) of mill-log was taken from the 23.5 ha harvested, compared with 2848 t of pulpwood. The basal areas of the original stands were reduced from averages of 25.8(SE 0.7) m^2 ha-1 in the 1991 harvest and 26.0(0.8) m^2 ha^{-1} in the 1992 harvest to 4.8(0.3) and 3.3(0.2) m^2 ha^{-1} respectively. This provided a residual stocking of 8 to 12 seed trees ha^{-1} in addition to a number of smaller well-formed poles.

Seedbed preparation treatments were carried out on plots of about 1 ha as follows:

i) broadcast burning of debris and ground vegetation;

ii) mechanical disturbance by cultivation.

These were applied either:

a) 6-12 weeks before harvest;or

b) 2-4 weeks after harvest.

Control plots were of similar size, with no augmentation of normal logging disturbance. Seed from fallen heads and natural seedfall were the only source of seed for regeneration.

The seedbed treatments were applied in 1990-91 to the four upland forest types and repeated on a second series of plots in 1991-92. To promote burning and to allow access for the lighting of fires a bulldozer crushed the dense understorey of shrubs in the broadcast burn plots. Fires were lit along parallel lines spaced 10-15 m apart. Multiple fronts were used to reduce the potential for a very hot fire that might have caused significant damage to standing trees. In the mechanical disturbed plots cultivation was carried out using a crawler tractor fitted with three rear-mounted rippers. The aim was to create disturbance to a depth of at least 0.4 m and to provide a well-cultivated seedbed over 50 % or more of the ground surface.

Regeneration survey

Permanent sampling points were located at intervals of 15 m on parallel lines spaced 25 m apart. This gave approximately 100 samples for each species type, and a median of 21 samples for each species/treatment combination. Areas of dense advance growth were generally not treated, and hence were excluded from the regeneration survey. At each sample point a circular plot (16 m^2) was assessed for the following factors: type and intensity of disturbance; fraction of plot treated; presence of fallen heads; proximity to unlogged areas; presence of lignotuberous seedlings and other advance growth; and presence of poles or seed trees. All plots were assessed about 3 months after harvest in July 1991 and July 1992, and then reassessed every three months for the next three years, after which the plots were reassessed annually. On each occasion information collected included the presence and survival of all forms of regeneration including new seedlings, pre-harvest seedlings and lignotuberous seedlings. A plot was considered to be stocked if one or more seedlings were present.

Results and Discussion

Proportion of receptive seedbed and cost of treatment

The fraction of area burnt was generally found to be higher in the pre-harvest burns (range 10%-93%, median 73%) than in the post-harvest burns (41%-63%, 55%) (Table 3). The intensity of the fire varied with the amount of fuel present and the weather conditions at the time of burning. Generally the drier sites dominated by *E. pulchella* and *E. amygdalina* carried fires of low intensity that consumed only part of the litter, understorey and slash. The poor pre-harvest burn achieved for the *E. pulchella* site in 1991 (10%) was due to the small fuel load of the grassy ground cover. On the sites dominated by *E. obliqua* and *E. tenuiramis* there were areas of moderately intense fire with nearly complete burning of litter, and small (<10 mm diameter) understorey and slash. The area of high intensity fire, indicated by the burning of larger slash and the presence of soil oxidation (orange ash-bed), was less than 2% of the total area.

The fraction of the plot area cultivated was higher on the pre-harvest treatment (range 44%-90%, median 74%) than on the post-harvest treatment (42%-65%, 52%). Logging slash on the post-harvest treatment had to be heaped in order to allow effective cultivation, both slowing the operation and reducing the area cultivated.

For the control areas, the normal low level of disturbance (excluding snig tracks) caused by the felling and skidding procedures covered between 10% and 19% of the area harvested. Contractors often used a variety of routes when dragging logs back to the landing, so that generally the intensity of disturbance would be rated as tertiary damage or less with only minor gouging of the A horizon and partial removal of the litter layer (level of soil damage based upon the *in situ* damage classes described by Williamson, 1990). In wet areas some snig tracks had secondary damage with the topsoil compacted *in situ* and minor rutting no deeper than 10 cm. Occasionally the rutting was greater than 10 cm in the A horizon.

Table 3. Fraction of area (%) burnt or cultivated by forest type and treatment.

	Forest type			
Treatment	*E. pul*	*E. amy*	*E. obl*	*E. tens*
1991				
Pre-harvest burn	10	50	65	90
Post-harvest burn	46	41	55	59
Pre-harvest cultivation	44	76	73	82
Post-harvest cultivation	52	65	53	51
1992				
Pre-harvest burn		93	90	73
Post-harvest burn		56	63	55
Pre-harvest cultivation	54	90	65	82
Post-harvest cultivation	52	45	55	42

In 1991 and 1992 the cost of burning, including the construction of fire breaks, the crushing of the scrub, and fire lighting and patrolling, averaged \$245 ha-1 for pre-harvest burns and \$335 ha-1 for post-harvest burns. Part of the high cost of post-harvest burns was due to the small size of the areas being treated (1 ha compared to >2 ha pre-harvest); hence average cost per hectare increased. Sharp (1993) found that the cost of conducting slash burns was \$206 ha^{-1} for medium to large gaps (0.25 to 1 ha) but was reduced to \$92 ha^{-1} for small to large clearfelled coupes (4 to 10 ha).

Owing to the need to heap the logging slash, the average cost of post-harvest cultivation was twice the cost of pre-harvest cultivation: \$250 ha^{-1} compared to \$125 ha^{-1}. The post-harvest cost is comparable to the \$230 ha^{-1} figure determined by Sharp (1993). For the control treatment the only outlay was the provision of firebreaks around the entire area.

Stocking standards

Regeneration survey techniques and stocking standards used vary with species, silvicultural systems and objectives of forest management. The current Tasmanian standard for the seedtree silvicultural system is that 80% or more of surveyed plots should be stocked (Forestry Commission 1991b). The result of the survey can also be influenced by the distribution of unstocked plots. In Victoria the minimum standard is that 65% of the potentially productive area must be stocked (Dignan and Fagg 1997). Lockett and Goodwin (1999) modelled the effects of initial stocking on stand development in even-aged mixed eucalypt regrowth on the east coast of Tasmania. They showed that initial stocking influenced the time taken for a stand to reach maximum potential volume. When an initial 60% of 4 m^2 plots were stocked, 95% of maximum volume would be achieved within 40 years; alternatively when only an initial 30% were stocked it would take more than twice as long to achieve 95% of the maximum possible volume. For the current study an acceptable stocking level was considered to be 65% of plots stocked.

An acceptable seedling density is difficult to determine and is strongly influenced by the clumpiness of the regeneration. Squire *et al.* (1991) considered that a minimal acceptable density would be 1000 seedling per hectare if the distribution was uniform, but would be 2500 if it were clumped. In Victoria, studies by Cunningham (1960), Grose (1960) and Irvine (1960) found that adequate stocking was achieved with seedling densities of between 2200 to 3500 seedlings per hectare. Campbell *et al.* (1984) recommended a second-year stocking of 3000 stems per hectare in Low Elevation Mixed Species forest in Victoria. For the current study an acceptable seedling density was considered to be 2500 seedlings per hectare.

Regeneration of new seedlings

General observations

During the first two spring/summer seasons all seedbed preparation treatments showed a continual increase in both the percent of plots stocked (Figure 1) and density of stocking (Table 4). Smaller increases in stocking and density were observed during the third and fourth years as the seedbed became less receptive. Squire *et al.* (1991) noted that in Victoria, seedbed receptivity declined rapidly and may be almost zero, six months to two years after site preparation; in this case the duration of seedbed receptivity depended on the rate of recolonisation by understorey species, and compaction of the exposed soil caused by heavy rain. On drier sites in Tasmania seedbeds may remain receptive for extended periods (Forestry Commission 1991b). In dry highland forest, Battaglia (1991) found that two years after site preparation the percentage of exposed soil had declined from 79.2% to 60.8% for a scarified seedbed, and from 28.2% to 18.3%, and 31.6% to 12.5%, respectively, for seedbeds created by logging disturbance and slash burning.

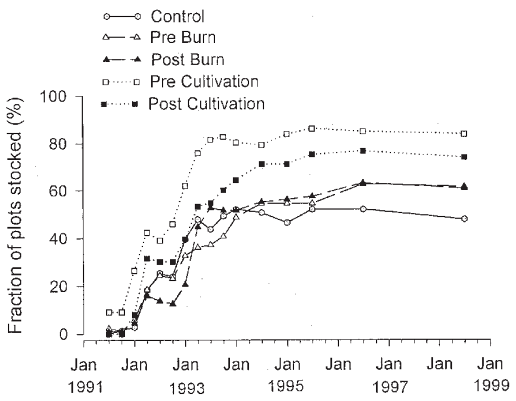
Table 4. Density of new seedling regeneration (number per hectare) associated with the different treatments from July 1992 to July 1998.

	Control (*)	Pre-harvest burn	Post-harvest burn	Pre-harvest cult	Post-harvest cult
1991 logging					
July 1992	280	240	110	670	390
July 1993	1000	800	710	2070	1110
July 1994	1200	1060	940	2580	1340
July 1995	1240	1070	1000	3160	1640
July 1996	1340	1290	1240	3210	1800
July 1998	1130	1320	1150	3010	1650
1992 logging					
July 1993	480	990	580	1920	950
July 1994	760	1500	1440	2880	1920
July 1995	890	1810	1490	3100	1980
July 1996	910	2110	1660	3080	1990
July 1998	790	1730	1560	2840	1700

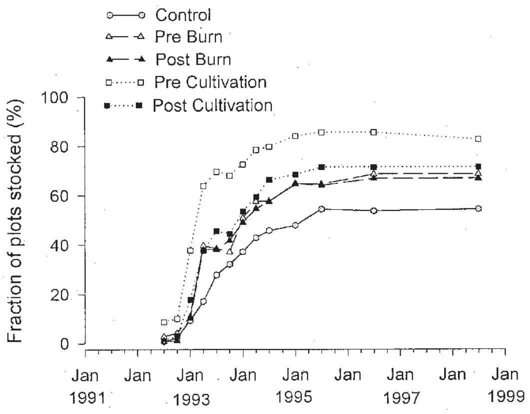
(*) Logging disturbance only.

Figure 1. Fraction of plots stocked with new seedling regeneration following differ different pre- and post-harvest seedbed preparation.

1991 Harvest



1992 Harvest



In the current study the notable increases in both the proportion of plots stocked and seedling density that occur into the second year, reinforces the current recommendation by Forestry Tasmania that regeneration surveys in dry forests should be conducted two years after logging (Forestry Commission 1991b). Since 1996 there has been a slight decline in the fraction of plots stocked (Figure 1) and in seedling density (Table 4).

Generally, the seedling densities following the 1992 harvest are greater than those following the 1991 harvest (Table 4). The greater densities are most likely a response to favourable weather conditions for regeneration in the early part of 1992. Data from an automatic weather station located on the site showed that the 5-month period, January to May 1991, had less rainfall, higher evaporation, and more days with high maximum grass temperatures than the corresponding period in 1992. During this period in 1991 there were 7 days when the maximum grass temperature was over 50°C, and 5 of these days occurred between 4/1/91 and 18/1/91. For the same period in 1992 the maximum grass temperature did not exceed 50°C. For January to May 1991 the total rainfall was 200 mm, or 76% of the long term mean, whereas for the same period in 1992 the total rainfall was 231 mm, or 89% of the long term mean. The months of February and May 1991 received only 16 and 14 % respectively of their long term means. From these data it would be expected that the early part of 1992 would have been more be expected that the early part of 1992 would have been more favorable for the establishment of regeneration than the early part of 1991.

Cultivated Plots

Statistical analysis of the fraction of plots stocked in 1998 showed significant differences among the five treatments (Chi-square, 1991 harvest p=0.00002, 1992 harvest p=0.0009). The most successful treatment was pre-harvest cultivation, on which the fraction of plots stocked rose rapidly to more than 65% in less than two years, and after 6 or 7 years, maintained a stocking of more than 80%. Pre-harvest cultivation treatment was also the only treatment to exceed the acceptable seedling density of 2500 seedlings per hectare. As expected, it took longer for the post-harvest cultivation treatment to reach the acceptable fraction of plots stocked, and after 6 years the stocking was still below that of the pre-harvest cultivation treatment, although the difference was not significant (Chi-square, 1991 harvest p=0.093, 1992 harvest p=0.122). Analysis of seedling density showed that in 1998 the pre-harvest cultivation treatment had the greatest proportion of plots with high seedling densities (Chi-square, 1991 harvest p=1.6×10^{-6}, 1992 harvest p=4.2×10^{-8}). For the entire measurement period there was a significant difference in the seedling densities between cultivation treatments, with density on the post-harvest treatment never reaching the acceptable value of 2500 seedlings per hectare.

The higher seedling density associated with the pre-cultivation treatment was probably due to the fact that the entire stand would have served as a seed source. An additional advantage of this treatment is that the regeneration established would be derived from a wider range of genotypes than might be the case for regeneration established from a limited number of seedtrees.

The success of the cultivation treatments may be due to the effect of microsite on seed germination and seedling survival. It is well established that with eucalypts a higher proportion of seed germinates on exposed and disturbed soils than on undisturbed sites (Grose 1960 and Cunningham 1960). Stoneman and Dell (1994) found a smaller number of emerging seedlings on exposed and disturbed seedbed, but this was directly attributed to increased harvesting of seed by both vertebrates and invertebrates. Battaglia and Reid (1993) found that there were significant differences among different microsites in the numbers of seedlings present, with the ‘depression’ microsite favoured over the ‘flat’ and ‘hillock’. They also found, in glasshouse trials, that a higher proportion of seedlings on ‘depression’ or ‘shade’ microsites survived greater drought periods than those on ‘flat’ and ‘hillock’ microsites. Stoneman et al. (1994) also found significantly lower mortality of *E. marginata* seedling on exposed and disturbed seedbed than on undisturbed sites. The relative success of the pre-harvest treatment was probably due to a combination of two additional factors, namely, a higher percentage of receptive seedbed (Table 3), and the fact that, in the pre-harvest treatments, the fallen heads have a high chance of landing on receptive seedbed.

A potential disadvantage of pre-harvest treatment is the pooling of rainfall in cultivation troughs. In years of heavy rainfall this pooling of water on disturbed soil may lead to excessive rutting by harvesting machinery. The retention of additional logging slash on both cultivated treatments may also lead to a high fire hazard.

Mechanical disturbance as a pre-harvest seedbed preparation technique was first tested in Victoria in wet *E. regnans* forest (Cunningham 1960). Cunningham found stocking levels of between 30 and 69 % on three trial areas, but also noted the significant cost ($120 per hectare in 1955) of the treatment due to the dense understorey present. He considered cost savings could be made if difficult areas were avoided or treatment limited to strips at 9 metre spacings, but the stocking level under this treatment was only 32%. The results of the current study indicate that in open dry forests the pre-cultivation treatment is highly successful and can be conducted at a manageable cost.

Other studies of mechanical disturbance have concentrated on disturbance after the harvesting operation has concluded. Thus, Squire and Edgar (1975) in a study of natural regeneration of mixed forest under partial cutting conditions indicated that regeneration would be obtained most reliably when seedbeds had been deep ripped. Minore *et al.* (1977) found that scarification after partial logging of a mixed conifer forest in southwestern Oregon increased both stocking and subsequent early growth of seedlings. Results of the current study support the belief that post-harvest mechanical disturbance followed by hand seeding to supplement natural seedfall would result in adequate regeneration stocking.

Burnt plots

The pre- and post-harvest burning treatments are considered together since they do not differ significantly in either the fraction of plots stocked or the density of seedlings. Four years after the 1992 harvest the fraction of plots stocked for both treatments was slightly above the accepted level of 65%. As indicated earlier, regeneration conditions in 1991 were less favourable than in 1992, and even after 7 years the fraction of plots stocked was only 60%, thus below the accepted standard. At no time during the survey period did new seedlings exceed the acceptable density of more than 2500 per hectare, and following the 1991 harvest the stocking reached a maximum of only 1320 and 1240 seedlings per hectare for the pre and post-burning treatments. This poor result contrasts with those in wetter *E. regnans* forests where Walters (1991) found no difference between seedling densities following site preparation by fire or mechanical disturbance; this result may be due in part to the higher intensity of burns achieved in that study.

A notable disadvantage of the pre-harvest burning treatment was the unavoidable presence of charcoal on the stems of trees. Orr and Todd (1992) found that fires in the year before logging also increased the difficulty of de-barking, which would make pre-harvest burning unpopular with logging contractors.

Some foresters consider the reduction in fire hazard by slash burning to be a distinct advantage. Dickinson (1985) found that the levels of fine fuel on unburnt sites was greater than on burnt sites for at least 8 years following the logging of dry eucalypt forest in Tasmania. Alternatively, others consider the loss of the seed crop and of the fallen heads that protect seedlings from frost and game to be a disadvantage of burning (Orr 1991 and Orr and Todd 1992).

Control (normal logging disturbance only)

Two years after harvest, the fraction of plots stocked in each of the control areas was approximately 45%. This figure is well below the acceptable level of 65%, hence it would be very likely that remedial treatments would be required. The cost of these treatments and additional hand seeding ($150-$200 ha^{-1}) is very likely to exceed the cost of the pre-harvest cultivation treatment. After two years the fraction of plots stocked had continued to rise, but then stabilised at the third year between 50 and 55%. The maximum seedling stocking of 1340 ha^{-1} after the 1991 harvest, and 910 ha^{-1} after the 1992 harvest, are well below the acceptable level of 2500 seedling per hectare.

Regeneration from all sources

A potential problem with any of the seedbed preparation techniques described above is the potential to either kill or damage advance growth. It would be an unnecessary exercise to contemplate expensive seedbed preparation if the forest already carries an adequate stocking of advance growth. In this study advance growth was present on approximately 40% of plots surveyed, with an average density of approximately 1000 ha^{-1}. On the areas harvested in 1992 the figures for both stocking and density were somewhat higher, with the control areas having advance growth present on approximately 60% of plots and at a density in the order of 1600 seedlings per hectare.

After damage caused by fire or mechanical disturbance most dry forest eucalypt species have the ability to regenerate vegetatively from lignotubers (Jacobs 1955) and that can be an important source of regeneration. Table 5 shows the fraction of plots stocked and the density of the regeneration from all sources (advance growth, lignotubers seedlings and new seedlings) present two years after harvesting and at the end of the survey period.

Table 5. Fraction (%) of plots stocked and density (stems/ha) of regeneration of all sources(*) after the 1991 and 1992 harvests.

	1991-Harvest				1992-Harvest			
	1993 Survey		1998 Survey		1994 Survey		1998 Survey	
	Stocking (a)	Density (b)	Stocking	Density	Stocking	Density	Stocking	Density
Control	59.2	1650	63.4	1800	78.5	2380	78.5	2500
Pre burn	66.3	1580	79.1	2130	68.5	2250	75.3	2460
Post Burn	74.7	1160	73.6	1610	78.7	2130	80.5	2300
Pre Cult	88.5	2500	92.0	3560	82.6	3430	84.0	3450
Post Cult	64.4	1380	82.2	1960	82.1	2740	84.2	2560

a) Percentage of plots stocked by regeneration (seedlings, lignotubers, or coppice <3m in height).

b) Density (stem/ha) of regeneration (seedlings , lignotubers, or coppice <3m in height).

* Seedlings old and new, lignotubers and coppice.

For the 1992 harvest it was found that on all of the treatments the fraction of plots stocked, and the density of regeneration either exceeded or was very close to acceptable stocking levels. This was due to a combination of factors. As previously noted, the areas harvested in 1992 (particularly the control) had a higher level of advance growth and secondly, weather conditions during the first half of 1992 were favourable for regeneration of new seedlings.

Two years after the 1991 harvest the fraction of plots stocked, and regeneration density exceed the acceptable level only on the pre-harvest cultivation treatment. This highlights the fact that, in areas with a low level of advance growth, or when harvesting occurs in years not conducive to supporting regeneration of new seedlings, it is highly unlikely that either of the burning treatments or normal logging disturbance would ensure adequate regeneration.

Conclusions

For the foreseeable future, dry forests (particularly privately-owned forests) will continue be an important source of timber products. It is both desirable and necessary that forest management practices on these lands be sustainable. To that end it is important that planning for regeneration should start well before harvest operations. A pre-harvest regeneration survey is desirable, in order to assess the species mix of the forest, the level of seedcrop and, most importantly, the amount of regeneration or advance growth already present on the site. From these data the need for appropriate regeneration procedures can be assessed. From general observation and from the data presented in this paper we consider that stocking of advance growth should be in the order of 50%. Part of this stocking will be lost during the harvesting operation, but the combination of new seedlings on disturbed seedbed and coppice is likely to ensure adequate stocking levels are reached. If the survey indicates that stocking of advance growth is inadequate, or that its distribution is not uniform, consideration should be given to the implementation of appropriate treatments. On the basis of the current findings the most successful and economical treatment would be pre-harvest cultivation. It was the only treatment which consistently achieved acceptable standards for the fraction of plots stocked and density of either new seedlings or regeneration from all sources. Post-harvest cultivation proved reasonably successful and, if augmented with additional hand seeding, would be an effective means of completing remedial work on understocked areas. It must be noted, however, that the cost of this operation is likely to be significantly higher than that of the pre-harvest cultivation treatment.

On the basis of the results of this study it would be hard to justify the added expense of either pre-harvest or post-harvest burning, since both gave only marginally better regeneration results than those obtained from normal logging disturbance. It must be noted though, that the use of burning as a management tool to reduce potential losses through wildfire or arson was not considered as part of this study. The potential risk of these factors will need to be considered by forest owners and managers for each individual coupe.

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References

Battaglia, M. 1991. Seedbed preparation under shelterwoods: termination report Snowhill 54 *Eucalyptus delegatensis* trial. Forestry Commission, Tasmania. (Unpubl)

Battaglia, M. and Reid, J.B. 1993. The effect of microsite variation on seed germination and seedling survival of *Eucalyptus delegatensis*. *Australian Journal of Botany* **41**:169-181.

Bowman, D.M.J.S. and Jackson, W.D. 1980. Slash-burning in the regeneration of dry eucalypt forests. *Australian Forestry* **44**:118-124.

Campbell, R.G. et al. 1984. *Silvicultural and environmental aspects of harvesting some major eucalyptus forests in Victoria:* A review. Forest Commission Victoria.

Cunningham, T. M. 1960. *The Natural Regeneration of Eucalyptus regnans*. Bulletin No 1. School of Forestry, University of Melbourne. 114-125.

Dickinson, K.J.M. 1985. *Vegetaion and fuel dynamics following clearfelling of dry eucalypt forets on dolerite in southeastern Tasmania with special reference to the use of fire in forest regeneration*. Ph.D. Thesis, Univ of Tas.

Dignan, P. and Fagg, P.C. 1997. *Eucalypt Stocking Surveys: Native Forest Silviculture Guideline No 10*. Department of Natural Resources and Environment – Victoria.

Felton, K. and Cunningham, T.M. 1971. Woodchip exports and pulpwood forestry in eastern Tasmania. Proceedings of 6th Institute of Foresters of Australia Conference. May 1971. Thredbo, NSW. B3-18.

Forestry Commission 1991a. *Native Forest Silvicultural Technical Bulletin No. 3, Lowland Dry Eucalypt Forests*, Forestry Commission, Tasmania.

Forestry Commission 1991b. Native Forest Silvicultural Technical Bulletin No. 6, Regeneration Surveys and Stocking Standards, Forestry Commission, Tasmania.

Grose, R.J. 1960. *Silviculture of Eucalyptus delegatensis*. Ph.D. Thesis, School of Forestry, University of Melbourne.

Irvine, H.G. 1960. Sample plot studies of utilization and natural regeneration in a mixed species forest of East Gippsland. Dip. For (Vic) Thesis, Forestry Commission, Victoria. 76pp.

Jacobs, M.R. (1955). *Growth Habits of the Eucalypts*, Forest and Timber Bureau, Canberra.

Keenan, R.J. 1986. Review of the shelterwood system and its potential for application in Tasmanian eucalypt forests. *Australian Forestry* **49**:226-235.

King, M. and Cook, J. 1992. The Regeneration of *Eucalyptus regnans* F. Muell. under Alternative Silviculture Systems: 2. Seedbed Descriptions (1st seasonal replicate). SSP Internal Progress Report 7, Department of Conservation and Environment, Victoria. 21 p.

Lockett, E.J. and Goodwin, A. 1999. Effects of initial stocking on stand development in even-aged mixed eucalypt regrowth: a preliminary model. *Australian Forestry* **63**:9-16.

Lockett, E.J. and Rich, R.P. 1977. The early years at Triabunna - a look at management and silvicultural practices developed for Tasmania's first wood chip export scheme. In: *Focus on the Foreste*r. Proceedings. of 8th Institute of Foresters of Australia Conference. 1977. Adelaide. Volume 2, 22 p.

Lutze M.T. 1998. *Species composition in mixed species regeneration following a range of harvesting and site prepartion treatments in a lowland eucalypt forest in east Gippsland*. VSP Technical Report No 33, Natural Resources and Environment, Victoria. 27 p.

Minore, D., Carkin, R.E. and Fredriksen, R.L. 1977. *Comparison of Silvicultural Methods at Coyote Creek Watersheds in Southwestern Oregon - A case history*. USDA Forest Service Research Note, PNW-307. Portland, Oregon. 12 p.

Orr, S. 1991. Managing your dry forests. *A guide to the management of privately owned dry eucalypt forests in Tasmania*. Private Forestry Council. 56p.

Orr, S. and Todd, G. 1992. Regeneration establishment in dry grassy forests. *Tasforest* **4**:1-13.

Pennington, P.I. and Ellis, R.C. 1995. The development of silvicultural practices for the regeneration of mixed-species, mixed-age dry sclerophyll forests. Establishment and interium report to the Tasmanian Forest Research Council. pp.81.

Sharp, R. 1993. *Regeneration Costs Under Alternative Silvicultural Systems in Lowland Sclerophyll Forest*. VSP Technical Report No 20. Department of Conservation, Forest & Lands, Victoria. 50 p.

Squire, R.O. and Edgar, J.G. 1975. *A study of the natural regeneration of mixed eucalypts under partial cutting conditions in the Wombat forest*. Research Branch Report No 60. Forests Commission, Victoria. 23 p.

Squire, R.O., Dexter, B.D., Eddy, A.R., Fagg, P.C. and Campbell, R.G. 1991. *Regeneration Silviculture for Victoria's Eucalypt Forests*. SSP Technical Report No. 6, Department of Conservation and Environment, Victoria. 38 p.

Stoneman, G.L. and Dell, B. 1994. Emergence of *Eucalyptus marginata* (jarrah) from seed in Mediterranean-climate forest in response to overstorey, site seedbed and seed harvesting. *Australian Journal of Ecology* **19**:96-102.

Stoneman, G.L., Dell, B. and Turner, N.C. 1994. Mortality of *Eucalyptus marginata* (jarrah) from seed in Mediterranean-climate forest in response to overstorey, site seedbed, fertilizer application and grazing. Australian Journal of Ecology 19:103-109.

Walters, M. 1991. The Regeneration of *Eucalyptus regnans* F. Muell. under Alternative Silviculture Systems: 1. Seedling establishment and early height growth (1st seasonal replicate). SSP Internal Progress Report 2, Department of Conservation and Environment, Victoria. 45 p.

Williamson, J.R. 1990. *The effects of mechanised forest harvesting operations on soil properties and site productivity*. Research Report No 5, Tasmanian Forest Research Council. pp.193.