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Seedling regeneration, growth and density of *Eucalyptus obliqua* following partial harvesting in the Warra silvicultural systems trial. 3. The first “clearfell, burn and sow with understorey islands” coupe, Warra 8B, age 3 years

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SUMMARY

At age three years, Warra 8B is fully stocked with seedling regeneration. Analysis of seedling growth is confounded by the fact that the coupe has two distinct sections – a poorly drained lower section and a well-drained upper section. The well-drained section has a higher stocking of faster growing seedlings than the poorly-drained section of the coupe. Seedlings growing on oxidised soil are taller than seedlings on unburnt seedbed in both sections.

1. Introduction

Tall *Eucalyptus obliqua* forests are the most widespread and abundant commercial native forests in Tasmania, occupying some 425 700 ha (Public Land Use Commission 1996). The Warra long-term ecological research (LTER) site was established in 1995 in order, amongst other things, to focus research on this forest type (Brown 1998). Neyland *et al.* (2000) demonstrated that the tall *E. obliqua* forests at Warra are representative of many of the *E. obliqua* tall forests in Tasmania, particularly of those in southern and south-eastern Tasmania but also, with some qualification, of forests elsewhere in the State.

The Warra silvicultural systems trial (SST) was established in 1998 to explore alternatives to the ‘clearfell, burn and aerially sow’ method of wet eucalypt forest silviculture (Hickey *et al.* 2001). The first understorey island coupe to be opened in the SST was Warra 8B (WR8B), a 20 ha coupe which was harvested to a prescription of clearfell burn and sow with understorey islands. The prescription called for a routine clearfelling operation, except that four understorey islands, each 40 metres by 20 metres, were retained undisturbed in the western half of the coupe. Within each island two plots of 10 m by 10 m each were surveyed for all higher plants and dominant bryophytes prior to the commencement of harvesting. Four ‘phantom’ islands were also demarcated in the eastern half of the coupe. These islands were surveyed as for the retained islands but were harvested during felling of the coupe.

This report examines the post-burn seedbed, seedfall and seedling establishment and growth for the first three years following the harvesting and regeneration treatment.

The null hypotheses being tested here are:

- that the local intensity of the burn and /or disturbance of the soil arising from the harvesting has no influence on the establishment and growth of the eucalypt regeneration.
- that the understorey islands do not contribute to the regeneration of understorey species following harvesting and burning of the coupe.

2. Methods

2.1. Study site

The Warra SST is located within the Warra LTER site (latitude: 43° 04' S; longitude: 146° 40' E) which is situated at the junction of the Weld and Huon Rivers in the southern forests of Tasmania. The SST occupies south-east facing slopes above the Huon River and ranges in altitude from 50 to 350 m asl. Slopes are gentle to moderate (<20°) and rainfall is about 1450 mm per annum. Soils are variable throughout the SST, but are largely derived from Jurassic dolerite (Laffan 2001).

The pre-harvest vegetation in WR8B was mixed oldgrowth-regrowth *E. obliqua* tall wet forest, a number of regrowth-generating fires having burnt through the study area in the last 150+ years (Hickey *et al.* 1999) (Alcorn *et al.* 2001). The understorey vegetation varied within the coupe. On the upper slopes, the understorey was dominated by species typical of thamnic rainforest, notably horizontal scrub (*Anodopetalum biglandulosum*) but also including celery-top pine (*Phyllocladus aspleniifolius*), myrtle (*Nothofagus cunninghamii*), leatherwood (*Eucryphia lucida*) and sassafras (*Atherosperma moschatum*) together with smaller shrubs and ferns. On the lower portion of the coupe, the understorey was dense, comprising closed stands of tallow-wood, (*Nematolepis squameum*), prickly wattle (*Acacia verticillata*), tea tree (*Leptospermum* spp.) and paperbark (*Melaleuca squarrosa*) over cutting grass (*Gahnia grandis*) and bauera (*Bauera rubioides*) (Neyland 2001).

2.2. Understorey island establishment

Four understorey islands were marked out with flagging tape in the western side of the coupe. Each island was 40 m long by 20 m wide, with the long axis of the island orientated parallel to the western edge of the coupe. The islands were located so as to sample, in two islands each, the two dominant vegetation types in the coupe (ie two were in the thamnic rainforest understorey type and two were in the tea-tree cutting grass understorey type). In the central part of each island two adjacent 10 m by 10 m floristic plots were established and the cover abundance of all higher plants and common bryophytes was recorded. Four 'phantom' understorey islands were also established (in the eastern side of the coupe), in which all the same information was collected, but which were not marked out with flagging tape and which were harvested along with the rest of the coupe.

The floristic data from the islands and from all the coupes within the trial will be reported separately. The impact of the harvesting and burning of this coupe on the islands is reported here.

2.3. Harvesting and burning

The harvesting prescription for WR8B called for the coupe to be clearfelled, burnt in a high intensity burn and sown, except that four understorey islands each of 40 m by 20 m were to be retained undisturbed through the course of the harvesting. The contractor was permitted to fell eucalypts out of the understorey islands if they could be felled clear of the islands without causing undue disturbance to the understorey.

Harvesting was completed on the 3rd December 1998. The coupe was prepared for burning in March 1999, with the standard mineral earth firebreak cleared around the perimeter of the coupe. On the 20th March a crew was in the coupe ready to light up but the weather conditions were unfavourable and the decision on the day was not to proceed with the burn (Table 1). High humidity and dense low cloud, which also included a considerable amount of smoke arising from other burns conducted the previous day, meant that a high intensity burn could not have been achieved. Subsequently it rained and the conditions remained unfavourable that year and the burn did not proceed.

On the 26th March 2000 the coupe was lit by aerial drip torch and a high intensity burn was successfully achieved (Table 1). There were no escape burns into the surrounding forest. Three of the four understorey islands were burnt.

Table 1. Weather conditions prior to burning (and attempted burning).

Date	Light-up time	Sticks (forest/coupe)	Temperature (°C)	Wind speed and direction (kph)	Relative humidity (%)
28 March 1999		25/15	20	NW <3	71
26 March 2000	12.56 pm	22/16	19	NW 0	52

Following harvesting, but before burning, a bare mineral earth firebreak approximately 6 m wide was mechanically cleared around the perimeter of the coupe. The heaped fuels arising from the firebreak created a windrow which also extended around the perimeter. All subsequent references herein to 'the coupe' include the interior of the coupe and the windrow, but not the firebreak. Because the firebreak was prepared more than a year prior to the burn, and because the coupe was aerially sown following the burn, seedlings of two ages are present on the firebreak. Scrub which had germinated on the firebreak was also a year older than in the rest of the coupe. As this would confound any analysis of the data, the additional transects which were established in all the other Warra SST coupes to put plots onto the unburnt and compacted seedbed which is characteristic of the firebreak, were not included at WR8B.

2.4. Aerial sowing

Six days after the high intensity burn, WR8B was aerially sown with 15.6 kg of *E. obliqua* seed. All the seed was 'in zone' and 62% was 'on site'. 'In-zone' seed is matched regionally for altitude and climate as described in Forestry Commission (1991); 'on-site' seed was collected from the coupe.

Harvesting, production and safety issues are discussed in Hickey and Edwards (in prep) and are not considered further here.

2.5. Seedbed assessment

The seedbed assessment of WR8C was conducted on 29th March 2000, three days after completion of the burn. A randomly located grid, 100 m by 10 m was placed over the coupe. The seedbed was assessed at each intersection point of the grid. Each point was permanently marked with a tagged wire peg to assist relocation. A fixed size plot was not used for the seedbed assessment; the nature of the seedbed was assessed at the point at which the pin was located. In some cases this meant that the piece assessed was quite small, eg 10 cm by 10 cm, and in some cases the assessed patch was larger than 1 m by 1 m.

The intensity of the burn and impact of the harvesting disturbance on the soil at each point was classified as shown in Table 2. The state of the vegetation at each point was classified as either intact (V0) or flattened (V1). Accumulated slash at each point was classified as being either significantly additional to that present pre-harvesting or not significantly additional.

Table 2. Seedbed: burn and disturbance classes.

B0	Unburnt (or burnt so lightly as to not affect the seedbed)	D0	Undisturbed
BL	Burnt but litter still present (minor soil heating but soil often not exposed)	D1	Revealed (litter removed from mineral soil or disturbed and aerated)
BM	Burnt to mineral soil (charcoal present over exposed and heated mineral soil)	D2	Compacted (litter removed and soil compacted, generally from machinery movement)
B2	Oxidised (intense soil heating, soil oxidation)		

The burning and disturbance impacts on the soil are not independent but have a combined effect in terms of the receptivity of the seedbed. Where the soil was burnt to mineral or oxidised soil, it was not considered possible to allocate the point to a disturbance class, partial or complete oxidation having altered the soil beyond the point at which disturbance could be reliably recognised.

The combinations of unburnt and undisturbed, unburnt and compacted, and burnt-to-litter and compacted seedbed were only very rarely observed and there were not sufficient seedlings in these classes to allow their use in the subsequent analyses.

The assessment determined the proportion of the coupe which had burnt and the intensity of the burn (where burnt), the extent of soil disturbance arising from the harvesting, the area of live vegetation remaining after the burn and the area of accumulated slash remaining unburnt.

2.6. Seedbed – understorey islands

The condition of each understorey island was assessed at the completion of harvesting and again following the regeneration burn. At the completion of harvesting, only a quick visual inspection was conducted for each island, and notes made about the general condition of the island. A more

formal assessment of each island was conducted following the burn; for each plot, a cover class (Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974)), was assigned for each seedbed burn and disturbance class (Table 2).

2.7. Regeneration

Seedling regeneration was assessed in March each year for three years after the regeneration burn, following the methods of Forestry Tasmania (1996). A randomly located grid was placed over the coupe with lines 100 m apart. Plots were located every 20 m along the lines. At each sample point a circular 16 m² plot centred on the sample point was searched for eucalypt seedlings. The height of the tallest seedling on the 16 m² plot was recorded, if present, as was the mean height of the competing understorey vegetation. The number of eucalypt seedlings on both the 4 m² and the 16 m² plot was counted so that seedling density (stems per hectare) could be estimated. The nature of the seedbed (Table 2) in which the tallest seedling on the 16 m² plot (the 4 m² plot is a sub-set of the 16 m² plot) was growing, was recorded for the surveys in both the first and second years but it was difficult to separate BL (burnt to litter) from BM (burnt to mineral soil) seedbed by year two and by year three the condition of the seedbed was very difficult to judge accurately and this part of the assessment was discontinued. Mapping rules as described in Forestry Tasmania (1996) were used to map the regeneration across the coupe. Portions of the coupe are mapped as stocked except where at least three unstocked plots occur in a row.

2.8. Browsing

A browsing transect of 50 seedlings was established on the 23rd January 2001 to monitor browsing of eucalypt seedlings by native mammals, following prescribed operational procedures for monitoring mammal browsing of regeneration (Forestry Tasmania 1999). The transect followed an irregular line from the landing to the northern edge of the coupe. Where possible, seedlings were selected at approximately two metre intervals. In some places, due to lack of seedlings, distances between seedlings were much larger. The browsing transect was monitored monthly. The height of each seedling was measured and any browsing damage to the seedling noted.

2.9. Seedling establishment and growth – the single-tree plots

A set of single-tree plots was established to assess the influence on seedling establishment and growth of the seedbed, competing vegetation and the adjacent unharvested forest around the coupe. The plots were established in the second autumn following burning (April 2001) when the seedlings were about one year old, from the same grid as used for the seedbed assessment. The plots have been remeasured at age three years (June 2003).

The nearest dominant seedling to each seedbed assessment point was identified, tagged with a numbered aluminium tag, and measured. Dominant seedlings were defined as seedlings that were healthy and at least as tall and preferably taller than the surrounding vegetation. As the plots were 10 m apart, the 'nearest' seedling was limited to a distance of 5 m. If no dominant seedling could be located within 5 m, nothing was recorded for that plot. The bearing and distance of the seedling from the plot point was recorded.

The height of each tree was measured to the nearest centimetre, the diameter of the root collar immediately above any basal swelling was measured to the nearest millimetre, the diameter of the stem either at one third of the height of the tree or 1.3 m, whichever was the least was measured to the nearest millimetre (stem diameter), the spread of the crown in both the north-south and east-west direction was measured to the nearest centimetre. Measurements pertaining to the tree are hereafter referred to as stem variables. The nature of the seedbed in which the seedling was growing was recorded as in Table 2.

The cover-abundance of the surrounding vegetation on a plot of 16 m² centred on the seedling was recorded using the Braun-Blanquet scale (1 = <1% cover, 2 = 2 to 5% , 3 = 6 to 25%, 4 = 26 to 50%, 5 = 51 to 75%, 6 = 76 to 100%) (Mueller-Dombois and Ellenberg 1974) for each vegetation guild. The mean height of each guild was measured to the nearest centimetre. The guilds used were trees, shrubs, ferns, sedges and herbs. Grasses were originally included in the assessment but the cover and abundance of grasses within the trial is so uniformly low that they were considered of little consequence. Only eucalypts were defined as trees. The shrub layer includes tall shrubs such as dogwood, (*Pomaderris apetala*), tea tree (*Leptospermum* spp), lancewood (*Nematolepis squamea*), paperbark (*Melaleuca squarrosa*) but also includes low shrubs such as *Bauera rubioides*. In most instances plots were dominated by either tall or low shrubs. The species dominating the plot was noted. Measurements pertaining to the vegetation are hereafter referred to as vegetation variables.

The basal area of the retained trees, and the trees in the adjacent unharvested forest around each seedling, was assessed at age 3 years using a prismatic wedge with a basal area factor of 2. At the same time each seedling was assessed as to its current crown class: dominant – taller than the surrounding vegetation including other trees, co-dominant – equal in height to the surrounding vegetation, sub-dominant – shorter than the surrounding vegetation but healthy, and suppressed – shorter than the surrounding vegetation.

Preliminary analysis of the distribution of the single tree plot data across seedbed classes revealed that the data was unbalanced, with some seedbed classes over-represented and some under-represented. To balance the data, a transect was set out to deliberately sample additional plots in the windrow on B2 (oxidised soil) plots. In this case, a seedling was selected where the nearest dominant seedling within 5 m was on B2 seedbed, or rejected if it was on any other seedbed class, every 25 m along the transect. The transect was started from the same randomly located point as used to establish the original grid. The additional transect was located a month after the original transect was established. Seedling growth in winter is very slow and any growth between the two measurements was considered minimal. A second grid was also established in order to sample additional plots on the other under-represented seedbed types. However, after establishing two lines of about 50 plots each and having established two plots on the target seedbed classes, this attempt was abandoned. It was clear from the attempt that dominant seedlings within the coupe were those which had established on burnt seedbed – the areas of unburnt seedbed in the coupe were very limited and seedlings which had established on unburnt seedbed were often overtopped by nearby seedlings on burnt seedbed. Thus in selecting the dominant seedling on the 5 m radius plot, it was almost invariably the seedling on the burnt seedbed that was selected.

One hundred and ninety-nine single-tree plots were established. No seedling could be located on twenty-seven plots. Further post-establishment losses (twelve seedlings) due to drought death resulted in the age three year data set comprising one hundred and sixty seedlings.

2.10. Upper versus lower slopes

To test the hypothesis that seedlings on the upper slopes (the ‘bank’) established and grew more successfully than seedlings on the lower gentler slopes (the ‘bog’), data from the single-tree plots and from the regeneration surveys were used to compare establishment and stocking for age 1, 2 and 3 years and height versus seedbed at age 3 years, for the two areas.

2.11. Analysis

All analyses of the single tree plot data were conducted using Statgraphics Plus 2.1 (Statistical Graphics Corporation 1994-1996). A Pearson's product moment correlation matrix was prepared to examine the relationships between the stem variables, seedbed, the vegetation variables and the retained basal area. The correlation matrix showed that all the stem variables were significantly correlated with each other. For the purposes of this report all the seedbed analyses were conducted using height as the dependent variable ('height'). Tree volume, for example, could also be used as the dependent variable but in this instance height was considered sufficiently informative.

Analysis of variance and/or the Kruskal-Wallis test were used to compare the mean and median heights of the seedlings respectively, by seedbed class. To test for significant differences amongst the means of height for each level of seedbed, the multiple range test procedure, using Fisher's least significant differences method to discriminate amongst the means, was used. The confidence level for the test was set at 95%.

3. Results

3.1. Seedbed assessment - coupe

Table 3. Results of the seedbed assessment. Figures in parentheses are percentages.

	D0	D1	D2	Total
B0	4 (3)	7 (5)	1 (1)	12 (9)
BL	29 (21)	12 (9)	n/a	41 (30)

BM	46 (34)		46 (34)
B2	38 (28)		38 (28)

n=137

B0	Unburnt	D0	Undisturbed soil, organic layer intact
BL	Burnt but litter still present	D1	Revealed/lightly disturbed mineral soil
BM	Burnt to mineral soil (charcoal present)	D2	Compacted bare soil, organic layer removed
B2	Oxidised, intense soil heating		

Three plots (2%) were found to still have significant additional amounts of slash arising from the harvesting and none were recorded as having essentially intact vegetation.

3.2. Understorey islands

3.2.1. Post harvesting

Only the real islands were inspected at the completion of harvesting, however from the post burn assessment it is clear that all the phantom understorey islands had been clearfelled during the harvesting. Two of the real islands (UI 5 and UI 193) had trees felled out from their edges, with consequent minor flattening of the nearby vegetation. In both cases the felled trees were within the understorey islands but were not within the central floristic plots, hence the physical disturbance of the plots was minimal.

Whilst the fireline clearing was being done, the contractor was asked to clear fine, flashy fuels from around the understorey islands. The original intention was not to clear four-metre wide swathes around each of the islands but as finessing with a 30-tonne excavator is a little difficult, this is what materialised.. Mineral soil was exposed around the entire perimeter of the islands and it is likely that the disturbance caused minor damage to roots of the trees within the islands.

3.2.2. Post burning

Three of the four real islands burnt during the regeneration burn. The intensity of the burning varied considerably, as described below and summarised in Tables 4, 5 and 6.

UI 7 (Summit) Thamnic, dominated by horizontal. Completely scorched by the regeneration burn, there was almost no green material left in this island at the completion of the burn. A lot of the peat in this island burnt away. Those trees that were rooted in the peat are likely to die. It is expected that some of the trees/shrubs will produce epicormic/coppice shoots. In UI 7b, the peat layer had been partly burnt, there was 100% scorch, and there was evidence of recent animal activity (animals resident in the plot). In UI7a, there was complete loss of the peat layer, and a lot of revealed soil arising from the root plates of lifted shrubs. So although there was no direct mechanical disturbance of the plot there is a lot of revealed soil, particularly in the top plot (UI7a).

UI 5 (Bank) Thamnic, dominated by horizontal. The only island in which there were notable differences between the two DZ plots, in terms of the impact of the burn. In this island the top plot burnt more vigorously than the lower plot. In the top plot, there was 100% scorch and there were a lot of fallen shrubs where the peat layer had completely burnt away. Parts of the horizontal in the plot have collapsed. In the lower plot there were small patches that had not burnt – scorch of the canopy is difficult to assess but is probably about 80% and there were not many fallen shrubs.

UI 193 (Gahnia) Unburnt, this was surprising given dominance of *Bauera* and *Gahnia* in the understorey. *Eucalyptus obliqua* over tall shrubs *Melaleuca squarrosa*, *Leptospermum lanigerum* and *Nematolepis squamea*. Understorey dominated by *Bauera rubioides* and *Gahnia grandis*. Little change between pre-harvesting and post-harvesting floristics, though some differences between the bryophytes which may be related to sampling or to desiccation. Clearing around the

island has created a virtual moat on the western and southern sides of the island.

UI 68 (Road) Completely scorched canopy and well burnt on the ground. In both floristic plots there was little (<5 m²) B0. Most of the ground was assessed as BL or BM, with tiny pieces of B2 in the top plot. From the video of the regeneration burn, this island caught fire early in the burn, and burnt vigorously, with the regeneration burn induced draught fanning the fire.

Table 4. Vegetation groups and impacts of the harvesting and burning on the understorey islands.

Understorey island	Vegetation type	Impact of harvest and burn
Real islands		
UI 7b	T	100% scorched
UI 7a (Summit)	T	100% scorched
UI 5b	T	100% scorched. One tree harvested out of top edge of plot.
UI 5a (Bank)	T	80% scorched. Seedlings, ferns, mosses and smaller shrubs all scorched, both plots.
UI 193b	G	Unburnt. One tree harvested out of top edge.
UI 193a (Gahnia)	G	Unburnt, undisturbed.
UI 68b	G	100% scorched
UI 68a (Road)	G	100% scorched
Phantom islands		
UI 124b	G	Clearfelled and burnt
UI 124a	G	Clearfelled and burnt
UI 232b	G	Clearfelled and burnt
UI 232a	G	Clearfelled and burnt
UI 130b	G	Clearfelled and burnt
UI 130a	G	Clearfelled and burnt
UI 4b	T	Clearfelled and burnt
UI 4a	T	Clearfelled and burnt
UI 6b	T	Clearfelled and burnt
UI 6a	T	Clearfelled and burnt

Table 5. Seedbed assessment of the understorey islands (Braun-Blanquet scale)

Plot number	Burn code				Disturbance code		
	BO	BL	BM	B2	DO	D1	D2
UI 7b	0	3	4	2	5	4	0
UI 7a (Summit)	2	5	3	1	6	2	0
UI 5b	4	3	3	3	6	1	0
UI 5a (Bank)	6	2	2	1	6	0	0
UI 193b	6	0	0	0	6	0	0
UI 193a (Flat)	6	0	0	0	6	0	0
UI 68b	2	4	4	2	6	0	0
UI 68a (Road)	2	5	4	0	6	0	0

Table 6. Seedbed assessment of the phantom understorey islands (Braun-Blanquet scale)

Plot number	Burn code				Disturbance code		
	BO	BL	BM	B2	DO	D1	D2
UI 124A	0	2	5	4	6	0	0
UI 124B	0	4	3	3	6	0	0
UI 232A	0	3	5	2	0	2	0
UI 232B	0	2	6	2	0	2	0
UI 130A	2	2	4	4	6	2	2
UI 130B	3	3	5	2	6	2	3
UI 4A	0	2	6	2	6	0	0
UI 4B	0	3	6	2	6	0	0
UI 6A	0	2	5	4	6	0	0
UI 6B	1	0	6	3	5	4	2

An assessment of the understorey islands floristics, and their recovery to age 3 years will be reported separately.

3.3. Regeneration

A summary of the results of the regeneration survey each March is shown in Table 7.

Table 7. Regeneration survey

Date of survey	% of coupe mapped as stocked	16m ² stocking, whole coupe (%)	Seedling density (stems/ha)	Mean height of eucalypt regeneration	Mean height of understorey species
29/3/01	100	82	3200	0.27 m	not measured
14/3/02	100	88	4600	1.08 m	0.80 m
24/3/03	100	93	4400	2.05 m	1.13 m

The seedling density is based on the mean count of seedlings on the 16 m² plots.

The nature of the seedbed carrying seedlings on stocked plots as assessed during the regeneration survey of March 2001 is shown in the table below.

Table 8. Burn and disturbance proportions for seedlings on stocked plots (%), March 2001, with initial seedbed proportion shown in brackets for each seedbed class.

	D0	D1	D2	Total
B0	0 (3)	4 (5)	9 (1)	13 (9)
BL	27 (21)	16 (9)	n/a	43 (30)
BM	30 (34)			30 (34)
B2	15 (28)			15 (28)

The seedlings in this coupe, as assessed during the regeneration survey, are distributed broadly in proportion to the available seedbed (eg 34% of the coupe was assessed as BM seedbed and 30% of the seedlings examined during the regeneration survey are on BM seedbed).

3.4. Browsing

Of the 50 seedlings sampled in the seedling browsing transect, only three had died by May 2002 when monitoring ceased. Browsing in WR8B was rare and had little influence on the seedling growth. The chart (Figure1) shows that seedling growth slowed over winter 2001 and then improved in summer of 2001/02. The coupe was not poisoned.

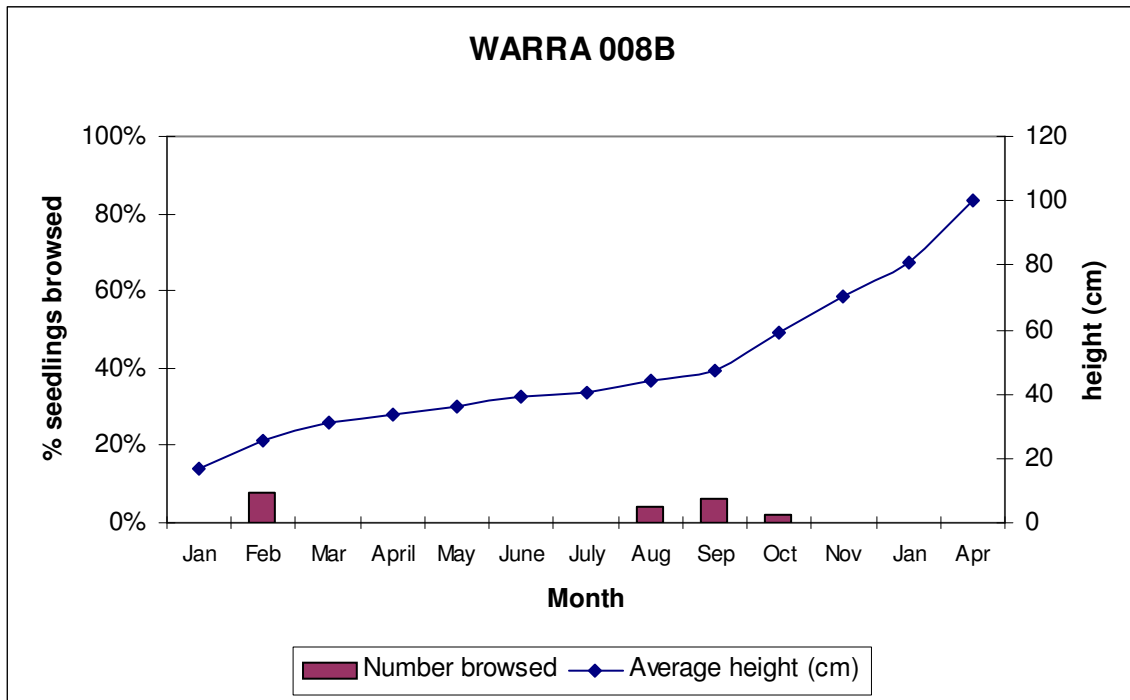


Figure 1. Average seedling height and incidence of browsing over time, Warra 8B

3.5. Seedling establishment and growth

The correlation matrix (Table 9) shows that all the stem variables (height, root collar diameter, stem diameter and crown width (both north-south and east-west) relating to the dominant seedling are significantly correlated, both to each other, and to seedbed class. The relationship between height and seedbed class is not strong – partly this is a consequence of the fact that the seedbed classes are numbered arbitrarily. Later analysis explores the relationship between seedbed class and height more thoroughly. The relationships between seedling height and the other stem variables are very strong and in subsequent analyses, height is used as the key variable.

Table 9. Pearsons product moment correlation matrix. Only the most statistically significant correlations are shown ($P \leq 0.0001$).

	Seed bed	Ht	RC diam	Diam 1/3	N'th S'th	East West	Shrb cover	Shr ht	Sed cov	Sed ht	Fern cov	Fe rht	Herb cover	Herb ht	Tree cover	Tree ht	BA
Seedbed class	----- -																
Height	0.312 6	----- -															
Root collar diameter	0.314 8	0.864 1	----- -														
Diam 1/3 ht	0.323 6	0.884 3	0.972 1	----- -													
North-south	0.339 5	0.862 3	0.897 8	0.898 3	----- -												
East west	0.322 1	0.879 0	0.906 9	0.913 8	0.933 6	----- -											
Shrub cover			- 0.339 0	- 0.276 5			----- -										
Shrub height							0.375 8	----- -									
Sedge cover		- 0.623 1	- 0.644 4	- 0.636 4	- 0.595 5	- 0.572 1			----- -								
Sedge height		- 0.452 7	- 0.500 0	- 0.491 0	- 0.423 6	- 0.445 5			0.69 34	----- -							
Fern cover											----- -						
Fern height											0.78 05	----- -					
Herb cover		- 0.289 0							0.38 63				----- -				
Herb height		- 0.357 3	- 0.302 6	- 0.318 7	- 0.314 7	- 0.316 0			0.40 42	0.278 8			0.872 9	----- -			
Tree cover	0.269 4	0.608 7	0.522 0	0.518 7	0.552 66	0.541 9			- 0.42 51	- 0.340 0				- 0.288 8	----- -		
Tree height		0.627 3	0.594 3	0.592 9	0.590 2	0.563 4			- 0.47 45	- 0.334 4					0.725 7	----- -	
BA rtd trees								0.33 50									----- -
Dom class		- 0.369 8	- 0.300 9	- 0.301 6	- 0.377 1	- 0.395 3											

Sedge cover and sedge height are both strongly negatively correlated with the stem variables. Where the plots were well burnt, the eucalypt seedlings are generally well developed and the sedge cover is generally low; such plots are typically dominated by *Pomaderris apetala* which tends to suppress the sedges.

Tree cover and height is correlated with the stem variables and is negatively correlated with sedge cover and height. Plots with tall seedlings tend to have tall adjacent seedlings and as discussed above plots with tall seedlings tend to have a low cover of sedges.

For shrubs, sedges, ferns, herbs and trees there is a correlation between height and cover; ie as the height increases the cover increases. This is readily apparent for the ferns, which at low heights are often establishing seedlings, but which readily move into higher height classes with much greater abundance.

There is a weak correlation between dominance class and the stem variables. Only a small number of seedlings in the coupe were rated as sub-dominant (n = 8) or suppressed (n = 3), but such seedlings are generally smaller than surrounding stems.

There is no correlation between the retained basal area and any other variables – the weak relationship between shrub height and retained basal area is considered a coincidence.

3.6. Single-tree plots

Table 10. The percentage of seedlings on each seedbed class for the single-tree plot data, with initial seedbed proportion (%) shown in brackets for each seedbed class.

	D0	D1	D2	Total
B0	1 (3)	10 (5)	1 (1)	11 (9)
BL	3 (21)	8 (9)	n/a	11 (30)

BM	52 (34)	52 (34)
B2	26 (28)	26 (28)

There is an obvious disparity between the abundance of the different seedbed types as assessed immediately post-burn and the seedbed types upon which single-tree plots were established. BM seedbed is over-represented, and BL/DO seedbed is significantly under-represented. The single-tree plots target the dominant seedling on the 5 m radius plot around each plot point, and it is clear from the above table that rarely were dominant seedlings found on B0/D0 or BL/D0. Additional searches were made in an attempt to locate additional seedlings on the under-represented seedbed classes but this was not successful. The dominant seedlings in WR8I are those growing on BM and B2 seedbeds. Sufficient seedlings were found on B0/D1 and BL/D1 seedbeds to allow their use in the analyses, but not on the remaining seedbed classes.

The crown class assessment at age 3 years showed that of the 168 trees assessed as dominant at age 1, when the plots were first established, 157 are now rated as dominant or co-dominant, 8 as subdominant and 3 as suppressed. On some plots it is clear that the plot seedling will be out-competed by surrounding stems despite the fact that it was the dominant seedling at age 1. The analyses described below were undertaken using both the full data set and the data set with the suppressed trees removed, but only the results for the full data set are reported, as removing the subdominant and suppressed trees had little influence on the results.

Preliminary analysis of the whole data set found that the standardised skewness and the standardised kurtosis were outside the acceptable range for ANOVA. Removing the single outlier, (a 7.0 m tall tree on BL/D1 seedbed) from the data set brought the standardised kurtosis within the acceptable range but the skewness was still too high for BM seedbed class. The variance check found that there was not a statistically significant difference amongst the standard deviations.

Overlooking the problem of skewness and kurtosis being outside the acceptable range, the mean height for seedlings on each seedbed class was ranked B2 > BM > B0/D1, with seedlings on BL/D1 not being significantly different from seedlings on the other three classes. Using the Kruskal Wallis test ranked the seedbed classes in the same order, but found a significant difference only between seedlings on B2 and B0/D1. Removing the outlier mentioned above had an effect on the median height for that seedbed class but changed little else.

Table 11. Mean height (cm) and height range by seedbed class

		Whole coupe	Outlier removed
BO/D1	mean	209 _a	
	range	30 – 450	
BL/D1		289 _{abc}	257
		130 – 700	130 – 400
BM		293 _b	
		50 – 700	
B2		353 _c	
		100 – 680	

Subscripts indicate homogenous groups

Multifactor ANOVA was used to test the hypothesis that there was a difference between the seedlings growing on the bank as compared to the seedlings growing in the bog.

Table 12. Multifactor analysis of variance for height by coupe section and seedbed class

Source	Sum of squares	Degrees of freedom	Mean square	F-ratio	P value
Main effects					
Section	744 301.0	1	744301.0	58.64	0.0000
Seedbed class	356 290.0	3	118763.0	9.36	0.0000
Residual	1 967 530	155	12693.7		
Total (corrected)	2 968 900	159			

It is clear from the ANOVA that the two sections of the coupe are significantly different in terms of the seedling heights. Mean seedling height on the bank was 369 cm whereas the mean seedling height on the bog was 241 cm.

To examine the differences between the two sections of the coupe, the data set was separated into bank and bog sections and the data reanalysed for each section.

Table 13. Mean height (cm) and range of seedlings by coupe section with and without single outlier

	Bank	Bog (outlier removed)	Bog (outlier included)
BO/D1 mean	253 _a	153 _a	
range	130 – 450	30 – 220	
BL/D1	291 _{ab}	217 _a	286
	170 – 400	130 – 300	130 – 700
BM	377 _{bc}	216 _a	
	170 – 700	50 – 430	
B2	445 _{cd}	297 _b	
	290 – 680	100 – 490	
Section mean	369	241	236

For the bank section, ANOVA was useable because the skewness and kurtosis were within the acceptable limits, and the variance check found that there was not a significant difference amongst the standard deviations. The subscripts next to each mean in the table above show the homogenous groups (B2, BM > BM, BL/D1 > BL/D1, BO/D1).

For the bog, with the outlier included, the skewness and kurtosis were outside the acceptable range for ANOVA. With the outlier excluded, the skewness and kurtosis were within the acceptable limits, and the variance check found that there was not a significant difference amongst the standard deviations. The subscripts next to each mean in the table above show the homogenous groups (B2 > BM, BL/D1, BO/D1).

Table 14. Stocking and seedling density on the bank and the bog.

Year	Bog		Bank	
	Stocking (%)	Seedling density (stems per ha)	Stocking (%)	Seedling density (stems per ha)
2001	77	2700	90	4100
2002	86	3700	91	5800
2003	90	3200	95	5900

It is clear from the table above that regeneration has been more successful on the bank than in the bog. The waterlogging and subsequent freezing that was observed on the bog during the first and second winters following the regeneration burn has clearly had a major impact on the

regeneration. Seedlings on BM seedbed on the bank are more than 50% taller, and on all seedbeds are nearly twice as dense, as seedlings on the bog. The bank versus bog effect in WR8B is a stronger effect on seedling establishment than the local impact of different seedbed classes.

4. Discussion

At age 3 years, WR8I is fully stocked and the seedlings on most seedbed types are growing steadily. BM (burnt to mineral soil) seedbed dominates the coupe, with oxidised seedbed (B2) and burnt to litter and undisturbed being the only other common seedbed types (about one third of the coupe in each of the three seedbed types). Oxidised seedbed is largely restricted to the perimeter of the coupe, under what was the windrow created by tracking of the coupe.

The results of the regeneration surveys at ages one, two and three years show that the coupe continued to stock up after the first season. Delayed germination may have contributed to the increase in stocking, and the standing trees in the adjacent uncut forest almost certainly also contributed additional seed and hence seedlings. Seedlings assessed during the regeneration survey were found to be distributed broadly in proportion to the distribution of seedbed classes eg 34% of the coupe was assessed as BM seedbed and 30% of the seedlings examined during the regeneration survey were on BM seedbed. This is in contrast to the results of the single-tree plots, where the dominant seedlings on 5 m radius plots were surveyed and over half of the dominant seedlings were on BM seedbed.

Three of the four understorey islands were burnt during the regeneration burn. At age three years, the islands are greening up, both with vegetative and seedling regeneration. Full analysis of the floristic plots was not undertaken at this stage. In the longer term, the interesting question will be whether the vegetatively reproducing late successional species in the islands (ie rainforest species) result in seedlings of these species establishing in the coupe sooner than they would have done were the islands not retained.

Separating the data into bog and bank data sets removed the confounding effect created by having two quite different sites within the one coupe. On the bank, the seedlings growing on oxidised or burnt to mineral soil are taller than seedlings growing on the burnt to litter and unburnt seedbeds. On the bog, the seedlings growing on oxidised soil are taller than seedlings growing on all the other seedbed types. It will be interesting to follow this coupe for longer to see how these

differences change over time, if indeed they do. The surrounding vegetation, ie the trees in the adjacent uncut forest, is not presently having a significant effect on growth of the seedlings.

5. Conclusion

Two null hypotheses were tested in this study. The first hypothesis, that the local intensity of the burn and /or disturbance of the soil arising from the harvesting have no influence on the establishment and growth of the eucalypt regeneration, can clearly be rejected. Seedlings on oxidised soil, on both the bank and the bog, are outperforming (in terms of early height growth), seedlings on other seedbed classes. The second hypothesis, that the understorey islands do not contribute to the regeneration of understorey species following harvesting and burning of the coupe, cannot yet be challenged due to a paucity of data. Further time and research is required in order to be able to address this question properly.

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