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Seedling regeneration, growth and density of *Eucalyptus obliqua* following partial harvesting in the Warra silvicultural systems trial. 2. Dispersed retention at Warra 8C and comparison with Warra 1B

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SUMMARY

Following harvesting and burning of the second dispersed retention coupe established in the Warra silvicultural systems trial (Warra 8C), early seedling establishment and growth on the range of different seedbed types present in the coupe was closely monitored. Three years after the regeneration burn the coupe is nearly stocked with about 1 200 stems per hectare of seedling regeneration plus about 3 m^2/ha of retained trees (about 70% regrowth and about 30% oldgrowth). Seedlings on oxidised soil seedbed are growing significantly faster than seedlings on unburnt and compacted seedbed.

The regeneration burn in Warra 8C was much hotter than that in WR1B, resulting in a higher proportion of oxidised and burnt to mineral soil seedbed in Warra 8C than in Warra 1B. The higher proportion of retained regrowth trees in 8C compared to 1B resulted in a much lower seedfall, and the stocking of eucalypt seedling regeneration at age 3 in 8C is less than half of that in 1B at the same age. Seedling growth rates in the two coupes are very comparable.

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 second coupe to be opened in the SST was Warra 8C (WR8C), a 10 ha coupe which was harvested to a dispersed retention prescription (see Neyland, 2003 for a report on the first coupe to be managed in this way). 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 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 retained trees have no influence on the establishment and growth of the eucalypt regeneration.

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 WR8C 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 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. Harvesting and burning

The harvesting prescription called for retention of approximately 10 % of the basal area of the standing forest as evenly dispersed trees, comprising a mixture of oldgrowth and regrowth (Hickey *et al.* 2001). Safety issues which arose during the harvesting of the first dispersed retention coupe, (WR1B) led to the harvesting prescription for WR8C being varied from that for WR1B. Where oldgrowth trees which had been marked for retention were deemed to be dangerous, the faller was permitted to fell the tree (or ask that it be felled using explosives) and then to substitute a regrowth tree in its place, the ultimate aim being to retain the appropriate number and spacing of stems on the coupe. It was acknowledged that retaining regrowth stems instead of oldgrowth stems would mean that whilst the target number of stems would be retained on the coupe, it would be difficult to achieve the original basal area target as the regrowth stems had a much smaller diameter at breast height than the oldgrowth stems. It was also anticipated that the likely seedfall on the coupe from the retained trees could be reduced as the seed crop in the regrowth trees was lighter than that in the oldgrowth trees. Following completion of harvesting (November 1999), the coupe was burnt by a moderate intensity fire, late in the burning season (9 April 2000, see Marsden-Smedley and Slipcevic (2001) for details). Harvesting, production and safety issues are discussed in Hickey and Edwards (in prep) and are not considered further here.

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. Parts of the windrow and also the accumulated debris around the landing burnt quite vigorously during what was otherwise a moderate intensity regeneration burn. All subsequent references herein to ‘the coupe’ include the interior of the coupe, the windrow and the firebreak.

2.3. Post-harvesting retention levels

All the retained trees on the coupe were assessed at the completion of harvesting. Damage arising from the harvesting and regeneration burning, crown health, diameter at breast height, height, position in the coupe (using a GPS) and loss due to windthrow was assessed for every retained tree.

2.4. Seedbed assessment

The seedbed assessment of WR8C was conducted on 28 April 2000, three weeks 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 1. The state of the vegetation at each point was classified as either intact or flattened. Accumulated slash at each point was classified as being either significantly additional to that present pre-harvesting or not significantly additional.

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 soil or burnt to ash-bed it was not considered possible to allocate the point to a disturbance class, partial or complete oxidation having altered the soil beyond the point to which disturbance could be reliably recognised.

The combinations of unburnt and undisturbed (B0/D0) and burnt-to-litter and compacted seedbed (BL/D2) were only very rarely observed and there were not sufficient seedlings in these classes to allow their use in the subsequent analyses.

Table 1. 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 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.

2.5. Seedfall

Twenty seed-traps (1 m^2) were randomly located across the coupe. Each of the retained trees was given a unique number. Random number tables were used to select 20 trees as start points for the location of the traps. Random number tables were also used to determine the actual distance each trap was placed east (downwind, based on the prevailing wind direction) of the selected tree; one-third of the traps were placed within 0 - 15 m of the selected trees, one-third within 15 - 30 m and one-third within 30 - 45 m.

The seed traps were established the day after burning was completed and were monitored quarterly for two years. The contents of each trap were collected, brought back to the laboratory and sorted. Seed in capsules was ignored. The cleaned seed was stratified for a week at 0 °C and then placed in a constant temperature chamber at 20 °C for three weeks and germinants counted. The total number of germinants from each trap was then used to estimate the total viable seedfall per square metre across the coupe. It is possible that some seed germinated in the traps and died (through drought or waterlogging) in the period between collections (Owen Bassett, pers. comm.). The reported seedfall may therefore be an underestimate of the true seedfall.

2.6. Regeneration

Seedling regeneration was assessed in March each year for three years after the regeneration burn, following the methods of Forestry Tasmania (2003) except as noted below. A randomly located grid was placed over the coupe with lines 100 m apart (standard is 100 m, *op. cit.*) for the first year, 50 m apart for the second and 40 m apart in the third (the aim at each sampling event was to achieve a minimum of 50 randomly located 16 m^2 plots and this was barely achieved in year one so the plot density was increased in years two and three). Plots were located every 20 m along the lines. At each sample point a circular 16 m^2 plot centred on the sample point was searched for eucalypt seedlings. The height of the tallest seedling on the 16 m^2 plot was recorded, if present, as was the mean height of the competing understorey vegetation. The number of eucalypt seedlings on both the 4 m^2 and the 16 m^2 plot was counted so that seedling density (stems per hectare) could be estimated. The nature of the seedbed (Table 1) in which the tallest seedling on the 16 m^2 plot (the 4 m^2 plot is a sub-set of the 16 m^2 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 accurately judge and this part of the assessment was discontinued. Mapping rules as described in Forestry Tasmania (2003) 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.

2.7. Browsing

A browsing transect of 50 seedlings was established in late 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 north-east 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.

2.8. Seedling establishment and growth

A set of single tree plots was established to assess the influence on seedling establishment and growth of the seedbed, competing vegetation, the retained trees and the adjacent unharvested forest around the coupe. The plots were established in the second winter following burning (June 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 as described below. Dominant seedlings were defined as seedlings which 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 is 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 1.

The cover-abundance of the surrounding vegetation on a plot of 16 m^2 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. 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 three years using a prismatic wedge with a basal area factor of two. 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 around the firebreak to deliberately sample additional plots on B0/D2 (unburnt/compacted) seedbed and to sample additional plots in the windrow on B2 (ash-bed) plots. In this case, a seedling was selected where the nearest dominant seedling within 5 m was on B0/D2 or B2, 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.

One hundred and ninety-two single tree plots were established. No seedling could be located on fifty-five plots. Further post-establishment losses due to drought death, suppression and/or mechanical damage resulted in the age three data set comprising one hundred and twenty-four trees.

2.9. Analysis

All analyses of the single tree plot data were conducted using Statgraphics Plus 2.1 (Statistical Graphics Corporation 1994-1996). A Pearsons product moment correlation matrix was prepared to examine the relationships between the stem variables, seedbed, the vegetation variables and the retained basal area.

2.10. Seedling height and seedbed

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.

The distribution of ‘height’ was found to be highly skewed. A variance check to test the null hypothesis that the standard deviations of ‘height’ within each of the seven levels of seedbed class were the same found that since the smaller of the P-values (Cochran's C test: 0.526101, p = 2.58E-8) was less than 0.05, there was in fact a statistically significant difference amongst the standard deviations at the 95 % confidence level. This violates one of the important assumptions underlying the analysis of variance and invalidates most of the standard statistical tests (SGC 1994-1996).

A logarithmic transformation normalised the distribution of 'height'. A variance check to test the null hypothesis that the standard deviations of LOG 'height' within each of the seven levels of seedbed class were the same also found that there was in fact a statistically significant difference amongst the standard deviations at the 95 % confidence level (Cochran's C test: 0.507117, p = 1.224E-7).

Due to the statistically significant differences amongst the standard deviations, metric procedures (eg ANOVA) could not be used, so the data was analysed using the Kruskal-Wallis test. The Kruskal-Wallis test is a non-parametric procedure which tests the null hypothesis that the medians of ranked height values within each of the 7 levels of seedbed class are the same. The data from all the levels is first combined and ranked from smallest to largest. The average rank is then computed for the data at each level (SGC 1994-1996). The box-and-whisker plot produced as part of the output of the Kruskal-Wallis test divides the data into four areas of equal frequency. A box contains the middle 50% of the data points and a line through the box shows the median value. A small box shows the mean. The whiskers either side extend from the quartile to the smallest or largest data point within 1.5 interquartile ranges from the lower or higher quartile respectively. Data values that lie outside the whiskers but within three interquartile ranges are shown as small boxes and are considered possible outliers. No data points more than three interquartile ranges outside the box (which are considered definite outliers) occurred in the data set. The notch in the box around the median represents an approximate 95 % confidence interval for the median (SGC 1994-1996).

To test for significant differences amongst the means of height for each level of seedbed, the multiple range test procedure, using Fishers least significant differences method to discriminate amongst the means, was used. The confidence level for the test was set at both 95 and 99 %.

3. Results

3.1. Post-harvesting retention levels

Eight regrowth and two oldgrowth trees per hectare were marked for retention, equivalent to a retained basal area of 6 m^2/ha (95 trees on a 10 ha coupe). At the completion of harvesting 85 trees (59 regrowth and 26 oldgrowth) remained on the coupe (9 trees per hectare) with a basal area of 4.7 m^2/ha. The 85 trees were made up of 69 of the originally marked trees, and 16 unmarked trees left by the contractors. The unmarked retained trees were 11 oldgrowth and 5 regrowth. Five of the oldgrowth were in a close group but the rest were scattered throughout the coupe. Of the 16 trees left by the contractors, 10 were culls, 4 pulp and 2 sawlog. The composition of all retained trees was 22 % culls (19), 37 % sawlog (31) and 41 % pulp only (35).

Three years after the regeneration burn windthrow and related causes of damage have had some impact on the coupe with 12 trees (14 %) lost. These trees have fallen one by one – as for WR1B there was not a single windstorm event that has toppled the trees but rather there has been a gradual loss. Four oldgrowth trees were amongst the trees lost and all had been severely impacted by the regeneration burn. One collapsed during the burn, one was felled during the mop-up operations after the burn as it was still burning, one was located close to the edge of the coupe and was deemed dangerous, and two more fell in the first three months after the burn – both broke off at mid-stem at a point which had been severely burnt during the fire. None of the oldgrowth trees were windthrown in the classical sense, that is with an intact but uplifted root plate. The eight regrowth trees which have been windthrown have all fallen with intact root plates. Three fell prior to the regeneration burn and four in the first quarter after the burn. Only one more tree has fallen since, in the subsequent twelve months.

Twenty-two trees (six oldgrowth and sixteen regrowth) have died since the regeneration burn. All were badly scorched by the regeneration burn. All weakly produced epicormic shoots in the first spring following the fire, but the shoots were neither vigorous nor abundant and by the following winter they had all died. All the dead trees are in the centre or on the eastern side of the coupe, where the fire was the hottest. There have been no subsequent deaths.

In total, ten oldgrowth (38 % of the original 26) and 24 regrowth trees (41 % of 59) have been lost since the completion of harvesting. At the completion of harvesting a basal area of 4.7 m^2/ha had been retained on the coupe. Three years later, the standing basal area is 3.0 m^2/ha, a reduction of 36 %.

3.2. Seedbed assessment

Table 2. Results of the seedbed assessment. Figures in parentheses are percentages.

	D0	D1	D2	Total
B0	6 (4)	15 (11)	3 (2)	24 (17)
BL	31 (22)	22 (16)	n/a	53 (38)

BM	43 (31)	43 (31)
B2	19 (14)	19 (14)

n=139

B0 Unburnt
BL Burnt but litter still present
BM Burnt to mineral soil (charcoal present)
B2 Oxidised, significant soil heating

D0 Undisturbed soil, organic layer intact
D1 Revealed or lightly disturbed mineral soil
D2 Compacted bare soil, organic layer removed

Seventeen plots (12%) were found to have significant additional amounts of slash arising from the harvesting and none were recorded as having essentially intact vegetation.

3.3. Seedfall

The seedfall on the coupe for the two years following harvesting is summarised in Table 3.

Over a similar sampling period the nett seedfall on WR1B was 1370 seeds, so the seedfall on WR8C is about 1% of that on WR1B.

Table 3. Seedfall: total viable seeds collected.

Date collected (Established 10 April 2000)	Number of days since previous collection	Total viable seeds collected
4-Jul-00	85	6
14-Sep-00	72	2
8-Dec-00	84	2
28-Feb-01	82	1
30-May-01	91	2
30-Aug-01	92	0
12-Dec-01	104	0
27-Feb-02	77	0
1-May-02	63	0
Total	750 days	13 seeds

3.4. Regeneration

A summary of the results of the regeneration survey each March is shown in Table 4.

Table 4. Regeneration survey results.

Date of survey	% of coupe mapped as stocked	$16m^2$ stocking, whole coupe (%)	Mean height of eucalypt regeneration	Mean height of understorey species
29/3/01	18	38	0.16 m	0.29 m
14/3/02	69	56	0.50 m	0.64 m
13/3/03	75	74	1.12 m	1.05 m

The nature of the seedbed carrying seedlings on stocked plots as assessed during the regeneration survey of March 2001 is shown in Table 5.

Table 5. Burn and disturbance proportions for seedlings on stocked plots (%), March 2001, with initial seedbed proportion shown in brackets for each seedbed class.

	DO	D1	D2	Total by burn class
BO	0 (4)	14 (11)	4 (2)	18 (17)
BL	10 (22)	26 (16)	n/a	36 (38)

	No disturbance class	
BM	36 (31)	36 (31)
B2	10 (14)	10 (14)

n=52

The seedlings in this coupe are distributed broadly in proportion to the available seedbed (eg 36 % of the coupe was assessed as BM seedbed and 31 % of the seedlings examined during the regeneration survey are on BM seedbed).

The seedling density up to age 3 is shown in Table 6. Forestry Tasmania (2003) shows that at 74% stocking (Table 4), the seedling density should be in the range of 1 200 to 2 500 stems per ha. That the seedling density is at the very bottom of this range indicates that the seedlings are randomly and sparsely distributed (Forestry Tasmania 2003).

Table 6. Seedling density based on average of $16m^2$ quadrat scores.

Age	Stocking (stems/ha)
1	400
2	1040
3	1200

3.5. Browsing

Of the 50 seedlings sampled in the seedling browsing transect, only one had died by May 2002 when monitoring ceased. The average height of the seedlings was 27 cm at the March 2001 measurement, where it stayed for the next two months. Sixty per cent of the seedlings were browsed, many of them significantly. The coupe was poisoned on the 17th of May 2001. Since that time the number of seedlings recorded as browsed has reduced to nil and the average seedling height has increased (Figure 1).

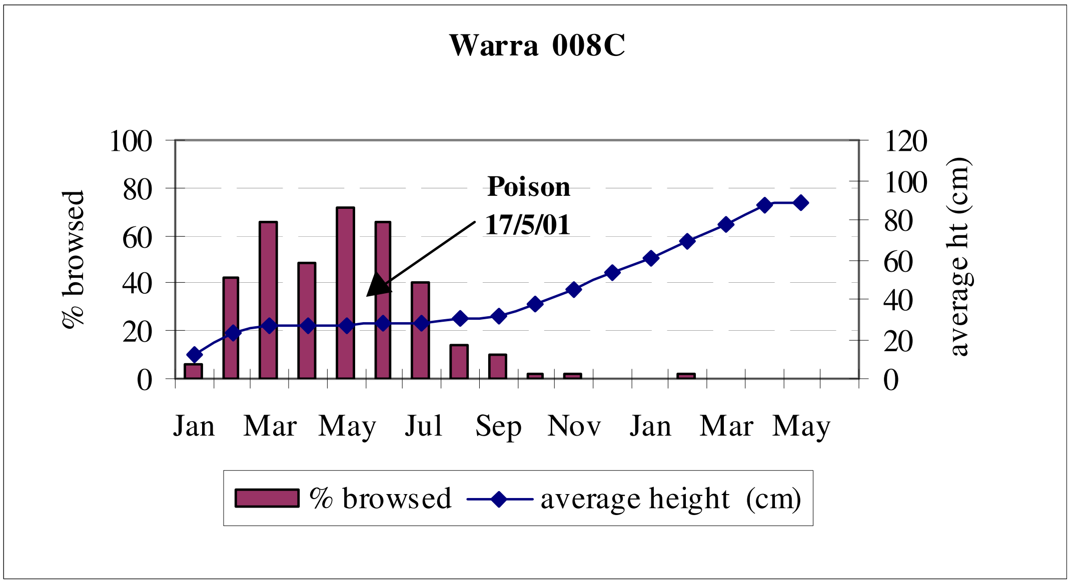

Figure 1. Average seedling height and incidence of browsing over time, Warra 8C

3.6. Seedling establishment and growth

The correlation matrix (Table 7) 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. Diameter at one-third stem height is more strongly correlated with the other stem variables than root collar diameter.

Shrub height (but not cover) is correlated with the stem variables; plots with tall eucalypt seedlings also have tall shrubs. Sedge cover is inversely related to the stem variables, ie plots with tall trees have low sedge cover and plots with short trees have high sedge cover. Almost all of the plots on the fireline have high sedge cover and short eucalypt seedlings.

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

Tree height is correlated with the stem variables and with shrub height (discussed above). Plots with tall seedlings tend to have tall adjacent seedlings.

Table 7. Pearsons product moment correlation matrix. Only statistically significant correlations are shown ($P < 0.0001$).

	Seedbed	**Ht**	**RC diam**	**Diam 1/3**	**N'th S'th**	**East West**	**Shrb cover**	**Shr ht**	**Sed cov**	**Sed ht**	**Fern cover**	**Fern ht**	**Herb cover**	**Herb ht**	**Tree cover**	**Tree ht**	**BA**
Seedbed class	-------																
Height	0.6010	-------															
Root collar diameter	0.5442	0.7748	-------														
Diam 1/3 ht	0.5764	0.9249	0.8125	-------													
North-south	0.5397	0.8006	0.6905	0.7866	-------												
East west	0.6345	0.9418	0.8026	0.9404	0.8358	-------											
Shrub cover							-------										
Shrub height	0.3387	0.5982	0.4416	0.5150	0.3955	0.5055	0.2938	-------									
Sedge cover	-0.4475	-0.4705	-0.3836	-0.4488	-0.4553	-0.4601			-------								
Sedge height									0.3741	----							
Fern cover											-------						
Fern height											0.7583	-------					
Herb cover													-------				
Herb height													0.8563	-------			
Tree cover															-------		
Tree height	0.4072	0.5043	0.4572	0.5106	0.3417	0.4948		0.3100							0.7297	-------	
BA rtd trees	-0.3755												-0.4255	-0.3965			------
Dom class	-0.4031	-0.7043	-0.5620	-0.6291	-0.6355	-0.7086			0.4601							-0.3512	

There is a correlation between the retained basal area and seedbed – the fireline plots are all on B0/D2 seedbed and have generally high local basal areas being close to the adjacent unharvested forest. Herb cover and height are also related to basal area, which may also be due to fireline influences.

The dominance class of the seedlings is negatively correlated with seedbed class and stem variables and tree height and positively correlated with sedge cover. Seedlings on the fireline are often suppressed beneath a massive cover of sedges.

3.7. Single-tree plots

The crown class assessment at age three years showed that of the 109 trees assessed as dominant at age one year, when the plots were first established, 83 are now rated as dominant or co-dominant, 19 as subdominant and 7 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 one year. 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 suppressed trees had little influence on the results. There was only a single seedling on B0/D0 seedbed and this seedling has been removed from the analysis.

The Kruskal-Wallis test showed that there was a significant difference between the median heights of seedlings growing on different seedbed classes (Table 8, Figure 2). The test ranked the seedbed classes in the same order for both the full data set and for the data set with the suppressed trees removed. The results reported below are for the full data set.

The Kruskal-Wallis test ranks the seedbed classes in the following order by height: 7, 6, 5, 4, 2, 3. The differences between classes 6, 5, 4 and 2 are small – the ranges for these groups clearly overlap and there are occasional exceptional seedlings in all of these classes (Figure 2). The median height in class 7 is clearly greater than that for any other class (272 cm against 176 cm for class 6) and the median height for class 3 is clearly less than that for any other class (38 cm against 92 to 150 cm for classes 4, 5 and 2).

The multiple range test with the confidence level set at 95% ranks the seedbed classes in the following order 7 > 6, 4 > 4, 5 > 5, 2 > 2, 3. With the confidence level set at 99% this changes slightly to 7 > 6, 4 > 4, 5, 2 > 5, 2, 3. (The order remains the same but the separation between groups is less well defined.)

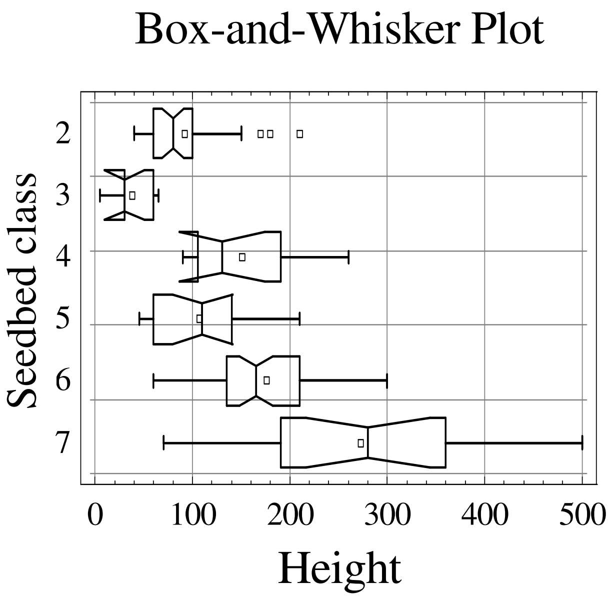

Figure 2. Box and whisker plot. The horizontal line shows the range of values of height for each seedbed class. The central large box shows the spread of values for the middle 50% of the data. the reduced vertical line in the large box shows the median value and the notch represents the 95% confidence interval for the median. The small box within the larger box shows the mean for that class. The smaller boxes (eg centre top) represent possible outliers.

Table 8. Kruskal-Wallis Test for height by seedbed class.

Seedbed class	Sample Size	Averag e rank	Median height	Range of heights	Rank of median height
2	30	35.3	92.3	40 – 210	5
3	5	8.3	38.0	5 – 65	6
4	9	65.1	150.6	90 – 260	3
5	16	43.4	107.5	45 – 210	4
6	46	77.7	176.2	60 – 300	2
7	17	98.3	272.4	70 – 500	1

Test statistic = 59.2325 P-Value = 1.751E-11

Seedbed class 1, unburnt, undisturbed, 2, unburnt disturbed, 3 unburnt , compacted, 4, burnt litter, undisturbed, 5 burnt litter, disturbed, 6 burnt to mineral soil, 7 oxidised.

4. Discussion

The planned low intensity burn in WR8C actually burnt with the vigour of a high intensity burn in parts of the coupe, and spilled into the unharvested forest to the east of the coupe. Assessment of the pre- and post-burn fuel loads (Marsden-Smedley and Slijepcevic 2001) showed that the burn reduced fuels to a level consistent with high intensity burning. The seedbed assessment showed that 38 % of the coupe was burnt to litter and 45 % of the coupe burnt to mineral or oxidised soil. Only 17% of the coupe remained unburnt (cf. WR1B, 73% unburnt). Unburnt fuels were mostly restricted to the western, more shaded edge of the coupe, which did not burn well, even with deliberate lighting of the edge later on the same day and again the next day. Throughout the Warra trial, burning of the shaded western edges has proved difficult. There was no intact vegetation left on the coupe at the completion of harvesting. Twelve per cent of plots had significant additional slash left on them after the burn – the majority of these plots are on the western edge of the coupe.

Longer term (three year) monitoring of the retained trees has shown that the fire had a significant impact on the retained trees. Twenty two badly scorched trees have died since the fire. Twelve trees have been windthrown and many of these (particularly four oldgrowth trees) had been badly burnt in the butt during the regeneration burn. A separate report on the retained trees in WR8C and WR1B is available (Neyland, in press) and they are not discussed further here.

The total seedfall collected in 20 traps over two years was 13 seeds, most of which fell in the first year after the burn. This is equivalent to 6 500 seeds per hectare. In clearfelled, burnt and aerially sown *E. obliqua* coupes in the southern forests of Tasmania, where the trial is located, the standard sowing rate of 0.875 kg/ha (Forestry Commission 1991) is equivalent to 44 000 viable seeds per hectare. The seedfall in WR8C is therefore equivalent to about 15% of the normal sowing rate.

The first regeneration survey of Warra 8C showed that the eucalypt regeneration failed to meet the Tasmanian stocking standard (Forestry Tasmania, 2003), with only 18 % of the coupe mapped-as-stocked and only a 38 % stocking of the 16 m^2 plots. Seed availability was probably the limiting factor, although the browsing transect showed that the coupe was being heavily browsed, so it is possible that some seedlings were lost to browsing at the cotyledon stage.

By year two the stocking of the coupe had improved considerably with 69 % of the coupe mapped-as-stocked and a 56 % stocking of the 16 m^2 plots. At this stage the northern section of the coupe was reasonably well stocked, but the area to the south of the landing was very poorly stocked. This area was waterlogged in parts and there were very few retained trees around or below the landing available to contribute what little seed they had.

By year three the coupe still did not meet the mapped-as-stocked standard (75 % of the coupe was mapped-as-stocked, the standard is 80 %), although it did meet the alternative standard of 65 % of 16 m^2 plots stocked at 74 % stocking. The area to the south and east of the landing remained the most poorly stocked section of the coupe.

Of interest is the amount of *E. delegatensis* seedlings that are present. No *E. delegatensis* was recorded from the vegetation prior to harvesting, although it was known to be present upslope from the coupe some distance. North of the landing and along the western side of the coupe there are many seedlings which are clearly *E. delegatensis*. *E. obliqua* and *E. delegatensis* are known to hybridise (Duncan 1989), so perhaps some of the apparent *E. obliqua* trees to the west of the coupe are carrying *E. delegatensis* genes?

At an estimated seedling density of 1200 stems per hectare at age three years, the coupe had the lightest stocking of any within the Warra SST. However the regeneration was well spread across the coupe, apart from the area to the south-east of the landing, and in time the coupe will look like a forest.

The seedling browsing transect clearly showed the influence of mammal browsing on seedling establishment and growth. One year after the regeneration burn, the monitored seedlings were not growing and 60 % showed clear evidence of browsing. The stated trigger for initiating poisoning (Forestry Tasmania 1999) is when the average height of the monitored seedlings is decreasing. This point may not be reached until many of the seedlings are dead. Even heavily browsed seedlings often retain the occasional green leaf at the top of heavily browsed branches. So although the seedling is being heavily browsed its height may change little from one measurement to the next. The condition of the seedlings is therefore as important a consideration as the average height. It is clear from the monitoring transect that following poisoning, the seedlings resumed steady growth and there was no subsequent death of seedlings from browsing. Low levels of browsing did continue after the poisoning which indicated that poisoning had had the desired effect of reducing the local animal population but not eliminating it entirely.

Mammal browsing of eucalypt cotyledons probably reduced the initial eucalypt stocking of the coupe but other factors, notably poor drainage and subsequent waterlogging, and desiccation on non-mineral earth seedbeds also reduced the number of successfully established seedlings.

The stem variables are all significantly correlated to each other and to the seedbed class. In other words, the vigorous seedlings growing on oxidised seedbed are taller, have more robust stems and broader crowns than seedlings on unburnt compacted seedbed.

No relationship was found between seedling height and the basal area of retained trees around the seedling. At this early stage in the life of the regeneration this was not surprising. Seedlings may have not yet reached the height at which the canopy of the retained trees has a significant influence on growth. In areas where the stocking of the retained trees was the highest, which also means that the harvesting disturbance of the vegetation was least and the amount of accumulated slash was low, which resulted in minimal burning, the stocking of seedlings was very low. In better stocked areas it is expected that in the future the influence of the retained trees will become more apparent.

5. Conclusions

At three years of age Warra 8C is stocked, despite the modest seedfall, and the seedlings on most seedbed types are growing steadily. Seedlings on oxidised seedbed are growing the most vigorously and seedlings on unburnt and compacted seedbed are struggling to persist amongst the surrounding vegetation. On the fireline the cutting grass has overtopped many seedlings and it is unlikely that they will persist much longer.

The retained trees were severely adversely affected by the regeneration burn. The retained basal area of 4.7 m^2/ha has been reduced to 3.0 m^2/ha three years after the burn. Both regrowth and oldgrowth trees were killed by the fire. The retained overstorey is not yet exerting an obvious influence on the growth of the seedlings.

6. Comparison of Warra 8C and Warra 1B

These two dispersed retention coupes were harvested to similar prescriptions. The prescription called for retention of 10 % of the standing basal area to be retained in a mixture of oldgrowth and regrowth trees, and with some variations (see Hickey and Edwards in prep) this was achieved. The regeneration burns for both coupes were planned to be low intensity burns, designed to create seedbed but to not damage the retained trees. Regeneration in both coupes relied on natural seedfall from the retained trees.

The regeneration burn in Warra 8C was much hotter than planned, and was much hotter than that in WR1B. The weather conditions were only marginally warmer and drier in WR8C than in WR1B, but the fuel was significantly drier (Table 9).

Table 9. The regeneration burn.

	Date	Light-up time	Sticks (forest/coupe	Temperature (°C)	Wind speed and direction (KPH)	Relative humidity (%)
Warra 1B	28 Apr 1998	1.25 pm	32/19	16	NW 1 (kph)	80
Warra 8C	9 Apr 2000	1.45 pm	24/17	20	WNW <10	66

Marsden-Smedley and Slijepcevic (2001) have shown that the post-burn fuel loads in Warra 8C were more comparable to those in Warra 8B, a planned high intensity burn, than to Warra 1B, and this finding is confirmed by the seedbed assessment, which shows a much higher proportion of burnt to mineral soil and oxidised seedbed in Warra 8C than in Warra 1B.

Table 10. Results of the seedbed assessment (1B (8C)).

	D0	D1	D2	Total
B0	51 (4)	17 (11)	5 (2)	73 (17)
BL	7 (22)	6 (16)	n/a	13 (38)
BM	16 (31)			16 (31)
B2	3 (14)			3 (14)

n = 146 (n=139)

The seedfall in WR1B was very much greater than in WR8C (Table 11) and this is reflected in the regeneration. Despite the fact that there was significantly less in the way of receptive seedbed in WR1B than in WR8C, there are more than twice as many established seedlings in WR1B than in WR8C. Growth rates in the two coupes are very comparable (Table 12).

Table 11. Seedfall – Viable seeds per hectare over two years

Warra 1B	720 000
Warra 8C	6 500

Table 12. Regeneration (1B(8C))

Date of survey	% of coupe mapped as stocked	$16m^2$ stocking, whole coupe (%)	Mean height of eucalypt regeneration (m)	Stems per hectare
Year 1	63 (18)	50 (38)	0.17 (0.16)	1050 (400)
Year 2	90 (69)	72 (56)	0.52 (0.50)	2100 (1040)
Year 3	100 (75)	83 (74)	1.04 (1.12)	2900 (1200)

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