CRC Technical Report No. 128

Seedling regeneration, growth and density of *Eucalyptus obliqua* following partial harvesting in the Warra silvicultural systems trial. 1. Dispersed retention

Mark Neyland

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

Mark Neyland

Project B3: Silvicultural Systems

Sustainable Management Program
CRC for Sustainable Production Forestry
GPO Box 252-12, Hobart TAS 7001 and
Forestry Tasmania, GPO Box 207, Hobart TAS 7001

November 2003

SUMMARY

Following harvesting and burning of the first dispersed retention coupe established in the Warra silvicultural systems trial (Warra 1B), early seedling establishment and growth on the range of different seedbed types present in the coupe were closely monitored. Three years after the regeneration burn the coupe is fully stocked, with 2 700 stems ha^{-1} of seedling regeneration plus 8 m^2 ha^{-1} of retained trees, comprising 60 % oldgrowth and 40 % regrowth. Seedlings on ash-bed seedbed are growing significantly faster and seedlings on unburnt and compacted seedbed are growing significantly slower than seedlings on lightly burnt, burnt to mineral soil and disturbed seedbeds.

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 coupe to be opened in the SST was Warra 1B (WR1B), a 14 ha coupe which was harvested to a dispersed retention prescription. 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 WR1B 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 squamea*), 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). Following completion of harvesting (March 1998), the coupe was burnt by a low intensity fire, late in the burning season (28 April 1998, 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 very low 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 were assessed for every retained tree.

2.4. Seedbed assessment

The first seedbed assessment of Warra 1B was conducted on 7 May 1998, a week 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.

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	Ashbed (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 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 combination of burnt-to-litter (BL) and compacted seedbed was only very rarely observed and there were not sufficient seedlings in this class 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.

2.5. Seedfall

Nineteen seed-traps (1m^2) were randomly located across the coupe. Each of the retained trees was given a unique number. Random number tables were used to select 19 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 50 m apart (standard is 100 m, *op. cit.*) for the first two years and 100 m apart in the third year. 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.

As part of a concurrent project (Lutze 2001), the regeneration was also surveyed using methods as currently applied in Western Australia (CALM 1989, 1990, 1995, 1997) and New South Wales (NSW) (New South Wales Forestry Commission 1994). These methods also allow for both mapping the stocking of the regeneration in the coupe and the quantification of regeneration density.

2.7. Browsing

Two transects were established successively to monitor browsing of eucalypt seedlings by native mammals, the first transect at the cotyledon stage and the second with developed seedlings. The first transect was established in spring (September 1998) and was monitored for four months. The second transect was established at the end of summer (February 1999) (ie. nearly a year after burning) and was monitored for 12 months. Both transects followed an irregular line from the centre to the edge of the coupe. Fifty cotyledons or fifty seedlings were marked with a wire peg. Where possible, cotyledons or seedlings were selected at approximately 2 m intervals. In some places, due to lack of seedlings, distances between seedlings were much larger. Each browsing transect was monitored monthly. The first transect was established as an experiment to test the application of cotyledon monitoring whereas the second followed prescribed operational procedures for monitoring mammal browsing of regeneration (Forestry Tasmania 1999).

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 third winter following burning (June 2000) when the seedlings were about two-years old, from the same grid as used for the seedbed assessment. The plots have been remeasured once at age three years (June 2001).

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 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, grasses 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 four 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, an additional grid was placed over the coupe, parallel to but 10 m offset from the original grid. Each plot point was located and the nearest dominant seedling identified. If the seedling was on a seedbed class that was under-represented, the seedling was measured in the usual way. If the seedling was on a seedbed class that was already over-represented in the data set, the seedling was disregarded. In addition, a transect was set out around the firebreak to deliberately sample additional plots on B0/D2 (unburnt/compacted) seedbed. In this case, a seedling was selected where the nearest dominant seedling within 5 m was on B0/D2, or rejected if it was on any other seedbed class, every 50 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. The first transect was established in June and the second in July. Seedling growth in winter is very slow and any growth between the two measurements was considered minimal.

Two hundred single-tree plots were established. No seedling could be located on twenty plots and three plots were eliminated because the seedlings had established in roadside debris up to a year prior to the regeneration burn. In addition, post-establishment losses due to drought death and mechanical damage resulted in the data set at age three years comprising one hundred and sixty-five 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 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 found that since the smaller of the P-values (Cochran's C test: 0.260037, $p = 0.033343$) 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).

Seedlings that had been rated as suppressed in the survey at age four years were removed from the data set and the data set re-analysed. The statistical problems described above were still present.

Due to the statistically significant differences amongst the standard deviations, metric procedures (eg ANOVA) could not be used, so both the full data set and the data set with suppressed trees removed were 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 seven 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 per cent 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 per cent.

2.11. Light measurements

To characterise the influence on the regenerating seedlings of shading by the retained trees, an array of light sensors was established within the coupe. The array was deliberately established beneath a small group of retained trees. The distribution of the retained trees across the coupe is uneven and as the aim of this study was to consider the influence of the retained trees, a location was chosen at which the density of the retained trees was at or slightly above the average retention level for the coupe. The basal area at the centre point of the array (assessed using a factor two basal area wedge) was 12 m^2 ha^{-1} whereas the mean basal area for the coupe (post-harvesting) is about 8 m^2 ha^{-1}. The array was laid out in the form of a cross, with the arms of the cross running north-south and east-west (magnetic) (Figure 1). A control sensor was located in a neighbouring clearfelled coupe, thus providing a control from a location where the sky view was unimpeded by any retained trees. The nearest trees to the control sensor were over 100 m away.

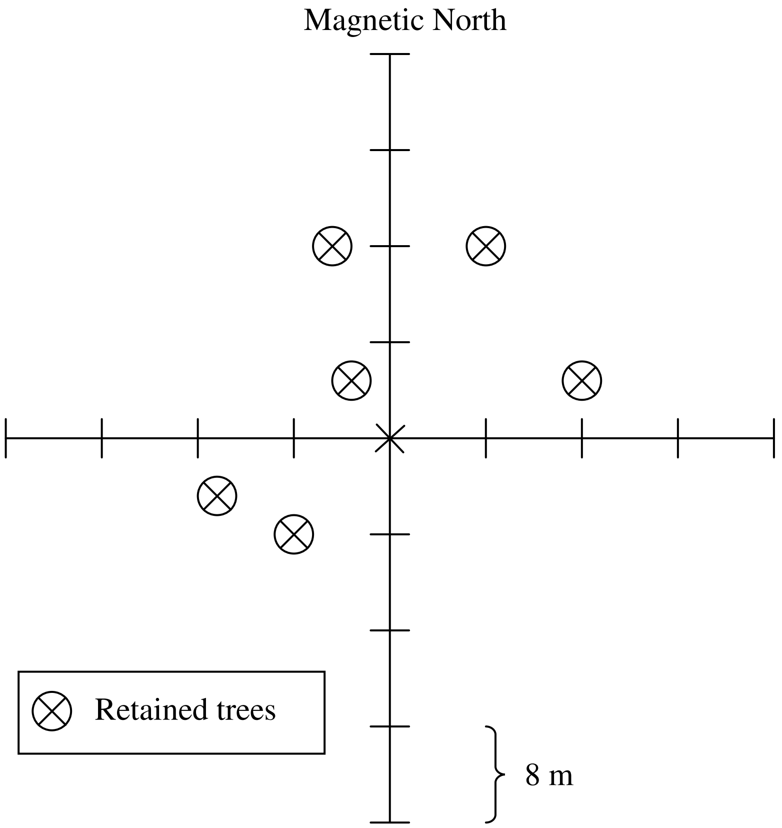

Figure 1. Layout of the light sensors. Sensors were located at eight metre intervals along each arm of the cross, plus one was located at the centre. The sensor closest to magnetic north failed early in the experiment and was not replaced.

The light sensors were calibrated independently (Jane Medhurst, pers. comm.). The sensors were calibrated over the range of 0-2000 µmol m^2 s^{-1} and as shown in the table below (R^2 values) the sensor outputs were all strongly linear over the tested range.

Table 2. Conversion factors and R^2 values for the light sensors.

Sensor #	Conversion factor	R²
2	267.66	0.9955
3	282.06	0.9930
4	125.21	0.9983
5	113.12	0.9984
6	289.19	0.9968
7	114.87	0.9996
9	87.029	0.9996
10	90.946	0.9964
11	89.041	0.9993
12	89.073	0.9991
13	85.325	0.9998
14	87.76	0.9998
15	84.878	0.9999
16	90.644	0.9985
17	87.232	0.9993
18	85.517	0.9980
19	102.53	0.9954
20	108.34	0.9950
21	98.973	0.9993
22	103.75	0.9991
23	112.69	0.9992
24	158.1	0.9916
25	99.335	0.9962

The mean output of each sensor was logged in millivolts. The conversion factors shown in the table above were then used to convert the output from millivolts to photosynthetically active radiation in µmol/m²/s. For three separate periods of one hour each: a clear blue sky morning, a clear blue sky afternoon, and for an overcast afternoon, charts were prepared of the average photosynthetically active radiation (PAR) received by each sensor. On these charts a 'contour line of retained tree influence' (as shown, see Figures 5, 6 and 7 in section 3.5) was estimated such that sensors where the PAR values were depressed relative to sensors in full sun, were within the line. The average PAR received by sensors in full or partial shade (i.e. within the line) for each of the three sample periods was calculated as was the average PAR received by sensors in full or near full light conditions (ie outside the line). The average monthly sun hours for the Grove research station, the nearest available station, were obtained from the Bureau of Meteorology and the median monthly day length was obtained from the World Clock website. These figures were then used to calculate the estimated reduction in available light over the period sampled (e.g. 1 to 2 pm) for the sample area and for the coupe as a whole.

3. Results

3.1. Post-harvesting retention levels

Assessment of the standing trees following completion of harvesting found that 144 trees had been retained on the 14 ha. Fifty seven percent of the trees were oldgrowth and 43 % regrowth and the total retained basal area was 8.7 m^2 ha^{-1} of an original 70 m^2 ha^{-1} (Dingle unpub.). In the three years since completion of harvesting, 15 trees (13 regrowth and two oldgrowth) have been windthrown and a small number of oldgrowth trees have died or appear to be dying. The retained basal area has thus been reduced by about 10 %, to 8 m^2 ha^{-1}.

3.2. Seedbed assessment

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

	D0	D1	D2	Total
B0	74 (51)	25 (17)	7 (5)	106 (73)
BL	10 (7)	9 (6)	n/a	19 (13)
BM	16 (11)			16 (11)
B2	5 (3)			5 (3)

n=146

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

Fifty-two plots (36 %) were found to have significant additional amounts of slash arising from the harvesting and ten plots (7 %) 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 4.

Table 4. Seedfall: total viable seeds collected and viable seed m^{-2} for the coupe.

Date collected (Established 30-April-98)	Number of days since previous collection	Total viable seeds collected	Viable seed m^{-2}	Standard deviation of viable seed count
10-Jun-98	41	488	26	37.0
20-Aug-98	71	153	8	12.6
13-Nov-98	85	637	34	38.4
9-Mar-99	116	46	2	3.4
8-Jun-99	91	9	0	0.8
6-Sep-99	90	21	1	2.1
23-Dec-99	108	14	1	1.3
6-Mar-00	75	7	0	0.8
Total	677 days	1368 seeds	72	

An average of 9 stems ha^{-1} were retained on the coupe, so the mean spacing is about 33 m which is about two-thirds mean tree height. Figure 2 shows that most of the seed fell within less than one tree height of the tree being sampled. As the distribution of retained trees across the coupe is uneven, the overall seedfall is also uneven but taken together the above data suggest that across most of the coupe, seedfall will not be limiting to regeneration.

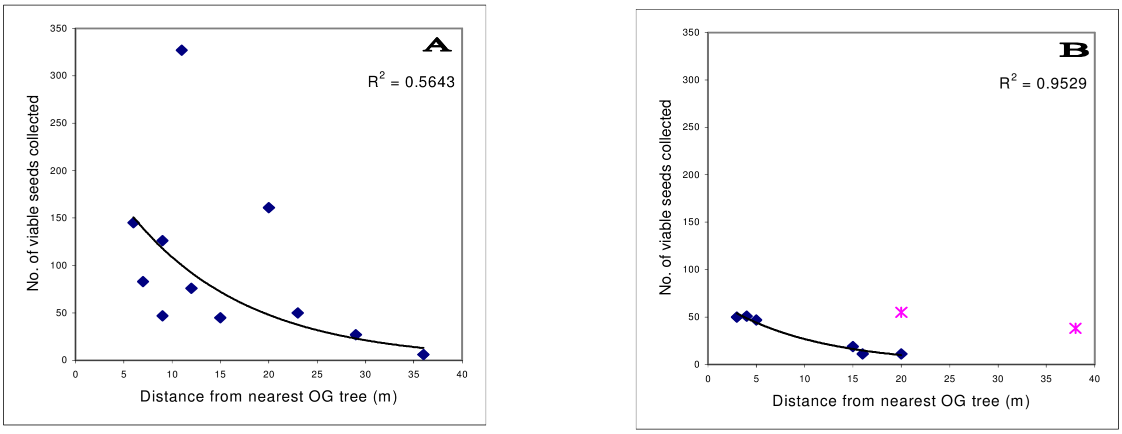

Figure 2. Viable seeds versus distance from oldgrowth (OG) tree for traps on the eastern side (A) and western side (B) of the coupe.

Traps marked with * are not included in the regression – although they are a large distance from the nearest oldgrowth tree they are immediately to the west of a dense patch of retained trees.

3.4. Regeneration

A summary of the results of the regeneration survey each March is shown in Table 5.

Table 5. Regeneration survey results.

Date of survey	% of coupe mapped as stocked	16 m^2 stocking, whole coupe (%)	Mean height of eucalypt regeneration	Mean height of understorey species
4-Mar-99	63	50	0.17 m	0.40 m
15-Mar-00	90	72	0.52 m	Not measured
13-Mar-01	100	83	1.04 m	0.42 m

The nature of the seedbed carrying seedlings on stocked plots as assessed during the regeneration survey of March 1999 is shown in Table 6.

Table 6. Burn and disturbance proportions for seedlings on stocked plots (%) in March 1999, with initial seedbed proportion shown in brackets for each seedbed class.

	DO	D1	D2	Total by burn class
BO	26 (51)	17 (17)	4 (5)	47
BL	15 (7)	7 (6)	n/a	22

	No disturbance class	
BM	24 (12)	24
B2	7 (3)	7

n=52

Initial seedbed assessment showed 73 % of plots to be unburnt but the dominant seedling was on unburnt seedbed in only 47 % of the cases. Fifteen percent of the plots were ashbed or burnt-to-mineral-soil yet 31 % of dominant seedlings were on this seedbed type.

Table 7. Results of WAPIS project assessment of Warra 1B at age three years (Edwards unpub.).

Survey system	Stocking (stems ha^{-1})
Average of 4 m^2 quadrat scores	3000
Average of 16 m^2 quadrat scores	2900
Point density (WA, calculated)	2600
Point to plant (NSW)	1100

Lutze (2001) showed that the NSW system, which assumes that seedlings are randomly distributed, is likely to underestimate the stocking, because the seedlings are actually aggregated, so from the above table, ignoring the results from the NSW system, the actual seedling density at age three years of Warra 1B is between 2600 and 3000 stems ha^{-1}.

3.5. Browsing

Cotyledon browsing transect. Of the original fifty seedlings only 16 (32 %) were present by the last measurement. The cause of the absence of the missing seedlings was often hard to determine. The loss of only two of the 34 missing or dead seedlings could positively be attributed to mammal browsing. Three others were suspected insect attack. Four had dried out, 13 were recorded as sick the month before they went missing. Of the other 12 missing seedlings only one had reached the two leaf pair stage; the cause of loss of these seedlings could not be determined.

Seedling browsing transect. Of the 50 seedlings sampled in the seedling browsing transect, five had died by October 1999. All of these deaths were confidently attributable to heavy browsing, based on observation of the seedlings over the autumn and winter. In March 2000 a sixth seedling was found dead, possibly due to desiccation. The average height of the remaining 44 seedlings began decreasing around the time of the July 2000 measurement. 1080 poison bait was laid out following the August measurement of the browsing transect. Since that time the number of seedlings recorded as browsed has reduced to nil and the average seedling height has increased (Figure 3). Measurement of the seedling browsing transect ceased when the average seedling height of living seedlings was 100 cm (March 2001).

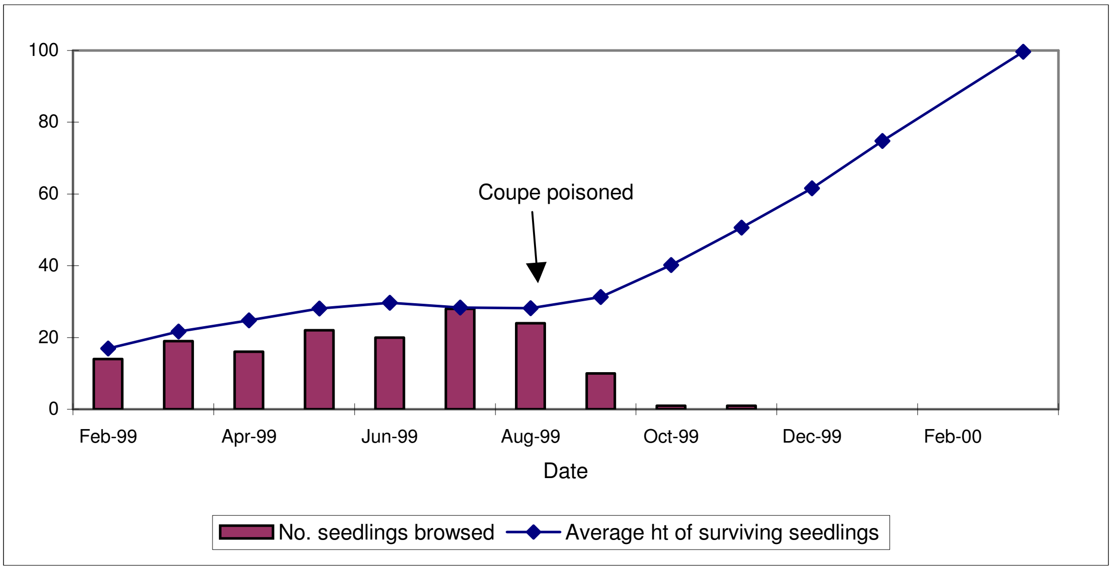

Figure 3. Average height of the 50 seedlings at each measurement of the seedling browsing transects.

3.6. Seedling establishment and growth

The correlation matrix (Table 8) 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. Root collar diameter at one-third stem height is more strongly correlated to the other structural variables than root collar diameter.

The vegetation variables show very little correlation, with the exception of tree height, which is significantly correlated with the stem variables, tree cover, shrub height and sedge height.

There was no correlation between the basal area of retained trees and any other variable.

The crown class assessment at age four years showed that of the 165 trees assessed as dominant at age two years, when the plots were first established, 110 are now rated as dominant or co-dominant, 25 as subdominant and 19 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 two years. The analyses described below were undertaken using both the full data set and the data set with the suppressed trees removed.

Table 8. Pearsons product moment correlation matrix. Only statistically significant correlations are shown.

	Ht	RC	Seed bed	Nth Sth	EW	Sh cv	Shrb ht	Sed cov	Sed ht	Fern cov	Fn ht	Herb cov	Hb ht	Tree cov	Tree ht	Dia 1/3
Height	-------															
Root collar diameter	0.8143	-------														
Seedbed class	0.4340	0.3141	-------													
North-south	0.8829	0.7715	0.4188	-------												
East west	0.7646	0.6727	0.3692	0.7747	-------											
Shrub cover						---										
Shrub height							-------									
Sedge cover								-------								
Sedge height								0.4707	-------							
Fern cover										-------						
Fern height										0.8889	--					
Herb cover												-------				
Herb height												0.5533	---			
Tree cover	0.3650													-------		
Tree height	0.6627	0.4372	0.3313	0.4764	0.4236		0.4821		0.3586					0.5991	-------	
Diam 1/3 ht	0.9502	0.8362	0.4222	0.8798	0.7585									0.3089	0.5694	---
BA rtd trees																

The Kruskal-Wallis test showed that there was a significant difference between the median heights of seedlings growing on different seedbed classes (Table 9, Figure 4). 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.

Table 9. Kruskal-Wallis Test for height by seedbed class.

[1]Seedbed class	Sample Size	Average rank	Median height	Range of heights	Rank of mean height
1	17	83.6	107	62 – 348	4
2	29	65.2	93	19 – 284	6
3	22	28.3	53	27 – 117	7
4	20	67.0	95	36 – 179	5
5	22	100.5	116	52 – 329	3
6	35	101.6	117	50 – 365	2
7	20	132.6	254	62 - 478	1

Test statistic = 64.9473 P-Value = 4.42224E-12

[1] Seedbed class 1, unburnt, undisturbed (B0D0), 2, unburnt disturbed (B0D1), 3 unburnt, compacted (B0D2), 4, burnt to litter, undisturbed (B1D0), 5 burnt to litter, disturbed (B1D1), 6 burnt to mineral soil (BM), 7 ashbed (B2).

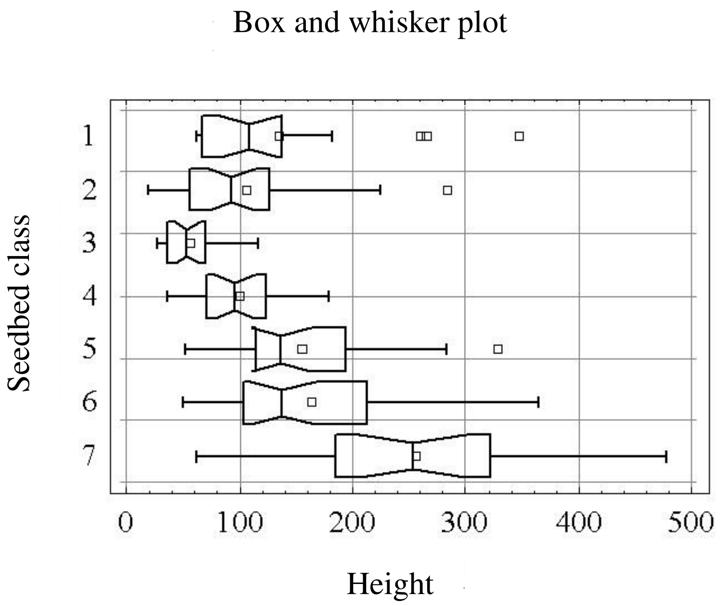

Figure 4. Box and whisker plot. The horizontal line shows the range of values of height for each seedbed class. The central large box shows the spread of values for the middle 50 % of the data. The reduced vertical line in the larger box shows the median value and the notch in the box represents the 95 % confidence interval for the median. The small box within the larger box shows the mean for that class. The smaller boxes (e.g. top right) represents possible outliers.

The Kruskal-Wallis test ranks the seedbed classes in the following order by height: 7, 6, 5, 1, 4, 2, 3. The differences between classes 6, 5, 1, 4 and 2 are small – the ranges for these groups clearly overlap and there are occasional exceptional seedlings in all of these classes (Figure 4). The median height in class 7 is clearly greater than that for any other class (254 cm against 117 cm for class 6) and the median height for class 3 is clearly less than that for any other class (53 cm against 93 to 107 cm for classes 4, 2 and 1.).

The multiple range test with the confidence level set at 95 % ranks the seedbed classes in the following order 7 > 6, 5, 1 > 1, 2, 4 >4, 3. With the confidence level set at 99 % this changes slightly to 7 > 6, 5, 1 > 5, 1, 2, 4 > 2, 4, 3. (The order remains the same but the separation between groups is less well defined.)

3.5. Light

Figures 5, 6 and 7 show the average photosynthetically active radiation (PAR) received by each sensor over three separate periods of one hour each; a clear blue sky morning, a clear blue sky afternoon, and an overcast afternoon.

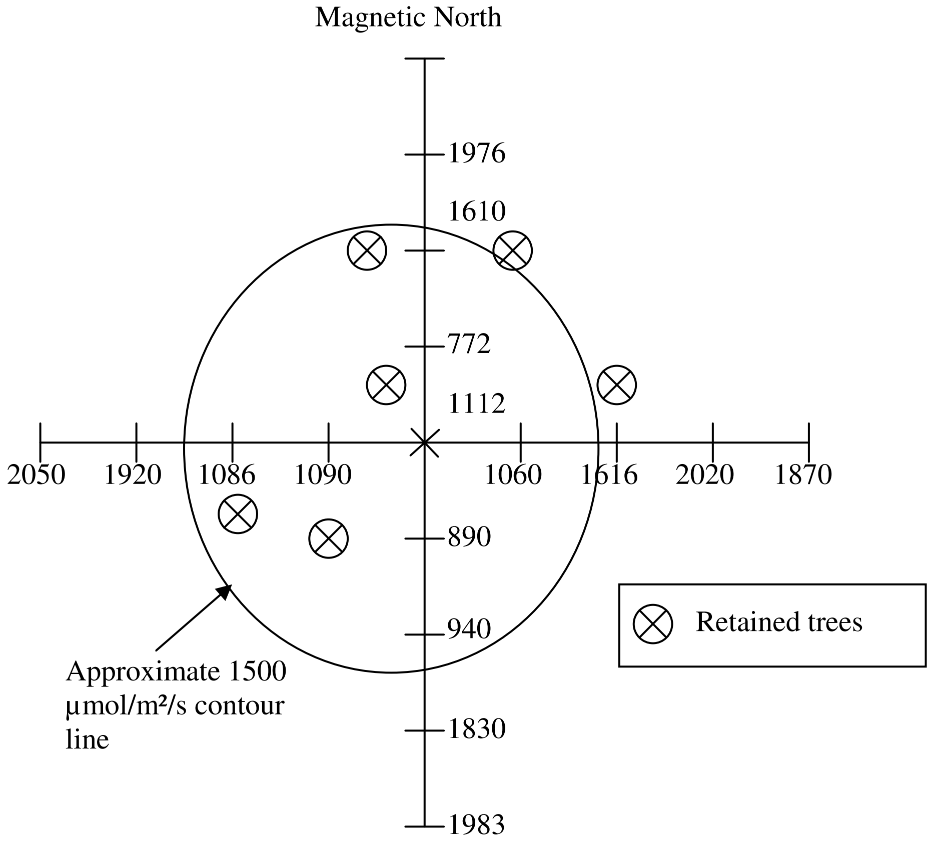

Figure 5. Perfect blue sky day – 10 am to 11 am EST, 1 February 2002.

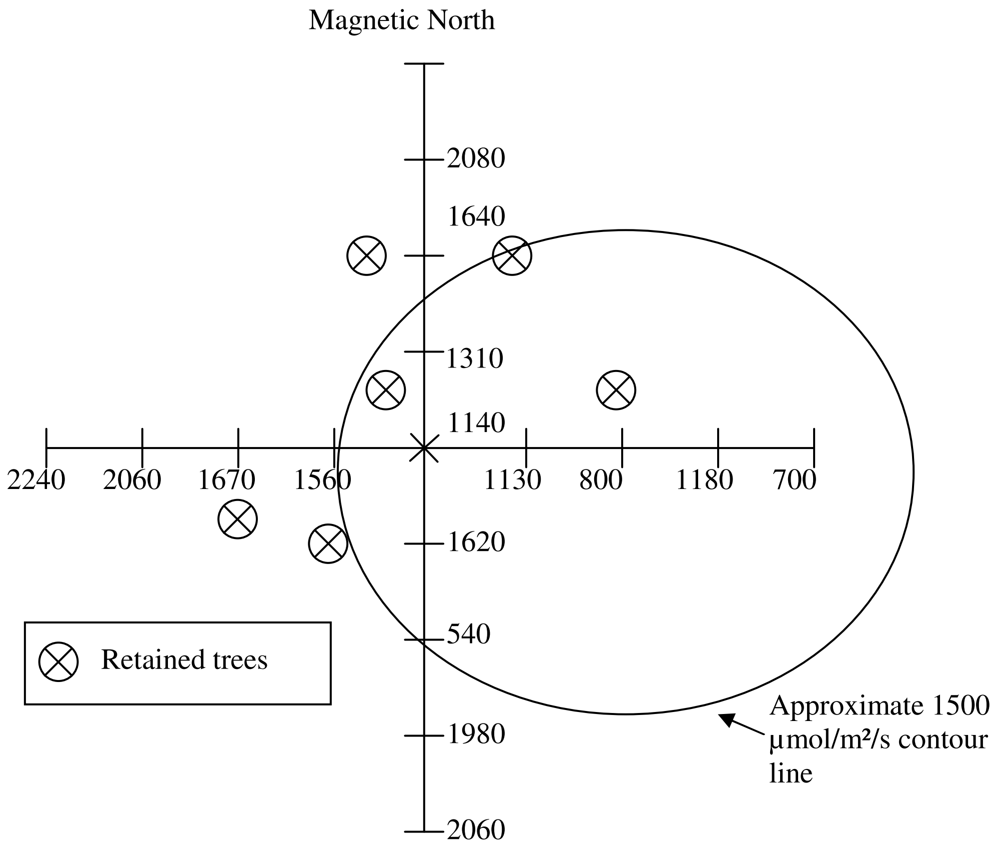

Figure 6. – Perfect blue sky day – 1.12 pm to 2.12 pm EST, 31 January 2002.

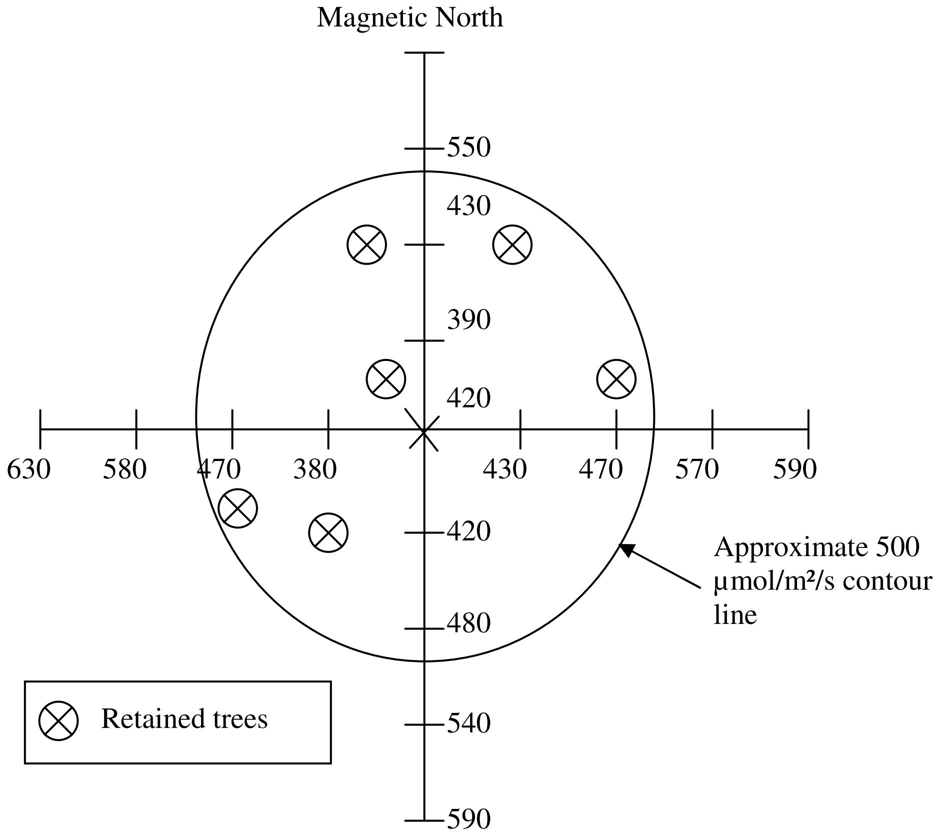

Figure 7. – Overcast day – 1.12 pm to 2.12 pm EST, 3 January 2002.

The mean PAR for the full light and shade sensors is shown in Table 10.

Table 10. Photosynthetically active radiation over three 1 h periods.

Time period	Mean PAR full light sensors	Mean PAR shade sensors	Mean reduction in PAR (%)
31 January 2002 1.12 pm to 2.12 pm Full sun	1950	1130	42
1 February 2002 10 am to 11 am Full sun	2080	1210	42
3 February 2002 1.12 pm to 2.12 pm Overcast	580	430	26

Mean daylight hours per day (Hobart, Tasmania)	13.4 (true decimal, not hours and minutes)
Mean sunshine hours per day	5.4
Mean overcast hours per day	8.0

Overcast conditions occur for an average of 8 out of 13.4 hours or for 60 % of the time; sunny conditions occur 40 % of the time. Therefore:

(0.6 x 26) + (0.4 x 42) = 32.4 % = mean reduction in incident light within the sample area due to the retained trees.

The basal area at the sample site is 12 m^2 ha^{-1} which is 1.5 times the mean basal area for the coupe (8 m^2 ha^{-1}). This suggests that the mean reduction in PAR for the coupe is estimated as 32.4 *0.66 = 21.4 %.

This is the mean reduction in PAR for the coupe as determined by samples taken in the middle of the day. At dawn and dusk the reduction is much less, so the reduction in PAR is likely to range from near 0 at dawn and dusk to about 21 % at noon.

Repeated analyses of different periods could be used to refine this figure further. However this will still only produce a mean for the coupe. Across the coupe the retained basal area at any given point varies significantly, so the PAR will also vary. There are doubtless many other ways of interpreting the light sensor data.

4. Discussion

The regeneration burn in Warra 1B burnt only a quarter of the coupe. Just 3 % of the coupe was rated as ash-bed (oxidised soil), 11 % as burnt to mineral soil and 13 % as burnt litter over unburnt material. The traditional view (based on clearfell, burn and sow coupes) is that a successful regeneration burn results in about 10 % of the coupe being ash-bed and the remaining 90 % being burnt to mineral soil or burnt litter. From a traditional viewpoint therefore the burn at Warra 1B would be regarded as a failure. However, the stated aim of the burn was to reduce fine fuel loads and create seedbed for natural sowing from the retained trees, without severely burning the retained trees (Neyland 2003) and this was achieved. One-third of the coupe was left after the burn with piled up, unburnt slash arising from the harvesting operation. Seven per cent of the coupe was assessed as having intact vegetation. This occurs as discrete clumps in areas where the harvesting took only selected trees.

Seedfall from the retained trees averaged 72 viable seeds per square metre which is equivalent to 720 000 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^{-1} (Forestry Commission 1991) is equivalent to 44 000 viable seeds per hectare. The overall seedfall in Warra 1B is therefore about 15 times the normal sowing rate. Whilst the retained trees are not evenly distributed across the coupe, with a cleared area of radius roughly equivalent to about two tree heights (c. 90 m) having been felled around the landing and above-prescription levels of retention in some areas of the coupe, the key finding from the seedfall study is that seedfall should not be a factor limiting regeneration of the coupe, except perhaps in the cleared area around the landing.

The first regeneration survey of Warra 1B showed that the eucalypt regeneration failed to meet the Tasmanian stocking standard (Forestry Tasmania 2003), with only 63 % of the coupe mapped as stocked. The well-stocked areas were those where there were both areas of burnt seedbed and good seed availability from retained oldgrowth trees to the west of the burnt seedbed. Peak seedfall ended before March 1999, yet the coupe continued to stock-up after that time. Continued recruitment may include some regeneration from the (very light) seedfall that continued into the second year of seed trapping. Very small seedlings may also have been overlooked in early surveys.

By year two the stocking of the coupe had improved considerably with 90 % of the coupe mapped as stocked. By this stage, the only areas that were mapped as understocked were an area of impeded drainage to the immediate west of the landing around which seedlings were present, and an area in the centre of the coupe on a steeper south-east facing slope which had burnt particularly poorly and which had very few trees to the west to provide seed. It was also noted at this time that the corded and matted snig tracks, where they had not been lifted at the end of harvesting, had not burnt and were effectively devoid of seedlings.

By year three the coupe was fully mapped-as-stocked (Forestry Tasmania 2003), and also met the recommended alternative standard of 65 % of 16 m^2 plots stocked (Forest Practices Board 2000). The coupe is now carrying about 2 800 seedlings per hectare plus a retained tree basal area of about 8 m^2 ha^{-1}.

That the coupe achieved a stocking by age three years which met the Tasmanian stocking standard demonstrates the value of retaining seed-trees in coupes which are planned to have low intensity regeneration burns. If this coupe had relied on aerially sown seed it is unlikely that it would ever have reached minimum stocking standards, particularly in view of the browsing pressure to which the coupe was subjected. That the coupe continued to stock-up even with very low levels of seedfall also suggests that the seed that fell in the first year may have contributed to recruitment for a longer period than the conventionally accepted one year. This cannot be tested with the current data but could be investigated with a formal study in a large clearfell burn and sow coupe where a time of germination trial could be established well away from adjacent uncut forest.

It is clear that seedlings establish more successfully on burnt or disturbed seedbed. Half of the coupe was assessed at the completion of the burn as being unburnt and undisturbed, yet only one quarter of the stocked plots are on this seedbed type. Only 15 % of the coupe was assessed as burnt-to-mineral-soil or ashbed, yet 30 % of the seedlings are on this seedbed type. Seedlings on burnt and disturbed seedbed also demonstrated more rapid growth than seedlings on unburnt and undisturbed seedbed (see below).

The cotyledon browsing transect was established in September 1998, tagging healthy cotyledons. The monitored cotyledons were all autumn germinants. During monitoring it was apparent that as the spring progressed many of the autumn germinants gradually died and new spring germinants quickly overtook the surviving autumn germinants. When sampling was discontinued, 68 % of the original cotyledons had disappeared but there was no confidence that their loss could be attributed to mammal browsing. Consequently there is no confidence that this monitoring method provides information that could be used to justify poisoning of the browsing animals. A concurrent research project being undertaken within the Warra SST and elsewhere has also cast doubt on the usefulness of the cotyledon browsing transect method as an indicator of mammal browsing pressure (Andrew Walsh, pers. comm.). The transect has served to show that late autumn germinants are unlikely to contribute significantly to the final stocking of the coupe, whereas the spring germinants grew vigorously and are definitely likely to contribute to the final stocking. It is thought that frost and waterlogging were major contributing factors to the loss of late autumn germinants. It was also noted that many of the late autumn germinants simply never grew. The cotyledons emerged, then sat there through winter looking gradually worse.

The seedling browsing transect clearly showed the influence of mammal browsing on seedling establishment and growth. One year after the regeneration burn, ten per cent of the monitored seedlings had died as a direct result of the browsing and many of the remaining seedlings were reduced to bare stalks. The stated trigger for initiating poisoning in Forestry Tasmania (1998) 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 it 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. Browsing at the seedling stage reduced the initial seedling density by about 10 % and certainly reduced the initial growth of seedlings (Figure 3). The seedlings showed strong recovery of growth following poisoning of the browsing animals and the subsequent reduction in the intensity of the browsing pressure. It is not possible to quantify the loss of growth as there is no comparable control coupe that has had no browsing pressure.

Analysis of the height growth of the seedlings was confounded by the fact that the distribution of height for each seedbed class was skewed beyond the limits acceptable for analysis of variance. It is possible that the variation in the values for height is caused by the fact that seedlings were recruited over at least two years, so seedlings of different ages could have been included in the sample.

The stem variables are all significantly correlated to each other and to the seedbed class. In other words, the vigorous seedlings growing on ashbed or burnt to mineral soil seedbed are taller, have more robust stems and broader crowns than seedlings on unburnt compacted seedbed. It was interesting to note in this analysis that stem diameter (taken at one-third seedling height or 1.3 m above ground level, whichever is the least), is more highly correlated with the other stem variables than root collar diameter. It was often noted when measuring the root collar diameter that basal swellings extended some way up the stem and a consistent measuring point was impossible to locate. Root collar diameter allows stem volume calculations to be undertaken but it seems that these calculations will be more reliable based on stem diameters taken well clear of any basal swelling.

Tree height and cover and seedling height were all significantly correlated. On many plots, tree height is the height of competing eucalypts which were at least as tall as the plot seedling. There is little in the way of correlations between the various vegetation variables. This may reflect the fact that in most cases the eucalypts are significantly taller than the competing vegetation and therefore little influenced by it. It is apparent from the repeated sampling that there is considerable change in the cover of the understorey vegetation over time. The early cover of herbs and grasses for example has almost disappeared and the very patchy cover of cutting grass has filled out dramatically between ages three and four. These changes are being documented and will be reported elsewhere.

No relationship was found between seedling height and the basal area of retained trees around the seedling (no correlation was found between any variable and the basal area of retained trees in fact). At this early stage in the life of the regeneration this is not surprising. Seedlings may have not yet reached the height at which they are being strongly influenced by the canopy (or indeed root systems) of the retained trees. In areas where the stocking of the retained trees is 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 is very low. In better stocked areas it is expected that in the future the influence of the retained trees may become more apparent.

Ten of the single-tree plot seedlings have died since establishment. Three seedlings on B0/D2 (unburnt, compacted), three on B0/D1, (unburnt, disturbed), two on B1/D0 (burnt to litter, undisturbed), and one each on B1/D1 (burnt to litter, disturbed) and B2/D0 (burnt to mineral soil, undisturbed). The last of these seedlings was noted as being in poor health at the measurement at age three years. Apart from this individual case, no other seedling on mineral soil or ash-bed seedbed has died.

Shading of the seedlings by the canopy of the retained trees will have an impact on seedling growth through reduction in the available photosynthetically active radiation. The light measurements showed that this reduction could be as high as 42% of available light under clear sky conditions and up to 28% under low light conditions. These are extreme values, measured in the centre of an atypically dense patch of retained trees, and the effect across most of the coupe will be lower.

5. Conclusions

At three years of age Warra 1B is fully stocked and the seedlings on most seedbed types are growing steadily. Seedlings on ashbed seedbed are growing the most vigorously and seedlings on unburnt and compacted seedbed are struggling to persist amongst the surrounding vegetation.

Seedling establishment was strongly influenced by seedbed type. Seedlings have established more successfully on burnt or disturbed seedbed than on unburnt and undisturbed seedbed. Areas of unburnt heavy slash are beginning to settle and there is some emergent vegetation, notably cutting grass, but these areas remain very poorly stocked compared to areas where the regeneration burn was more intense, albeit patchily. The retained overstorey is not yet exerting an obvious influence on the growth of the seedlings.

References

Alcorn, P.J., Dingle, J.K. and Hickey, J.E. (2001). Age and stand structure in a multi-aged wet eucalypt forest at the Warra silvicultural systems trial. *Tasforests,* 13(2): 245-259.

Brown, M.J. (1998). Establishment of long-term biodiversity monitoring sites in Australian forests. In: *Forest Biodiversity Research, Monitoring and Modelling* (eds F. Dallmeier and J.A. Comiskey), Man and Biosphere Series. 469-479 pp. UNESCO and Parthenon, Paris.

CALM (1989). Silviculture Specification 2/89. Tree-marking and regeneration in Wandoo woodlands. Dept. Conservation and Land Management, Western Australia.

CALM, (1990). Silviculture Specification 1/90. Karri regeneration surveys. Dept. Conservation and Land Management, Western Australia.

CALM, (1995). Silviculture Guideline 1/95. Silviculture Practice in the Jarrah Forest. Dept. Conservation and Land Management, Western Australia.

CALM, (1997). Silviculture Specification 4/97. Jarrah regeneration surveys. Dept. Conservation and Land Management, Western Australia.

Dingle, J. K. (unpub) Warra 1B retained trees. Windthrown trees progress report, 3/5/00 and updates. Internal report to Forestry Tasmania.

Edwards, L.G. (unpub) Establishment Report: Alternative Regeneration Survey 2001 WR001B & 8B. Internal report to Forestry Tasmania.

Forest Practices Board (2000). *Forest Practices Code*. Forest Practices Board, Hobart, Tasmania.

Forestry Commission (1991). Eucalypt seed and sowing. Native Forest Silviculture Technical Bulletin No. 1. Forestry Commission, Tasmania.

Forestry Tasmania (1998). Lowland wet eucalypt forests. Native Forest Silviculture Technical Bulletin No. 8. Forestry Tasmania.

Forestry Tasmania (1999). Monitoring and protecting eucalypt regeneration. Native Forest Silviculture Technical Bulletin No. 12. Forestry Tasmania.

Forestry Tasmania (2003). Regeneration surveys and stocking standards. Native Forest Silviculture Technical Bulletin No. 6. Forestry Tasmania.

Hickey, J.E. and Edwards L.G. (in prep) Operational feasibility of the alternative silvicultural systems in lowland wet eucalypt forests in Tasmania.

Hickey, J.E., Neyland, M.G. and Bassett, O.D. (2001). Rationale and Design for the Warra Silvicultural Systems Trial in wet *Eucalyptus obliqua* forests in Tasmania. *Tasforests,* 13(2): 155-182.

Hickey, J.E., Su, W., Rowe, P., Brown, M.J. and Edwards, L.G. (1999). Fire history of the tall wet eucalypt forests of the Warra ecological research site, Tasmania. *Australian Forestry,* 62(1): 66-71.

Laffan, M.D. (2001). Geology and soils of the Warra LTER site: a preliminary description. *Tasforests,* 13: 23-30.

Lutze, M. (2001) Standardised measures of regeneration success for sustainable management of Australian native forests. Final report of Wood and Paper Industry Strategy Project PN99.810, Regeneration success measures and monitoring methods for sustainable forest management in native forest (Indicator 2.1(g)). Centre for Forest Tree Technology, Orbost, Victoria.

Marsden-Smedley, J.B. and Slijepcevic, A. (2001). Fuel characteristics and low intensity burning in *Eucalyptus obliqua* wet forest at the Warra LTER site. *Tasforests,* 13: 261-280.

Mueller-Dombois, D. and Ellenberg, H. (1974). *Aims and methods of vegetation ecology*. John Wiley and Sons Inc.

New South Wales Forestry Commission (1994). Stand Monitoring of Eucalypt Forests. Post-Logging Surveys. Operational Circular No. 94/2.

Neyland, M.G. (2001). Vegetation of the Warra silvicultural systems trial. *Tasforests,* 13(2): 183-192.

Neyland, M.G. (2003) Warra silvicultural systems trial research plan 1997-2007, June 2003 edition, Part 2 Measurement, monitoring and reporting, Unpublished report to Forestry Tasmania.

Neyland, M.G., Brown, M.J. and Su, W. (2000). Assessing the representativeness of long-term ecological research sites: a case study at Warra in Tasmania. *Australian Forestry,* 63: 194-198.

Public Land Use Commission (1996). *Tasmanian - Commonwealth Regional Forest Agreement background report Part C. Environment and Heritage Report Vol. 1.* Tasmanian Public Land Use Commission, Hobart.

Statistical Graphics Corporation (1994-1996) Statgraphics Plus 2.1 for windows. Statistical Graphics Corporation, Rockville, Maryland, USA.