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FIRE HAZARD AND PRESCRIBED BURNING OF THINNING SLASH IN EUCALYPT REGROWTH FOREST

RESEARCH REPORT No. 29

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SUMMARY

Operational thinning trials were conducted at five coupes, of total area 75 ha, in coastal and foothill regrowth forest, east of Orbost, East Gippsland during 1988 and 1989. This report describes the results of research into the fire hazard and the prescribed burning of the slash resulting from these thinning trials.

The average fine fuel load before thinning, which included an aerated, flammable shrub fuel layer, was assessed at four sites to be between 17 and 23 t/ha, with coarser stick debris contributing an average of an additional 2 to 6 t/ha and branch and large diameter old log material contributing an average of 159 to 234 t/ha.

Thinning operations increased significantly the hazard of the fuel complex by adding, at a typical coupe, about 10 t/ha of leaf and twig material and about 14 t/ha of coarse fuels in the diameter class 2.6 to 10.0 cm. These higher fuel loads combined with the greater flammability of the fine fuels compared to the fine fuels in the uncut forest would, if a wildfire was to occur, increase suppression difficulty significantly and cause severe damage to the retained trees.

Results from nineteen experimental burns, conducted from mid autumn to early spring over a wide range of meteorological and fuel moisture conditions, were used to derive prescriptions for fuel reducing thinning slash in eucalypt regrowth stands of top height greater than 25 m. The prescribed burning should aim to burn greater than 75% of the slash and shrub fine fuels, up to 50% of the litter fuels and to burn most of the coarse slash fuels less than 5 cm in diameter, while causing minimal crown and stem damage. Burning in two stages will probably be required on up to 50% of the harvested area to achieve this objective.

The prescriptions require fire behaviour of low intensity, with a maximum rate of spread of 20 to 30 m/h and a maximum flame height which generally does not exceed 1.5 to 2 m. The minimum moisture content is prescribed for fine fuels in four separate fuel classes and a maximum forest fire danger index of 2.5 and 5 is prescribed respectively for first and second stage burning.

Levels of stem damage were assessed at coupes burnt during late winter 1988 under conditions of relatively high drought index, and were found to be unacceptably high. Burning old logs were found to be the major source of this damage. Low levels of stem damage were, however, measured at coupes burnt under conditions of low drought index during late winter and early spring and these are the conditions that are recommended for operational practice. Burning thinning slash in autumn, even under conditions of low drought index, is not recommended.

Minimizing mechanical damage, maximizing wood utilization, fuel reducing stands prior to thinning, removing all trees within 2 m of old log debris and heaping slash in outrows at a distance of greater than 1 m from edge trees are the management and harvesting prescriptions relating to fire that are recommended for reducing stem damage and which will therefore allow thinned stands to be fuel reduced under conditions of higher drought index without damaging significantly the retained trees.

The average cost of fuel reducing thinning slash was estimated to be a relatively high $92/ha (1990 dollars). Further research is recommended into the fuel management of eucalypt regrowth forests.

INTRODUCTION

This investigation is part of a joint research program between the Victorian State Government and the CSIRO to establish a factual basis to assist the State Government to decide on the optimal use of the forest resource in East Gippsland. This resource is managed as the East Gippsland Forest Management Area[1] and is situated in the eastern part of the State of Victoria incorporating the sawlog supply areas of Cann River, Bendoc, Orbost and Nowa Nowa. An opportunity exists to increase significantly the productivity of the forests through improved silvicultural practices such as the selective thinning of regrowth stands. Thinning would promote future sawlog growth and supplement the available wood supply.

Past timber harvesting and wildfire events in the coastal and foothill forests of East Gippsland have resulted in extensive areas of even-aged eucalypt regrowth. Current harvesting and regeneration operations result in significant annual additions to this area. Similar problems to those faced in managing regrowth forests in south east New South Wales, south west Western Australia and Tasmania (Sneeuwjagt 1981), are also faced in protecting this resource from wildfire.

The understorey of these forests is a dense, aerated layer of flammable fine fuel which combines with high levels of litter fuels and the presence of stringybark eucalypts with high potential for generating spot fires to present one of the highest fuel hazards found in Australian forests. A potentially long fire season, which can commence in early October, combined with this high fuel hazard, has resulted in a long history of major fire events.

Fuel reduction burning or prescribed burning, which is the primary tool for reducing fuel quantities, and hence the impact of wildfire, in a range of Victorian and Australian forests (McArthur 1962; Luke and McArthur 1978), is routinely practised in the dry sclerophyll forests of East Gippsland. However, fuel reduction burning has not generally been applied to unthinned regrowth forests because of difficulties of implementation in the hazardous fuel type and concerns about damage to the growing trees. The Fire Management Branch of the Department of Conservation and Environment (DCE) and the Bushfire Research Unit (BRU) of the CSIRO Division of Forest Products are conducting research into fuel reducing these regrowth forests.

The addition of slash fuels to the forest floor following thinning operations has been recognised as a significant hazard in *Pinus radiata* plantations and the prescribed burning of these fuels has been successfully conducted in Victoria (Billing 1979) and in Western Australia (Burrows *et al.* 1988). However, there has been no similar published information on the hazard of, or the prescribed burning of, thinning slash from eucalypt regrowth forest in Victoria.

Operational thinning trials were conducted at five coupes in coastal and foothill mixed species forest, east of Orbost, during 1988 and 1989. The general locations of these coupes, which total 75 ha in area, are shown on Figure 1. Full details of the regrowth resource, thinning prescriptions, utilization standards, harvesting systems, wood production and flora and fauna impacts are described in other technical reports in the series. To assist the reader's understanding, some brief information on the thinning trials is presented in Appendix 1.

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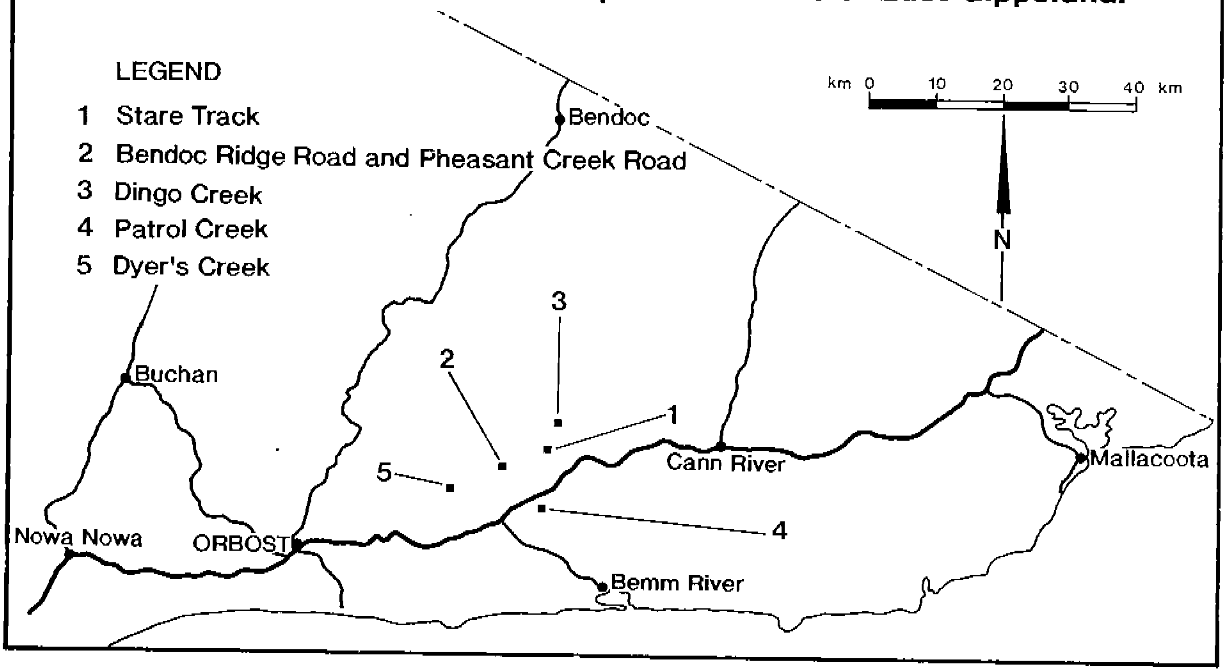
[1] The East Gippsland Forest Management Area is one of 15 hardwood sawlog management areas in Victoria, defined in the Victorian Timber Industry Strategy (1986).

Figure 1. Location of the 1988-89 eucalypt regrowth thinning trials in coastal and foothill mixed-species forests of East Gippsland.



The following aims were defined for the fire protection component of the eucalypt regrowth research:

1. Identify stand conditions and fuel loads pre- and post-thinning for a variety of stand types and under various thinning/harvesting regimes, and following fuel reduction burning or other fuel modification technique.

2. Investigate fuel modification techniques including burning regimes and document conditions under which such techniques can be effectively undertaken as per 1.

3. Identify damage to retained stems as a result of fuel reduction/modification as per 1 (Damage due to thinning/harvesting regimes is also under investigation).

4. Determine cost effectiveness of various fuel modification/fuel reduction regimes.

5. Investigate the effects of fuel reduction/fuel modification techniques on flora and fauna[1].

6. Develop detailed prescriptions for the application of cost effective and environmentally sound fuel modification/fuel reduction techniques to protect regrowth forests from wildfire.

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[1] The impacts of thinning and of fuel reduction burning on flora and fauna are to be reported in separate technical reports in this series.

CSIRO and DCE co-operated to undertake this study. CSIRO aims were to review fuel sampling procedures, detail a standard prescription for future fuel sampling, measure the period of flaming combustion (residence time) of fuel components greater than 6 mm in thickness and estimate the proportion of those fuels likely to be burnt in the continuous flaming zone of a forest fire. DCE aims were to measure fuel and stand parameters, conduct fuel reduction burns over a wide range of weather and fuel moisture conditions, assess the effectiveness of the experimental burns in reducing fuel loads, develop prescriptions for the prescribed burning of fuels following thinning and estimate the cost effectiveness of the burning operations prescribed. Both organizations aimed to assess the damage to the retained stems from the experimental burns. The CSIRO studies have been reported by Cheney *et al.* (1990).

The purpose of this report is to describe and quantify the hazard of thinning slash fuels, detail the results of the experimental burns and define conditions under which this slash fuel hazard can be reduced by prescribed burning.

METHODS

Fuel load assessment before thinning

Fuel load and fuel arrangement within the regrowth stands were assessed prior to the commencement of thinning operations at the Patrol Track, Tarlton Track (near Dyers Creek Track) and Dyers Creek coupes, and in regrowth stands adjoining coupes which had been thinned at Pheasant Creek Road. The following classes of fuel were defined for the purposes of this study:

Fine fuel:	All fuels less than 6 mm in thickness. At the Patrol Track and Tarlton Track sampling sites, fine fuels which were considered not to ignite or burn readily (such as eucalypt capsules and charcoal) were excluded.
Litter bed fuel:	Dead fine fuel, including surface fuel and fuel lower in the fuel profile.
Elevated dead fuel:	Dead fine fuels forming part of, or being suspended in, the shrub layer. In this study, fuels in this class were concentrated at lower levels of the shrub complex and, although the boundary between the litter bed and the elevated dead fuel was often unclear, the boundary was usually assessed at about 10 cm above ground level.
Living shrub fuel:	Living understorey shrub fuels less than 6 mm in thickness and less than 2 m above ground level.
Stick debris:	Dead stick material of 6 to 25 mm in thickness. At the Dyers Creek and Pheasant Creek sampling sites, living stem material of 6 to 25 mm thickness was also included in this class.
Coarse fuel:	Fallen branch and log material greater than 25 mm in underbark thickness.
Shrub height:	The height of the living shrub complex on the sample plot. The height of emergent shrub species was recorded separately.

Fuel elements of less than 25 mm in thickness were assessed by destructive sampling of square plots of area 0.37 m^2 or 0.5 m^2. The plots were systematically located on a grid pattern with a sampling intensity of between four and fourteen plots per coupe and were located at each sampling point to be representative of the fuels at that point. At each plot, the fuel complex was described and the sample of fine fuel and stick debris was partly sorted, then removed to the laboratory for further sorting and weighing. Sub-samples of fuel from each fuel class from each plot were oven dried to enable the weight of each fuel sample to be adjusted for moisture content.

Coarse fuels were assessed by a line intercept technique (van Wagner 1968, Brown 1974). Fuels were measured and then recorded into under-bark diameter classes (2.6 to 5.0 cm, 5.1 to 10.0 cm and in 10 cm classes for larger diameters) along 50 m transects, which varied in cumulative length between sampling sites from 100 m to 450 m. The wood volume data calculated from the diameter distributions were converted to dry weight using two estimates of wood density. The figures used were 0.75 g/cm^3 (calculated from seven samples of harvested regrowth; S = 0.04) for fuel components with diameter less than or equal to 30 cm and 0.64 g/cm^3 (calculated from four samples of old log material; S = 0.04) for fuel components with diameter greater than 30 cm.

Fuel load assessment after thinning

The quantity of fine fuel which had been added to the fuel load by the thinning operations was estimated indirectly by using the frequency distribution of harvested stems (by diameter class) from Dyers Creek coupes 1 and 2 (Geary *et al.* unpubl. data) as the independent variable in two regression equations (Stewart *et al.* 1979) which related stem diameter to the crown variables of leaf and twig weight for *Eucalyptus sieberi*. The equations for *Eucalyptus sieberi* were chosen because this species represented more than 75% of the regrowth basal area at the Dyers Creek coupes.

Geary *et al.* (unpubl. data) had derived the diameter class distribution of stems before and after thinning at Dyers Creek coupes 1 and 2 using the technique of variable probability sampling. The diameter class distribution of harvested and culled stems greater than 10 cm in diameter was derived from these data and Table 1 shows that 92% of these stems were less than 30 cm in diameter.

Table 1. Diameter class distribution of harvested and culled stems at Dyers Creek coupes 1 and 2 (from Geary et al. unpubl. data).

	Diameter class (cm)						
	10-20	20-30	30-40	40-50	50-60	60+	Total
Stems/ha	379.1	150.0	25.4	16.2	0.3	1.2	572.2

Stewart *et al.* (1979) had derived each regression equation from a sample of ten trees with a range in diameter-breast-height-over-bark (DBHOB) of 28.0 to 89.0 cm. These equations, with the standard deviation of the regression (SYX) and the coefficient of determination (r^2), were:

$$Y = 4.7424 + 0.01026 X^2 \quad SYX = 7.6438 \quad r^2 = 0.931 \quad ...(1)$$

where Y denotes dry weight of leaves (kg)
X denotes DBHOB (cm)

and

$$Y = 3.4289 + 0.01330 X^2 \quad SYX = 9.5012 \quad r^2 = 0.936 \quad ...(2)$$

where Y denotes dry weight of twigs (kg)
X denotes DBHOB (cm)

The quantity of coarse fuel on the forest floor after thinning was estimated at the two Dyers Creek coupes using the line intercept technique. Triangular transects, each of total length 75 m, and having a cumulative length of 525 m at coupe 1 and 590 m at coupe 2, were subjectively located to sample the range of coarse fuels over the harvested area. The quantity of coarse fuel added to the fuel load by thinning (in diameter classes 2.6 to 10.0 cm, 10.1 to 30.0 cm, greater than 30.0 cm) was then estimated by subtracting the quantity of coarse fuel measured before thinning from the quantity of coarse fuel measured after thinning. The t-test (Freese 1967) was used to test for significant difference, at the 0.05 level of probability, between the two coarse fuel load measurements in each diameter class.

Experimental fuel reduction burning

Experimental fuel reduction burns were conducted from mid autumn to early spring during 1988, 1989 and 1990 at eight coupes, where slopes varied from zero to about 20^{o}. Some burns were conducted in two stages: the first stage burn followed thinning and the second stage burn involved igniting fuels that had partly burnt or that had remained unburnt during the first stage burn. The Bendoc Ridge Road coupe 2 had been fuel reduced during autumn 1986, two years prior to thinning, so an opportunity existed also to investigate the effect of fuel reduction before thinning on the fire behaviour of experimental burns after thinning.

The moisture content of the fine fuel was determined by collecting fuel samples in jars before and during each burn, which were later oven dried. The samples were collected from the aspects and the positions on the slope which would be burnt within 15 to 30 minutes. For the purposes of measuring moisture content, the following classes of fuel were identified:

Elevated slash: Elevated, dead slash fuels less than 6 mm in thickness (mainly leaves and petioles).

Surface litter: Dead fuels less than 6 mm in thickness (mainly leaves and petioles) found in the top 1.5 cm of the litter bed and either exposed to the weather elements of sun and wind or shaded by shrub or slash material.

Profile litter: Dead litter bed fuels less than 6 mm in thickness situated below the surface litter and slash fuels from the base of slash heaps.

Weather data were measured at the site of, and during each experimental burn. Dry and wet bulb temperatures were measured using a Bacharah sling psychrometer (1988 trials) or an Assman psychrometer (1989 and 1990 trials). Wind speed at canopy level was estimated using the Beaufort Scale (Bureau of Meteorology 1984) and measured at a height of 2 m above ground level using a Dwyer or Anemo hand-held anemometer. Rainfall was measured by a rain-gauge located in each of the coupes burnt during 1989 or 1990. The metric Byram Keetch Drought Index (Keetch Byram 1968) was calculated from Orbost rainfall and temperature data. The McArthur forest fire danger index (Luke and McArthur 1978) was calculated using Orbost and on-site data.

The timing of the experimental burns was between two to ten days after a rainfall event, depending on the amount of rainfall and the subsequent weather conditions. Ignition commenced between 1100 hours and 1515 hours and was completed as late as 1600 hours.

Burning of the total coupe area in a single stage was attempted during some of the trials conducted in winter 1988. During subsequent trials, smaller sections of thinned coupes were burnt so as to enable more experimental burns to be conducted and to minimize any stem and crown damage that may have resulted from burns which became too intense. Drip torches were used to ignite the burns using line and broken line techniques. The distance between lines of fire was varied from about 10 m to about 50 m. Different lighting techniques were used to burn fuels with head fire, flank fire, back fire or a combination of these fire types. The type of fuel being consumed was recorded and flame height and rate of spread, where applicable, was estimated.

Measurements after burning

The quantity of fine fuel which had remained unburnt after each of two experimental fires at the Dingo Creek coupe was estimated by destructively sampling ten plots of area 0.5m^2. The effectiveness of the reduction of fine fuels was assessed visually at all coupes according to the following broad classes:

Very good:	slash and shrub fuels greater than 75% burnt litter fuels greater than 50% burnt.
Good:	slash fuels greater than 75% burnt shrub fuels 25 to 75% burnt litter fuels 25 to 50% burnt.
Fair:	slash fuels 25 to 75% burnt shrub and litter fuels less than 25% burnt.
Poor:	slash fuels less than 25% burnt shrub and litter fuels not burnt.

The quantity of coarse fuel which had remained unburnt following two experimental fires at the Dingo Creek coupe and three experimental fires at the Dyers Creek coupes was assessed by the line intercept technique. Triangular transects, of total length 60, 75 or 90 m, were located subjectively to sample the range in burn effectiveness. The cumulative transect length ranged from 75 m to 330 m at the Dingo Creek coupe and from 210 m to 360 m at the Dyers Creek coupes. The quantity of coarse fuel burnt at Dyers Creek (in diameter classes 2.6 to 10.0 cm, 10.1 to 30.0 cm, greater than 30.0 cm) was subsequently estimated by subtracting the quantity of coarse fuel measured after the burn from the quantity of coarse fuel measured before the burn. The t-test (Freese 1967) was used to test for significant difference, at the 0.05 level of probability, between the two coarse fuel measurements in each diameter class.

Scorch height was measured and butt damage was visually assessed shortly after each burn. However, unless the bark at the base of stems had been completely burnt, any death of the vascular cambium on a stem was not apparent until tree growth subsequently caused bark splitting to occur along the occluding edge of the butt scar. Consequently, stem damage was re-assessed about eight to nine months after each burn. The sampling technique used was developed by Cheney *et al.* (1990) at the Pheasant Creek Road and Bendoc Ridge Road coupes and involved the use of 4 m wide strips located to sample a range of burn intensity. A similar technique, which sampled 1.8% and 3.1% of the burnt areas, was used at the Dingo Creek coupe. Within each strip, all trees were examined for fire damage, mechanical damage and instances where mechanical damage had been expanded by fire and, where possible, the distance from each fire damaged tree to a possible major heat source (such as old logs from previous logging or slash piles from within thinning bays or outrows) was measured.

The "cost effectiveness" of fuel reducing slash from eucalypt regrowth thinning was obtained, based on the tasks involved in a burning operation, the current costs (1990 dollars) of plant, vehicles and manpower and the time required to complete the tasks. The relationship between the number of burning crews, harvested area and number of suitable burning days was also highlighted.

RESULTS

Forest type and fuel characteristics before thinning

The coastal and foothill forest where thinning trials were conducted is broadly classified as Silvertop Stringybark Open Forest III (Land Conservation Council 1974). Dominant tree species are *Eucalyptus sieberi* (Silvertop) and *Eucalyptus globoidea* (White Stringybark) with the associated tree species *Eucalyptus baxteri* (Brown Stringybark) and *Eucalyptus muelleriana* (Yellow Stringybark). Dominant shrub species include *Tetrarrhena juncea* (Wiregrass), *Pterideum esculentum* (Austral Bracken), *Lepidosperma laterale* (Broad Sword Sedge), *Platylobium formosum* (Handsome Flat-pea), *Hakea sericea* (Silky Needlewood) and *Acacia terminalis* (Sunshine Wattle).

The elevated fuel arrangement in this forest type is illustrated in Photo 1. The data on fine fuel load, which are summarised in Table 2, show a high average weight before thinning of 17 to 23 t/ha, comprising an average of 11 to 14 t/ha of litter fuel and an average of 5 to 9 t/ha of elevated fuel. Stick debris contributes an average of 2 to 6 t/ha and the coarse fuel data, which are summarised in Table 3, show a very high average weight of branch and old log material of 159 t/ha to 234 t/ha.

Table 2. Fine fuel loads before thinning.

Location (block/ compartment)	Fuel type	Fuel load (t/ha) Mean	S[1]	Mean shrub height (m)	No. of plots
Patrol Track coupe 1 (12/503)	Litter bed fuel (0-6mm)	13.7	7.1		
	Elevated dead fuel (0-6mm)	1.8	6.1		
	Living shrub fuel (0-6mm)	3.4	7.8		
	Total fine fuel (0-6mm)	18.9	7.1	1.0	9
	Stick debris (6-25mm)	2.1	1.5		
Tarlton Track (09/506)	Litter bed fuel (0-6mm)	14.3	4.2		
	Elevated dead fuel (0-6mm)	5.9	4.6		
	Living shrub fuel (0-6mm)	3.1	2.6		
	Total fine fuel (0-6mm)	23.3	6.3	1.4	4
	Stick debris (6-25mm)	3.0	3.5		
Dyers Creek coupes 1 and 2 (09/501)	Litter bed fuel (0-6mm)	11.8	6.6		
	Elevated dead fuel (0-6mm)	3.6	3.0		
	Living shrub fuel (0-6mm)	1.9	1.8		
	Total fine fuel (0-6mm)	17.3	8.1	1.3	8
	Stick debris (6-25mm)	6.3	3.3		
Pheasant Creek (11/507)	Litter bed fuel (0-6mm)	11.4	2.2		
	Elevated dead fuel (0-6mm)	3.3	3.2		
	Living shrub fuel (0-6mm)	2.2	1.3		
	Total fine fuel (0-6mm)	17.0	2.8	1.4	14
	Stick debris (6-25mm)	7.0	3.7		

1 Standard deviation.

Table 3. Coarse fuel loads before thinning.

Location (block/ compartment)	Diameter class (cm)	Volume (m³/ha)	Dry weight (t/ha) Mean	S[1]	Transect length (m)	No. of transects
Patrol Track coupe 1 (12/503)	2.6-10.0	12.8	9.6	7.8		
	10.1-30.0	64.6	48.5	34.0		
	30.1+	274.6	175.7	163.3		
	Total	352.1	233.8	175.7	50	4
Tarlton Track (09/506)	2.6-10.0	24.6	18.5	13.3		
	10.1-30.0	103.4	77.6	25.2		
	30.1+	97.8	62.6	7.5		
	Total	225.8	158.7	32.0	50	2
Dyers Creek coupes 1 and 2 (09/501)	2.6-10.0	15.0	11.3	3.5		
	10.1-30.0	51.9	38.9	26.0		
	30.1+	216.5	138.6	90.0		
	Total	283.5	188.8	110.8	50	6
Pheasant Creek (11/507)	2.6-10.0	31.7	23.8	15.0		
	10.1-30.0	53.1	39.8	42.9		
	30.1+	155.9	99.8	99.4		
	Total	240.6	164.4	104.3	50	9

[1] Standard deviation.

Fuel characteristics after thinning

The thinning operations increased the quantity and changed the distribution of fuels on the forest floor, as is illustrated in Photo 2. The felling and snigging partly flattened the shrub layer and therefore decreased the hazard of this fuel component and, depending upon the type of harvesting system used and the harvesting prescriptions applied to the operation, slash fuels were heaped in outrows and broadcast over the coupe. Harvested and culled stems greater than 10 cm DBHOB increased the fine fuel load at Dyers Creek coupes 1 and 2 by about 5 t/ha of leaf material and by about 5 t/ha of twig material[1]. These dead fine fuels dried faster than the fine fuels in the uncut forest and were therefore more flammable.

The quantities of coarse fuel in three diameter classes measured at Dyers Creek coupes 1 and 2 are shown in Table 4. Fuel loads in the diameter classes 10.1 to 30.0 cm and greater than 30.0 cm did not significantly change after thinning, as judged by the t-test. However, thinning operations increased significantly the average coarse fuel load in the 2.6 to 10.0 cm diameter class from 11.3 t/ha to 25.1 t/ha, an increase of about 14 t/ha.

Table 4. **Coarse fuel load after thinning at Dyers Creek coupes 1 and 2.**

Diameter class (cm)	Volume (m^3/ha)	Dry weight (t/ha) Mean	S[1]	Transect length (m)	Number of transects
2.6-10.0	33.5	25.1	8.3		
10.1-30.0	32.9	24.7	9.8		
30.1+	120.4	77.1	81.9		
Total	186.8	126.9	83.5	75	15

1 Standard deviation.

Experimental fuel reduction burns

Data on weather, average moisture content of fine fuels, fuel reduction effectiveness, scorch height and stem damage for nineteen experimental burns are summarised in Table 5. The fire behaviour varied within each burn and varied widely between some burns, with rates of spread from 0 m/h to greater than 60 m/h. Successful fuel reduction and low intensity fire behaviour was achieved at various burns with rates of spread of 20 to 30 m/h; and flame heights of 1.5 to 2 m, with occasional flaring of elevated slash material of up to 3 to 4 m. An example of low intensity fire behaviour at the Dingo Creek coupe on 7 September 1989 is illustrated in Photo 3. Fire behaviour of higher intensity occurred at three experimental burns where lower fuel moisture content, higher wind speed and slopes of up to 20° were combined with an ignition pattern of widely spaced lines of fire to result in scorch heights of up to 31 m and, consequently, complete crown scorch of the retained trees.

1 The original data set used to derive equations 1 and 2 was needed to calculate the variance of each estimate of cumulative crown weight that had been added to the fuel load by thinning. However, these data cannot be located.

Table 5. Weather, fuel moisture, fuel reduction effectiveness, scorch height and stem damage results from experimental fuel reduc

Coupe location	Type of burn	Date of burn	Part of coupe ignited	Drought index (Orbost)	Temperature (°C)	Relative humidity (%)	Windspeed at canopy (km/h)	Fire danger index	Average fine fuel moisture content (% ODW) Sample location aspect; slope	Elevated slash	Exposed surface	Shaded surface
Patrol Track, coupe 1 (12/503)	Stage 1	27.6.89	Spot	3	12.5	63-68	0-5	<1	Ridge	21.1	58.6	129.3
	Stage 1	29.6.89	Spot	5	14.5-15.3	62-66	0	<1	Ridge	19.1	65.3	118.3
	Stage 1	3.7.89	Spot	9	14.2.-16.1	62-69	0-2	<1	Ridge	23.8	23.1	58.9
	Stage 1	14.8.89	Spot	2	13.5-14.0	56-60	0	1.5	Ridge	22.4	25.8	57.4
Bendoc Ridge Rd, coupe 1 (11/507)	Stage 1	3.8.88	All aspects	62	13.0-17.0	43-61	0-15	2-5	North; upper	13.1	12.9	-
									North; mid	-	-	-
									South; mid	17.6	24.6	53.2
Bendoc Ridge Rd, coupe 2 (11/507)	Stage 1	4.8.88	All aspects	63	13.5-14.0	61-71	0-5	<1-1.5	Ridge	15.4	16.3	17.3
									East; upper	15.9	16.8	40.0
	Stage 2	15.8.88	All aspects	66	19.0-20.0	42-47	0-20	3-6	Ridge	12.8	12.5	15.3
									East; upper	12.6	17.8	19.6
Pheasant Ck Rd, coupe 1 (11/507)	Stage 1	2.6.88	South aspect	18	15.0-17.0	78-80	0-5	<1	-	-	-	-
	Stage 1	3.6.88	North aspect	19	16.5-18.0	76-86	5	<1	-	-	-	-
	Stage 2	15.8.88	South aspect	66	18.0-19.5	48-51	5-10	3.5-4	Ridge	12.1	11.7	-
									South; upper	13.9	12.1	29.3
									South; mid	-	-	-
Pheasant Ck Rd, coupe 3 (11/507)	Stage 1	3.8.88	All aspects	62	16.0-16.5	43-46	0-10	2.5-4.5	North; upper	12.8	12.1	-
									South; upper	14.1	-	29.1
Dingo Creek, coupe 1 (11/515)	Stage 1	15.8.89	Ridge	3	13.0-15.3	44-52	0-10	2-3	North; upper	15.5	18.7	38.4
									South; upper	-	30.4	-
	Stage 1	18.8.89	North west aspect	6	15.5-17.0	55-62	0-5	1.5-2	North; upper	20.0	16.3	34.6
									North; mid	13.9	20.0	39.5
	Stage 2	18.8.89	Ridge	6	16.5-17.0	55-59	0-10	1-2	South; upper	18.3	20.0	43.8
	Stage 1	7.9.89	North and N.E. aspects	3	14.8-17.4	53-59	0-11	<1	-	-	-	-
Dyers Creek, coupe 1 (09/501)	Stage 1	4.5.90	No burn	6	21.5-22.0	47-49	6-25	4-4.5	North; upper	14.9	13.8	14.7
	Stage 1	7.5.90	North aspect	11	13.8-14.6	54-65	1-10	1-2.3	North; upper	14.8	16.1	20.5

Bendoc Ridge Road coupe 2 had been fuel reduced in autumn 1986. During a first stage burn on 4 August 1988, the fire behaviour was of low intensity with the lines of fire generally not carrying between the slash heaps in the low quantities of litter fuel. Despite lower moisture content of fine fuels during the second stage burn, the fire behaviour observed was also of low intensity.

Data on the moisture content of fine fuels at Dyers Creek coupe 2 on 15 June 1990, which are representative of data from other burns, are shown in Table 6. These data indicate that the average moisture content of fine fuels varied:

* widely between different classes of fuel (e.g. eastern aspect, upper slope: elevated slash 17.8%, exposed surface litter 18.8%, shaded surface litter 42.2%, profile litter 169.0%).

* within a given class of fuel, depending on the location on the slope (e.g. elevated slash, south eastern aspect: upper slope 14.4%, mid slope 20.5%).

* within both the elevated slash and exposed surface fuel classes between morning and afternoon (e.g. elevated slash, upper slope: eastern aspect at 1130 hours 17.8%, south eastern aspect at 1305 hours 14.4%).

* within a given fuel class between different aspects of the coupe (this was more clearly shown from data collected at other burns).

The data in Table 6 also show that the moisture content of fine fuels varied between the replicates of samples from the same fuel class collected from the same position on the slope. For example, three samples of elevated slash collected from the upper slope of the south eastern aspect had moisture contents of 13.6%, 14.2% and 15.3%.

Table 6. Moisture content of fine fuels, Dyers Creek coupe 2 on 15 June 1990.

Fuel sample location: aspect; slope (collection time, hours)	Fine fuel moisture content (% ODW)							
	Elevated Slash		Exposed surface		Shaded surface		Profile	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Eastern; upper (1130-1135)	17.8	15.2-22.0	18.8	-	42.2	41.9-42.7	169.0	164.0-173.0
Eastern; mid (1210-1220)	18.7	18.0-19.4	20.4	18.1-22.8	56.1	49.2-63.0	86.8	-
S. eastern; upper (1305-1320)	14.4	13.6-15.3	20.4	15.7-24.2	41.6	-	63.1	-
S. eastern; mid (1400-1410)	20.5	16.8-23.8	52.7	49.8-55.5	38.7	-	wet	

The quantity of fine fuel consumed by fire varied widely within and between the experimental burns. "Very good" fuel reduction was assessed where higher intensity fire behaviour had caused higher fuel consumption, although a related result was often excessive crown scorch. The upper level of "good" fuel reduction, which was assessed on part of the northern aspect of Pheasant Creek Road coupe 1, is illustrated in Photo 4. The effectiveness of a first stage burn of low intensity at the Dingo Creek coupe on 7 September 1989 was assessed as "good" on the upper slopes and "fair" on the lower slopes. Data on the fine fuels that had remained unburnt are shown in Table 7. Five of the eight plots on the transect had been burnt, and on the burnt plots, elevated fine fuels were reduced to an average of 0.7 t/ha and the litter bed fuels were reduced to an average of 5.5 t/ha. Low intensity fire behaviour will reduce, but not completely remove, the fine fuel hazard.

Table 7. **Fine fuel load on five[1] plots which had been burnt during an experimental burn at the Dingo Creek coupe on 7 September 1989.**

Plot number	Fuel load (t/ha) Litter bed fuel (0-6 mm)	Living shrub fuel (0-6 mm)	Total fine fuel (0-6 mm)	Stick debris (6-25 mm)
6	0.8	0.3	1.1	11.1
7	0.4	0.3	0.7	6.0
8	7.5	0.4	7.9	8.6
10	5.9	1.1	7.0	5.5
13	13.1	1.2	14.3	11.5
Mean	5.5	0.7	6.2	7.1
Standard deviation	5.2	0.5	5.6	4.3

[1] The other three plots on the transect had not been burnt.

The quantity of coarse fuel consumed by fire also varied widely within and between experimental burns, with considerably more coarse fuel observed to be burnt where these fuels were heaped rather than broadcast over the coupe. Large quantities of coarse fuel were observed to be burnt at Dyers Creek coupe 1 under cool to mild weather and low drought index conditions in mid autumn and at Bendoc Ridge Road coupe 1 and Pheasant Creek Road coupe 3 under mild weather and relatively high drought index conditions in late winter. Measurements of quantities of coarse fuel in three diameter classes which had remained unburnt at Dyers Creek coupe 2 after an experimental burn on 24 July 1990 are shown in Table 8. Average fuel loads were lower in each diameter class after burning, but, as shown by the t-test, the fuel loads before and after burning were not significantly different. The burning of this coarse fuel, particularly the old log material, was found to be an important factor in causing stem damage.

Table 8. Coarse fuel load after first stage burning at Dyers Creek coupe 2 on 24 July 1989.

Diameter class (cm)	Volume (m^3/ha)	Dry weight (t/ha) Mean	S[1]	Transect length (m)	Number of transects
2.6-10.0	26.2	19.7	6.3		
10.1-30.0	27.1	20.3	12.2		
30.1+	86.4	55.3	80.8		
Total	139.6	95.2	147.6	90	3

[1] Standard deviation

Stem damage

The damage survey conducted by Cheney *et al.* (1990) on coupes burnt in late winter 1988 under conditions of relatively high drought index (Orbost BKDI 62 to 66) showed that:

* Thinning operations caused mechanical damage of 13 to 30% of retained stems.
* Fire expanded the area of damage on 67% of the trees which had suffered mechanical damage.
* Fire damaged a further 25 to 48% of retained stems where the fuel reduction was "good" or "very good". (These percentages exclude fire damage to stems that were initially damaged during mechanical thinning).
* Fire damage from burning heaps of thinning slash was slight when the heaps were greater than 0.5 m from retained stems.
* Old logs which had burnt were the cause of most of the damage to the retained stems. The distance from heat source to damaged stem was up to 3.2 m.

The results from the Dingo Creek coupe, which was burnt in late winter and early spring 1989 under conditions of low drought index (Orbost BKDI 3 to 6) are shown in Table 9. The data show that:

* Thinning operations caused mechanical damage of 6 to 20% of retained stems.
* Fire expanded the area of damage on 57% of trees which had suffered mechanical damage.
* Fire damaged a further 0 to 4% of retained stems where the fuel reduction was "fair" to "good". (These percentages exclude fire damage to stems that were initially damaged during mechanical thinning).
* Burning slash which had been piled against retained stems damaged those trees.

Table 9. **Stem damage from experimental burns conducted at the Dingo Creek coupe on 18 August and 7 September 1989.**

Date of burn	Total transect length (m)	Number of stems assessed	Number of stems by damage class: Nil	Fire	Mechanical	Mechanical plus fire[1]
18 August 1989	100	20	16	0	4	1
7 September 1989	250	51	46	2	3	3

[1] Trees that were mechanically damaged and subsequently damaged by fire were classified initially in the "mechanical damage" class.

Dead old growth trees (known as stags) were observed to ignite easily, even under conditions of low drought index, and in many cases they continued to burn, fell to the ground and then burnt out. Retained regrowth stems were damaged by the falling stags as were the stems adjacent to where the fallen stags had burnt out.

Cost effectiveness and resource requirements

Based on a four-person lighting crew being able to ignite a maximum of 15 ha during the available burning time on a given day, the average unit costs involved in preparing control lines and conducting burning are calculated in Table 10 to be $16.70/ha for preparation and $50.50/ha for each stage of burning. For a 200 ha thinning program, which involves 200 ha of first stage burning and 100 ha of second stage burning, the cost of fuel reducing the harvested area would be a total of $18,450 or $92/ha.

Table 10. **Estimate of the average costs involved in fuel reducing slash from thinning on a 15 ha coupe.**

Task	Resources	Unit	Cost ($/unit)	Number of units	Cost ($)	Total ($)	Cost/ha ($/ha)
1. Preparation	D6						
- fire break	bulldozer	hr	100	2	200		
construction	Float	km	2	25	50	250	16.7
2. 1st stage burning							
- lightning	Crew	person	110	4	440		
- fuel and weather monitoring;	Tech staff	person	120	2	240		
supervision	Vehicles (x 2)	km	0.29	200	58		
	Burning mix				20	757	50.5

The interdependence of the number of lighting crews and the number of burning days required to fuel reduce a harvested area or burning target of 200 ha and 400 ha is shown in Table 11. Assuming that 20 suitable burning days are available in East Gippsland from early winter to early spring, an average of two lighting crews would be needed on each available burning day to fuel reduce a harvested area of 400 ha.

Photo1
Elevated fuel arrangement before thinning, typical of forests in the study area (height pole = 1.2 m).

Photo 2 Fuel arrangement after thinning, Bendoc Ridge Road, coupe 2.

Photo 3 Low intensity fire behaviour, first stage burn, Dingo Creek coupe 1, 7/9/89.

Photo 4 'Good' fuel reduction on part of the northern aspect of Pheasant Creek Road coupe 1, which shows the upper level of fuel reduction that can be expected from low intensity fire behaviour in thinning slash trials.

Table 11. The number of burning days required to meet a fuel reduction target of 200 and 400 ha with between one and three lighting crews.

No of lighting crews[1]	Area harvested (ha)	First stage burn Area burnt (ha)	First stage burn No of burning days required	Second stage burn Area burnt (ha)	Second stage burn No of burning days required	Total No of burning days required
1	200	200	13	100	7	20
	400	400	27	200	13	40
2	200	200	7	100	3	10
	400	400	13	200	7	20
3	200	200	4	100	2	6
	400	400	9	200	4	13

[1] Total crew size is 6 : supervisor, fuel moisture/weather officer, 4 person lighting crew.

DISCUSSION AND BURNING GUIDES

Fuel hazard is defined by Luke and McArthur (1978) to be the condition of the fuel considering such factors as quantity, arrangement, current or potential flammability and the difficulty of suppression if the fuel was to be ignited. The effect of thinning operations is to partially flatten the shrub layer, broadcast and heap large quantities of leaf, twig, bark and small size branch and stem material over the coupe and reduce canopy coverage. Faster drying of the fine fuels by the sun and wind results from reduced canopy coverage and hence fuel flammability is increased. The net result is a significant increase in fuel hazard and, in the event of a wildfire, the wildfire's rate of spread will be higher and the wildfire will be significantly more difficult to suppress. Given that the levels of tree damage which resulted from some of the experimental burns (ignited under mild weather conditions during late winter) were high, a summer wildfire could be expected to cause widespread crown defoliation and very extensive cambiul death.

Quantifying the fuel hazard is difficult, because of uncertainties about which size classes of fuel are relevant to fire behaviour and stem damage, the uneven distribution of the elevated fuels of the study area before thinning, the uneven distribution of the slash fuels after thinning, the physical difficulty of sorting and measuring different classes of fuel in heaps of thinning slash and the time required to implement a program with a sampling intensity which estimates a given fuel parameter with reasonable accuracy. The methods used in this study to resolve these difficulties are briefly discussed below.

In Australia, fuel beds have been defined in fire behaviour guides for specific forest types (Cheney 1981) by the fuel components typical of these forests and by an upper size limit for the fine fuel particles. McArthur (1962) defines fine fuels as dead leaf, bark and twig litter less than 6 mm in diameter in open forests, while Sneeuwjagt and Peet (1985) selected 10 mm diameter for fine fuels in fire behaviour guides for *Eucalyptus marginata* (Jarrah) and *Eucalyptus diversicolor* (Karri) fuels. When burning thinning slash fuels, there is less interest in fire rate of spread (which is dependent on fine fuel quantity) and greater interest in stem damage (which is also affected by coarse fuel quantity). In this study, fine fuels are defined as having an upper size limit of 6 mm, with stick material defined as a separate 6-25 mm class, while Cheney *et al.* (1990) suggests 0-10 mm. However, as the definition is not a factor in implementing the prescriptions for fuel reducing slash from thinning operations, consistency in applying the definition between fine and coarse fuels is more important than the definition itself.

Using a regression technique to estimate the amount of fine fuel added to the coupe by thinning, rather than measuring the amount actually on the site, avoids the difficulties of sampling, sorting and weighing. However the regressions developed by Stewart *et al.* (1979) are based on a sample of ten trees from a mixed age stand, which may have had a different relationship between DBHOB and the crown variables than a stand of even-aged regrowth trees. Also, the harvested stems from Dyers Creek coupes 1 and 2 (Geary *et al.* unpubl. data) are distributed mainly in the diameter classes less than 30 cm DBHOB, which is at the lower extremity of stem diameter used in the regression equations. Therefore, the estimates of leaf and twig weight added to the fuel load by thinning should be viewed as being approximate.

The estimates of coarse fuel load obtained by using the line intercept technique (van Wagner 1968, Brown 1974) vary considerably between transects and therefore, the standard deviation of the mean fuel loads are high. As shown by the t-test (Freese 1967), the thinning caused no significant change to the fuel load in the 10 to 30 cm diameter class at Dyers Creek and the decrease in fuel load in each of the three diameter classes after one of the burns at Dyers Creek was also shown not to be significant. However, this was clearly not the case as coarse fuel had burnt. The sampling design was deficient and, considering the size of the old logs and the uneven distribution of both the logs and the coarse slash material, the sampling intensity should have been as recommended by Brown (1974), a minimum of 450 m per sampling site. Also, before and after comparisons of coarse fuel should only be made after re-sampling the same transect.

Severe butt scarring occurred when fuel reduction burning of thinning slash was conducted in late winter under conditions where the drought index (BKDI) at Orbost was about 60 and had not decreased to zero over the winter months. This severe damage resulted in the death of the living cambiul layer and facilitated the entry of wood decay fungi and wood destroying insects which will subsequently degrade the valuable lower log section of the tree, hence negating any benefits of increased growth resulting from thinning. These levels of stem damage are totally unacceptable to the forest manager.

The major source of this stem damage at the coupes burnt under the conditions of relatively high drought index was old log material. The broadcast thinning slash had a considerable effect in kindling and maintaining the early stages of combustion of the old log material. Stems were also damaged by high radiation levels from burning stags which had fallen to the ground and continued to burn. This damage result was in marked contrast to the very low level of stem damage measured at the Dingo Creek coupe, which was burnt under conditions of very low drought index in late winter and early spring. However, burning under conditions of low drought index at Dyers Creek in autumn resulted in old log material burning. Although heavy, short term rain had reduced the drought index to zero after the summer period, there had not been substantial wetting of the heavy fuels. Previous studies into fuel reducing thinning slash in Victorian pine plantations by Billing (1979) and Woodman and Rawson (1982) found little or no stem damage when fuel reduction burning operations were conducted under conditions of low drought index and carefully prescribed conditions of fuel moisture and wind speed in spring. Similarly, and especially in the absence of harvesting prescriptions relating to fire, damage will be least when the prescribed burning of eucalypt thinning slash is conducted when the drought index is low during late winter and early spring.

Fire damage to retained stems can also be reduced by applying appropriate fire management and harvesting prescriptions. Minimizing mechanical damage will, in addition to achieving direct benefits, reduce subsequent fire damage; and maximizing the utilization of harvested stems will reduce the quantity of material that is available to be burnt on the forest floor. Cheney *et al.* (1990) recommends that an additional three actions be taken to reduce the stem damage to retained trees:

* Fuel reduce the stand prior to thinning so that old log material will be exposed and so that if this material burns, damaged stems can be removed during thinning.

* Mark and remove all trees within at least 1 m (say 2 m) of old log material.

* Heap thinning slash in outrows and clearings at least 1 m from retained trees, rather than broadcast the slash over the coupe.

Based on the experimental burns conducted at Bendoc Ridge Road coupe 2, fuel reduction burning of stands before thinning will decrease the difficulty of conducting low intensity burning after thinning. Also, as suggested by Cheney *et al.* (1990), the overall fuel management of regrowth stands will be improved. However, this burning should be conducted at least two years prior to thinning to avoid any increased soil disturbance and erosion that may be caused by rubber-tyred harvesting machinery operating on soils exposed by burning. Fire behaviour guides and prescriptions for the specific fuel type are also required to enable widespread prescribed burning of regrowth stands before thinning.

The heaping of slash in outrows will result in more coarse fuel burning and less damage will be caused to retained trees, provided that the heaps are as small as practical and at least 1 m from retained trees. This improved burning of fuels in heaps is supported by observation during the trials and practice in other operations such as the burning of windrows and as shown by Cheney *et al.* (1990), provided that combustion is sustained by the burning of adjacent fuel, the residence time of regrowth stem material depends on the initial diameter of the log, not the fuel moisture content. However, the heaping of all thinning slash may not be possible for all harvesting systems or thinning intensities. A further benefit of heaping in outrows would be to reduce the impact of rubber-tyred harvesting machinery on forest soils in outrows, particularly if the soils are wet. Implementing the marking for removal and slash-heaping prescriptions, even if the stands are not fuel reduced prior to thinning, would enable prescribed burning to be conducted over a wider range of drought index conditions without damaging a significant proportion of trees and hence, the number of days available for burning would be increased.

A significant proportion of the total fine fuel load must be unavailable for burning, based on conditions of fuel moisture, if low intensity fire behaviour and acceptable levels of stem and crown damage are to be achieved in the high fuel loads following thinning. Based on the experimental results, a suitable aim for reducing fine fuels following thinning would be to burn greater than 75% of slash and shrub fuels and to burn up to 50% of litter fuels.

A proportion of the coarse fuels from thinning should also be removed by burning. As shown by Cheney *et al.* (1990), slash fuels up to 10 cm in diameter will contribute a substantial proportion of the fuel consumed in the first five minutes of the passage of a flame front during a wildfire and a suitable aim for reducing these coarse fuels would be, as recommended by Cheney *et al.* (1990), to remove most of the material less than 5 cm in diameter.

Prescriptions for fuel reducing thinning slash from stands of eucalypt regrowth forest of top height greater than 25 m in East Gippsland are shown in Table 13. The fire behaviour required is of low intensity with a maximum rate of spread of 20-30 m/h and a maximum flame height which generally does not exceed 1.5 to 2 m.

Table 13. Prescribed conditions for fuel reducing thinning slash from eucalypt regrowth forest, East Gippsland[1].

	Stage 1	Stage 2[2]
Meteorological conditions		
Season	Early winter to early spring	Late winter to early spring
Max drought index (BKDI)	25 (63[3])	25 (63[3])
Max temperature	17°C	20°C
Min relative humidity	50% (45%[4])	45% (40%[4])
Max wind speed (at canopy)	10 km/h	15 km/h
Max fire danger index	2.5	5
Minimum average fine fuel moisture contents		
Elevated slash	15%	12%
Exposed surface litter	16%	12%
Shaded surface litter	30%	20%
Profile litter	70%	70%
Fire behaviour		
Max flame height[5]	1.5-2.0 m	1.5-2.0 m
Max forward rate of spread	20-30 m/h	20-30 m/h
Average scorch height	Less than 15 m	Less than 15 m

1 These prescriptions should be applied only to stands with a top height of greater than 25 m.

2 To ensure low intensity fire behaviour during second stage burning, the less stringent conditions should not be prescribed when large quantities of slash fine fuels remain to be burnt.

3 Burning under conditions of drought index (BKDI) of between 26 and 63 should not take place unless harvesting prescriptions to minimize stem damage have been implemented.

4 First stage burning under conditions of relative humidity of between 45 and 50% and second stage burning under conditions of relative humidity between 40 and 45% should be limited to sheltered aspects of the coupe.

5 Occasional flaring of elevated slash material to 3 m following ignition is acceptable, provided further ignition ceases until the flame height is reduced to less than 2 m.

To achieve this fire behaviour for first stage burning, temperatures less than 17°C, wind speeds of less than 10 km/h, relative humidities greater than 50% and a maximum forest fire danger index (Luke and McArthur, 1978) of 2.5 are prescribed. The minimum average moisture content of the fine fuels should be: elevated slash 15%, exposed surface litter 16%, shaded surface litter 30% and profile fuels 70% (preferably higher). The experimental burns achieved satisfactory fuel reduction when the average moisture content of elevated slash was as high as 18% or 19% but fuels were not satisfactorily reduced when the average moisture content of both the elevated slash and exposed surface litter exceeded about 22%. These moisture contents are considerably higher than those prescribed for fuel reducing litter fuels in open forests; and, if fuel moisture content is less than that prescribed, burning operations should not commence or they should be re-directed to a more sheltered aspect.

Second stage burning will be required to improve the effectiveness of fuel reduction at some coupes. The conditions of drought index for both first and second stage burning should not exceed 25 (BKDI), unless the marking for removal and slash heaping prescriptions are implemented. The prescriptions are more flexible for second stage burning; temperatures should be less than 20°C, wind speeds less than 15 km/h, relative humidities greater than 45% and a maximum forest fire danger index of 5 is prescribed. The minimum average moisture content of the fine fuels should be: elevated slash 12%, exposed surface litter 12%, shaded surface litter 20% and profile fuels 70%. However, care must be taken to ensure that the less stringent conditions are not prescribed when large quantities of slash fine fuels remain to be burnt.

Implementing the fuel reduction burning of thinning slash requires an understanding of the factors that affect fuel moisture content. Fuels dry faster when the shrub layer has been disturbed, with increasing levels of canopy removal, on upper slopes and northern aspects and during late winter and early spring compared to mid winter. Fuels on lower slopes and southern aspects are often too wet to burn when other parts of the coupe burn successfuly with mild fire behaviour and consequently, the effectiveness of burning will vary considerably over most coupes. Hence, on up to about 50% of the harvested area, second stage burning will probably be required.

Fire behaviour is further affected by lighting pattern and the interaction of lighting pattern with slope and wind factors. As with other types of prescribed burning, the more fire that is ignited within a given area, the greater is the overall fire intensity; the rate of spread of any single fire increases with increasing slope; and wind speed and wind direction superimposes over both factors. Lighting crews should operate in pairs and proceed to slowly ignite separate areas of the coupe so as to achieve the maximum burnt area while ensuring low intensity fire behaviour. Lighting should commence with a line of backfire ignited against the prevailing wind from a high point within the coupe. After observing the fire behaviour, a second line of fire can be placed 10-15 m upwind or downslope of the first fire and subsequently a third line of fire placed 20-30 m upwind or downslope of the second fire. The lighting pattern should be planned and altered in response to the observed fire behaviour. Future burning operations will benefit from further research into techniques of igniting thinning slash while maintaining low intensity fire behaviour.

Experience from the experimental burns indicates that small coupes less than 15 ha in size and six-person crews favour successful fuel reduction operations. The officer-in-charge should be responsible for all aspects relating to the conduct of the burn. A separate fire weather officer should be responpbsible for measuring and recording conditions of fuel moisture, weather and fire behaviour before and during the burn. Lighting crews must take care to avoid slipping on wet or damp logs or slash material, and they should proceed cautiously if weather and fuel moisture conditions are approaching the prescribed limits.

Control lines surrounding the coupe, such as wet gullies, creeks, roads or mineral earth tracks, are essential because the moisture differential between the relatively dry fuels within the coupe and the damper fuels within the uncut forest will not always be reliable, particularly in early spring. Existing tracks within the coupe or an outrow on a ridge can also be cleared so as to allow greater control over the burning operation within the coupe.

Fuel reducing thinning slash in eucalypt regrowth forest is a new technique of fire management in East Gippsland. If the aims of the operation are to be achieved, planning officers, supervisors and lighting crews will require training in these aims and the technical requirements of the operation.

The unavoidable two stage burning process and slow rates of ignition mean high costs of treatment per hectare. The estimated cost (1990 dollars) of $92/ha required for reducing thinning slash fuels is considerably greater than the cost of $60-$65/ha required for regeneration slash burning in Bairnsdale Region (J. McCormack pers. comm.[1]). Alternative techniques to treat the slash fuel hazard, such as chipping and mulching, should therefore also be investigated and their practicality and cost effectiveness assessed. As part of a continuing program of fire research, the burning prescriptions proposed in this report should be evaluated following operational use and the effectiveness of the harvesting prescriptions in minimizing stem damage should be assessed.

CONCLUSIONS

Thinning operations in eucalypt regrowth forest substantially increase the hazard of the fuel complex with the consequence, should a wildfire occur, of significantly increased suppression difficulty and severe damage to the retained trees.

This hazard can be reduced and the potential damage from wildfire minimized by implementing the prescribed burning of thinning slash using the prescriptions derived from research. The monitoring of the moisture content of fine fuels, weather parameters and fire behaviour is essential for successfully implementing these prescriptions.

The harvesting prescriptions that are recommended to minimize the damage to stems during subsequent burning should be followed and all staff involved in planning and implementing the prescribed burning of thinning slash should be trained in the aims and technical requirements of the operation.

Research into the fire protection aspects of eucalypt regrowth management should continue. The research should assess the effectiveness of the harvesting prescriptions in minimizing stem damage, evaluate the burning prescriptions following their operational use, investigate alternative lighting techniques and investigate any other alternative, cost effective technique available to treat the slash hazard. Research into fire behaviour guides and prescriptions for fuel reducing regrowth stands prior to thinning should also continue.

Research has defined methods of harvesting and hazard reduction. Provided that operations are carefully planned and implemented, the selective thinning of regrowth stands can now be introduced to significantly increase the productivity of the forests of East Gippsland.

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[1] John McCormack, Senior Planning Officer, Bairnsdale Region, DCE.

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APPENDIX 1

The suitability of a stand for mechanised thinning is determined mainly by stand age, site quality, the stocking level and basal area of both the regrowth and overwood and the quantity of old log material on the forest floor. For the current thinning trials, the details of regrowth forest type, harvested area and coupe identification are shown in Table 1 and a summary of harvesting systems and contractor details are shown in Table 2. The pre- and post-thinning stand characteristics of the harvested coupes including stand density, basal area, top height and diameter class distribution are detailed by Geary *et al.* (unpubl. data).

Table 1. Summary of the harvested area and regrowth forest type.

Location	Coupe No.	Area (ha)	Year of thinning	Regrowth forest type Year	Origin	Overwood basal area
11/502 Stare Track	1	3.3	1988	1969	logging	low
	2	4.7	1988	1969	logging	low
	3	7.5	1988	1969	logging	low
	4	3.7	1988	1969	logging	low
11/507 Bendoc Ridge Rd	1	12.0	1988	1958	wildfire	low
	2	7.5	1988	1958	wildfire	low
11/507 Pheasant Ck Rd	1	4.8	1988	1958	wildfire	low
	2	1.0	1988	1958	wildfire	low
	3	3.1	1988	1958	wildfire	high
11/515 Dingo Creek	1	14.3	1988	1969	logging	high
12/503 Patrol Track	1	4.1	1988	1967	wildfire	high
09/501 Dyers Creek	1	3.9	1989	1965/6	logging	low
	2	5.6	1989	1965/6	logging	low
Total (ha)		75.5				

Table 2. **Summary of contractors and harvesting systems.**

Location	Coupe No.	Contractor	Harvesting system
11/502 Stare Track	1	Leeson	Feller buncher, skidder, crab grab loader
	2	Leeson	Feller buncher, skidder, crab grab loader
	3	Leeson	Feller buncher, skidder, crab grab loader
	4	Leeson	Feed-roll feller-processor, forwarder
11/507 Bendoc Ridge Rd	1	Crawford	Feller buncher, skidder, processor, forwarder
	2	Crawford	Feller buncher, skidder, processor, forwarder
11/507 Pheasant Ck Rd	1	Leeson	Feller buncher, skidder, crab grab loader
	2	Emmett	Chainsaw, skidder, crab grab loader
	3	Emmett	Chainsaw, skidder, crab grab loader
11/515 Dingo Creek	1	Crawford	Feller buncher, skidder, processor, forwarder
12/503 Patrol Track	1	Heather	Directional feller, skidder, crab grab loader
09/501 Dyers Creek	1	Heather	Feller buncher, skidder, processor, (logs stockpiled)
	1,2	Heather	Feller buncher, processor, forwarder

Harvesting prescriptions were developed and refined during the thinning trials. The interim thinning prescription applied to the 1989 harvesting operations was as follows:

1. The objective of the prescription is to leave regrowth stands in the optimum condition for the growth of future sawlogs and veneer logs.

2. Control will be by basal area thinning to 15-18 m^2/ha, with the proviso that not more than 60% of the basal area is removed.

3. Trees retained should be:

   3.1 In the dominant and co-dominant class.
   3.2 Of healthy crown.
   3.3 Of good form without excessive branching.
   3.4 Selected with due regard to spacing (close spacing will be necessary at the edges of gaps).
   3.5 Selected in order to achieve the desired species mix of the stands. Species other than *Eucalyptus sieberi* will be selected for retention wherever a reasonable choice exists.
   3.6 Selected so that stems immediately adjacent to major snig tracks are favoured for removal. Minor existing butt damage in vigorous, well growing trees can be tolerated.

4. Overwood trees not required for habitat purposes will be removed as part of the thinning operation, provided that they can be removed without damage to growing stock and there is a regrowth stem or stems to fill the gap created.

Other components of the harvesting prescriptions included standards of utilization and slash removal. The utilization standard prescribed that all material from trees felled as part of the thinning operation which meets the following specifications is to be extracted to a landing:

1. Logs from overwood and regrowth trees which meet grade D or better standards as defined in the Department's log grading specifications.

2. Other material from regrowth stems of merchantable length and with small-end diameters under-bark greater than 10 cm.

The merchantable length was accepted as 5.0 m for billet systems and 12.0 m for truck length systems.

Bark, crown and unutilized stem material was required to be removed from the landing site and redistributed over the coupe.

Erratum: the photographs on page 16 have been transposed