Comparison of regeneration success of alternative silvicultural treatments in blackwood swamps

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Abstract

The regeneration of 13 blackwood swamp coupes treated between 1978 and 1992 was assessed for blackwood seedling density, stocking, early growth and form. Nine silvicultural treatments were applied during the period. They were clearfell, burn and fence; clearfell and burn with failed fence (within 12 months); clearfell only; selectively logged; selectively logged and poisoned; scrub-rolled and burnt; scrub-rolled and burnt with supplementary planting; scrub-rolled and burnt in strips; and scrub-rolled, burnt and fenced. The scrub-roll treatments were applied in areas where there was insufficient blackwood to allow commercial harvesting. The 13 coupes were classed as younger coupes (7–12 years since treatment) or older coupes (13–21 years), with different regeneration assessment techniques used for each class.

Blackwood seedling density varied widely among the treatments according to the success of browsing control. Fencing resulted in up to 7000 established blackwood seedlings per hectare for coupes up to 12 years old. Unfenced coupes at the same age ranged from less than 100 to 360 seedlings per hectare. Only successfully fenced treatments achieved preliminary stocking standards set at 65% of sample plots stocked with blackwood. This standard was equivalent to about 3000 seedlings/ha for coupes aged 7–12 years. Blackwood form appeared to be positively influenced by the presence of nurse species that included Melaleuca *and* Leptospermum *spp.,* Acacia mucronata, A. verticillata *and* Cassinia aculeata. *Both blackwood and nurse species grew between 0.5–0.7 m/yr in height for stands aged 7–12 years.*

Planted seedlings protected in mesh cages grew at similar rates to natural regeneration; 63% of plantings survived after 15 years. However, planting is expensive and not normally required for blackwood swamp regeneration.

Scrub-rolling in 25 m strips retained more rainforest species and structural diversity than broadcast scrub-rolling. However, retained belts were damaged by burning and windthrow so that less than one-third of their original basal area remained 15 years after treatment.

Current costs of successful blackwood swamp treatments were estimated at $450–500/ha for burning and fencing after clearfelling, and $750–1100 for scrub-rolling, burning and fencing.

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Introduction

Blackwood (*Acacia melanoxylon* R.Br.) is a high value timber species that occurs in eastern Australia from northern Queensland to Tasmania (Boland *et al.* 1984). The best stands occur in the blackwood swamps of north-western Tasmania. Management of the swamps for sustainable blackwood timber production commenced in the 1970s, following the dedication of substantial areas of Crown Land as State forest (Jennings 1998). Approximately 6500 ha of blackwood swamps on State forest are being managed for blackwood sawlog under the Swamp Working Circle (Forestry Tasmania 2000).

Various silvicultural treatments have been applied to the swamps, ranging from selective logging with no regeneration treatment, to clearfelling, burning and fencing. All treatments rely on regeneration from ground-stored blackwood seed germinated by logging disturbance or fire (Forestry Commission 1991a; Wilkinson and Jennings 1994).

Blackwood stocking in the swamps is extremely variable, ranging from almost nothing to more than 250 mature stems per hectare. Where blackwood stocking is high, disturbance from commercial harvesting results in sufficient seedbed for regeneration. Where blackwood stocking is low, non-commercial scrub-rolling following harvesting may be required to produce suitable regeneration conditions.

This paper compares the regeneration success of selected coupes harvested since 1978 and subjected to a range of silvicultural treatments. In the absence of a replicated silvicultural trial, this retrospective study aims to determine which treatments are successful. Regeneration success was measured using stocking and density of blackwood seedlings but also included a form measurement, as the silvicultural objective is to regrow blackwood sawlogs.

Methods

Identification of treatments

Twenty-three swamp blackwood coupes were identified as being logged or silviculturally treated between 1978 and 1999. These included four coupes which had only a sparse blackwood stocking and were treated by non-commercial scrub-rolling with no yields, or minimal yields, of timber. An average of about one coupe per year has been treated since 1978, although the actual rate of coupe establishment varied from year to year with the availability of drier summers for harvesting, and market conditions.

Treatment options included:

- Clearfell or selective harvesting;
- Non-commercial scrub-rolling, with or without supplementary planting;
- Slash-burning or non-burning;
- Fencing or non-fencing; and
- Poisoning of browsing animals, or non-poisoning.

Records for some of the older coupes were sparse, but aerial photographs, photo-interpreted (PI) forest-type maps, old surveys and local knowledge were used to locate the coupes where possible. Coupes less than five years old were not assessed because blackwood regeneration remains vulnerable to browsing animals for several years and is not considered to be established until year five. Ten commercially harvested coupes aged from seven to 21 years were surveyed for regeneration over the summer of 1998/99. Three understocked coupes treated by non-commercial scrub-rolling, aged from nine to 16 years, were surveyed during the summer of 1999/2000.

The nine harvesting and regeneration treatments included among the 13 coupes surveyed were:

- **Clearfell, burn and fence (CBF):** These coupes were clearfelled during one or more summers and burnt at low to medium intensity in either autumn or spring. Browsing animals were excluded by enclosing the whole coupe in a 1 m high, wire-netting fence.
- **Clearfell and burn with failed fence (CBFF):** These coupes were an accidental result from the CBF treatment where the fence failed within 12 months, allowing browsing of the young seedlings.
- **Clearfell only (C)**: Clearfell coupes, where logging disturbance stimulated germination but no deliberate regeneration treatment was carried out.
- **Selective (S)**: Selectively logged coupes where logging disturbance stimulated germination but no deliberate regeneration treatment was carried out.

Table 1. Classification of harvest and regeneration treatments by coupe age class. (CBF = clearfell, burn and fence; CBFF = clearfell and burn with failed fence (within 12 months); SRBF = scrub-rolled, burnt and fenced; C = clearfell only; S = selectively logged; SP = selectively logged and poisoned; SRB = scrub-rolled and burnt, SRBP = scrub-rolled and burnt with supplementary planting; SRBS = scrub-rolled and burnt in strips)

	CBF	CBFF	SRBF	C	S	SP	SRB / SRBP	SRBS
Younger coupes (7–12 years)	2	2	1					
Older coupes (13–21 years)				2	3	1	1	1

- **Selectively logged and poisoned (SP)**: Selectively logged coupes where 1080 poisoning was carried out twice during the first 12 months to reduce browsing pressure.
- **Scrub-rolled and burnt (SRB)**: A trial plot of 1 ha, in an understocked blackwood swamp that was scrub-rolled over the summer and burnt during the autumn.

  Scrub-rolling involved pushing over live understorey vegetation and small, non-commercial trees with a bulldozer or excavator. The soil surface was not deliberately scraped to expose mineral soil.
- **Scrub-rolled and burnt with supplementary planting (SRBP)**: Individually caged blackwood seedlings were planted over part of the SRB area during the following winter.
- **Scrub-rolled and burnt in strips (SRBS)**: An adjacent trial plot of 1 ha which was scrub-rolled in three parallel, 25 m wide strips. A 20–25 m belt of vegetation was retained between each strip, but these were scorched during the burning.
- **Scrub-rolled, burnt and fenced (SRBF)**: The sparse blackwood sawlogs in this coupe were salvage logged during the summer, and then the entire coupe was scrub-rolled. The coupe was fenced with wire-netting in the autumn and burnt the following spring.

The treatments were informally trialled or used on an operational basis as they evolved. For example, whole-coupe fencing was introduced as a regeneration treatment only within the last 12 years. The 13 areas surveyed were segregated into younger coupes (7–12 yrs) and older coupes (13–21 yrs) because of the different silvicultural treatments and because different regeneration assessment techniques are appropriate as the regeneration grows. The younger coupes were all either clearfelled or scrub-rolled, then burnt and fenced to exclude browsing mammals. These coupes were subsequently divided into those where the fence was satisfactorily maintained for several years and those where the fence failed within the first 12 months.

Consequently, there is no overlap of treatments between younger and older age classes. Table 1 shows the number of coupes in each of the treatments that were surveyed in the younger and older age classes.

Survey techniques

A sample of 50 plots was set for each surveyed coupe. The plots were distributed across the coupe on transects whose locations were pre-selected in the office from PI (photo-interpreted) maps and aerial photographs. For larger coupes, this distribution did not necessarily cover the whole coupe.

Plot size varied with the age of the coupe. Younger coupes were measured using a modified 'Standard A' eucalypt regeneration survey (Forestry Commission 1991b), based on circular 16 m^2 plots. A plot was considered to be stocked if it contained a blackwood sapling at least 1.5 m tall.

For older coupes, plot size was 50 m^2 to ensure a suitable number of trees per plot.

Selectively logged coupes were surveyed using a combination of these larger plots and a 'Standard D' regeneration survey for uneven-aged eucalypt forest (Forestry Commission 1991b). Plot centres were used to estimate retained blackwood basal area using a 'factor 2' basal area wedge. Plots were considered stocked if they contained regeneration at least 1.5 m tall or if the basal area sweep showed at least 12 m^2 basal area of blackwood trees with sawlog form.

The following information was collected for each coupe:

- Ground or canopy disturbance (determined by looking for snig tracks, stumps and regrowth vegetation);
- Blackwood regeneration density (the mean number of blackwood stems from sampled plots);
- Blackwood stocking (the proportion of plots stocked with at least one blackwood seedling or 12 m^2 basal area of blackwood sawlog);
- Blackwood mean dominant diameter (the mean of the diameter of the tallest seedling on each plot);
- Blackwood mean dominant height (the mean of the height of the tallest seedling on each plot—younger coupes only);
- Blackwood form (the mean form score using the scoring described below);
- Nurse species (the most common nurse species for each plot); and
- Height of nurse competition (an estimate of the height of the nurse competition for each plot—younger coupes only).

The form of the tallest blackwood regrowth stem on each plot, for both younger and older coupes, was assessed for potential sawlog form using the following categories:

1+ = more than 6 m sawlog;
1 = 3–6 m sawlog;
2 = 0–3 m sawlog;
3 = pulpwood only;
4 = no merchantable product.

Assessing the future form of seedlings on younger coupes was sometimes difficult but, in all cases, an attempt was made, as success of the regeneration treatment depends on being able to produce future blackwood sawlogs.

One of the understocked coupes had been supplementary planted after a scrub-rolling treatment. A 100 m x 10 m transect was surveyed through this area and all planted trees measured at age 15 years. Planted trees were distinguished from natural regeneration by the presence of woven black bags around the stem of the tree and the remnants of planting stakes (Photo 1). The same information was collected for planted blackwood as for regenerated stems.

Photo 1. An 18-year-old planted blackwood showing remains of the seedling protector.

Another treatment for an adjacent understocked area involved scrub-rolling in strips of 25 m width separated by belts of retained forest of similar width. This was a cheaper method of site disturbance and also sought to retain some structural diversity and an ongoing presence of rainforest species and their propagules. In addition to a survey of the stripfelled areas, transects were established through the retained belts and the forest surrounding the treated area. Trees greater than 10 cm DBH were measured for diameter to determine basal area and species composition of the retained forest. The presence of seedlings of rainforest tree species on plots within the scrub-rolled clearings was also noted. Myrtle *(Nothofagus cunninghamii*) was chosen as a sensitive indicator species for assessing rainforest regeneration because it has relatively short-lived seed and a low dispersal distance (Hickey *et al.* 1982).

Selection of stocking standards

Younger coupes.—As the distribution of measured plots did not always cover the entire coupe, the standard regeneration survey mapping rules (Forestry Commission 1991b) were not appropriate for determining successful stocking. Instead, the percentage of plots stocked with blackwood was used. If each 16 m^2 plot is stocked with at least one suitable stem, this is equivalent to a stocking of at least 625 potential crop trees per hectare. The Victorian eucalypt stocking standard is for 65% of 16 m^2 plots to be stocked (Dignan and Fagg 1997). This is equivalent to at least 400 potential crop trees per hectare. This stocking standard was used for coupes less than 13 years old.

Older coupes.—An appropriate existing stocking standard based on 50 m^2 plots has not been devised, so one was developed for this study. If all 50 m^2 plots are stocked, this is equivalent to at least 200 potential crop trees per hectare. This is assumed to be close to maximum carrying capacity for a well-stocked blackwood stand at cutting age. A previous study (Forestry Commission 1982) of 136 (0.1 ha) plots in mature swamps found that stands had a maximum density of 200 stems / ha of blackwood trees greater than 25 cm. A 50 cm diameter blackwood has a conservative sawlog volume of 1 m^3 (assuming a sawlog height of 7 m and a stump height of 0.3 m). It was assumed that any stands with at least 100 such crop trees per hectare at rotation age (i.e. 100 m^3 blackwood sawlog) can be considered well stocked. This is equivalent to 50% of 50 m^2 stocking if the trees are evenly distributed. The current study assumed a minimum stocking of 65% of 50 m^2 plots at about age 20 (at least 130 potential crop trees) was likely to produce 100 m^3 / ha and this was used as the minimum stocking standard for older coupes surveyed.

Relationship between stocking and density

Data from the younger coupes were used to explore a statistical relationship between stocking and density. The number of stocked plots was assumed to be binomially distributed and modelled as a Generalised Linear Model (GLM). The model used a complementary log-log link function, with the linear predictor being a simple linear function of the natural logarithm of density (McCullagh and Nelder 1989). This link function gave a better fit than logit or probit link functions. To predict density for a given stocking, the GLM was inverted. A log transformation of density was used in the GLM to ensure the prediction of density was greater than zero. Relationships between presence / absence samples and direct count samples are often used to develop binomial sampling plans for crop protection (Binns and Nyrop 1992). In this case, Fieller's theorem (Finney 1971) was used to obtain 95% confidence intervals for predictions of blackwood seedling density. GENSTAT (Genstat 5 Committee 1997) was used to fit the GLM and carry out Fieller's method using procedure FIELLER (Payne *et al.* 1997).

Cost comparison

Indicative treatment costs were calculated from several coupes, including some

recently treated areas that are not otherwise covered in this report. Scrub-rolling costs from 1984 and 1985 were estimated using actual machine hours for the treatments but calculated on current hourly price rates.

Results

Ground or canopy disturbance

All clearfelled coupes showed 100% logging disturbance to the ground or canopy. These coupes were characterised by a predominance of tea-tree and cutting grass regrowth. Disturbance may have been more severe on burnt coupes but burning did not affect the extent of disturbance.

The selectively logged coupes showed an average of 60% ground or canopy disturbance but this is an overestimate because areas within coupes that appeared entirely untracked and unlogged were not surveyed. The occurrence of blackwood seedling regeneration was strongly correlated with logging disturbance. Blackwood regeneration was not abundant, with only 29% of 50 m^2 plots stocked with seedlings. Only 2% of the surveyed plots were both undisturbed and carried regeneration, while 27% of the plots were disturbed and stocked with regeneration (Figure 1).

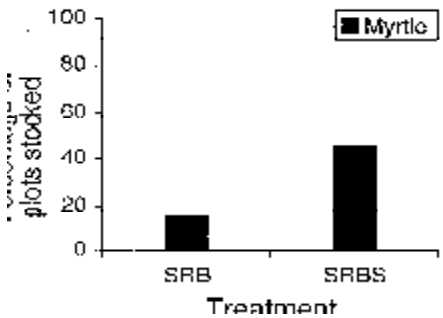

Figure 1. Relationship between disturbance and 50 m^2 blackwood stocking on selectively logged coupes.

Blackwood regeneration density

Blackwood seedling density varied widely among the treatments (Figure 2). The major factor affecting density was the success of browsing control. The successfully maintained fencing treatments (CBF, SRBF) produced 6000–7000 blackwood stems / ha (Photo 2). Fences that failed prematurely (CBFF) were still more successful in protecting blackwood regeneration than any of the other treatments. Density for the unburnt, unfenced treatments (C, S, SP) was low and ranged from 160–360 stems / ha. Density of regeneration was also low in the previously understocked coupes that were scrub-rolled and burnt (SRB, SRBS). Poisoning of the selectively logged coupe (SP) did not appear to have increased blackwood density.

Photo 2. Dense seven-year-old blackwood regeneration protected by a wire-netting fence.

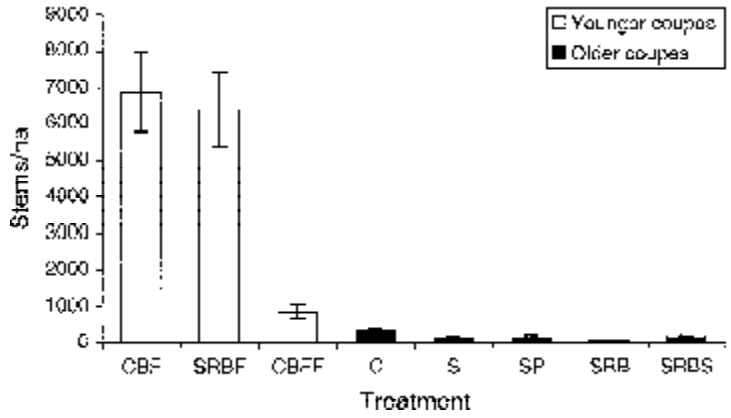

Figure 2. Mean blackwood seedling density by treatment. (Bars show standard errors; abbreviations for treatments follow those of Table 1.)

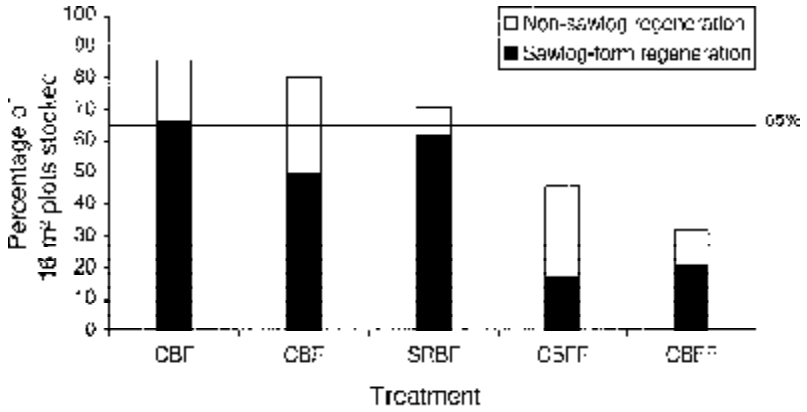

Figure 3. Blackwood stocking for the five younger coupes (7–12 years since treatment), showing potential sawlog and non-sawlog stocking components. (Abbreviations for treatments follow those of Table 1.)

Blackwood regeneration tended to be patchy, with some extremely dense clumps contributing to the high numbers of seedlings. Regeneration success is also dependent on even distribution, which was measured using blackwood stocking.

Blackwood stocking

Younger coupes.—Figure 3 shows the percentage of 16 m^2 stocking for each of these coupes and indicates the percentage of plots stocked with regeneration of sawlog form. All coupes with maintained fences reached the minimum standard of 65% 16 m^2 stocking, with the majority of these plots carrying regeneration of sawlog form. Neither of the coupes with failed fences reached the minimum stocking standard; less than 25% of the plots surveyed were stocked with sawlog-form regeneration.

Older coupes.—The older coupes were treated by either clearfelling, scrub-rolling, or selective logging (Photo 3). Only the scrub-rolled areas were burnt, but all areas

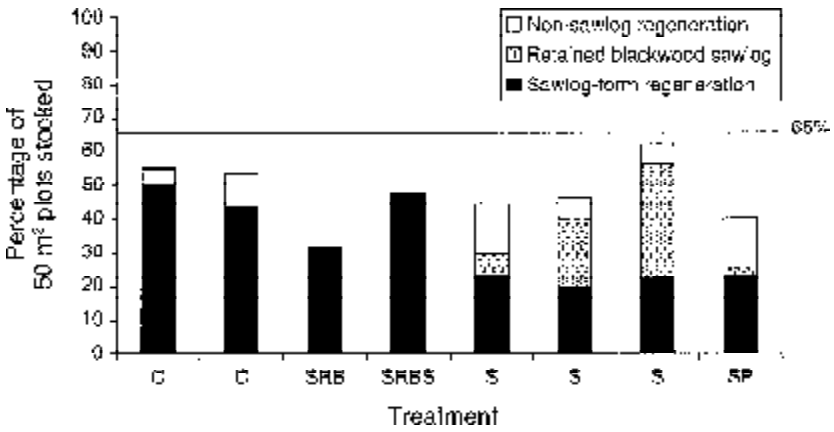

Figure 4. Blackwood stocking for the eight older coupes (13–21 years since treatment), showing potential sawlog, advance growth sawlog and non-sawlog stocking components. (Abbreviations for treatments follow those of Table 1.)

Photo 3. Selective logging produced trees of good form, but these were scarce.

remained unfenced. Figure 4 shows the percentage of 50 m^2 plots on each of these coupes that were stocked, including percentages for plots stocked with sawlog-form regeneration, non-sawlog regeneration and at least 12 m^2 retained basal area of blackwood trees of sawlog form.

None of the older coupes reached the minimum stocking standard of 65% of 50 m^2 plots stocked, although three of the eight coupes achieved over 50% stocking. Poisoning of one of these coupes did not result in higher stocking.

The proportion of sawlog form trees for the scrub-rolled coupes (SRB, SRBS) was very high, with all stocked plots carrying trees of sawlog potential.

Relationship between density and stocking

The relationship between density and stocking is shown in Figure 5 and can be described by the model below:

$$\text{Density} = \exp[(3.888 + \ln\{-\ln(1-\%\text{stocked}/100)\})/0.4888]$$

The model predicts that 65% stocking of 16 m^2 plots is equivalent to a blackwood seedling density of 3142 seedlings / ha, with a 95% confidence interval of 2134–4356.

Diameter growth

The mean annual diameter increments (MAI) for the mean of dominant blackwood seedlings on stocked plots for each coupe are shown in Figure 6.

The MAI (diameter) over the measured coupes was remarkably consistent. Most coupes showed an average diameter growth of 0.6–0.7 cm / year. The two exceptions were:

(a) A clearfell, burn and fence coupe with nearly 7000 blackwood stems / ha and dense nurse competition which only averaged 0.5 cm / year; and

(b) A clearfell, burn and failed-fence coupe with nearly 600 blackwood stems / ha and very little nurse competition where a faster growth rate (0.8 cm / year) corresponded with extremely bad form.

Blackwood height and form

Figure 7 shows the mean annual height increments (MAI) for the mean of dominant blackwood seedlings on stocked plots and mean nurse competition height for the five younger coupes. The most common species of nurse competition for each coupe is labelled as tea-tree (*Melaleuca* or *Leptospermum*

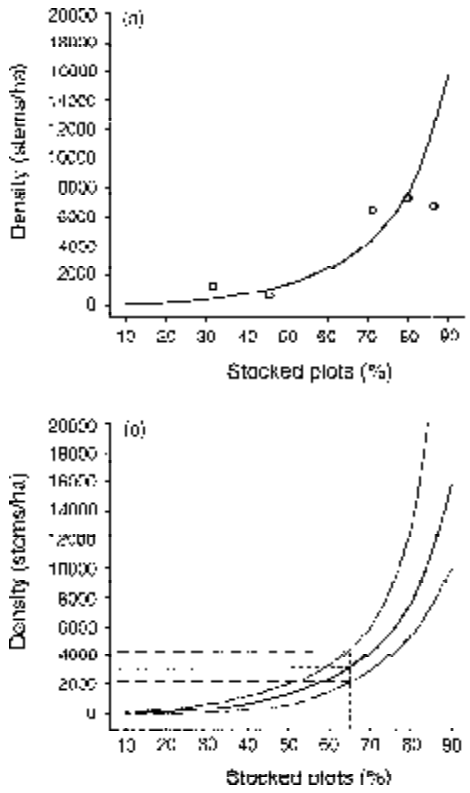

Figure 5. Relationship between density versus 16 m² stocking for blackwood swamp regeneration aged 7–12 years: (a) fitted relationship with data points, (b) 95% confidence band for the relationship showing confidence interval for 65% stocking.

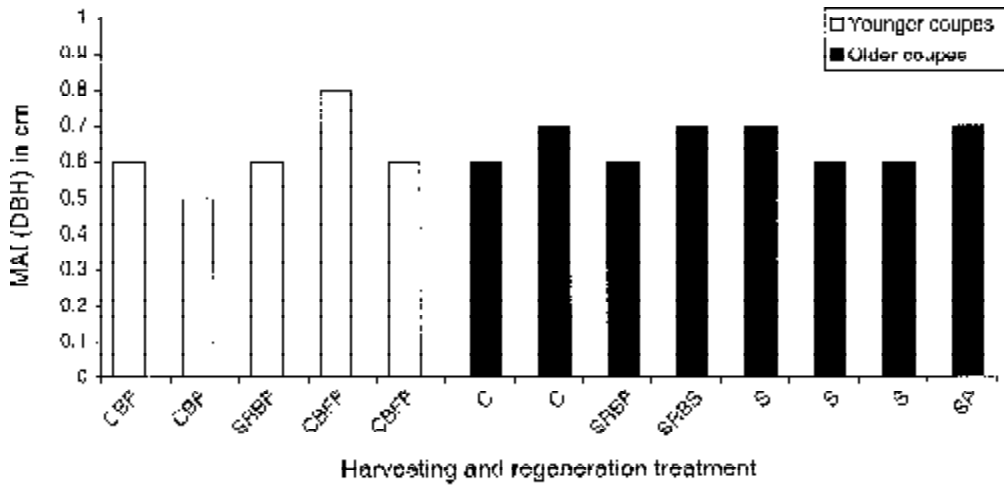

Figure 6. Blackwood mean dominant diameter increment for the 13 coupes. (Abbreviations for treatments follow those of Table 1.)

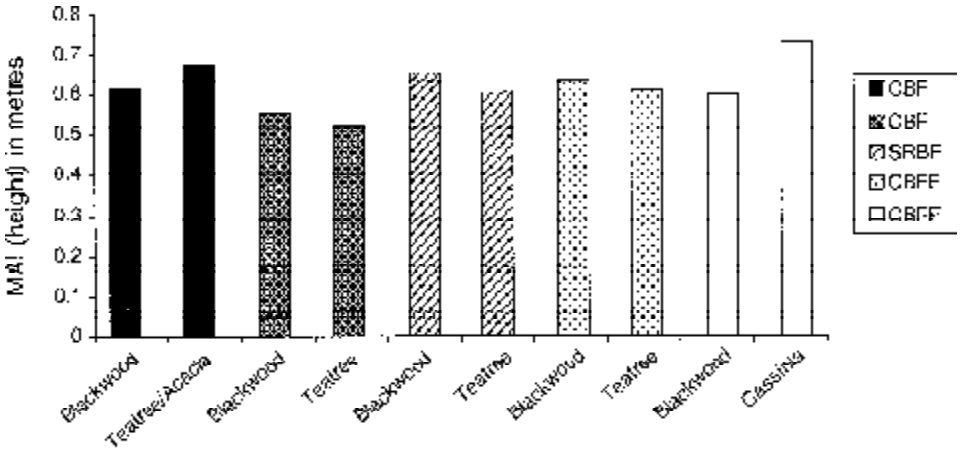

Figure 7. Blackwood and nurse competition height growth for the five younger (7–12-year-old) coupes. (Legend abreviations for treatments are as shown in Table 1.)

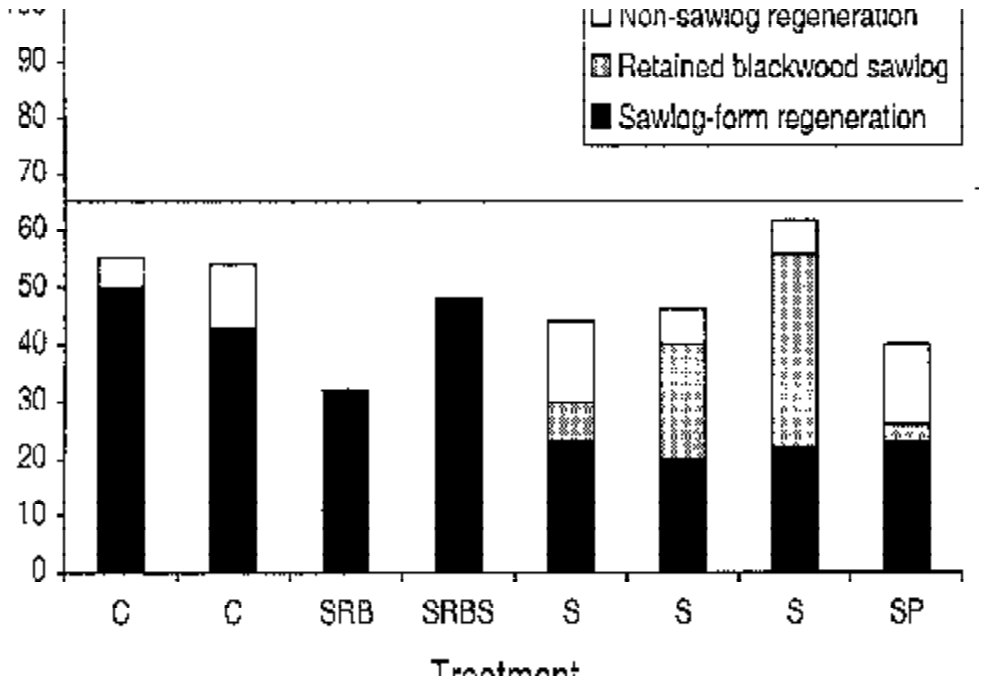

Photo 4. Inadequate nurse competition produced poorly formed blackwood regeneration at age 7.

spp.), *Acacia* (*A. mucronata* or *A. verticillata*) or *Cassinia* (*Cassinia aculeata*).

Figure 7 indicates that the nurse competition, regardless of species, was usually about the same height as the blackwood saplings. The blackwood and nurse competition on all coupes all grew between 0.5 and 0.7 m / year in height. This allowed the nurse competition to influence the form of the blackwood by reducing side-light, without suppressing blackwood height growth.

Figure 8 suggests a relationship between blackwood form and nurse competition stocking for younger coupes. Generally,

coupes with more than 80% of 16 m^2 plots stocked with nurse competition carried more than 60% sawlog-form regeneration, while one coupe with less than 60% nurse competition stocking achieved less than 40% sawlog-form regeneration (Photo 4).

Supplementary planting

A total of 51 plantings were inspected on a 100 m x 10 m sample, giving an original planting rate of 510 seedlings / ha. Of these, 62.7% now contain established blackwood; successful establishment of 320 planted stems / ha. Blackwood seedlings planted within the scrub-rolled block experienced the same site conditions and nurse competition as naturally regenerated blackwood seedlings. Of the planted trees, 91% were assessed as having potential sawlog form.

The mean diameter and height increments for the planted trees are very similar to those for the natural regeneration within the scrub-rolled block (Figure 9).

Retention of rainforest species

Figure 10 shows the percentage of 50 m^2 plots within the scrub-rolled and burnt block (SRB) and the scrub-rolled and burnt strips (SRBS) that contained myrtle (*Nothofagus cunninghamii*) seedlings. The occurrence of myrtle seedlings was higher in the scrub-rolled strips.

The basal area by species of the surviving trees in the internal green belts was compared with that of the undisturbed forest surrounding the scrub-rolled and burnt strips. The total basal area of all species was 55 m^2 / ha for the undisturbed forest. This was predominantly tea-tree species, in addition to myrtle, horizontal (*Anodopetalum biglandulosum*) and some sassafras (*Atherosperma moschatum*). The internal greenbelts had a total basal area of 13–17 m^2 / ha, less than one-third of the undisturbed forest. The depletion of trees in the belts was due to combined mortality from fire and windthrow.

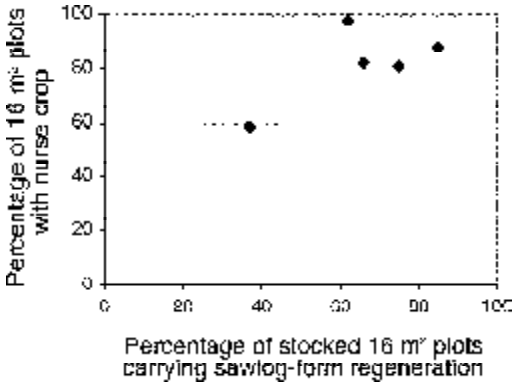

Figure 8. Blackwood form and nurse competition stocking.

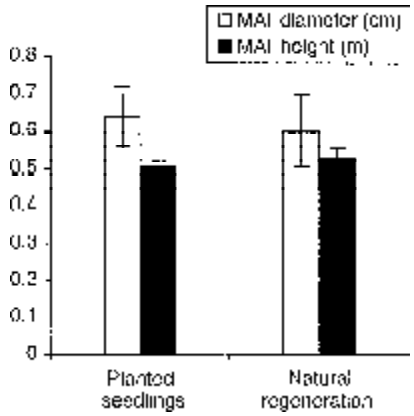

Figure 9. Comparison of growth for planted and natural blackwood seedlings over 16 years. (Bars show standard errors.)

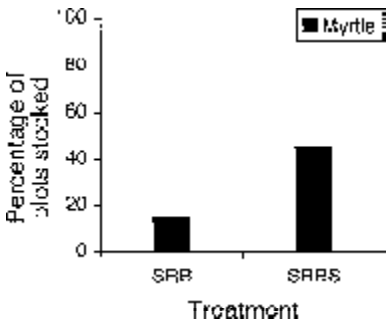

Figure 10. Percentage of plots stocked with myrtle seedlings.

Table 2. Comparison of costs of five regeneration treatments. Treatments that did not reach the minimum stocking standard are shown in italics. (SRBF = scrub-rolled, burnt and fenced; CBF = clearfelled, burnt and fenced; SRB = scrub-rolled and burnt; C = clearfell only; S = selectively logged; n/a = not applicable.)

	Harvesting and regeneration treatment				
	SRBF	CBF	*SRB*	*C*	*S*
Scrub-rolling / ha	$300–600	n / a	*$300–600*	*n/a*	*n/a*
Burning / ha	$50	$50	*$50*	*n/a*	*n/a*
Fencing / ha	$400–450	$400–450	*n/a*	*n/a*	*n/a*
Total establishment cost/ha	**$750–1100**	**$450–500**	***$350–650***	***nil***	***nil***

Cost comparison

Cost estimates of five regeneration treatments are shown in Table 2. The treatments that did not reach the minimum stocking standard are shown in italics.

Discussion

This retrospective study is limited by a lack of replication which was inevitable as operational practices evolved over time. However, it clearly indicates the most successful regeneration treatments for blackwood involved a high level of disturbance and successful browsing control. Hence, clearfell, burn and fence and scrub-roll, burn and fence were the most successful treatments. Clearfelling without fencing, and selective logging, even with poisoning, achieved much lower levels of regeneration due to excessive browsing.

Fencing, which provides almost total exclusion of browsing animals for a period of approximately three years, is spectacularly successful in protecting blackwood regeneration in eucalypt coupes (Jennings and Dawson 1998) and has proved similarly successful in blackwood swamp coupes reported here. All fenced treatments, both in commercially harvested areas and scrub-rolled areas, met the stocking standard. None of the unfenced treatments met the standard but there were several older, unfenced coupes with greater than 50% 50 m^2 stocking that may prove to be satisfactory later in the rotation if there is little mortality of crop trees as the stand ages. Fencing of swamp coupes has some logistical problems, including a very short opportunity for erecting fences, which is limited to the dry summer months. Poisoning with 1080, which reduces browsing pressure for months rather than years, is not a suitable alternative method of protection for unfenced areas. Blackwood seedlings are extremely palatable to browsing animals and frequent poisonings over several years would be required before the seedlings attained heights beyond the reach of browsing animals.

Although the burnt treatments were among the most successful, adequate disturbance for regeneration can be provided by harvesting alone (Wilkinson and Jennings 1994). It is therefore not necessary to burn a blackwood coupe for regeneration purposes, and slash burning in swamps was largely discontinued as a disturbance treatment in the mid 1990s as a result of biodiversity issues raised by Pannell (1992) and Duncan *et al.* (1994). Unburnt swamp coupes (even if clearfelled) are believed to retain greater biodiversity than burnt ones, due to the continued presence of some of the rainforest elements (Duncan *et al.* 1994). The regeneration status of these clearfelled and fenced coupes is yet to be determined.

Scrub-rolling can be a useful method of maximising the opportunity for blackwood regeneration in understocked patches within or adjacent to areas of commercial blackwood harvesting. Such areas may

need to be assessed, prior to treatment, for ground-stored blackwood seed supply if the pre-logging density of blackwood trees is very low. Scrub-rolling should not be used without fencing as a treatment for blackwood regeneration because most of the seedling regeneration will be browsed.

The strip-cleared treatment (SRBS) was an attempt to improve the environmental effects of clearfelling swamps by retaining some structural diversity and some mature rainforest trees on-site for ongoing recruitment. The strip treatment produced more myrtle regeneration and was marginally cheaper than the adjacent block-cleared area (SRB) but would have cost more in supervision and marking out. Despite scorching of the internal green belts and considerable windthrow, some mature rainforest trees were retained, particularly myrtle and leatherwood. However, as half of the forest area in the strip treatment remains unharvested, then half of the blackwood resource is unavailable, and only half of the area is disturbed and regenerated. A better result would be achieved by retaining undamaged clumps of rainforest species (particularly myrtle on peaty banks) where they do not contain blackwood sawlog, and by not burning the coupe.

This study has developed a relationship between density and stocking that can be used to inform selection of appropriate stocking standards. The standard adopted here was 65% of 16 m^2 plots for young blackwood coupes but it is yet to be determined if the corresponding density of about 3000 seedlings / ha is appropriate. Unlike eucalypts, blackwood stands do not rapidly self-thin and it is possible that pre-commercial or commercial thinning would be needed in order to maintain growth rates of crop trees in dense blackwood stands. The relationship between density and stocking was derived from only five coupes; a more robust relationship would require many more samples. However, such data would take some time to accumulate as, on average, only one blackwood swamp coupe is harvested per year. In addition, the survey effort to obtain density versus stocking data from young blackwood swamp coupes with dense tea-tree and cutting grass is very high.

Diameter increment for all treatments was shown to be remarkably consistent over coupes with ages from 7 to 21 years, regardless of blackwood seedling density. Browsing was the most significant factor determining the density of blackwood seedlings but does not seem to have significantly affected growth. There was no evidence of reduced height increment of dominant seedlings where fences failed or were not built. This could be explained by the presence of nurse competition that protected those seedlings that escaped browsing. It was anticipated that coupes with heavy browsing would take up to five years to establish, with ongoing recruitment from ground-stored seed in protected micro-sites. However, evidence suggests that most of the crop trees on these coupes survived right from the start; there were just much fewer of them.

Blackwood regeneration systems rely on the recruitment of a nurse competition of understorey species to produce saplings of sawlog form. This was achieved in all but one coupe, although the nurse species varied. One of the coupes did not produce adequate nurse competition, which resulted in blackwood of very poor form.

The individually caged, planted seedlings produced similar trees to the natural regeneration on the same site. However, with only 63% of planting spots producing a successful tree, about 320 seedlings / ha would need to be planted to successfully establish 200 stems / ha. This is an expensive way of regenerating blackwood, particularly as this method would still require disturbance to produce sufficient light for sapling growth. Planting should not be used as a method of blackwood swamp re-establishment except in very small areas that do not contain ground-stored seed and where regeneration is a very high priority.

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