The effect of three silvicultural treatments on eucalypt regeneration in dry, inland *Eucalyptus amygdalina* forest in the northern Midlands, Tasmania

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Abstract

The success of eucalypt regeneration following logging was investigated in a dry, grassy, inland Eucalyptus amygdalina *forest near Bracknell in the northern Midlands of Tasmania. Three typical silvicultural treatments (logging only, logging followed by mechanical scarification, and logging followed by top-disposal burning) were compared with an unlogged control. Conventional selective logging was conducted in 1999, reducing the stand to a basal area of approximately 9–12 m^2/ha. Each treatment was applied over more than 1 ha, and a regeneration survey and basal-area sweep was conducted 27–32 months later. Eucalypt regeneration was most successful in the logged and scarified treatment and least successful in the logged-only treatment. Available seedbed was important to regeneration success, but browsing pressure by native and introduced animals was also a major factor.*

Introduction

Logging intensities and methods used in dry forests in Tasmania have varied considerably over the last 40–50 years (Hickey and Wilkinson 1999). Prior to the 1970s, the lower productivity and higher timber defect of drier forests allowed only selective harvesting for sawlogs and other minor products. With the introduction of the export pulpwood industry in 1971, improvements in stand productivity were thought possible through the use of clearfelling, burning and sowing to convert heavily cut-over, poor quality stands to vigorous, high quality stands (Hickey and Wilkinson 1999). As the regeneration successes and failures of these operations became more apparent by the 1980s (Bowman and Jackson 1980; Elliott *et al.* 1991), various partial logging systems were trialled (McCormick and Cunningham 1989). By the 1990s, the majority of logging operations in dry forests were undertaken using partial harvesting systems, including seed-tree retention, shelterwood, and selective harvesting methods. The success of different logging and silvicultural techniques for regenerating dry forests has been examined recently by Pennington *et al.* (2001) in south-eastern Tasmania, and the efficacy of techniques of strip clearfelling, clump retention and ground preparation using excavators has been examined by Neyland (2000).

Grassy forest types in the northern Midlands of Tasmania have been heavily disturbed since European settlement by land clearing, logging, weed invasion and domestic stock grazing (Fensham and Kirkpatrick 1989; Kirkpatrick and Gilfedder 2000). Inland *Eucalyptus amygdalina*[1] (black peppermint)

[1] Scientific names of plants follow Buchanan (2005). Species' authorities are also given there.

Photo 1. Eucalyptus amygdalina *dry forest with an open understorey and a ground cover of bracken* (Pteridium esculentum) *and grasses.*

forest in the Midlands bioregion is one of the most poorly reserved forest communities in Tasmania, with only 1700 ha (9%) of its current area (19 800 ha) reserved in 2001 (Forest Practices Board 2002). Conversion to non-forest or plantations is now restricted in this forest type under the *Forest Practices Act 1985*, as required by the permanent forest estate provisions of the Tasmanian Regional Forest Agreement (1997). However, private landowners may elect to harvest timber in this forest type and regenerate with native species. Selection of effective silvicultural techniques is therefore critical for obtaining adequate regeneration and maintaining long-term ecological viability in inland *E. amygdalina* forests.

Few studies on the successes and failures of silvicultural techniques in the inland *E. amygdalina* forests can be found in the literature, although there has been some research in similar dry forests in other parts of Tasmania. Orr and Todd (1992) provide a guide for grassy dry forests, and the conclusions of Elliott *et al.* (1991), Neyland (2000) and Pennington *et al.* (2001) are relevant but based on dry forests in the eastern and south-eastern parts of the State. Elliott *et al.* (1991) reported regeneration success following clearfelling, burning and sowing of shrubby dry sclerophyll forest. Orr (1991) and Forestry Tasmania (2002) provide summaries for the general dry grassy forest type.

This study was part of a broader research project looking at the impacts of logging on the threatened herbaceous understorey species *Brunonia australis*, and reports on the eucalypt regeneration in a dry, grassy, inland *E. amygdalina* forest in the northern Midlands following partial harvesting and three typical silvicultural treatments. The lack of replication is a limitation of this study and so the results must be interpreted with caution.

Methods

Study site

The study site was a 15 ha, privately owned, inland *Eucalyptus amygdalina* forest on Tertiary alluvial soil, near Bracknell (GR 493200 5390700, AGD, *Cluan* 1:25 000 map sheet). Topography was flat, with an elevation of approximately 210 m a.s.l. Mean annual rainfall, based on 38 years of records from 'Sand Park', 3 km east of the study site (Phil Spencer, pers. comm.), was 820 mm, with a winter peak.

The stand was dominated by mature and over-mature *E. amygdalina*, with occasional *E. viminalis* (white gum) (Photo 1). Past disturbances included firewood-cutting and light grazing by sheep and cattle, which ceased shortly before commencement of logging. No fire was known to have occurred in the area for at least 20 years. The understorey was generally open and dominated by herbs and native grasses, with frequent denser patches of bracken (*Pteridium esculentum*). Floristically, the site was in a relatively natural condition, with weeds limited to a few patches of gorse (*Ulex europaeus*), some thistles (e.g. *Cirsium vulgare*), exotic grasses (e.g. *Holcus lanatus*) and other species (e.g. *Centaurium* sp.).

The management objective of the land-owner was to achieve effective seedling regeneration, with the aim of conducting a future overstorey removal harvest, and to reintroduce domestic grazing stock into the forest as soon as the eucalypt regeneration had reached a stage where minimal damage was likely to occur.

Pre-treatment

Prior to logging, basal-area sweeps (Kulow 1966) of eucalypts and regeneration surveys were conducted every 20 m along parallel transect lines spaced 50 m apart, to assess existing regrowth at the site and stand uniformity. The first transect line was randomly located. At each survey point, the basal area of each species was calculated using a 4 m^2/ha optical wedge, and eucalypt advance growth was counted by species in a 16 m^2 circular plot centred on the point.

Treatments

Four squares of approximately 2 ha each were subjectively located and marked within the 15 ha site. Squares of 2 ha each were selected in order to provide a central area of at least 1 ha for intensive monitoring after harvesting (after Pennington *et al.* 2001). Each of the four areas was randomly assigned to a control (Photo 1) or to a harvesting and regeneration treatment: logging only (Photo 2), logging and post-logging scarification (Photos 3, 4), and logging and post-logging top-disposal burning. All of the site was harvested (logged) except the control. There was no replication of the treatments.

Conventional logging commenced in April 1999 using manual tree falling, and snigging with a rubber-tyred skidder. The logging crew was instructed to retain a basal area of approximately 8–12 m^2/ha of mature trees with relatively good form and healthy crowns. There were several objectives in retaining this level of overstorey: to minimise grass competition in the regenerating forest, to provide an ongoing seed source for eucalypt regeneration, and to provide environmental benefits by retaining an element of mature forest structure.

Scarification was conducted on 31 May 1999 using a front-mounted root rake on an International TD15 bulldozer (Photo 3). It was aimed at removing all vegetation and debris back to bare earth over more than 50% of the total area except within about 2 m of retained trees. Top-disposal burning was conducted in mild conditions on 20 October 1999. No additional regeneration works involving seed application or browsing control were undertaken during the course of the study.

Photo 2. The logged forest after conventional harvesting, including manual tree felling, and snigging with a rubber-tyred skidder.

Photo 3. Front-mounted root rake on the International TD15 bulldozer.

Photo 4. The scarification treatment. The aim was to expose bare earth over more than 50% of the area, excluding the area around retained trees.

Post-logging

A modified version of the standard Tasmanian regeneration survey (Forestry Tasmania 2003) was used to assess the treatments for regeneration success and residual stand stocking in January 2002, 32 months after logging and 27 months after top-disposal burning. Each treatment was intensively surveyed with fifty-six 16 m^2 regeneration plots. One logged and scarified plot fell on a road and was omitted. Plots were located every 15 m along transect lines spaced 15 m apart. The first point was located 5 m in from the corner of the area. Regeneration plot locations were not the same for pre- and post-treatment surveys.

For each plot, the number and relative health of eucalypt seedlings were recorded. The presence of one or more seedlings constituted a stocked plot. Coppice was infrequent across the study area and was not considered part of the regeneration. Pre-existing advance growth less than 1.5 m tall could not be consistently distinguished from seedling regeneration, some of which was already forming lignotubers, so was included as regeneration. Unhealthy seedlings were subjectively assessed as plants affected by heavy browsing, insect attack, severe leaf discoloration or other defect. The height of the tallest seedling in each plot was also recorded to the nearest 5 cm. Plots were recorded as burnt if more than 25% of their area showed recently burnt debris or ground charring, indicating at least a medium-to-hot burn where litter layers were consumed and bare seedbed provided (Wilkinson and Jennings 1994). A plot was considered scarified if more than 50% of its area showed visible mechanical soil disturbance.

Basal area was measured (as described above) every 30 m on every second line (30 m apart), giving 16 plots across the sample area for each treatment. A comparison of stocking against the multi-aged stocking standard (Forestry Tasmania 2003) could therefore be made only for these plots.

Table 1. Stand basal area (BA) and proportion of Eucalyptus amygdalina *and* E. viminalis *in the overstorey before and after logging for three silvicultural treatments and a control.*

	Logged	Logged and scarified	Logged and burnt	Control
Original BA (m^2/ha)	32.9	26.6	30.1	32.7
Retained BA (m^2/ha)	11.5	12.3	9.5	32.7
Original *E. amygdalina/E. viminalis* BA (%)	82/18	81/19	80/20	88/12
Residual *E. amygdalina/E. viminalis* BA (%)	89/11	68/32	76/24	88/12

Table 2. A comparison of the three silvicultural treatments and the control for particular levels and types of disturbance. Plot disturbance types refer to harvesting disturbance only. 'na' denotes plots in which there was no harvesting disturbance.

	Logged	Logged and scarified	Logged and burnt	Control
Percentage of plots with:				
Some mechanical disturbance (non-scarified)	35–60	10	35–60	na
Greater than 50% heavy slash remaining	21	7	0	na
Greater than 50% scarified	na	75	na	na
Greater than 25% burnt at medium-to-high intensity	na	na	40	na

Analysis

Regeneration success was measured in terms of percentage of plots stocked with one or more seedlings irrespective of retained trees. A minimum of 65% of plots stocked was considered adequate (Pennington *et al.* 2001; Forestry Tasmania 2003). The height of the tallest seedling on each plot was compared between treatments using a 1-way ANOVA with a Bonferroni *post hoc* comparison, and average number of seedlings per plot was compared using a 1-way ANOVA with a Dunnett T3 *post hoc* comparison. SPSS (version 10.0) was used for the analyses.

Results

Pre-treatment

The standing forest was relatively uniform across treatment areas as expected given the consistent geology, flat topography and homogeneous overstorey and understorey (Table 1), with an average basal area across the site of 30.6 m^2/ha. The proportion of *E. amygdalina* to *E. viminalis* was consistent across all treatments (Table 1), with *E. amygdalina* comprising 80–88% of the basal area. Advance growth was generally sparse, ranging from 12% of plots stocked in the area to be logged and burnt to 39% of plots stocked in the control area (Figure 1). All the advance growth was *E. amygdalina* and less than 1.5 m tall. No seedling regeneration was observed prior to treatment.

Effect of treatments

Basal area was reduced to between 9.5–12.3 m^2/ha in all logged treatments (Table 1). Species proportions by basal area were less uniform than before logging, with a decrease in the proportion of *E. amygdalina* in the logged and scarified treatment.

Mechanical disturbance other than that caused by scarification was difficult to confirm due to understorey recovery but was estimated as occurring in 35–60% of

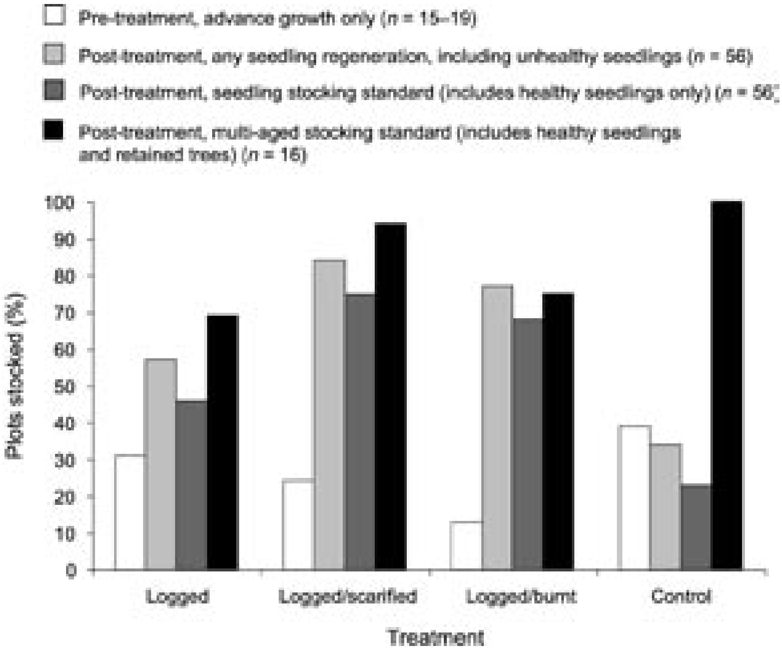

Figure 1. Stocking in the control and the three logging treatments before harvesting and 27–32 months after harvesting. The post-treatment stocking standards follow Forestry Tasmania (2003). Post-treatment seedling regeneration includes advance growth.

plots in logged-only and logged-and-burnt treatments, and 10% of plots in the logged-and-scarified treatment (Table 2). Twenty-one per cent of plots were recorded with heavy slash in the logged-only treatment (Table 2), but the majority of slash was pushed into piles in the logged-and-scarified treatment or burnt in the logged-and-burnt treatment. Scarification had a coverage of approximately 50–75% in the logged-and-scarified treatment, and burning of at least medium intensity was estimated to cover approximately 40% of the logged-and-burnt area.

Stocking and regeneration height

Regeneration success is summarised in Figure 1 and Table 3. The overall regeneration of eucalypts, irrespective of seedling health, was higher in the logged-and-scarified (84% of plots stocked) and logged-and-burnt (77% stocked) treatments than in the logged-only treatment (57% stocked). Almost all the regeneration was *E. amygdalina*. Heavy slash piles restricted the development of seedlings in many plots in the logged-only treatment. Controls maintained a stocking consistent with pre-treatment measures. Within the logged-and-scarified treatment, 93% of plots that were recorded as successfully scarified (> 50% disturbed) were stocked with seedlings. In the logged-and-burnt treatment, 71% of plots considered successfully burnt (> 25% burnt) were stocked with seedlings, although it was difficult to accurately assess the burn status of the seedbed at the time of the regeneration survey due to the time elapsed since the burn.

All individual advance growth and seedlings recorded as unhealthy were heavily browsed. When only healthy regeneration was considered, the stocking rate was lower in all treatments and the control, but remained at relatively high levels in the logged-and-scarified and logged-and-burnt treatments. Under the multi-aged stocking standard (Forestry Tasmania 2003), which takes into account

Table 3. Summary of regeneration success for three silvicultural treatments and a control in an inland Eucalyptus amygdalina *dry sclerophyll forest 27–32 months after treatment. All seedlings except two were* E. amygdalina. *The* E. viminalis *seedlings were on plots already stocked with* E. amygdalina. *(Note: seedlings include advance growth less than 1.5 m tall.)*

	Logged only	Logged and scarified	Logged and burnt	Control
Number of plots (*n*)	56	55	56	56
Number of stocked plots	32	46	43	19
Plots stocked (%)	57	84	77	34
Mean height of tallest seedlings (m)	0.41	0.41	0.32	0.35
Mean number of *E. amygdalina* seedlings/plot	1.4	3.2	2.3	0.9
Mean number of *E. viminalis* seedlings/plot	0	0	0.04	0
Proportion (%) of *E. amygdalina*/*E. viminalis* seedlings	100/0	100/0	99/1	100/0
Proportion (%) of healthy seedlings	69	67	64	45
Total number of seedlings in plots	78	177	129	48
Equivalent number of seedlings per hectare	871	2011	1440	536

standing trees, all treatments were relatively well stocked. The logged-only treatment was the lowest, with 69% of plots stocked.

There was no significant difference ($P < 0.05$) between treatments in the height of the tallest seedlings (Figure 2), but average seedling density per plot was significantly higher for the logged-and-scarified and logged-and-burnt treatments than in the control ($P < 0.05$) (Table 3, Figure 3). Logged-and-scarified plots also had a significantly higher seedling density than did logged-only plots ($P = 0.01$) (Figure 3).

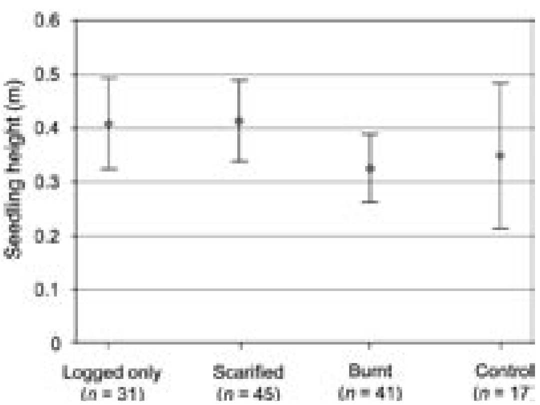

Figure 2. Mean height of the tallest seedling (± 2 S.E.) in each stocked plot 27–32 months after treatment.

Good seedbed conditions had virtually disappeared within the 32 months since logging in the logged-only treatment due to grass, bracken and other understorey regrowth. The logged-and-scarified and logged-and-burnt treatments maintained a small percentage (< 20%) of seedbed but that was gradually being revegetated. Observations during regular visits between logging and survey suggested that there was reasonable seedbed availability for up to 20 months after completion of operations.

Discussion

Stocking

The logged-only treatment achieved only 57% of plots stocked with eucalypt regeneration compared to the logged-and-scarified (84%) and logged-and-burnt (77%) treatments (Table 3). Regeneration in the latter two treatments was clearly favoured by the improved seedbed conditions, while slash piles and dense grass or bracken combined to reduce the seedbed available in the logged-only treatment. A level of 65% of plots stocked with regeneration is considered a minimum acceptable level (Forestry Tasmania 2003) and was used by Pennington *et al.* (2001) for a seed-tree retention system in dry forests with a basal-area retention of 3.3–4.7 m^2/ha. The higher basal-area retention in this study may suppress regeneration (Squire and Edgar 1975; Battaglia and Wilson 1990) but, as the aim was to achieve regeneration beneath the retained stand, the target stocking remains desirable. Such a high expectation for seedling regeneration is not typical for harvested dry forests in Tasmania as the contribution of retained trees to stocking is normally taken into consideration. However, in this study, the management objective of the landowner was to achieve effective regeneration in order to permit a future harvest. In view of this objective, regeneration in the logged-only treatment has not achieved the nominated target. These results are comparable to those of Pennington *et al.* (2001) in south-eastern Tasmania, who found 70–80% of 16 m^2 plots stocked three years after post-logging scarification, 60% after a post-logging burn and 50% after logged-only treatments. Pre-logging scarification was the most successful treatment in that work, with over 80% of plots stocked.

An indication of overall forest stocking, including standing trees, was made using the Tasmanian multi-aged stocking standard for partially harvested forests (Forestry Tasmania 2003). A forest is considered fully stocked under this standard when 65% of plots are stocked. All treatments are therefore considered fully stocked using this measure. The outward appearance of all treatments was of acceptable stocking, with occasional open patches containing less than desirable levels of regeneration. The results of this study are not directly comparable to typical regeneration surveys using the multi-aged stocking standard because the scale of the survey is normally larger than one hectare, recognising the natural heterogeneity and clumpiness of dry open forests.

In terms of seedling density per hectare (Table 3), the logged-and-scarified and logged-and-burnt treatments (2011 and 1440 seedlings/ha respectively) again showed much better regeneration than the logged-only treatment (871/ha). Given the high basal-area retention in this study (9–12 m^2/ha), an acceptable stocking could be in the order of 1200–1500 seedlings/ha, provided they are not clumped. In comparison, Pennington *et al.* (2001) proposed 2500 seedlings/ha to be an acceptable regeneration stocking for their seed-tree retention prescription. The significantly smaller number of overstorey trees in a seed-tree retention system (typically 7–12 trees/ha, Forestry Tasmania 2002) necessitates a much higher seedling stocking to maintain maximum productive capacity of the site. Pre-treatment advance growth would have consisted almost entirely of lignotuberous seedlings in the three logged treatments, so increased post-treatment stocking reflects the contribution of both pre-existing lignotuberous advance growth and new seedling recruitment (Figure 1). Squire and Edgar (1975) also reported that lignotubers alone would not provide sufficient regeneration stocking in a Victorian dry forest and recommended provision of suitable conditions for seedling germination.

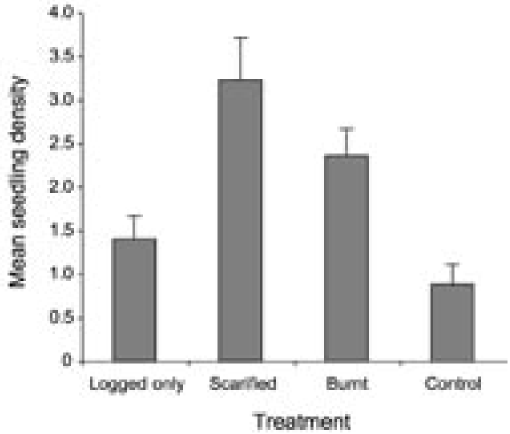

Figure 3. Mean seedling density (seedlings/plot) in all regeneration plots 27–32 months after treatment. (Error bars, S.E.)

Improved seedbed conditions are likely to be responsible for a better level of eucalypt germination in the logged-and-scarified and logged-and-burnt treatments (Stoneman 1994). The scarified treatment had the largest area of exposed seedbed and 84% of logged-and-scarified plots were stocked with seedlings. Research on scarification in *E. delegatensis* forests has suggested that the variation in microsites provided through furrows and ridges allows more opportunities for successful germination and development of eucalypt seedlings (Battaglia and Reid 1993). Additional recruitment is possible over the next few years in all treatments (Orr and Todd 1992), but the diminishing seedbed in the logged-only treatment will limit regeneration success. The increase in grass cover was noted across all treatments except the control and is attributed to the removal of the overstorey (Forestry Tasmania 2002).

The very dry and hot spring/summer of 1999/2000 may also have affected seedling survival in the first season after logging. The excellent growing conditions in the following two years (2000/01, 2001/02) may have allowed protracted recruitment in the logged-and-scarified and logged-and-burnt treatments, which retained a higher level of acceptable seedbed than the logged-only treatment after the first year.

Orr and Todd (1992) recommend that, unless required for hazard reduction, burning of felled crowns (top-disposal) should be avoided in dry grassy forests. The 'cage' effect of the felled crowns helps protect regeneration from browsing. Grass does not readily re-invade where there has been a high intensity burn (Forestry Tasmania 2002), but the detrimental impact of hot burns on retained trees and possibly on soil properties (Bowman and Jackson 1980) makes this option undesirable in partially logged forests. Nevertheless, where burning can be conducted without canopy scorch and stem damage, the localised ashbed may still be important for regeneration (Florence 1996). Pennington *et al.* (2001) found that pre-logging scarification was the most successful regeneration treatment for a range of dry forest types. The combination of the caging effect of the felled crowns and the fact that they were felled onto receptive seedbed permitted better regeneration than other treatments, including burning and logging disturbance only. Post-logging scarification was also found to be relatively successful compared to other treatments.

The lack of *E. viminalis* regeneration is of concern, with only two plots in the logged-and-burnt treatment containing the species. *Eucalyptus viminalis* constituted 11–32% of the pre- and post-logging basal area of the stand. The *E. viminalis* seed crop on felled tree crowns observed during logging was not as consistent as that of *E. amygdalina*. Any *E. viminalis* seedlings observed across the study area were always severely browsed. In 1999, the landowner planted a dozen *E. nitens* at the study site, but all were heavily browsed shortly after and could not be relocated in January 2002.

The brushtail possum (*Trichosurus vulpecula*), Bennett's wallaby (*Macropus rufogriseus*), Tasmanian pademelon (*Thylogale billardierii*) and rabbit (*Oryctolagus cuniculus*) are major browsers of eucalypts in Tasmania (Forestry Commission 1990; Orr 1991; Bulinski and McArthur 2000) and all of these species were observed at the study site. Large populations of brush-tailed possums, in particular, occur in the study area, which is surrounded by cropping land and pastures, but macropod and rabbit populations were not considered high (G. Spencer, landowner, pers. comm. 2002).

Browsing is likely to have been an important factor in the initial success of regeneration in the area (Orr and Todd 1992). However, it is difficult to determine whether preferential browsing caused higher losses to *E. viminalis* than *E. amygdalina* or whether initial establishment of *E. viminalis* was lower for other reasons. McArthur and Turner (1997) showed preferential browsing of eucalypt species by captive brushtail possums, with Symphyomyrtus species (*E. nitens*, *E. globulus*) likely to be preferred over Monocalyptus species (*E. regnans*, *E. delegatensis*), and preferential grazing has been shown to occur in certain macropods (Montague 1994), including the Tasmanian pademelon (Lawler and Foley 1999), and also in rabbits (O'Reilly and McArthur 2000). Therefore, it is possible that preferential grazing by brush-tailed possums may have affected *E. viminalis* (Symphyomyrtus) more than *E. amygdalina* (Monocalyptus). The loss of all *E. nitens* (Symphyomyrtus) planted at the site further supports this. The brush-tailed possum population at the site was relatively small 30 years ago (G. Spencer, pers. comm.) and was unlikely to have substantially influenced the mix of eucalypt species that existed prior to logging in this study. The population explosion of brush-tailed possums in the two to three decades since cessation of the possum fur trade, particularly in forests surrounded by pasture and cropping land (Kirkpatrick and Gilfedder 1999; Gilfedder *et al.* 2003), may have important implications for the future species mix of these forests following logging or other disturbances. The use of fenced, browsing indicator plots would be of benefit in a future study.

Growth rates

Animal grazing may also have contributed to the slow seedling growth rates observed, with mean seedling heights of only 0.3–0.4 m across all treatments over almost three years after logging. Healthy plants up to 1 m tall were observed in all treatments but heavily grazed individuals and younger seedlings reduced the average height. In comparison, Lockett and Goodwin (1999) found mean tallest seedling heights to range from 0.43–1.03 m two years after clearfelling in moist sclerophyll forest on Tasmania's east coast. The growth rate of competing vegetation was not measured in this study, but average grass height was typically less than 0.3 m and patches of bracken were approximately 0.4–0.6 m high.

In addition to grazing, browsing and grass competition, growth rates of regeneration in dry grassy forests may also be affected by retained overstorey (Orr 1991; Orr and Todd 1992; Bassett and White 2001). Average retained basal areas of 9.5–12.3 m^2/ha for this study may have reduced regeneration growth rates. Battaglia and Wilson (1990) found in high altitude *E. delegatensis* forest that seedling height growth was negatively correlated with retained basal area, particularly over 12 m^2/ha, and Squire and Edgar (1975) found growth of regeneration was restricted with retained basal areas over 11.5 m^2/ha in mixed species dry forests in Victoria. However, McCormick and Cunningham (1989) suggest that up to 20–25 trees/ha in grassy *E. amygdalina* forest on granites do not suppress seedling growth and have the added benefit of reducing grass re-invasion. Suppression of eucalypts is also correlated with distance from mature stems, with better seedling growth in the larger gaps (Florence 1996; Bassett and White 2001). Allelopathy and soil water relations as affected by the overstorey have been noted as possible causes (Florence and Crocker 1962; Bowman and Kirkpatrick 1986).

The combination of factors influencing regeneration growth means that at current growth rates, without additional intensive game control, it is likely to be at least another four to five years before sheep should be allowed back into the logged area. In order to achieve a consistent height of regeneration across the site above the level of sheep grazing (given as 1.5 m by Orr 1991), a period of seven to eight years or longer may be required. Even longer periods may be required before reintroduction of cattle.

Conclusion

Regeneration in this study was most successful in the logged and scarified treatment. Based on landowner expectations, regeneration was also within acceptable limits in the logged-and-burnt treatment but possibly inadequate in the logged-only treatment. Heavy browsing by native animals could have been a factor in the poorer regeneration of the logged-only treatment and for the slow growth rates observed in all treatments. Poorer seedbed availability was suggested as a major factor limiting regeneration in the logged-only treatment. Overall stocking, when retained trees were included, was acceptable in all treatments. At current growth rates, sheep grazing may need to be restricted from the area for a period of seven to ten years following logging. Pre-logging scarification or more effective browsing control may have been the best option for eucalypt regeneration in the Bracknell study site due to the high level of browsing observed.

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